DOCUMENT RESUME

ED 320 030 CE 055 219

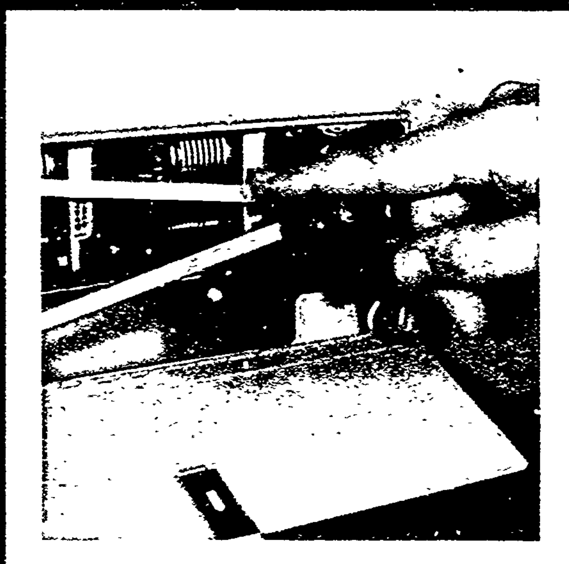
| | |
|---|---|
| AUTHOR | Brown, A. O., III |
| TITLE | Introduction to Instrumentation. Teacher Edition. |
| INSTITUTION | Mid-America Vocational Curriculum Consortium, Stillwater, Okla. |
| PUB DATE | 89 |
| NOTE | 299p.; For related documents, see CE 055 220-221. |
| AVAILABLE FROM | Mid-America Vocational Curriculum Consortium, 1500 West Seventh Avenue, Stillwater, OK 74074 (order no. CN602401: $21.50). |
| PUB TYPE | Guides - Classroom Use - Guides (For Teachers) (052) |
| EDRS PRICE | MF01 Plus Postage. PC Not Available from EDRS. |
| DESCRIPTORS | Classroom Techniques; Course Content; Electronic Control; Electronic Equipment; *Entry Workers; *Instrumentation; *Instrumentation Technicians; *Job Skills; Learning Activities; Learning Modules; Lesson Plans; *Measurement Equipment; Postsecondary Education; Secondary Education; Skill Development; Teaching Methods; Test Items; Units of Study |

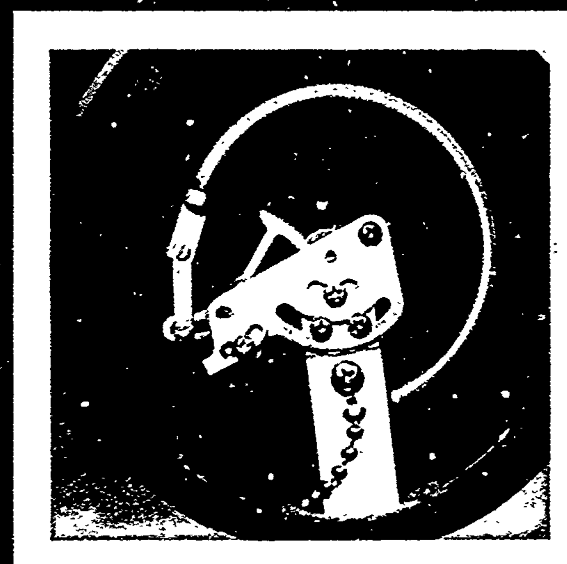

ABSTRACT

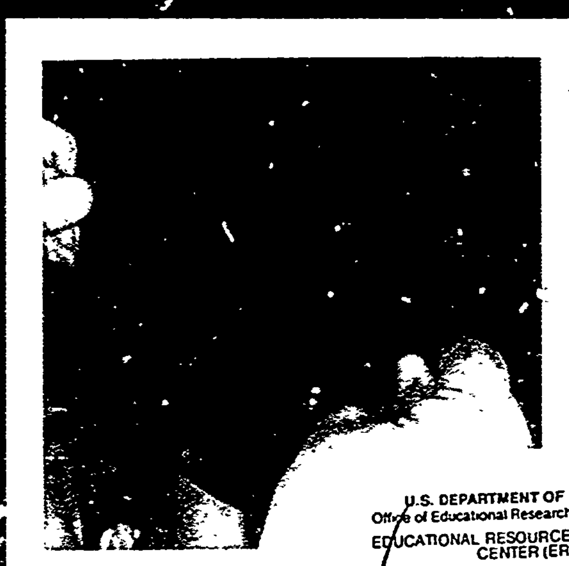
This module contains instructional materials on instrumentation to help teachers train students in the job skills they will need as beginning instrumentation technicians. The module addresses the nature of accessing, measuring, and controlling phenomena sucn as level, flow, pressure, and temperature. Students are introduced to the devices and formulas that make process instruments work. The module contains seven instructional units that cover the following topics: introduction to control systems; system components; principles of pressure measurement; principles of level measurement; principles of temperature measurement; principles of flow measurement; and process systems. Each instructional unit follows a standard format that includes some or all of these eight basic components: performance objectives, suggested activities for teachers and students, information sheets, assignment sheets, job sheets, visual aids, tests, answers to tests, and assignment sheets. The information sheets explain elements of physics and mathematics needed to evaluate functions, and the job sheets provide guides for experiments that turn theory into a physical event. Instructional task analyses; a tools, equipment, and materials list; and 15 references are also included. (KC)

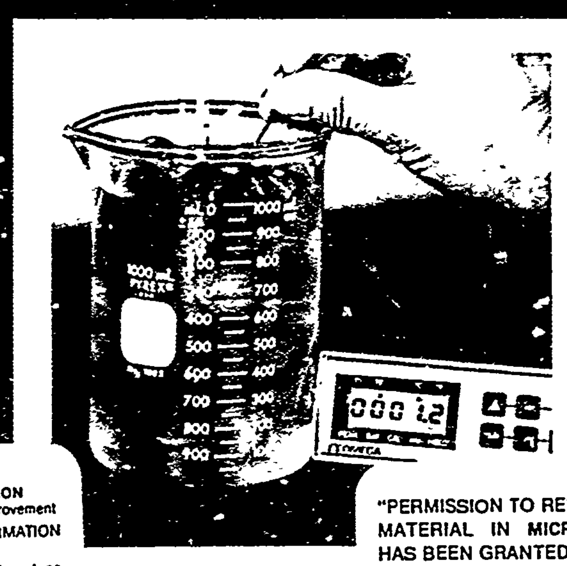
# Introduction to Instrumentation









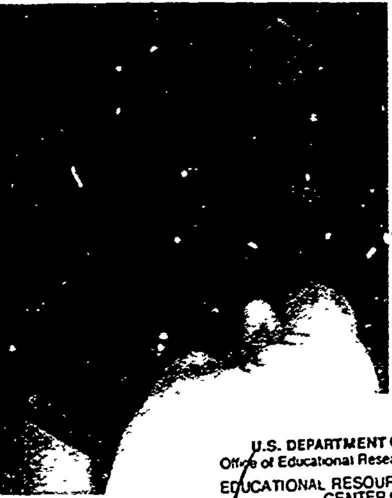


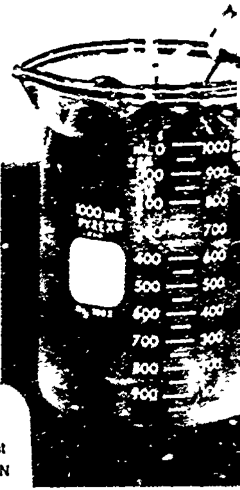




MAVCC

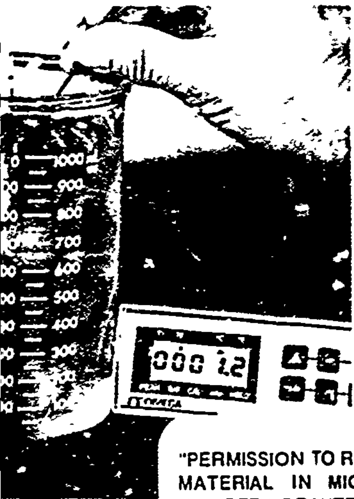
Teacher Edition








# Teacher Ed






on


North Dakota
South Dakota
Nebraska
Iowa
Colorado
Kansas
Missouri
Oklahoma
Arkansas
Texas
Louisiana

# INTRODUCTION TO INSTRUMENTATION

Written by

Dr. A.O. Brown III

Technical Consultant

Malcolm Fowler

Edited by

Dan Fulkerson

Developed by

The Mid-America Vocational Curriculum Consortium, Inc.





CN602401

Printed in the United States of America by the
Oklahoma State Department of Vocational-Technical Education
Stillwater, OK 74074

Mid-America Vocational Curriculum Consortium, Inc.
1500 West Seventh
Stillwater, Oklahoma 74074-4364

# INTRODUCTION TO INSTRUMENTATION

## TABLE OF CONTENTS

## FORFWORD

To compete effectively in the world market, America's process industries are relying more and more on state-of-the art process instrumentation. As industries retool to meet the demands of competition, the need for instrumentation technicians will continue to grow. What's more, entry level salaries are substantial, and sometimes impressive. *Introduction to Instrumentation* addresses the nature of accessing, measuring, and controlling phenomena such as level, flow, pressure, and temperature. Students are introduced to the devices and formulas that make process instruments work. The information sheets contain elements of physics and math needed to evaluate functions, and the job sheets provide excellent guides for what might be termed the "experiments" that turn theory into a physical event. That is why we call this text exciting, and we feel that students and instructors will agree.

Ron Mehrer, Chairman
Board of Directors
Mid-America Vocational
Curriculum Consortium

Greg Pierce
Executive Director
Mid-America Vocational
Curriculum Consortium

# ACKNOWLEDGEMENTS

To identify competencies and plan and approve materials, MAVCC works with a Resource Committee composed of outstanding instructors in the field of development and representatives from industry. For their excellent work with *Introduction to Instrumentation*, we extend a special thank you to the Resource Committee which included:

| | |
|---|---|
| **Malcolm Fowler** | Francis Tuttle AVTC, Oklahoma City, Oklahoma |
| **Alfred Rardin** | The Aviation Education Center, Wichita, Kansas |
| **Charles Solanik** | John Jay High School, San Antonio, Texas |
| **Dave Johnson** | Adolph Coors Company, Golden, Colorado |
| **Dennis Davis** | Northwest Iowa Technical College, Sheldon, Iowa |
| **Bill Ashley** | Northwest Louisiana Vo-Tech School, Minden, Louisiana |
| **Ron Shertzer** | Arkansas State Department of Education, Vo-Tech Division, Little Rock, Arkansas |
| **Dave Moum** | Amoco Refinery, Bismarck, North Dakota |

For his valuable role as technical consultant, we extend another special thank you to Malcolm Fowler of Francis Tuttle Area Vocational Technical Center in Oklahoma City, Oklahoma. Malcolm contributed not only his time and expertise, but permitted use of his classroom and laboratory at the Francis Tuttle High Tech Center to develop and prove many of the assignment and job sheets that complement this text.

We also thank the distributors of instrumentation equipment for providing us with reference material, and also thank the manufacturers who permitted us to reprint graphic materials to help reinforce many objectives in this text.

Thanks also go to Linda Lancaster of Francis Tuttle AVTC for producing many of the graphics that support the objectives.

The text was phototypeset by Eva Robbins and Stephanie Smola of the Graphics Department at Oklahoma State Vo-Tech, and the text was printed in the print shop at the Oklahoma State Department of Vocational-Technical Education. We thank graphics and print shop personnel for a job well done.

## USE OF THIS PUBLICATION

### Instructional Units

*Introduction to Instrumentation* contains seven units of instruction. Each instructional unit includes some or all of the basic components of a unit of instruction; performance objectives, suggested activities for teachers and students, information sheets, assignment sheets, job sheets, visual aids, tests, and answers to the tests. Units are planned for more than one lesson or class period of instruction.

Careful study of each instructional unit by the teacher will help to determine:

A. The amount of material that can be covered in each class period
B. The skills which must be demonstrated

   1. Supplies needed
   2. Equipment needed
   3. Amount of practice needed
   4. Amount of class time needed for demonstrations

C. Supplementary materials such as pamphlets or filmstrips that must be ordered
D. Resource people who must be contacted

### Objectives

Each unit of instruction is based on performance objectives. These objectives state the goals of the course, thus providing a sense of direction and accomplishment for the student.

Performance objectives are stated in two forms: unit objectives, stating the subject matter to be covered in a unit of instruction; and specific objectives, stating the student performance necessary to reach the unit objective.

Since the objectives of the unit provide direction for the teaching-learning process, it is important for the teacher and students to have a common understanding of the intent of the objectives. A limited number of performance terms have been used in the objectives for this curriculum to assist in promoting the effectiveness of the communication among all individuals using the materials.

Reading of the objectives by the student should be followed by a class discussion to answer any questions concerning performance requirements for each instructional unit.

Teachers should feel free to add objectives which will fit the material to the needs of the students and community. When teachers add objectives, they should remember to supply the needed information, assignment and/or job sheets, and criterion tests.

**Suggested Activities for the Instructor**

Each unit of instruction has a suggested activities sheet outlining steps to follow in accomplishing specific objectives. Duties of instructors will vary according to the particular unit; however, for best use of the material they should include the following: provide students with objective sheet, information sheet, assignment sheets, and job sheets; preview filmstrips, make transparencies, and arrange for resource materials and people; discuss unit and specific objectives and information sheet; give test. Teachers are encouraged to use any additional instructional activities and teaching methods to aid students in accomplishing the objectives.

**Information Sheets**

Information sheets provide content essential for meeting the cognitive (knowledge) objectives in the unit. The teacher will find that the information sheets serve as an excellent guide for presenting the background knowledge necessary to develop the skill specified in the unit objective.

Students should read the information sheets before the information is discussed in class. Students may take additional notes on the information sheets.

**Transparency Masters**

Transparency masters provide information in a special way. The students may see as well as hear the material being presented, thus reinforcing the learning process. Transparencies may present new information or they may reinforce information presented in the information sheets. They are particularly effective when identification is necessary.

Transparencies should be made and placed in the notebook where they will be immediately available for use. Transparencies direct the class's attention to the topic of discussion. They should be left on the screen only when topics shown are under discussion.

**Assignment Sheets**

Assignment sheets give direction to study and furnish practice for paper and pencil activities to develop the knowledge which is a necessary prerequisite to skill development. These may be given to the student for completion in class or used for homework assignments. Answer sheets are provided which may be used by the student and/or teacher for checking student progress.

**Job Sheets**

Job sheets are an important segment of each unit. The instructor should be able to demonstrate the skills outlined in the job sheets. Procedures outlined in the job sheets give direction to the skill being taught and allow both student and teacher to check student progress toward the accomplishment of the skill. Job sheets provide a ready outline for students to follow if they have missed a demonstration. Job sheets also furnish potential employers with a picture of the skills being taught and the performances which might reasonably be expected from a person who has had this training.

### Practical Tests

Practical tests provide the instructor with an evaluation instrument for each of the job sheets.

### Test and Evaluation

Paper-pencil and performance tests have been constructed to measure student achievement of each objective listed in the unit of instruction. Individual test items may be pulled out and used as a short test to determine student achievement of a particular objective. This kind of testing may be used as a daily quiz and will help the teacher spot difficulties being encountered by students in their efforts to accomplish the unit objective. Test items for objectives added by the teacher should be constructed and added to the test.

### Test Answers

Test answers are provided for each unit. These may be used by the teacher and/or student for checking student achievement of the objectives.

# INTRODUCTION TO INSTRUMENTATION

## INSTRUCTIONAL TASK ANALYSIS

| JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor) | RELATED INFORMATION: What the Worker Should Know (Cognitive) |
|---|---|

### UNIT I: INTRODUCTION TO CONTROL SYSTEMS

| JOB TRAINING | RELATED INFORMATION |
|---|---|
| | 1. Terms and definitions |
| | 2. Safety |
| | 3. Open-loop control systems |
| | 4. Closed-loop control systems |
| | 5. Control system applications |
| | 6. Measuring pressure |
| | 7. Measuring temperature |
| | 8. Measuring flow |
| | 9. Measuring level |
| | 10. Mechanical controls |
| | 11. Pneumatic controls |
| | 12. Electrical/electronic controls |
| | 13. Career overview |
| | 14. Troubleshooting |
| 15. Evaluate your potential as an instrumentation technician | |
| 16. Evaluate your interest in an ISA student chapter | |

| JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor) | RELATED INFORMATION: What the Worker Should Know (Cognitive) |
|---|---|

**UNIT II: SYSTEM COMPONENTS**

| | |
|---|---|
| | 1. Terms and definitions |
| | 2. Sensors used for measuring temperature |
| | 3. Sensors used for measuring pressure |
| | 4. Sensors used for measuring flow |
| | 5. Sensors used for measuring level |
| | 6. Other sensing devices |
| | 7. Transmitter devices |
| | 8. Special transmitter designs |
| | 9. Receiver devices |
| | 10. Indicators |
| | 11. Recorders |
| | 12. Controllers |
| | 13. Control elements |
| | 14. Valves and actuators |
| | 15. Servo devices |
| | 16. The P&ID (Process and Instrumentation Diagram) |
| | 17. Basic ISA symbols |
| | 18. ISA identification letters and symbols |
| 19. Identify instruments used in a simple process system | |

| JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor) | RELATED INFORMATION: What the Worker Should Know (Cognitive) |
|---|---|

## UNIT III: PRINCIPLES OF PRESSURE MEASUREMENT

| | |
|---|---|
| | 1. Terms and definitions |
| | 2. Basics of pressure measurement |
| | 3. Units of pressure measurement |
| | 4. Other units of pressure measurement |
| | 5. Pressure and specific gravity |
| | 6. Measuring pressure with manometers |
| | 7. U-tube manometers and their uses |
| | 8. Well manometers and their uses |
| | 9. Inclined tube manometers and their uses |
| | 10. Measuring pressure with Bourdon tubes |
| | 11. Measuring pressure with helix and spiral Bourdon tubes |
| | 12. Measuring pressure with diaphragms, capsules, and bellows |
| | 13. Measuring pressure with strain gauges |
| 14. Select appropriate pressure measuring devices for given applications | |
| 15. Use Pascal's law to calculate force, area, and pressure | |
| 16. Make pressure readings from U-tube, well, and inclined tube manometers | |
| 17. Construct a test apparatus, make and record pressure measurements, and complete pressure measurement conversions | |

| JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor) | RELATED INFORMATION: What the Worker Should Know (Cognitive) |
| --- | --- |

**UNIT IV: PRINCIPLES OF LEVEL MEASUREMENT**

| | |
| --- | --- |
| | 1. Terms and definitions |
| | 2. Basics of level measurement |
| | 3. Measuring liquids in tanks |
| | 4. Measuring liquids with sight glasses |
| | 5. Measuring level with float devices |
| | 6. Measuring level with displacers |
| | 7. Measuring level with capacitance level sensors |
| | 8. Measuring level with bubbler systems |
| | 9. Measuring level with differential pressure |
| | 10. Measuring level with infrared systems |
| | 11. Measuring level with radioactive devices |
| | 12. Measuring level with ultrasonic devices |
| | 13. Other methods of level measurement |
| | 14. Specific gravity and level measurement |
| | 15. Applications of level measurement |
| 16. Examine and interpret performance charts | |
| 17. Make an emergency level measurement in a make-up water storage tank | |
| 18. Measure, cut, and bend copper tubing to specifications | |
| 19. Use a bubbler system to determine liquid level in a tank open to atmosphere | |

15

| JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor) | RELATED INFORMATION: What the Worker Should Know (Cognitive) |
|---|---|

## UNIT V: PRINCIPLES OF TEMPERATURE MEASUREMENT

1. Terms and definitions
2. Units of temperature measurement
3. Measuring temperature with thermometers
4. Measuring temperature with thermocouples
5. Measuring temperature with RTDs (Resistance Temperature detectors)
6. Measuring temperature with thermistors
7. Measuring temperature with FTSs (Filled Thermal Systems)
8. Classes and applications of FTSs
9. Measuring temperature with bimetallic devices
10. Measuring temperature with infrared devices
11. Measuring temperature with LICS (Linear Integrated Circuit Sensors)
12. Digital and analog readouts
13. Temperature scale conversions
14. Applications of temperature measurement

15. Use a hot water bath, an ice bath, and a digital VOM to confirm the temperature output of the hot junction on a thermocouple

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)

RELATED INFORMATION: What the Worker Should Know (Cognitive)

## UNIT VI: PRINCIPLES OF FLOW MEASUREMENT

1. Terms and definitions
2. Basics of flow measurement
3. Units of flow measurement
4. Methods of flow measurement
5. Measuring flow with differential pressure
6. Measuring flow with differential pressure transmitters
7. Measuring flow with orifice plates
8. Measuring flow with venturi tubes
9. Venturi tube variations
10. Measuring flow with pitot tubes
11. Measuring flow with elbow meters
12. Measuring flow with vortex shedding
13. Measuring flow with rotameters
14. Measuring flow with turbine meters
15. Measuring flow with positive displacement meters
16. Methods of non-invasive flow measurement
17. Measuring flow with Doppler effect flowmeters
18. Measuring flow with time-of-travel flowmeters
19. Measuring flow with magnetic flowmeters

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)

RELATED INFORMATION: What the Worker Should Know (Cognitive)

20. Measuring flow with mass flow instruments

21. The square root conversion

22. Construct a flow control apparatus, and use a Mercury manometer and a rotameter to measure flow in a system

## UNIT VII: PROCESS SYSTEMS

1. Terms and definitions
2. Basics of signal transmission systems
3. Methods of signal transmission
4. Pneumatic transmission
5. Standards for pneumatic transmission
6. Electrical transmission
7. Elements in a current transmitted signal
8. Standards for electrical transmission
9. Frequency transmission
10. Pulse width or duration transmission
11. Digital pulse code transmission
12. Bit transmission formats

13. Identify and explain the function of the instrument loops in a typical industrial application

# INTRODUCTION TO INSTRUMENTATION

## TOOLS, EQUIPMENT, AND MATERIALS LIST

**Important!**
Safety glasses are required for all performance activities in this text.

**Basic hand tools**

Flat blade and Phillips screwdrivers
Combination wrench set
Combination slip-joint pliers
Needlenose pliers
Electricians pliers
Putty knife or gasket scraper
Allen wrench set
Hammer

**Materials**

Copper tubing, 6 feet of 1/4" OD
Plastic hose, 30 feet of 1/4"
Quick-connect fittings as required

**Equipment**

Instrument supply air source
Needle valves, 2 1/4"
Tubing cutter
1/4" level-type tubing bender with graduated degree scale
Tape measure
Marker
Pencil
1/4" tee
1000 mL pyrex beakers
Hot plate
Hot pads
30-gallon tank with graduated markings and bottom spigot drain
Type J thermocouple

**Test and measurement instruments**

Calculator
Digital VOM
−1 to 101°C thermometer (F° may be used)
−8 to 32°C thermometer (F° may be used)
0-2000 SCFH rotameter
36" U-tube Mercury manometer
0-150" water pressure gauge (bellows type)
0-15 psi test gauge (Bourdon tube)
0-15 psi pressure gauge (bellows type)
Air pressure regulator

## INTRODUCTION TO INSTRUMENTATION

## ALPHABETICAL LIST OF REFERENCES USED IN DEVELOPING THIS TEXT


A. *Dwyer Controls and Gauges*. Michigan City, IN 46360: Dwyer Instruments, Inc., 1985.

B. *Dwyer Engineering and Product Applications Handbook*. Michigan City, IN 46360: Dwyer Instruments, Inc., 1986.

C. Gillum, Donald R. *Control Loop Systems*. Austin, TX: Extension Instruction and Materials Center, Division of Continuing Education, The University of Texas at Austin, 1984.

D. Hall, Ronald P. *Automated Process Control Systems (Concepts and Hardware)*. Englewood Cliffs, NJ: Prentice-Hall Book Co., 1981.

E. *Instruction Book 2358*. Foxboro, MA 02035: The Foxboro Company, 1983.

F. *Instrumentation Basics Module D, Instrumentation Diagrams and Symbols*. Research Triangle Park, NC 27709: Instrument Society of America, 1981.

G. Johnson, Curtis D. *Process Control Instrumentation Technology*. New York, NY: John Wiley & Sons, 1982.

H. Liptak, Bela G. *Instrumentation Processing in the Industries*. Philadelphia, PA: Chilton Book Company, 1973.

I. *Modulevel® EZ Series Electronic Level Transmitters*. Downers Grove, IL 60515-4499: Magnetrol International, 1984.

J. *Omega Complete Flow and Level Measurement handbook and Encyclopedia*. Stamford, CT 06907: Omega Engineering, Inc., 1988.

K. *Omega Complete Pressure and Strain Measurement Handbook and Encyclopedia*. Stamford, CT 06907: Omega Engineering, Inc., 1986.

L. *Omega Complete Temperature Measurement Handbook and Encyclopedia*. Stamford, CT 06907: Omega Engineering, Inc., 1988.

M. Potvin, John. *Applied Process Control Instrumentation*. Reston, VA: Reston Publishing Co., 1983.

N. Tyson, Forrest. *Industrial Instrumentation*. Englewood Cliffs, NJ: Prentice-Hall Book Co., 1980.

O. Whalen, Bruce R. *Basic Instrumentation*, Third Edition. Austin, TX 78758: Petroleum Extension Service, University of Texas at Austin, 1983.

FRANCIS TUTTLE HIGH TECH CENTER
Instrumentation & Process Controls

# INTRODUCTION TO CONTROL SYSTEMS
## UNIT I

## UNIT OBJECTIVE

After completion of this unit, the student should be able to differentiate between open-loop and closed-loop control systems, and discuss typical processes that measure pressure, temperature, flow, and level. The student should also be able to list job opportunities, and evaluate his/her potential as an instrumentation technician. These competencies will be demonstrated by properly completing the assignment sheets, and by scoring a minimum of 85 percent on the unit test.

## SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to introduction to control systems with their correct definitions.
2. Solve problems concerning safety.
3. Complete statements concerning open-loop control system.
4. Complete statements concerning closed-loop control systems.
5. Select true statements concerning control system applications.
6. Complete statements concerning measuring pressure.
7. Complete statements concerning measuring temperature.
8. Complete statements concerning measuring flow.
9. Complete statements concerning measuring level.
10. Select true statements concerning mechanical controls.
11. Select true statements concerning pneumatic controls.
12. Select true statements concerning electrical/electronic controls.
13. Complete statements concerning career overview.
14. Complete statements concerning troubleshooting.

# OBJECTIVE SHEET

15. Evaluate your potential as an instrumentation technician. (Assignment Sheet #1)

16. Evaluate your interest in an ISA student chapter. (Assignment Sheet #2)

# INTRODUCTION TO CONTROL SYSTEMS
# UNIT I

## SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information and assignment sheet.

C. Make transparencies.

D. Discuss unit and specific objectives.

E. Discuss information sheet.

F. Use overheads and other resource materials to reinforce materials in the information sheet.

G. When completed, Assignment Sheet #1 will contain confidential information. Advise students that the assignment sheets will not be collected, and that the assignment is a "personal awareness" activity which students will evaluate individually.

H. Arrange a field trip to a local or area industry where students can observe process control equipment, and talk to the personnel who manage and maintain the installation. Have a general discussion of the field trip in class.

I. Emphasize the importance of safety with process control devices, and personal safety when working around electrical and pneumatic devices.

> **CAUTION: Job sheets in this text include procedures designed to demonstrate principles and general applications. Under no circumstances should these procedures be used in substitution for in-plant industrial procedures or manufacturers' recommendations.**

J. Give test.

## REFERENCES USED IN DEVELOPING THIS UNIT

A. Gillum, Donald R. *Control Loop Systems.* Austin, TX: Extension Instruction and Materials Center, Division of Continuing Education, The University of Texas at Austin, 1984.

B. Whalen, Bruce R. *Basic Instrumentation.* Third Edition. Austin, TX 78758: Petroleum Extension Service, University of Texas at Austin, 1983.

C. *Introduction to Process Control.* Student Workbook. Research Triangle Park, NC 27709: Instrument Society of America, 1981.

## SUGGESTED TRAINING MATERIALS

A. The *Instrument Technician Training Program* prepared by the Instrument Society of America is a video tape/workbook format that covers the general field of instrumentation. Information about the program is available from:

INSTRUMENT SOCIETY OF AMERICA
67 Alexander Drive
P.O. Box 12277
Research Triangle Park, NC 27709
(919) 549-8411

B. Omega Engineering, Inc. of Stamford, Connecticut offers a variety of free handbooks which support Omega products but also contain valuable articles about many aspects of instrumentation. The available materials include: *Omega Complete Pressure, Strain, and Force Measurement Handbook and Encyclopedia*; *Omega Complete Flow and Level Measurement Handbook and Encyclopedia*; *Omega Complete Temperature Measurement Handbook and Encyclopedia*; *Omega Complete Pressure and Strain Measurement Handbook and Encyclopedia*; *Omega Complete Data Acquisition and Computer Interface Handbook and Encyclopedia*; and others. For information call 1-800-826-6342 or write:

Omega Engineering, Inc.
One Omega Drive
P.O. Box 4047
Stamford, CT 06907

C. The Petroleum Extension Division (PETEX) of the University of Texas at Austin has republished Bruce R. Whalen's *Basic Instrumentation*. The Third Edition of the text is available along with a new student workbook and instructor's guide. For information, call (512) 471-3154 or write:

Petroleum Extension Service
Balcones Research Center
10100 Burnet Road
Austin, TX 78758-4497

# INTRODUCTION TO CONTROL SYSTEMS
# UNIT I

## INFORMATION SHEET

I. Terms and definitions

A. Control — That part of a system that produces a desired response to given input conditions

B. Feedback — A signal or other form of information sent back from a system output for use by the system controller

C. Loop — The arrangement of components to complete a system that can perform a control function

D. Measurement — The procedure of determining the value of a variable of interest such as measuring temperature with a thermometer

E. Process — The complex system used to manufacture a product, or the actual procedure used to manufacture a product

F. Regulation — The control action that holds a variable of interest close to its setpoint when a control system is in operation

G. Setpoint — A desired value such as degrees of temperature or pounds of pressure used as a reference point that a controller can compare with a variable of interest to determine if the variable requires change

H. System — The input, controller, and output components integrated to accomplish a given task in a process

II. Safety

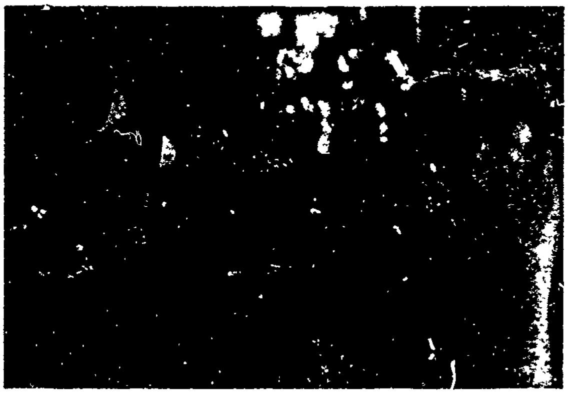
A. Personal safety:

1. Posted safety rules should be carefully read and just as carefully obeyed.

2. Proper clothing should be worn at all times, and items such as safety glasses, face shields, ear plugs, and gloves should be worn as required. (Figure 1)

# INFORMATION SHEET

FIGURE 1



3. Never engage or permit others to engage in horseplay in the workplace or the laboratory.

4. Keep a mental attitude that promotes safety at all times.

B. Equipment safety:

1. In many process control situations, the equipment and the environment around the equipment is very dangerous; in fact, that is why automatic monitoring and control are used.

2. Know the rules for safely using any instrument or piece of equipment that you work with. (Figure 2)

FIGURE 2

3. Do not violate safety rules for the proper use of instruments or equipment.

# INFORMATION SHEET

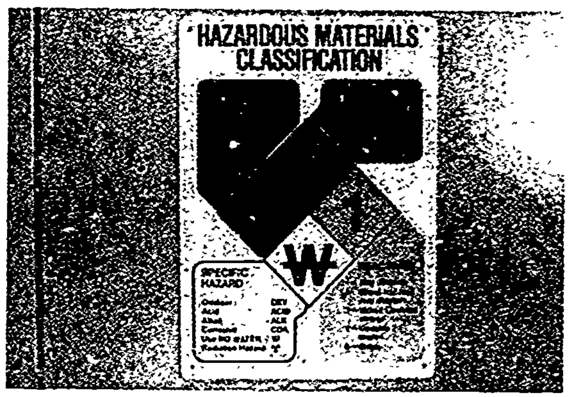
C. Hazardous materials:

1. The federal government requires that all workers be informed of hazardous materials that may be present in the workplace.

2. Every company has special training for hazardous tasks, and rules and procedures related to such tasks should be carefully followed.

3. Read and respect signs, posters, and written materials posted in the workplace because they are there to alert you to potential danger. (Figure 3)

FIGURE 3




**III. Open-loop control systems** (Transparency 1)

A. A control system that has no means of sending information back to a control device is called an open-loop system.

B. An open-loop system is usually a simple control where a variable is set, and the control device proceeds on that setting.

C. An open-loop system has no means of sending information back to a controls device, and the lack of feedback is what differentiates an open-loop system from a closed-loop system.

EXAMPLE: Filling a bath tub requires physically monitoring water flow into the tub, and physically closing a faucet when water reaches a desired level because there is no feedback information about water level, and no automatic control action to close the faucet.

# INFORMATION SHEET

IV. Closed-loop control systems (Transparency 2)

A. An automatic process control system is a set of devices which when set at a given value will produce an outcome appropriate to the setting.

B. A typical closed-loop system operates in an order:

1. The system is set on a point of control, and that setpoint is compared with some input from the system which indicates the condition of a variable such as temperature.

2. The feedback to the controller is compared with the setpoint, and if the two do not match, the controller sends a signal to a final control device.

3. The final control device initiates the activity which will correct the variable to setpoint.

C. The essential difference between an open-loop and a closed-loop system is the capacity of the closed-loop controller to act on feedback.

EXAMPLE: On a heating/cooling thermostat in a home, the setpoint is the temperature set on that thermostat, and this is automatic because you don't have to watch it. The room temperature measured by the thermometer in the thermostat is the variable to which setpoint is compared. If the setpoint and variable are different, the thermostat will close a contact to start an air conditioner/furnace, or open a contact to turn the air conditioner/furnace off.

V. Control system applications

A. Controls can be applied to any physical phenomena that can be accessed and measured.

B. Certain physical phenomena that can be readily accessed and measured have become classical applications, and these include:

1. Pressure.

2. Temperature.

3. Flow.

4. Level.

C. The ability to measure something that has to be controlled is vital to process controls, and all applications involve some method of measurement.

(NOTE: The methods of measuring pressure, temperature, flow, and level that are presented in the next four objectives are only a fraction of the applications for these types of controls.)

# INFORMATION SHEET

VI. **Measuring pressure** (Transparency 3)

A. Pressure is created by resistance to flowing liquids, by air, and by steam, and common applications are water pressure in the home, and steam pressure in a pressure cooker.

B. Pressure is often measured in pounds per square inch (PSI) or it can also be measured in kiloPascals (kPs).

C. A common application of pressure control takes place in an air compressor:

1. The compressor must pump air into a holding tank in order to provide a user with a sufficient volume of air.

2. As air is used, the air pressure in the holding tank drops, and a pressure management device such as a diaphragm, a bellows, or a bourdon tube will physically turn on a switch that starts the compressor pumping more air into the holding tank. (Figure 4)

FIGURE 4

3. When the pressure in the holding tank builds to setpoint, the same device that closed the switch to start the compressor will open the switch to stop the compressor.

D. Industrial process such as refining oil and chemical manufacturing rely heavily on pressure measurement and control.

VII. **Measuring temperature** (Transparency 4)

A. Temperature is created by the presence or lack of heat.

B. Temperature is often measured by thermometers in degrees celsius, °C, or degrees fahrenheit, °F.

## INFORMATION SHEET

C. In industrial applications, temperatures may also be measured by thermistors, thermocouples, and infrared devices.

D. A common application of temperature control takes place in the preparation of soup for canning:

1. Raw meats and vegetables are placed in a large vessel of water and cooked for a specific length of time at a fixed temperature.

2. This is called batch processing, and the soup is cooked by steam in the jacket of the cooking vessel.

3. The batch process has a controller that receives an input signal and compares the input temperature with the setpoint temperature.

4. If the temperatures are not equal, the controller sends an error signal to an output device, normally a control valve.

5. The final control element, in this case a steam control valve, will be turned on if the temperature is too low, or turned off or partially off if the temperature is too high.

6. The controlled batch process avoids cooking or overcooking the soup, and maintains a consistent, quality product.

E. Temperature measuring devices may produce electrical output signals, or produce mechanical or pressure changes, and the devices used for input must match the system.

VIII. Measuring flow (Transparency 5)

A. Flow is created by movement of liquids or gases through pipes or ducts.

B. Flowing liquids are usually measured in quantities related to time, such as gallons per minute or barrels per hour.

C. Flowing gases and steam are measured by several means ranging from venturi tubes to ultrasonic flow meters, and an orifice plate is a much used flow measuring device.

D. A common application of flow is the measurement and control of gas flow into the burner of a boiler that produces steam for use in manufacturing:

1. Gas flow into the burner will be affected by many variables such as water flow into the boiler tubes, the amount of oxygen leaving the furnace via the gas flue, the air input to the burner, and the temperature and quantity of steam output.

## INFORMATION SHEET

2. Other variables aside, the flow of gas into the burner must function in relation to the demand for steam from the boiler.

3. Both the flow of gas and the flow of steam in a pipe must be measured, and this is usually accomplished by restricting the flow of material in a pipe.

4. The restriction in the pipe will cause a pressure drop at the point of restriction, and an orifice plate is the device most commonly used for this measurement.

5. The pressure drop method seems a round about way to measure flow, but it is an inexpensive procedure, and does not cause a great loss of energy in exchange for an accurate measurement.

6. As the demand for steam increases, the change in flow is detected by the orifice plate and associated instrumentation, and a signal is sent to the controller.

7. The controller compares the gas flow with the steam flow, and if the two do not match, the controller will open or close the gas control valve to increase or decrease steam production.

E. In many industrial applications, variables are interactive, and a change in flow rate could be produced by a change in pressure or temperature.

IX. Measuring level (Transparency 6)

A. Level is the degree to which any container is filled with or emptied of a liquid, gas, or solid.

B. Level measurements reflect the amount of contents in a container, and may be accomplished by measuring the static head, with bubble tubes, or with ultrasonic or capacitive sensors.

C. A common, yet reliable device for level measurement is a float with a cable eel or a tape which indicates liquid level.

D. To measure the level of solids in a bin requires methods such as measuring the weight of the bin or using radiation source/counter techniques.

E. A common application of level is the measurement of level in a storage tank at a petroleum refinery:

1. A typical tank would be filled with a finished product which feeds into a pipeline for transport to another part of the country.

2. When the tank is down to 20% full, it will be switched from the pipeline to a fill pipe, so if the tank holds 100,000 gallons of product, it will switch to the refill cycle when it is down to 20,000 gallons.

## INFORMATION SHEET

3. The tank has a fixed, covered top with a level sensor attached to it.

4. The level sensor consists of a float with a stainless steel band perforated with holes that code the location of the float in the tank.

5. The float rides on a cable that is anchored to the bottom and top of the tank, and the float rides up and down the cable in a tube, called a stilling well, so that it will not be affected by fluid movement during pumping.

6. As liquid is pumped from the tank, the float moves downward as the perforations are read by the sensor on top of the tank.

7. When the code for 20,000 gallons is transmitted to the controller, the controller finds a match with the setpoint.

8. The controller sends a signal to the valve that controls output from the tank, and also signals to turn off the output pump and turn on the input pump.

9. The tank will fill until the float with its coded tape reaches a set point, and then the filling action will stop, the action will reverse, and pumping will begin again.

X. **Mechanical controls**

A. Controls systems in general have their beginnings in the Industrial Revolution which began in England in 1760, and soon spread to the rest of the world.

B. The machines that helped make work easier and less monotonous required additional devices to control them, and mechanical controls were the first controls in the evolution of control systems.

C. The steam engine that was invented to pump water from deep mines had mechanical controls in the form of valves for admitting and exhausting steam.

D. The reciprocating pit saws used in shaping lumber had mechanical controls to reverse their blades.

E. The automatic speed regulator for steam engines worked on the principle of the centrifugal force of a spinning weight which moved up a clevice to shut off the steam supply when the engine reached a certain speed, and the same control concept is used in the starter switches on modern electric motors.

F. Safety became a factor with mechanical devices, and the dead-man brake was invented for steam run devices so that if an operator fell asleep or lost control, the device would stop.

# INFORMATION SHEET

G. Mechanical controls were present in an 1801 invention for weaving cloth, and in 1833, Charles Babbage in England built the first mechanical computers.

H. Mechanical controls still play a part in modern control devices because chart drive mechanisms, printers, reversing levers, pointers, and alarms are still basically mechanical.

XI. **Pneumatic controls**

A. Air-operated or pneumatic controls were a result of expanding industries and the need for control devices that could be extended out from central units to peripheral devices in an installation.

B. Expanding mechanical controls required running shafts and control rods through a plant, but such controls were expensive and created mechanical hazards.

C. Early in the industrial revolution, scientists discovered the properties of hydraulics and pneumatics (liquids and gases), and even designed oil- and air-operated servo devices which became the muscle in control systems.

D. The discovery of great oil reserves in the early 1900's, and the invention of oil and gas operated engines increased the popularity of hydraulic devices.

E. Designers found oil to be far too messy to use as a medium for control, and turned more and more to air as a control medium.

F. Pneumatics grew in popularity because air is readily available, air is clean and nonflammable, and air could be piped to any part of an installation in relatively small tubes.

G. Another advantage of using air was that a break in air line caused no mess, and the tubes were inexpensive and easy to repair.

H. Pneumatic controls have been developed to a high degree of sophistication including full analog proportional/integral/derivative (PID) control which, next to computers, is the most human-like control available.

(NOTE: PID control will be discussed in a later unit.)

I. Pneumatic control systems with their successes in flexibility and miniturization served as models for electrical systems that came along later.

J. Pneumatic systems are still used in conditions where the use of electricity would create a potential for explosion, and mechanica/pneumatic systems are still in use because they are durable.

# INFORMATION SHEET

XII. Electrical/electronic controls

A. In the late 1930s, two things happened that changed the history of control systems:

1. Electrical power was becoming widely distributed and reliable.

2. The new area of vacuum tube electronics was being expanded from radio applications to control applications.

B. A new control industry expanded rapidly, and electrical/electronic control devices were invented to work with mechanical/pneumatic devices.

C. Because of their low cost and flexibility, the new electrical/electronic control devices began to replace mechanical and pneumatic applications.

D. The development of solid-state devices in the 1960s, and the advent of microprocessors in the 1970s helped the movement to electronic controls.

E. The energy crisis of the late 1970s, and the accelerating price of energy serviced to strengthen the switch to electronic controls.

F. With the arrival of microcomputers and large memories, electronic controls have taken another giant step, and the introduction of artificial intelligence into controls is taking the field closer to the ultimate objective of humanlike control devices.

XIII. Career overview

A. Because of rising energy costs, all employers are interested in control systems that can reduce energy consumption.

B. The need for effective, cost-reducing control systems has created a great deal of interest in controls and their related careers.

C. Because control systems rely heavily on sophisticated formulas, a potential instrumentation technician should have high school mathematics through algebra, and if possible, introduction to trigonometry.

D. Other prerequisites for the would-be technician include a general knowledge of technology, a sound mechanical aptitude, and a good command of both oral and written communications.

E. Among job responsibilities, the control instrumentation technician installs controls and control systems, calibrates systems, performs routine maintenance, and recalibration as required.

F. The technician will also have to troubleshoot and repair devices in a system, and accurately log records of maintenance and repair activity.

# INFORMATION SHEET

G. Because instrumentation requires a clean environment to maintain accuracy, a technician must be neat and have orderly work habits.

H. There is a favorable job outlook for control instrumentation technicians because the drive to reduce energy costs has opened the door to extensive instrumentation in both business and industry.

I. The instrumentation area offers good to excellent salaries, and since instrumentation is related to analog and digital electronics, microprocessors, and energy management, the field offers entry access to other fast growth areas.

XIV. Troubleshooting

A. Unpredicted downtime can be an enormous expense to industry, and that is why technicians who can efficiently troubleshoot and solve downtime problems are treasured by industry.

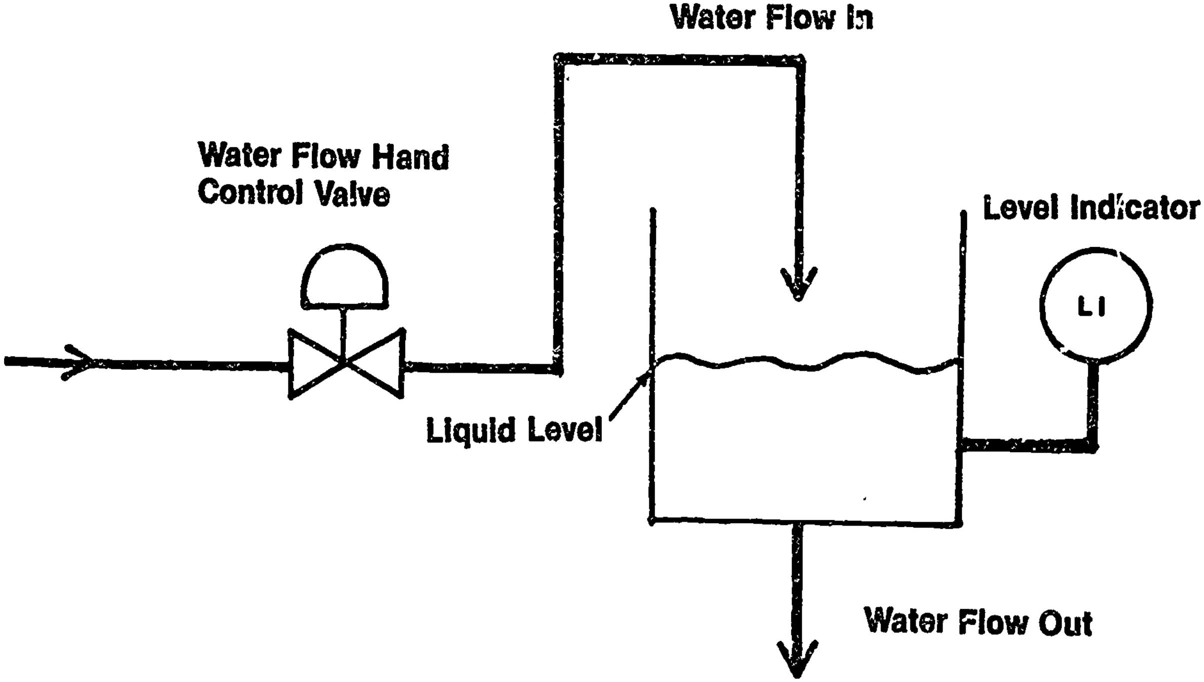
(NOTE: Downtime at a petroleum refinery or an electric power plant could easily cost more than a hundred thousand dollars an hour.)

B. To be a good troubleshooter, a technician must have an intimate knowledge of a process, all the equipment used in the process, and the concepts of the system design.

C. Years of study and hard work are required to become a skilled troubleshooter, but the economic rewards are excellent, and the prestige of the job is rewarding.

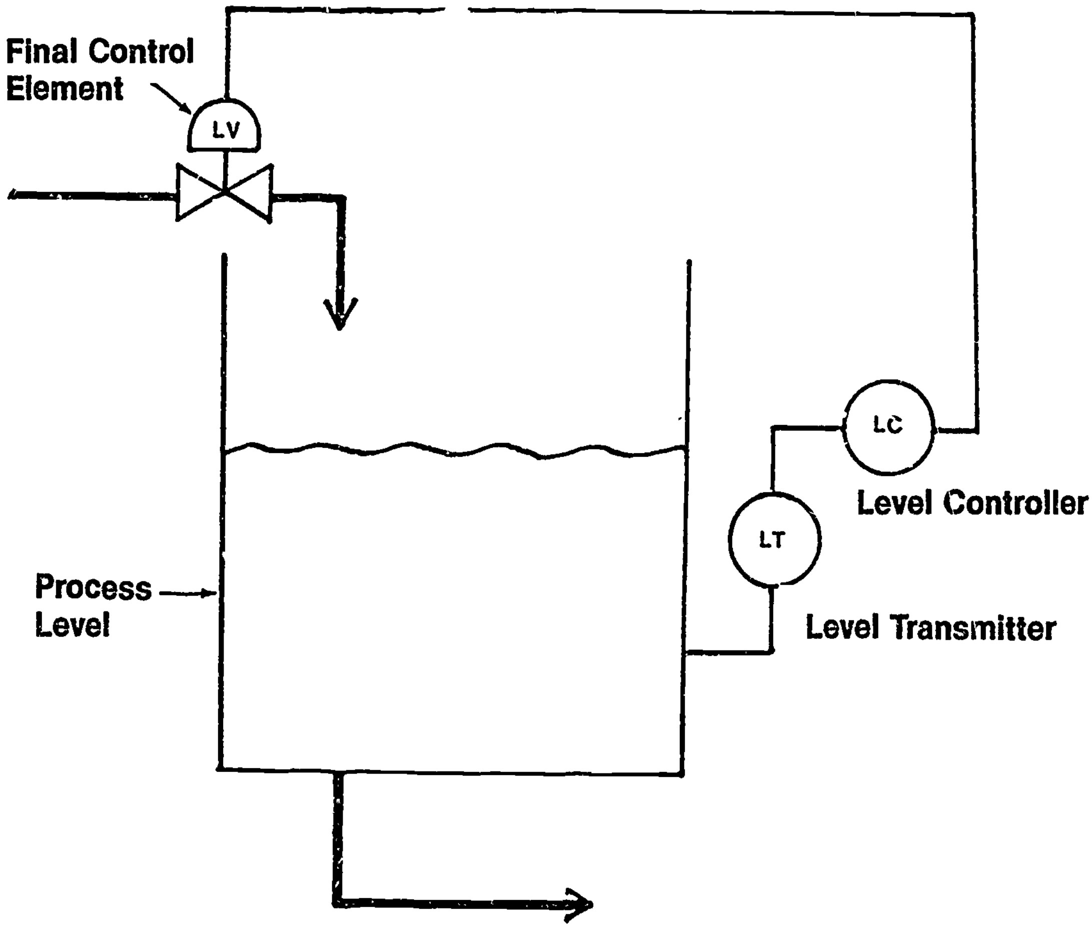
(NOTE: During downtime, a skilled troubleshooter has authority exceeded only by the plant manger.)

# Open-Loop Control



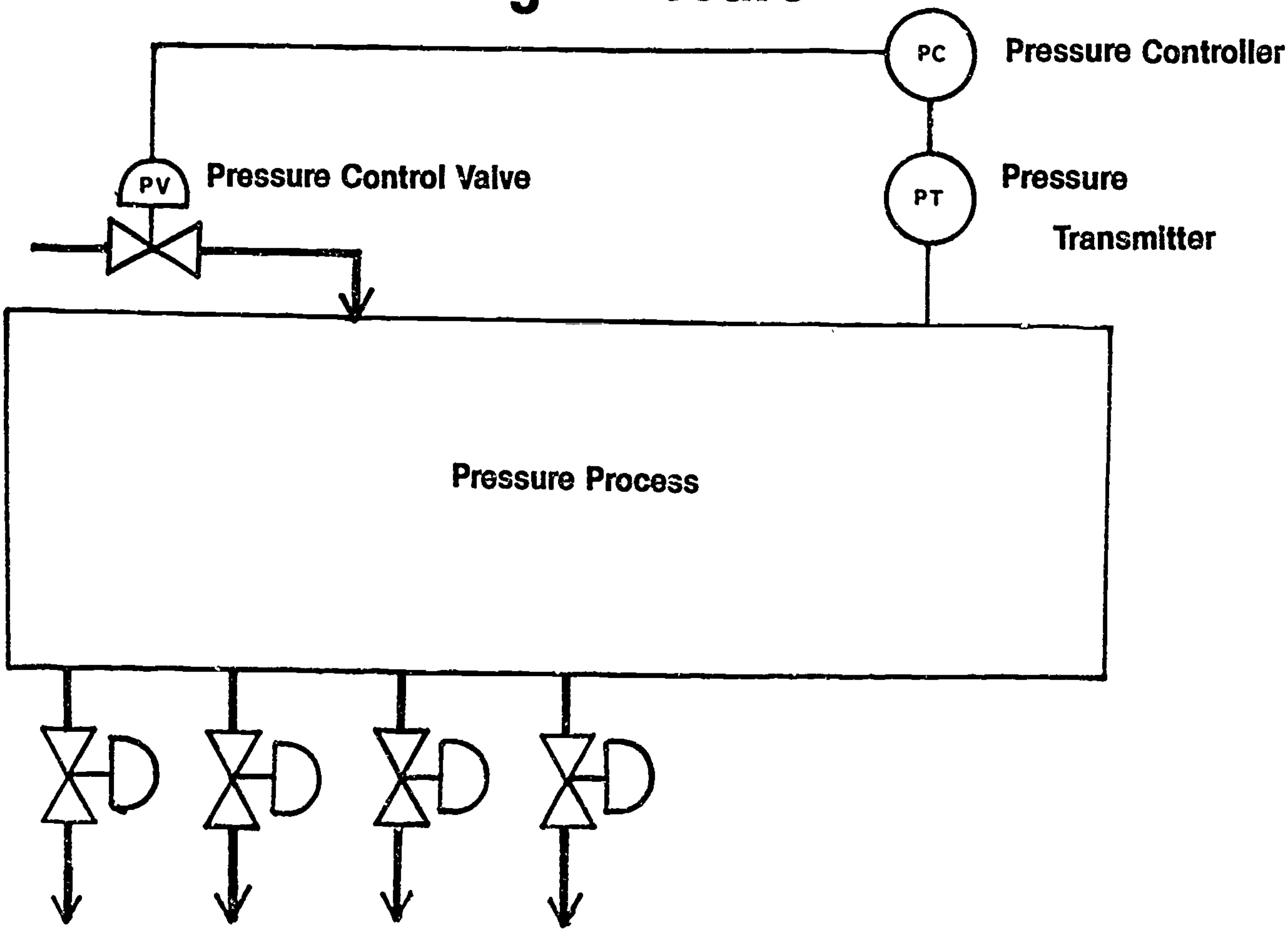

Courtesy Extension Instruction and Materials Center (EIMC)
The University of Texas at Austin

# Closed-Loop Control




Courtesy Extension Instruction and Materials Center (EIMC)
The University of Texas at Austin

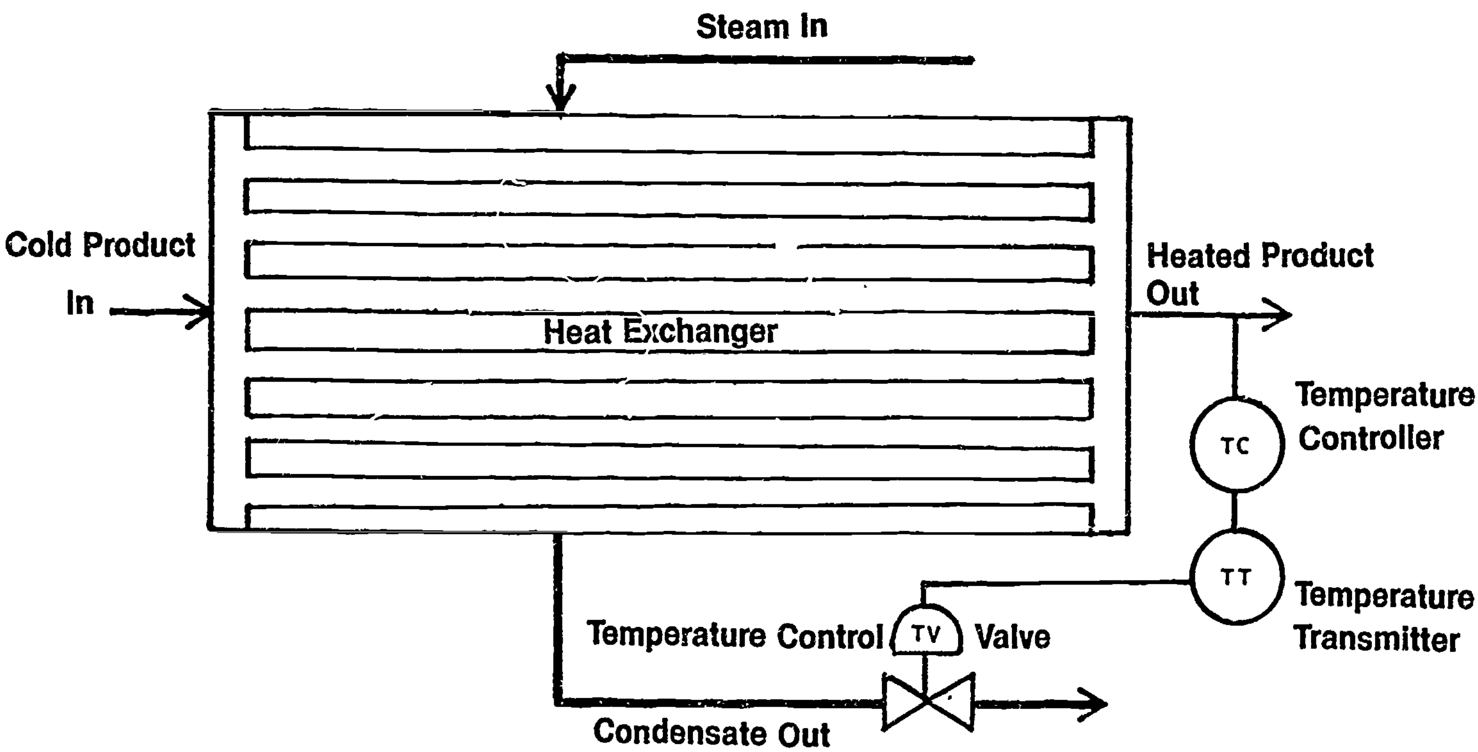
# Measuring Pressure




Process Load or Disturbance Variables

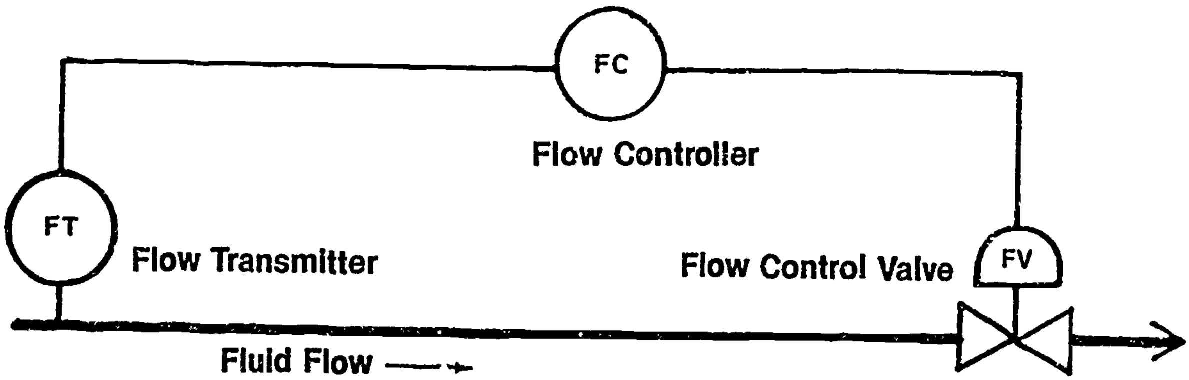
Courtesy Extension Instruction and Materials Center (EIMC)
The University of Texas at Austin

# Measuring Temperature



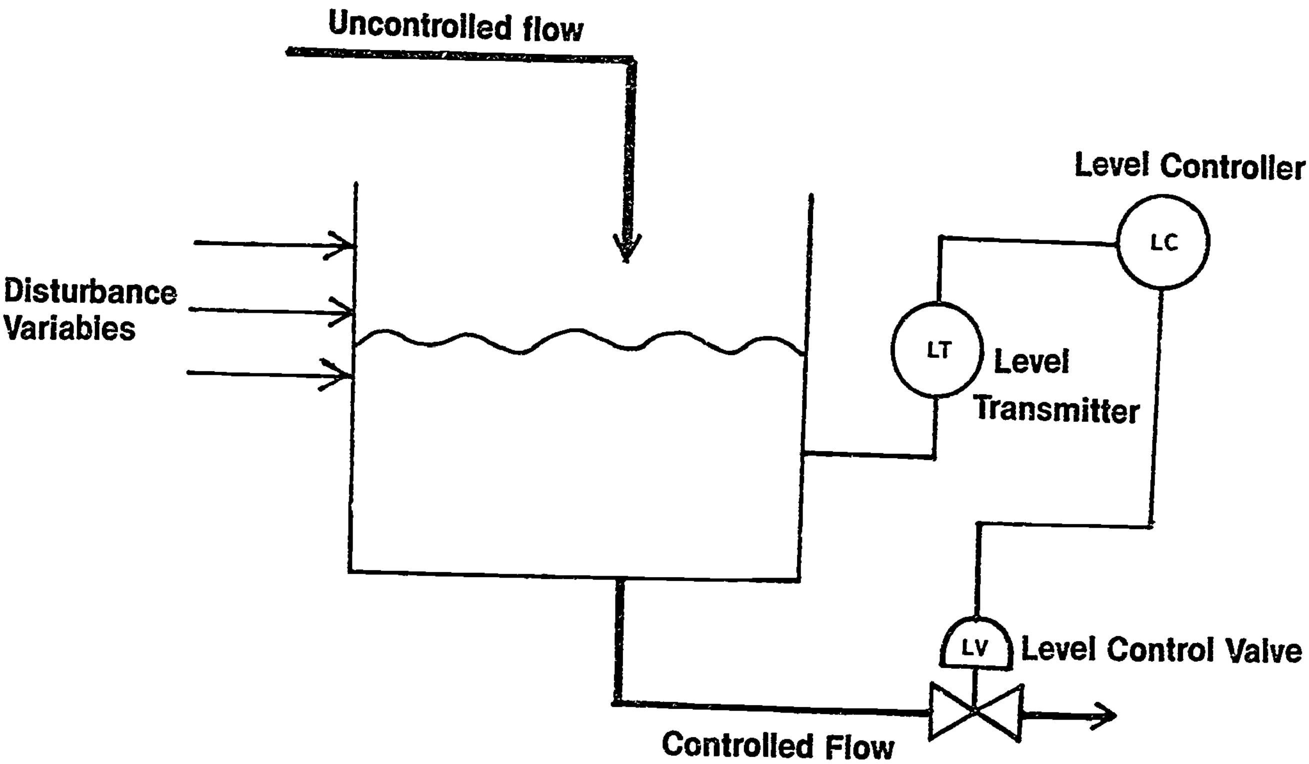

Courtesy Extension Instruction and Materials Center (EIMC)
The University of Texas at Austin

# Measuring Flow




Courtesy Extension Instruction and Materials Center (EIMC)
The University of Texas at Austin

# Measuring Level




Courtesy Extension Instruction and Materials Center (EIMC)
The University of Texas at Austin

# INTRODUCTION TO CONTROL SYSTEMS
# UNIT I

## ASSIGNMENT SHEET #1 — EVALUATE YOUR POTENTIAL AS AN INSTRUMENTATION TECHNICIAN

Directions: Answer the following questions honestly. Enter a number or zero for each question, then total your score and record it as indicated. Your evaluation is confidential and will not be seen by your instructor, but when it is completed, your instructor will interpret class scores generally so all class members will, so to speak, know the score.

1. a. How many times have you had your hair cut or styled in the past year? a. ________

   b. How often do you take a bath or shower each week? b. ________

   c. How often have you seen your dentist in the past two years? c. ________

   d. How many new pieces of clothing, including shoes, have you acquired in the past year? d. ________

   e. On a scale of 1 to 10, with 10 being the highest, how do you think you look when you're really dressed up? e. ________

   TOTAL ALL ITEMS FROM QUESTION 1 AND ENTER HERE 1. ________

2. a. How many jobs have you had that required you to greet or work with customers? a. ________

   b. How often in the past year have you really lost your temper? b. ________

   c. When you argue, give yourself a 1 if you think you argue intelligently, a 2 if you think you get too emotional when you argue, and a 3 if you really have fun arguing. c. ________

   d. How many times in the past year have you helped an acquaintance, friend, or relative alleviate or solve some problem simply by talking with them? d. ________

   e. If you were a baseball official, give yourself a 3 if you'd like to be a home-plate ump and call balls and strikes, a 2 if you'd like to be a first-base ump, and a 1 if you'd like to be a third-base ump. e. ________

   TOTAL ALL ITEMS FROM QUESTION 2 AND ENTER HERE 2. ________

## ASSIGNMENT SHEET #1

3. a. When it comes to going out with a friend to a movie or any activity, give yourself a 2 if you usually initiate the action and a 1 if you usually respond to invitations from others who invite you to come along. a. ________

   b. How many times in the past year have you decided that something you use needed repairing and then fixed it yourself? b. ________

   c. How many times in the past year have you called somebody long distance just to surprise them? c. ________

   d. If there were a leaky faucet in your bathroom or kitchen, give yourself a 1 if you would call a plumber and have it repaired, a 2 if you would ask someone how to repair it, and then try to do it yourself, and a 3 if you would tackle the job all alone with no outside help. d. ________

   e. Imagine you are trying to convince your best friend that you are a "go getter." give yourself a 1 if your friend would laugh hysterically, a 2 if your friend would simply change the subject, and a 3 if your friend would admit that it is a quality evident in your behavior. e. ________

   TOTAL ALL ITEMS FROM QUESTION 3 AND ENTER HERE 3. ________

4. a. How would you rate your own mechanical aptitude? Give yourself a 1 if your could at least change a tire safely, a 2 if you could tune up a car or motorcycle, and a 3 if you have ever accomplished any sort of major engine overhaul. a. ________

   b. How would you rate your skills as a mathematician? Enter a 1 if you can mentally run through the mul''plication tables, a 2 if you can add, subtract, multiply, and divide fractions, and a 3 if you can solve basic algebra problems. b. ________

   c. Which of the following jobs would you find most interesting. Give yourself a 1 if you'd prefer the simple task of putting a new washer on a leaky kitchen faucet, a 2 if you'd prefer to clean and align the heads of a tape recorder, or a 4 if you'd like to install and program a new setback thermostat for an air conditioning system. c. ________

   d. Give yourself a 3 if you can come within a dollar of accounting for all the money you have spent in the past week, a 2 if you can come within five dollars, and a 1 if you think you'll miss the estimate by more than seven dollars. d. ________

   e. On a scale of 1 to 10, with 10 being the highest, how would your friends rate your dependability factor? e. ________

   TOTAL ALL ITEMS FROM QUESTION 4 AND ENTER HERE 4. ________

   TOTAL ITEMS 1,2,3, AND 4 AND ENTER HERE ________

# INTRODUCTION TO CONTROL SYSTEMS
# UNIT I

## ASSIGNMENT SHEET #2 — EVALUATE YOUR INTEREST IN AN ISA STUDENT CHAPTER

Directions: The ISA (Instrument Society of America) is a professional organization that supports and promotes the broad field of instrumentation through local chapters around the world. The ISA also has student chapters at vo-tech schools, colleges, and universities. Activities in student chapters provide beneficial exposure to contemporary activities in instrumentation, and numerous opportunities for worthwhile social activities. The following evaluation will help you determine your interest in joining or helping form an ISA student chapter in your area or at your school. Respond to each question by placing an "X" in the appropriate blank.

1. I would like to eventually find work in the field of instrumentation or a related field.

   Yes ☐ No ☐

   (NOTE: As a member of an ISA student chapter, you'll receive *IN-TECH*, a monthly ISA magazine which contains job advertisements from employers looking for qualified technicians. Also, when you complete your technical training, you'll be able to place your own job-wanted ad in the *IN-TECH* at no cost. What's more, your student chapter association with an area or local ISA chapter makes local and area employers more aware of your school's instrumentation training.)

2. I feel that I have leadership potential, and would enjoy opportunities to improve my skills.

   Yes ☐ No ☐

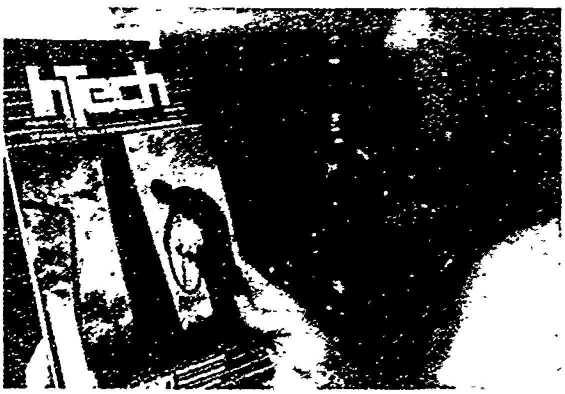
   (NOTE: Participating in student chapter activities will provide you many opportunities to improve your communication skills, and running for an ISA office provides invaluable experience in executing a plan of action.)

3. I like to keep up to date on new products and advancing technical developments in the field of instrumentation. (Figure 1)

   Yes ☐ No ☐

   (NOTE: ISA's *IN-TECH* magazine is dedicated to product and process news that reflects rapidly changing technology in the instrumentation field. Through *IN-TECH*, well-written, well-illustrated articles come to you every month.)

   FIGURE 1



# ASSIGNMENT SHEET #2

4. I would enjoy visiting local and area industries which hire instrumentation technicians, and would also enjoy hearing professional technicians and engineers talk about instrumentation

   Yes ☐ No ☐

   (NOTE: Local ISA chapters have guest speakers, and student chapter members are frequently invited to these special occasions. Field trips by student chapters do not have to be confined to local activity because many chapters finance extended field trips through their own fund-raising activities.)

5. I would be interested in participating in activities such as public relations, community work, fund raising, and organizing special events.

   Yes ☐ No ☐

   (NOTE: ISA student chapters help with United Fund Drives, do their own funding, plan special programs for themselves and local chapters, and find ways to present a positive chapter image to the school and the community.)

# INTRODUCTION TO CONTROL SYSTEMS
# UNIT I

## ANSWERS TO ASSIGNMENT SHEETS

**Assignment Sheet #1**

A. The major objective of the evaluation is to determine the student's ability to read and follow directions carefully. As directions indicated, every item should be answered, items in each of the four sections should be subtotaled, and the grand total of items 1, 2, 3, and 4 should be the very last entry in the evaluation. Any number left blank indicates a failure to follow instructions carefully.

1. With the exception of 1c, all items not answered with a minimum of 6 indicates a need for improvement in personal appearance or habits that promote good personal appearance, and anything less than a 6 on 1e indicates problems in self-esteem. If the total score on item 1 is less than 30, it points to habits and attitudes that need to be improved.

2. Anything less than a 5 as a total for item 2 indicates someone who may need to improve his or her verbal skills. A 3 as an answer to both 2c and 2e indicates good verbal skills and favorable self-esteem.

3. Anything less than a 5 as a total for item 3 indicates a lack of initiative. At least a 1 in item 3c indicates a concern for people, a good quality, and 1 is a perfect answer for 3e since it indicates appreciation for honesty in personal relationships.

4. Anything less than an 8 for item 4 may indicate a lack of math skills or a person who is not mechanically inclined or may simply have an interest in other than mechanical things. A 3 on 4b reflects good basic math skills that instrumentation technicians must have, and a 4 on 4c indicates one who appreciates the challenge of a complex job.

Anything less than 50 as a total score indicates attitudes and habits that need attention, and could also indicate a lack of math or mechanical aptitude.

**Assignment Sheet #2**

If you marked "no" to most or all of the questions, you may want to reexamine your reasons for entering an instrumentation program. If you marked "yes" to two or more of the questions, you will benefit by talking with your instructor about becoming a member of an ISA student chapter.

# INTRODUCTION TO CONTROL SYSTEMS
# UNIT I

NAME ____________________

## TEST

1. Match terms related to introduction to control systems with their correct definitions.

| | | | |
|---|---|---|---|
| _____a. | That part of a system that produces a desired response to given input conditions | | 1. Regulation |
| _____b. | A signal or other form of information sent back from a system output for use by the system controller | | 2. Measurement |
| _____c. | The arrangement of components to complete a system that can perform a control function | | 3. Feedback |
| _____d. | The procedure of determining the value of a variable of interest such as measuring temperature with a thermometer | | 4. System |
| _____e. | The complex system used to manufacture a product, or the actual procedure used to manufacture a product | | 5. Process |
| _____f. | The control action that holds a variable of interest close to its setpoint when a control system is in operation | | 6. Control |
| _____g. | The input, controller, and output components integrated to accomplish a given task in a process | | 7. Loop |
| _____h. | A desired value such as degrees of temperature or pounds of pressure used as a reference point that a controller can compare with a variable of interest to determine if the variable requires change | | 8. Setpoint |

2. Solve problems concerning safety by providing solutions for the following problems.

   a. Two fellow employees are throwing paper airplanes around the workplace. Is the condition unsafe, and if so, what solution would correct the condition?

   Answer ____________________________________________

   ____________________________________________________

# TEST

b. What will help correct the condition of employees exposed to loud noises in the workplace?

Answer ____________________

c. Beyond general dangers, what might be present in the workplace that signs or posters would warn employees about?

Answer ____________________

3. Complete statements concerning open-loop control systems by inserting the word(s) that best completes each statement.

   a. A control system that has no means of sending information back to a ____________ ____________ is called an open-loop system.

   b. An open-loop system is usually a simple control where a ____________ is set, and the control device proceeds on that setting.

   c. An open-loop system has no means of sending information back to a control device, and the lack of ____________ is what differentiates an open-loop system from a closed-loop system.

4. Complete statements concerning closed-loop control systems by inserting the word(s) that best completes each statement.

   a. An automatic process control system is a set of devices which when ____________ at a given value will produce an outcome appropriate to the ____________.

   b. A typical closed-loop system operates in an order:

      1) The system is set on a point of control, and that ____________ ____________ is compared with some input from the system which indicates the condition of a variable such as temperature.

      2) The feedback to the controller is compared with the ____________ ____________, and if the two do not match, the controller sends a signal to a final control device.

      3) The final control device initiates the activity which will correct the variable to ____________.

   c. The essential difference between an open-loop and a closed-loop system is the capacity of the closed-loop ____________ to act on feedback.

## TEST

5. Select true statements concerning control system applications by placing an "X" beside each statement that is true.

   (NOTE: For a statement to be true, all parts of the statement must be true.)

   _____a. Controls can be applied to any physical phenomena that can be accessed and measured.

   _____b. Certain physical phenomena that can be readily accessed and measured have become classical applications, and these include:

   1) Pressure.

   2) Temperature.

   3) Flow.

   4) Level.

   _____c. The ability to measure something that has to be controlled is vital to process controls, and all applications involve some method of measurement.

6. Complete statements concerning measuring pressure by inserting the word(s) or figure(s) that best complete each statement.

   a. Pressure is created by resistance to flowing liquids, by air, and by steam, and common applications are __________ pressure in the home, and __________ pressure in a pressure cooker.

   b. Pressure is often measured in __________ __________ __________ __________, or it can also be measured in KiloPascals.

   c. A common applications of pressure control takes place in an air compressor:

   1) The compressor must pump air into a holding tank in order to provide a user with a sufficient __________ of air.

   2) As air is used, the air pressure in the holding tank drops, and a __________ __________ __________ such as a diaphragm, a bellows, or a bourdon tube will physically turn on a switch that starts the compressor pumping more air into the holding tank.

   3) When the pressure in the holding tank builds to __________ __________, the same device that closed the switch to start the compressor will open the switch to stop the compressor.

   d. Industrial processes such as refining __________ and chemical manufacturing rely heavily on pressure measurement and control.

# TEST

7. Complete statements concerning measuring temperature by inserting the word(s) or figure(s) that best completes each statement.

   a. Temperature is created by the presence or lack of ____________.

   b. Temperature is often measured by ____________ in degrees celcius, °C, or degrees fahrenheit, °F.

   c. In industrial applications, temperatures may also be measured by thermistors, ____________, and infrared devices.

   d. A common application of temperature control takes place in the preparation of soup for canning:

      1) Raw meats and vegetables are placed in a large vessel of water cooked for a specific length of time at a ____________ temperature.

      2) This is called ____________ ____________, and the soup is cooked by steam in the jacket of the cooking vessel.

      3) The batch process has a ____________ that receives an input signal and compares the input temperature with the set point temperature.

      4) If the temperatures are not equal, the controller sends an error signal to an ____________ device, normally a control valve.

      5) The final control element, in this case a steam control valve, will be turned ____________ if the temperature is too low, or turned ____________ or partially ____________ if the temperature is too high.

      6) The controlled batch process avoids cooking or overcooking the soup, and maintains a consistent, ____________ product.

   e. Temperature measuring devices may produce electrical output signals, or produce mechanical or pressure changes, and the devices used for input must ____________ the system.

8. Complete statements concerning measuring flow by inserting the word(s) or figure(s) that best completes each statement.

   a. Flow is created by movement of ____________ or gases through pipes or ducts.

   b. Flowing liquids are usually measured in quantities related to time,such as ____________ per minute or ____________ per hour.

   c. Flowing gases and steam are measured by several means ranging from venturi tubes to ultrasonic flow meters, and an ____________ ____________ is a much used flow measuring device.

# TEST

d. A common application of flow is the measurement and control of gas flow into the burner of a boiler that produces steam for use in manufacturing:

1) Gas flow into the burner will be affected by many ____________ such as water flow into the boiler tubes, the amount of oxygen leaving the furnace via the gas flue, the air input to the burner, and the temperature and quantity of steam output.

2) Other variables aside, the flow of gas into the burner must function in ______ _____ to the demand for steam from the boiler.

3) Both the flow of gas and the flow of steam in a pipe must be measured, and this is usually accomplished by ____________ the flow of material in a pipe.

4) The restriction in the pipe will cause a ____________ ____________ at the point of restriction, and the orifice plate is the device most commonly used for this measurement.

5) The pressure drop method seems a round about way to measure flow, but it is an inexpensive procedure, and does not cause a great ____________ of energy in exchange for an accurate measurement.

6) As the demand for steam increases, the change in flow is detected by the orifice plate and associated instrumentation, and a signal is sent to the ____________.

7) The ____________ compares the gas flow with the steam flow, and if the two do not match, the ____________ will open or close the gas control valve to increase or decrease steam production.

e. In many industrial applications, variables are interactive, and a change in flow rate could be produced by a change in ____________ or ____________.

9. Complete statements concerning measuring level by inserting the word(s) or figure(s) that best complete each statement.

a. Level is the degree to which any container is filled with or emptied of a ____________, ____________, or ____________.

b. Level measurements reflect the ____________ of contents in a container, and may be accomplished by measuring the static head, with bubble tubes, or with ultrasonic or capacitive sensors.

c. A common, yet reliable device for level measurement is a ____________ with a cable eel or a tape which indicates liquid level.

d. To measure the level of ____________ in a bin requires methods such as measuring the weight of the bin or using radiation source/counter techniques.

# TEST

e. A common application of level is the measurement of level in a storage tank at a petroleum refinery:

1) A typical tank would be filled with a finished product which feeds into a ____________ for transport to another part of the country.

2) When the tank is down to 20% full, it will be switched from the pipeline to a fill pipe, so if the tank holds 100,00 gallons of product, it will switch to the refill cycle when it is down to ____________ gallons.

3) The tank has a fixed, covered top with a level ____________ attached to it.

4) The level ____________ consists of a float with a stainless steel band perforated with holes that code the ____________ of the float in the tank.

5) The float rides on a cable that is anchored to the bottom and top of the tank, and the float rides up and down the cable in a tube called a stilling well so that it will not be affected by ____________ ____________ during pumping.

6) As liquid is pumped from the tank, the float moves ____________ as the perforations are read by the sensor on top of the tank.

7) When the code for 20,000 gallons is transmitted to the controller, the controller finds a match with the ____________ ____________.

8) The controller sends a signal to the valve that controls output from the tank, and also signals to turn off the ____________ pump and turn on the ____________ pump.

9) The tank will fill until the float with its coded tape reaches a setpoint, and then the filling action will ____________, the action will reverse, and pumping will begin again.

10. Select true statements concerning mechanical controls by placing an "X" beside each statement that is true.

_____a. Control systems in general have their beginnings in the Industrial Revolution which began in England in 1900, and soon spread to the rest of the world.

_____b. The machines that helped make work easier and less monotonous required additional devices to control them, and mechanical controls were the first controls in the evolution of control systems.

_____c. The steam engine that was invented to pump water from deep mines had mechanical controls in the form of valves for admitting and exhausting steam.

# TEST

_____d. The reciprocating pit saws used in shaping lumber had mechanical controls to reverse their blades.

_____e. The automatic speed regulator for steam engines worked on the principle of the centrifugal force of a spinning weight which moved up a clevice to shut off the steam supply when the engine reached a certain speed, and the same control concept is used in the starter switches on modern electric motors.

_____f. Safety became a factor with mechanical devices, and the dead-man brake was invented for steam run devices so that if an operator fell asleep or lost control, the device would stop.

_____g. Mechanical controls were present in an 1801 invention for weaving cloth, and in 1833, Charles Babbage in England build the first mechanical computers.

_____h. Mechanical controls are seldom used in modern control devices.

11. Select true statements concerning pneumatic controls by placing an "X" beside each statement that is true.

_____a. Air-operated or pneumatic controls were a result of expanding industries and the need for control devices that could be extended out from central units to peripheral devices in an installation.

_____b. Expanding mechanical controls required running shafts and control rods through a plant, but such controls were expensive and created mechanical hazards.

_____c. Early in the industrial revolution, scientists discovered the properties of hydraulics and pneumatics, and even designed oil- and air-operated servo devices which became the muscle in control systems.

_____d. The discovery of great oil reserves in the early 1900s, and the invention of oil and gas operated engines increased the popularity of hydraulic devices.

_____e. Designers found oil to be far too expensive to use as a medium for control, and turned more and more to air as a control medium.

_____f. Pneumatics grew in popularity because air is readily available, air is clean and nonflammable, and air could be piped to any part of an installation in relatively small tubes.

_____g. Another advantage of using air was that a break in an air line caused no mess, and the tubes were inexpensive and easy to repair.

_____h. Pneumatic controls have not been developed to a high degree of sophistication.

## TEST

_____i. Pneumatic control systems with their successes in flexibility and miniaturization served as models for electrical systems that came along later.

_____j. Pneumatic systems are still used in conditions where the use of electricity would create a potential for explosion, but seldom used elsewhere.

12. Select true statements concerning electrical/electronic controls by placing an "X" beside each statement that is true.

    (NOTE: For a statement to be true, all parts of the statement must be true.)

    _____a. In the late 1930s, two things happened that changed the history of control systems:

    1) Electrical Power was becoming widely distributed and reliable.

    2) The new area of vacuum tube electronics was being expanded from radio applications to control applications.

    _____b. A new control industry expanded rap.dly, and electrical/electronic control devices were invented to work with mechanical/pneumatic devices.

    _____c. Because of their low cost and flexibility, the new electrical/electronic control devices began to replace mechanical and pneumatic applications.

    _____d. The development of solid-state devices in the 1960s, and the advent of microprocessors in the 1970s helped the movement to electronic controls.

    _____e. The energy crisis of the late 1970's, and the accelerating price of energy served to strengthen the switch to electronic controls.

    _____f. With the arrival of microcomputers and large memories, electronic controls have taken another giant step, and the introduction of artificial intelligence into controls is taking the field closer to the ultimate objective of humanlike control devices.

13. Complete statements concerning career overview by inserting the word(s) that best completes each statement.

    a. Because of rising energy costs, all employers are interested in control systems that can ____________ energy consumption.

    b. The need for effective, cost-reducing control systems has created a great deal of interest in controls and their related ____________.

    c. Because control systems rely heavily on sophisticated formulas, a potential instrumentation technician should have high school mathematics through ____________, and if possible, introduction to ____________________.

## TEST

d. Other prerequisites for the would-be technician include a general knowledge of technology, and a sound ____________ aptitude.

e. Among job responsibilities, the control instrumentation technician installs controls and control systems, calibrates systems, performs routine ____________, and ____________ as required.

f. The technician will also have to ____________ and ____________ devices in a system, and accurately log records of maintenance and repair activity.

g. Because instrumentation requires a clean environment to maintain accuracy, a technician must be neat and have ____________ work habits.

h. There is a ____________ job outlook for control instrumentation technicians because the drive to reduce energy costs has opened the door to extensive instrumentation in both business and industry.

i. The instrumentation area offers ____________ ____________ ____________ salaries, and since instrumentation is related to analog and digital electronics, microprocessors, and energy management, the field offers entry access to other fast growth areas.

14. Complete statements concerning troubleshooting by inserting the word(s) that best complete each statement.

a. Unpredicted downtime can be an enormous expense to industry, and that is why technicians who can quickly troubleshoot and solve downtime problems are ____________ by industry.

b. To be a good troubleshooter, a technicians must have an intimate knowledge of a process, all the equipment used in the process, and the concepts of the ____________ ____________.

c. Years of study and hard work are required to become a skilled troubleshooter, but the economic rewards are ____________, and the prestige of the job is ____________.

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

15. Evaluate your potential as an instrumentation technician.

16. Evaluate your interest in an ISA student chapter.

# INTRODUCTION TO CONTROL SYSTEMS
# UNIT I

## ANSWERS TO TEST

1. a. 6
   b. 3
   c. 7
   d. 2
   e. 5
   f. 1
   g. 4
   h. 8

2. a, The condition is unsafe. Anyone engaged in horseplay should be encouraged to stop or be reported to a supervisor.
   b. Wearing ear plugs
   c. The presence of hazardous materials

3. a. Control device
   b. Variable
   c. Feedback

4. a. Set, setting
   b. 1) Setpoint
      2) Setpoint
      3) Setpoint
   c. Controller

5. a, b, c

6. a. Water, steam
   b. Pounds per square inch
   c. 1) Volume
      2) Pressure measurement device
      3) Setpoint
   d. Oil

## ANSWERS TO TEST

7. a. Heat
   b. Thermometers
   c. Thermocouples
   d. 1) Fixed
      2) Batch processing
      3) Controller
      4) Output
      5) On, off, off
      6) Quality
   e. Match

8. a. Liquids
   b. Gallons, barrels
   c. Orifice plate
   d. 1) Variables
      2) Relation
      3) Restricting
      4) Pressure drop
      5) Loss
      6) Controller
      7) Controller, controller
   e. Pressure, temperature

9. a. Liquid, gas, solid
   b. Amount
   c. Float
   d. Solids
   e. 1) Pipeline
      2) 20,000
      3) Sensor
      4) Sensor, location
      5) Fluid movement
      6) Downward
      7) Set point
      8) Output, input
      9) Stop

10. b, c, d, e, f, g

11. a, b, c, d, f, g, i

12. a, b, c, d, e, f

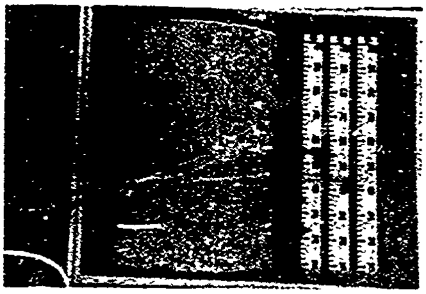
# ANSWERS TO TEST

13.
  a. Reduce
  b. Careers
  c. Algebra, trigonometry
  d. Mechanical
  e. Maintenance, recalibration
  f. Troubleshoot, repair
  g. Orderly
  h. Favorable
  i. Good to excellent

14.
  a. Treasured
  b. System design
  c. Excellent, rewarding

15. Evaluated to the satisfaction of the instructor

16. Evaluated to the satisfaction of the instructor



# SYSTEM COMPONENTS
## UNIT II

## UNIT OBJECTIVE

After completion of this unit, the student should be able to relate sensing devices to their uses in measuring temperature, pressure, level, and flow. The student should also be able to discuss transmitters, receiving devices, controllers, control elements, valves, and servo devices and their applications in process controls. The student should also be able to discuss ISA standards for the field of instrumentation, and use standard ISA symbols to identify instruments in a simple process system. These competencies will be evidenced by correctly completing the procedures outlined in the assignment sheet, and by scoring a minimum of 85 percent on the unit test.

## SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to system components with their correct definitions.
2. Select true statements concerning sensors used for measuring temperature.
3. Solve problems concerning sensors used for measuring pressure.
4. Complete statements concerning sensors used for measuring flow.
5. Select true statements concerning sensors used for measuring level.
6. Solve problems concerning other sensing devices.
7. Match transmitter devices with their characteristics.
8. Complete statements concerning special transmitter designs.
9. Match receiver devices with their characteristics.
10. Complete statements concerning indicators.
11. Select true statements concerning recorders.
12. Solve problems concerning controllers.
13. Complete statements concerning control elements.

## OBJECTIVE SHEET

14. Select true statements concerning valves and actuators.
15. Complete statements concerning servo devices.
16. Select true statements concerning the P&ID (Process and instrumentation Diagram).
17. Interpret basic ISA symbols.
18. Interpret ISA identification letters and symbols.
19. Identify instruments used in a simple process system. (Assignment Sheet #1)

# SYSTEM COMPONENTS
# UNIT II

## SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information sheet.

C. Make transparencies.

D. Discuss unit and specific objectives.

E. Discuss information sheet.

F. Use overheads and other illustrations or video materials to reinforce items in the information sheet.

G. As individual system components are discussed, have the components available to demonstrate to students what they look like, and how they function.

H. Review safety requirements for handling components, and discuss the dangers of high-temperature and high-pressure systems.

I. Give test

## REFERENCES USED IN DEVELOPING THIS UNIT


A. Johnson, Curtis D. *Process Control Instrumentation Technology*. New York, NY: John Wiley & Sons, 1982.

B. Tyson, Forrest. *Industrial Instrumentation*. Englewood Cliffs, NJ: Prentice-Hall Book Co., 1980.

C. Hall, Ronald P. *Automated Process Control Systems (Concepts and Hardware)*. Englewood Cliffs, NJ: Prentice-Hall Book Co., 1981.

D. Potvin, John. *Applied Process Control Instrumentation*. Reston, VA: Reston Publishing Co., 1983.

E. *Instrumentation Basics Module D, Instrumentation Diagrams and Symbols*. Research Triangle Park, NC 27709: Instrument Society of America, 1981.

F. Whalen, Bruce R. *Basic Instrumentation*. Third Edition. Austin, TX 78758: Petroleum Extension Service, University of Texas at Austin, 1983.

# SYSTEM COMPONENTS
# UNIT II

## INFORMATION SHEET

I. **Terms and definitions**

A. Sensor — A device for detecting or measuring a physical property or characteristic

B. Transducer — A device that detects information in one form and transforms it into another form or quantity

C. Transmitter — A transducer which converts a measured variable into a standard transmission signal

D. Non-invasive — The making of a measurement or completion of an operation by an instrument that can function without having to open or enter the process being measured

E. Piezoelectric — Electrical generation produced when natural or manufactured crystals are subjected to pressure; some man-made crystals are very powerful in voltage output

F. Instrumentation — The equipment and software required to monitor energy levels and other variables in a process, and to control the energy exchanges required to complete the processing of raw materials

G. Inferential — An indirect method of measuring a variable by inferring a result such as inferring flow measurement from a pressure differential reading

H. Process variable — The media or condition in a process that is being measured and controlled

I. Restrictor — A reduced section of pipe which causes a measurable pressure drop and permits measurement of flow through a line

J. Ultrasonic — High frequency sound waves (200 KHz to 500 KHz) used to measure process variables

K. Local — A device such as a controller that is installed at the point of application

L. Remote — Removed from the point of application such as readouts for sensing devices in hazardous environments

# INFORMATION SHEET

II. **Sensors used for measuring temperature**

A. The most common device for measuring temperature is the liquid filled thermometer.

B. Sensors common in industrial temperature measuring include:

1. Thermistors.

2. RTD's (resistance temperature detectors).

3. Filled-thermal systems.

4. Linear IC (integrated chip) devices.

5. Bimetallic devices.

6. Thermometers and IR (infrared) thermometers.

7. Thermocouples.

8. Optical sensors.

C. Because they are rugged, low cost, do not require a power source, and are available in a wide range of types, thermocouples are the most frequently used temperature measuring devices in industry.

III. **Sensors used for measuring pressure**

A. Pressure sensing devices using bellows, diaphragms, and bourdon tubes date back to the early days of process controls and are still available for a wide variety of applications.

B. Because many pressure sensors are mechanical, it is necessary to transduce and transmit the pressure reading, so most pressure sensors are also transmitters.

C. Newer types of pressure sensors include piezoelectric devices, strain gauge devices, and pressure-sensitive IC devices which are all smaller and lower in cost than traditional pressure sensing devices.

D. Some IC sensing devices are being designed with miniature electronic controls or with microprocessors to make "smart" sensors that function closer to the objective of human-like monitoring.

# INFORMATION SHEET

IV. **Sensors used for measuring flow**

A. Most flow sensing devices are designed to measure flow through a pipe or a tube.

B. Measuring flow has always been a design challenge because measuring flow directly usually interferes with the flow of media through the pipe.

C. The simplest method used to measure flow is to channel the flow into a tank and measure the quantity flowing into the tank in seconds, minutes, or hours.

EXAMPLE: A 1,000 gallon tank that is filled every two hours has a flow rate of 500 gallons per hour.

D. Some sensors such as turbines and displacement pistons measure flow by filling and dumping liquid, and recording the number of times per interval this occurs.

E. Flow rate is often "inferred" by measuring another condition, and an orifice plate does this by measuring the pressure differential across a restricted area in a pipe.

EXAMPLE: As the flow rate rises, the pressure drop will increase, and as the flow rate drops, the pressure drop will decrease.

F. Vortex flow meters extend into a pipe and create swirling currents (a vortex) behind the projection, and the energy of the disturbance can be measured to indicate the flow rate.

G. Vortex meters are relatively new and gaining in popularity because they do not create the energy loss experienced with other systems.

H. Venturi tubes are used to measure flow, but they are very expensive and require a considerable length of pipe to be effective.

I. Ultrasonic sensors are being developed to measure flow, and although they are non-invasive, they are very expensive.

V. **Sensors used for measuring level**

A. One of the most common level measuring devices is a device that looks like an empty box covered with a diaphragm, and the device is placed at the bottom of a tank.

B. As liquid presses on a level measuring diaphragm, it provides a measure of the amount of liquid in the tank above the diaphragm.

## INFORMATION SHEET

C. A bubble tube is another level measuring device placed at the bo**om of a tank, and air or gas is forced out of the tube to indicate the amou..t of pressure needed to overcome the weight of the liquid, and this is a measure of the amount of liquid above the bubble tube.

D. Sight tubes are simple devices that permit visual monitoring of liquid level, and another simple procedure is to weigh the vessel, and then determine the amount of liquid by subtracting the weight of the vessel, and dividing by the unit of weight of the liquid.

E. Ultrasonic sensors send a sound wave to the bottom of a tank and record the time it takes the signal to return to the top of the liquid, and this technique works on some solids too.

F. Another system of measuring the level of solids is to install a radioactive isotope source in the bottom of the storage, and then reading the amount of radioactivity at the top; the level of the solid is determined by the amount of signal loss from bottom to top.

G. Level sensors are selected according to the material being measured, and the location of the vessel, and for these reasons, level sensors may give direct measurement or "inferred" measurement as the process dictates.

VI. **Other sensing devices (Transparency 1)**

A. In addition to temperature, pressure, flow, and level, there are other variables in process control and other sensors to measure them.

B. There are literally hundreds of different types of sensors, and Transparency 1 displays some of the diversity of sensor technology.

C. Other properties such as hardness and elasticity can be measured or inferred, and complex chemical and biological variables are sometimes measured with analyzers which combine sensors, controllers, and computers to solve difficult measuring applications.

VII. **Transmitter devices and their characteristics**

A. Process signal transmitters — Since sensor signals may be buried in the noise of the process itself, these transmitters usually enhance the sensor signal which can be transmitted a long distance to a controller in a control room.

B. Pneumatic transmitters — These are instruments that send air signals sent from a remote sensor or transducer to a receiver in a control system, and they are transmitted in a range of 3 to 15 psi to comply with ISA standards.

EXAMPLE: 3 psi represents the zero signal, and 15 represents the maximum signal, so a zero reading indicates the system is down, and the 12-wide range of 3 to 15 psi helps compensate for loss and prevents noise from masking the signal.

# INFORMATION SHEET

C. Electrical transmitters — These devices send signals in a range from 4 to 20 mA to comply with ISA standards; since 4 mA represents the zero signal, an actual reading of zero indicates the system is down.

D. Sensing transmitters — These transmitters reflect the move to miniaturization because they combine a sensor and a transmitter in one unit, and they have the capacity to transmit information a relatively long distance.

EXAMPLE: The differential pressure (d/p) cell is a typical sensing transmitter because it not only receives the difference in pressure from two points such as across an orifice plate, but it can transmit pressure drop directly to a controller, an indicator, or other device.

VIII. **Special transmitter designs**

A. Many sensors/transducers produce an electrical output that can be changed to the 4 to 20 mA signal easily with minimum cost; ICs that are very reliable can serve transmitter needs at a much lower cost than pneumatic transmitters, and the electrical signal can be transmitted farther than a pneumatic signal.

B. The wires that carry process variable signals sometimes pick up undue electrical noise in certain process environments, and the designer is sometimes forced to use a pneumatic signal.

C. A newer way around electrical noise is to transmit the signal on optical cables which are almost impervious to electrical noise.

D. Process signals can also be transmitted as electrical voltages, and this is common when signals are digitized and sent by a digital transmission voltage standard such as RS-242 or IEEE-488.

(NOTE: Voltage signals are generally used in high impedance systems (high resistance), and are subject to more noise and signal loss problems than the ISA 4-20 standard signals, and the ISA 4-20 standard signals are generally used in low impedance systems because they stay relatively noise free.)

E. In addition to sensor/transmitter single units, IC design permits the addition of intelligence in the form of a microcomputer, and this has produced a new breed of "smart" sensing transmitters that can perform local control tasks, gather and evaluate information, and send it on in digital form to a master computer.

IX. **Receiver devices and their characteristics**

A. Indicators — Show an operator the condition of a system at a moment in time.

EXAMPLE: A steam gauge which shows an operator boiler steam pressure output is an indicator.

## INFORMATION SHEET

B. Recorders — An extension of indicators in that they have timer-driven charts attached so that a momentary reading can be recorded for reference at a later time by an operator.

(NOTE: There may be hundreds of control loops in a large system, and a hard copy provides an operator with the critical information needed to look back on total system operation at a point in time.)

C. Controllers — Digital or analog systems that have the capability of sending back corrective signals to the system rather than passive monitoring of the process.

(NOTE: Controllers may include indicators and/or recorders along with a control mechanism.)

X. Indicators

A. A local indicator may or may not have separate indicator and sensor parts, but a remote indicator is always a two-part system, or sometimes more than two parts.

EXAMPLE: An air pressure gauge is a combined indicator/sensor because as air enters the gauge, it forces a bourdon tube or a bellows to change shape, and this change is sent by mechanical linkage to a pointer that moves in front of a calibrated scale to provide the operator with an indication of air pressure.

B. A minimum system would consist of a sensor/transmitter and an indicator device that would respond directly to the output of the transmitted signal.

C. Many systems have sensors, transmitters, signal conditioners, and receivers ahead of the indicator device.

XI. Recorders

A. A recorder receives an electrical or pneumatic input which is changed into mechanical motion which causes a pen or a stylus to write on a chart which is powered by some kind of clock.

(NOTE: Recording devices may or may not include an indicator, but they all move in response to a variable change and make a record of it.)

B. Input into a recorder may be pneumatic or electric.

C. When recorder input is electrical, it runs a meter movement device which converts current into pointer movement that swings in an arc and records on a chart.

# INFORMATION SH'

D. Electrical input into a recorder can also activate a solenoid or motor which converts current into a linear motion that moves the stylus back and forth over the chart.

E. When a recorder input is pneumatic, air comes into a bourdon tube, a spiral tube, or a bellows where it is converted mechanically to swing the stylus in an arc or in a back and forth linear motion over the chart.

F. The recorder mechanical parts are complex because they must convert the signal into the form required to run the stylus, and must also be adjustable to permit calibration and corrections for motion discrepancies and scale differences.

G. The mechanical mechanism is normally used to make scale changes if the user decides to adapt the recorder to a new task.

H. The mechanical parts of the recorder must also fit the cases that hold the round or scroll charts, and the mechanical design may vary considerably from large to small recorder boxes.

I. The clock that moves the chart may be a synchronous motor like an electric-clock motor, an air motor if electricity is not available, a battery-operated clock for remote units, and some older units still have wind-up clocks.

J. The timing mechanism of a recorder must operate in a time frame required by the process, and common reporting times are 24, 48, and 72 hours, long periods such as weeks or months at remote sites, and legal or governmental reports may have special reporting periods.

XII. Controllers

A. The function of a controller is to interpret incoming information by comparing it with desired points of operation, and then take action to correct deviation from setpoint.

B. The receiver element of a controller must accept the signal from a transmitter or transducer, match the input, and then transform the signal into a form that can be used by a control device.

EXAMPLE: If a differential transmitter sent a 3-15 psi air signal to the receiving portion of an electronic control device, the receiving portion of the controller must match the incoming pneumatic signal, interpret the pressure information, and then convert this information into electrical form for use by electrical control circuits.

(NOTE: Controllers will be discussed at length later in this text.)

# INFORMATION SHEET

XIII. Control elements

A. Control elements are that part of a system that cause a change in the item or media being controlled, and the change may happen because of direct or indirect action of the control element.

EXAMPLE: When a valve closes to reduce the flow of liquid in a process where flow rate is being controlled, that is direct action; when a valve controls the flow of steam into an exchanger that in turn heats a liquid and causes a rise in temperature, that is indirect control.

B. Control elements or final elements have two very important characteristics:

1. Since they operate directly on the item or media being controlled, they must be capable of withstanding the environment of the process.

2. The element must be capable of exercising considerable power over whatever is being controlled because it may have to close off flow to a process where considerable energy is expended.

C. The control element or final element is considered to be the "muscle" in a control system.

XIV. Valves and actuators

A. The final element in a control process is usually a valve.

B. Valves are operated by actuators which open and close valves.

C. Actuators are required because the control signal must be converted to enough mechanical energy to open or close a valve, and actuators do this.

D. Valves provide two basic kinds of control:

1. On/off.

2. Proportional.

E. The part of the valve that changes the flow rate may be designed as a plug, gate, cock, butterfly, or it may control by "pinching off" the flow.

XV. Servo devices

A. Servo devices, electrical or pneumatic, are sometimes used as actuators for control valves.

B. Pneumatic servos need a large area to run from instrument air, or they need an air-to-air amplifier or an air-over-oil system to provide the power necessary to move a valve.

## INFORMATION SHEET

C. Electrical servo devices include AC drive motors used mostly for smaller applications, and DC drive motors used for larger, high torque applications.

D. Stepper motors which can be driven by computer signals are becoming popular, but are found only in fractional horsepower sizes.

XVI. The P&ID (Process and Instrumentation Diagram)

A. Process and Instrumentation Diagrams, commonly called P&IDs, are used in designing systems, and afford technicians appropriate reference for monitoring, maintenance, and troubleshooting.

B. P&IDs use letters, lines, and symbols that are taken from ISA-S5.1, which means Instrument Society of American, Standard 5.1.

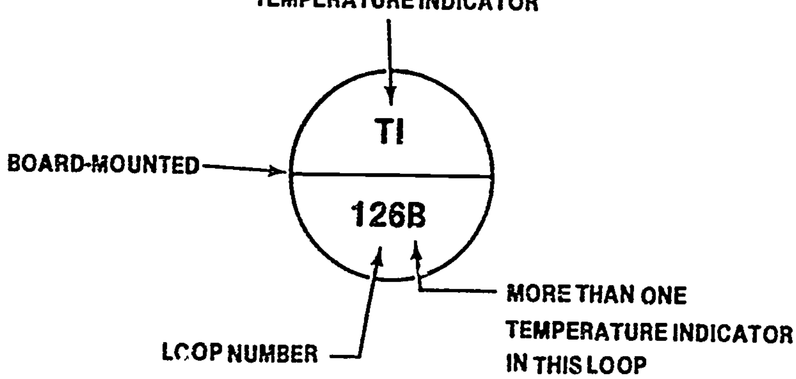
C. Loop diagrams are simplified P&IDs that isolate individual loops in a system.

D. P&IDs use ISA identification letters, instrument line symbols, and device symbols designed to provide uniformity in the field of instrumentation, and technicians need to know ISA letters and symbols.

XVII. Basic ISA symbols

A. Process instruments are always shown in a circle that is called a balloon, with the upper part of the balloon used to identify the variable and the instrument function, and the bottom part of the balloon used to identify the loop number.

FIGURE 1



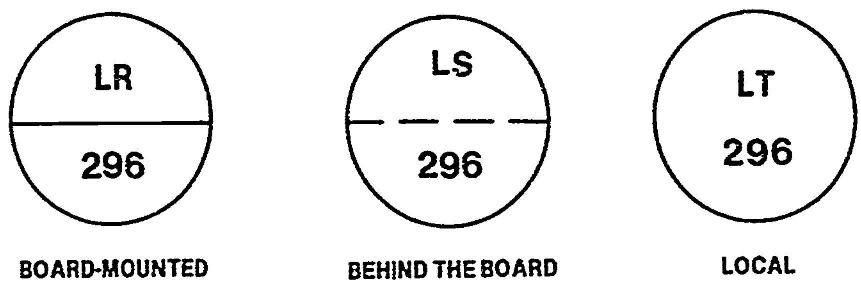

Reprinted by permission. Copyright ©Instrument Society of America 1984. From *ISA-S5.1—Instrumentation Symbols and Identification (ANSI/ISA-1984)*.

# INFORMATION SHEET

B. A solid line through a balloon indicates a board-mounted instrument, a dotted line through a balloon indicates an instrument mounted behind a board, and a balloon with no line through it indicates a field-mounted instrument.

(NOTE: Board-mounted instruments are usually accessible to a technician, instruments mounted behind a board are not normally accessible, and a local or field-mounted instrument is near a point of measurement or a final control element.)

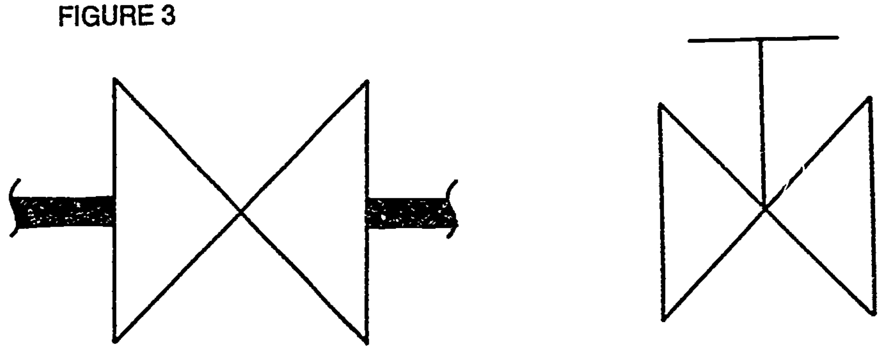
FIGURE 2






C. Valves used to control the flow of liquids use the basic symbol of connected triangles, and if the valve is operated by hand, a "T" is connected to the valve.

FIGURE 3

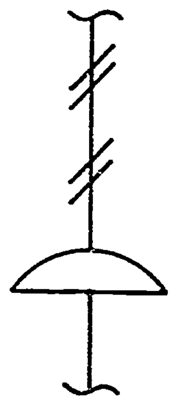


# INFORMATION SHEET

D. Actuators used to control valves frequently use a diaphragm device that is designated by a special symbol.

(NOTE: The diaphragm in Figure 4 is connected by a pneumatic signal.)

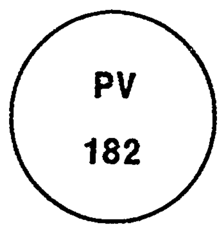
FIGURE 4





E. Valves may also be shown in balloons just as instruments are, and the balloon will indicate the type and the loop number.

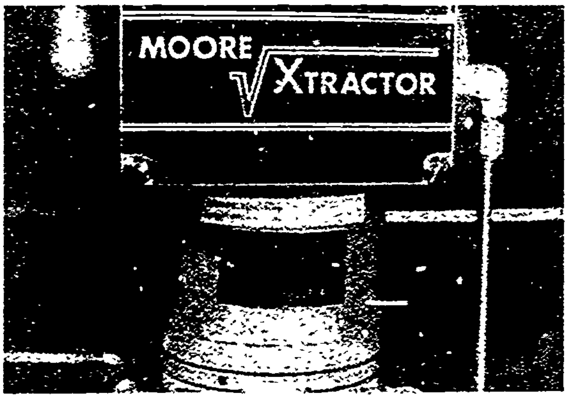
FIGURE 5



# INFORMATION SHEET

F. The mathematical symbol for square root is used to indicate a square root extractor, and is a device that will be seen often in P&IDs.

FIGURE 6




G. P&IDs, like blueprints, include notes that explain special characteristics of instruments, operation limits, and specifications for instrument types by name and model number.

(NOTE: Identification letters, line symbols, and other instrument symbols appear in the transparency masters that accompany the next objective.)

XVIII. **ISA identification letters and symbols**

A. Identification letters help define measured or initiating variables. (Transparency 2)

B. Instrument line symbols indicate types of power supplies and power transmission modes. (Transparency 3)

C. General instrument or function symbols define functions, and frequently indicate locations. (Transparencies 4 & 5)

D. Control valve body symbols and damper symbols indicate type and degree of function such as three-way or four-way. (Transparency 6)

E. Actuator symbols indicate both design and function. (Transparencies 7 & 8)

F. Symbols for self-actuated regulators, valves, and other devices indicate service features and applications. (Transparencies 9, 10, & 11)

## INFORMATION SHEET

G. Symbols for actuator action in event of actuator power failure indicate design and application. (Transparency 12)

H. Square root extractors have a special symbol, and are usually easy to spot because they are almost always beside relays. (Transparency 13)

# Sensor Types

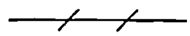
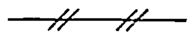
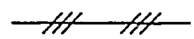
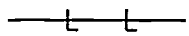
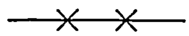
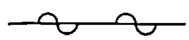
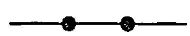
| Variable | Sensor | Typical unit of measure |
|---|---|---|
| Rotation | Tachometer | RPM |
| Timing | Counter/timer | Sec/Min/Hr |
| Humidity | Humidistat | Relative Percent |
| Light | Phototube, Solarcell | Candela |
| Acceleration | Accelerometer | $m/sec^2$ |
| Sound | Microphone | Decibels |
| Static (Electricity) | Electrometer | Volts |
| Color | Spectrometer | Angstrom |
| Position (Linear) | Potentiometer, Linear Variable, Differential, Transformer (LVDT) | Degrees |
| Position (Rotational) | Synchro or Digital Encoder | Degrees |
| EMF | Voltmeter | Volts |
| Current (Electrical) | Ammeter | Amperes |
| Magnetism | Magnetometer | Webers |
| Chemical | Specific Probes for Each Chemical Property | pH |

# Identification Letters

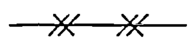
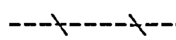
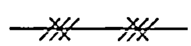
| | FIRST-LETTER (4) | | SUCCEEDING-LETTERS (3) | | |
|---|---|---|---|---|---|
| | MEASURED OR INITIATING VARIABLE | MODIFIER | READOUT OR PASSIVE FUNCTION | OUTPUT FUNCTION | MODIFIER |
| A | Analysis(5,19) | | Alarm | | |
| B | Burner, Combustion | | User's Choice(1) | User's Choice(1) | User's Choice(1) |
| C | User's Choice(1) | | | Control(13) | |
| D | User's Choice(1) | Differential(4) | | | |
| E | Voltage | | Sensor (Primary Element) | | |
| F | Flow Rate | Ratio (Fraction)(4) | | | |
| G | User's Choice(1) | | Glass, Viewing Device(9) | | |
| H | Hand | | | | High(7,15,16) |
| I | Current (Electrical) | | Indicate(10) | | |
| J | Power | Scan(7) | | | |
| K | Time, Time Schedule | Time Rate of Change(4,21) | | Control Station (22) | |
| L | Level | | Light(11) | | Low(7,15,16) |
| M | User's Choice(1) | Momentary(4) | | | Middle, Intermediate(7,15) |
| N | User's Choice(1) | | User's Choice(1) | User's Choice(1) | User's Choice(1) |
| O | User's Choice(1) | | Orifice, Restriction | | |
| P | Pressure, Vacuum | | Point (Test) Connection | | |
| Q | Quantity | Integrate, Totalize(4) | | | |
| R | Radiation | | Record(17) | | |
| S | Speed, Frequency | Safety(8) | | Switch(13) | |
| T | Temperature | | | Transmit(18) | |
| U | Multivariable(6) | | Multifunction(12) | Multifunction(12) | Multifunction(12) |
| V | Vibration, Mechanical Analysis(19) | | | Valve, Damper, Louver(13) | |
| W | Weight, Force | | Well | | |
| X | Unclassified(2) | X Axis | Unclassified(2) | Unclassified(2) | Unclassified(2) |
| Y | Event, State or Presence(20) | Y Axis | | Relay, Compute, Convert(13,14,18) | |
| Z | Position, Dimension | Z Axis | | Driver, Actuator, Unclassified Final Control Element | |

# Instrument Line Symbols

ALL LINES TO BE FINE IN RELATION TO PROCESS PIPING LINES.

| | | |
|---|---|---|
| (1) | INSTRUMENT SUPPLY * OR CONNECTION TO PROCESS |  |
| (2) | UNDEFINED SIGNAL |  |
| (3) | PNEUMATIC SIGNAL ** |  |
| (4) | ELECTRIC SIGNAL | ------------ OR  |
| (5) | HYDRAULIC SIGNAL |  |
| (6) | CAPILLARY TUBE |  |
| (7) | ELECTROMAGNETIC OR SONIC SIGNAL *** (GUIDED) |  |
| (8) | ELECTROMAGNETIC OR SONIC SIGNAL *** (NOT GUIDED) |  |
| (9) | INTERNAL SYSTEM LINK (SOFTWARE OR DATA LINK) |  |
| (10) | MECHANICAL LINK |  |

OPTIONAL BINARY (ON-OFF) SYMBOLS

| | | |
|---|---|---|
| (11) | PNEUMATIC BINARY SIGNAL |  |
| (12) | ELECTRIC BINARY SIGNAL |  OR  |

NOTE: 'Or' means user's choice. Consistency is recommended.

* The following abbreviations are suggested to denote the types of power supply. These designations may also be applied to purge fluid supplies.

AS - Air Supply
  IA - Instrument Air } Options
  PA - Plant Air
ES - Electric Supply
GS - Gas Supply

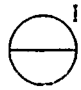
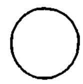
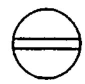
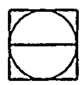
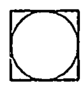
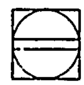
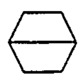
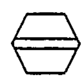
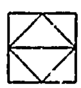
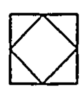
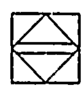
HS - Hydraulic Supply
NS - Nitrogen Supply
SS - Steam Supply
WS - Water Supply

The supply level may be added to the instrument supply line, e.g., AS-100, a 100-psig air supply; ES-24DC, a 24-volt direct current power supply.

** The pneumatic signal symbol applies to a signal using any gas as the signal medium. If a gas other than air is used, the gas may be identified by a note on the signal symbol or otherwise.

*** Electromagnetic phenomena include heat, radio waves, nuclear radiation, and light.

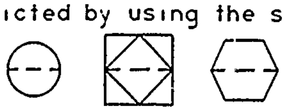
# General Instrument or Function Symbols

| | PRIMARY LOCATION *** NORMALLY ACCESSIBLE TO OPERATOR | FIELD MOUNTED | AUXILIARY LOCATION *** NORMALLY ACCESSIBLE TO OPERATOR |
|---|---|---|---|
| DISCRETE INSTRUMENTS | 1 * IPI **  | 2  | 3  |
| SHARED DISPLAY, SHARED CONTROL | 4  | 5  | 6  |
| COMPUTER FUNCTION | 7  | 8  | 9  |
| PROGRAMMABLE LOGIC CONTROL | 10  | 11  | 12  |

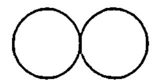
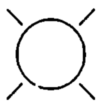
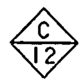
* Symbol size may vary according to the user's needs and the type of document. A suggested square and circle size for large diagrams is shown above. Consistency is recommended.

** Abbreviations of the user's choice such as IPI (Instrument Panel #1), IC2 (Instrument Console #2), CC3 (Computer Console #3), etc., may be used when it is necessary to specify instrument or function location.

*** Normally inaccessible or behind-the-panel devices or functions may be depicted by using the same symbols but with dashed horizontal bars, i.e.



# General Instrument or Function Symbols (Continued)

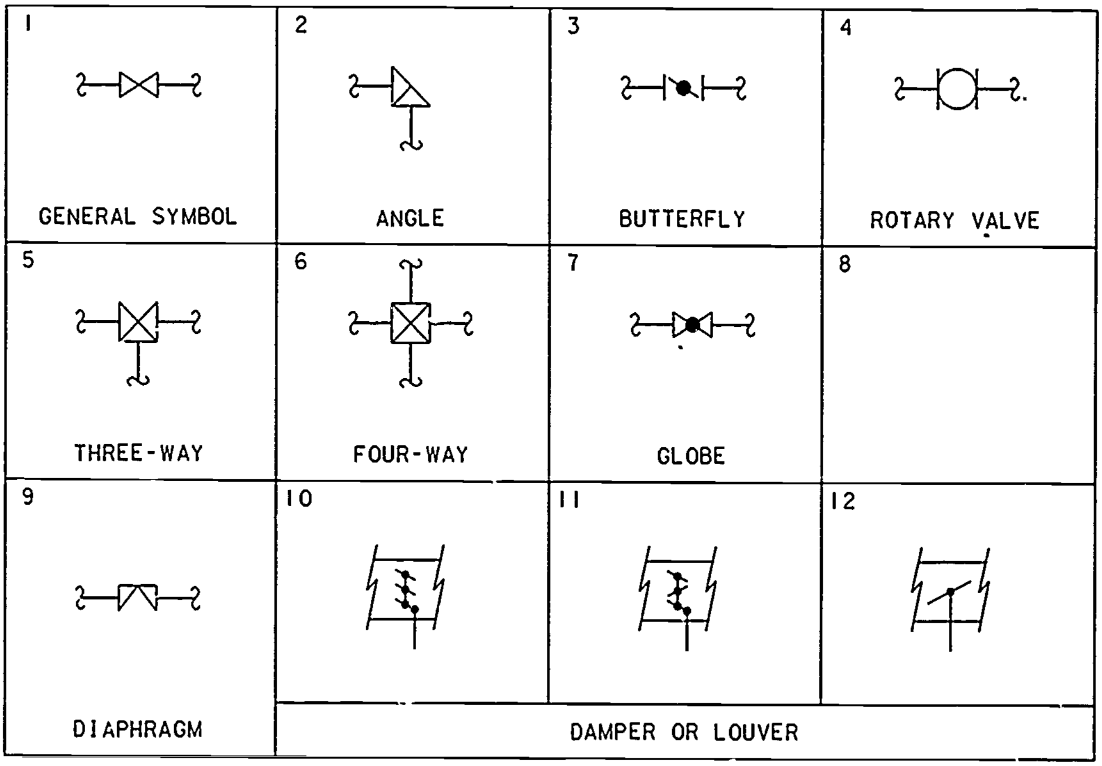
| | | |
|---|---|---|
| 13 | 14   INSTRUMENT WITH LONG TAG NUMBER | 15  INSTRUMENTS SHARING COMMON HOUSING* |
| 16  PILOT LIGHT | 17   PANEL MOUNTED PATCHBOARD POINT 12 | 18   ** PURGE OR FLUSHING DEVICE |
| 19   ** RESET FOR LATCH-TYPE ACTUATOR | 20  DIAPHRAGM SEAL | 21   ** *** UNDEFINED INTERLOCK LOGIC |

* It is not mandatory to show a common housing.

** These diamonds are approximately half the size of the larger ones.

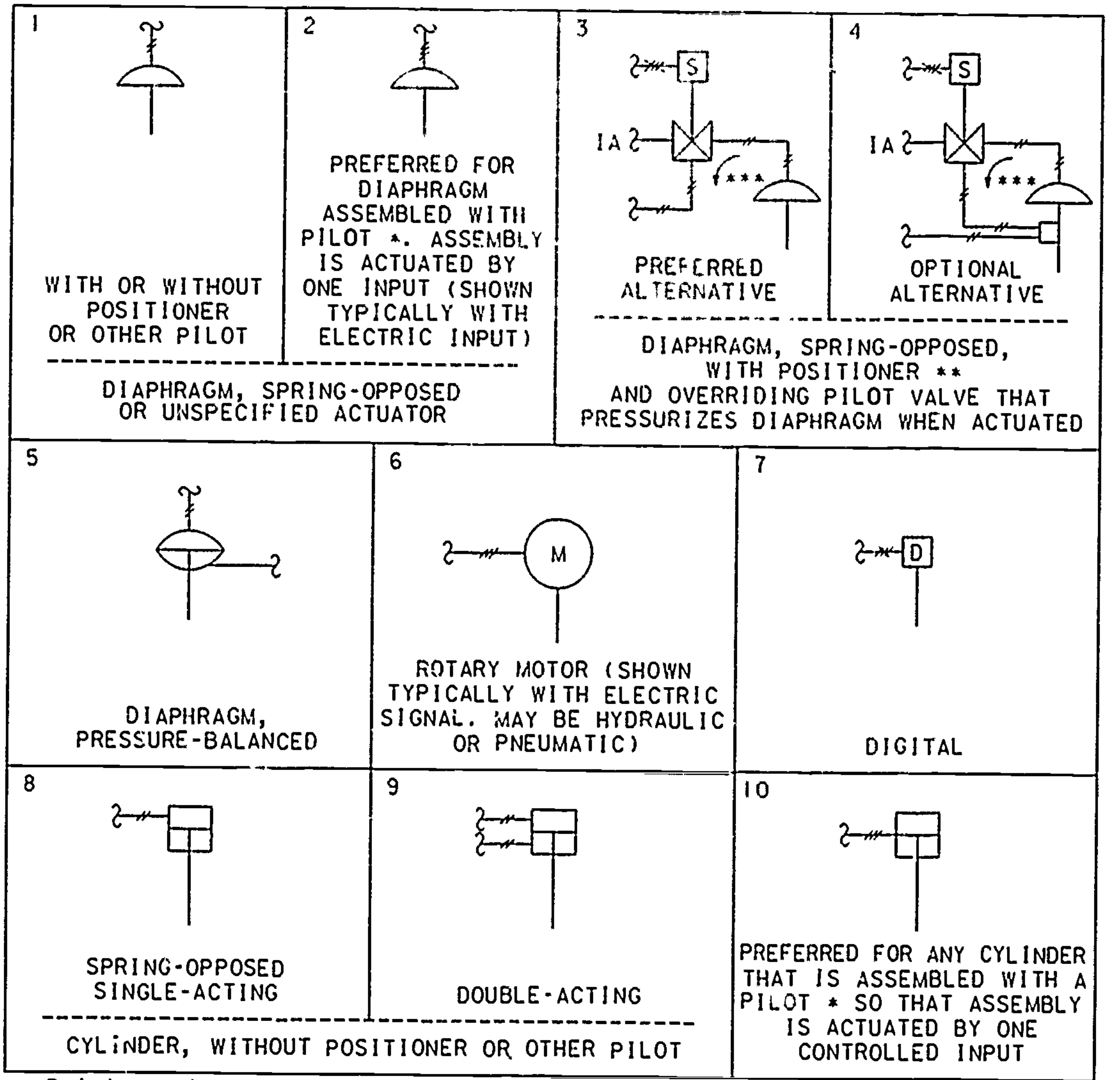
*** For specific logic symbols, see ANSI/ISA Standard S5.2.

# Control Valve Body and Damper Symbols




Further information may be added adjacent to the body symbol either by note or code number.

# Actuator Symbols

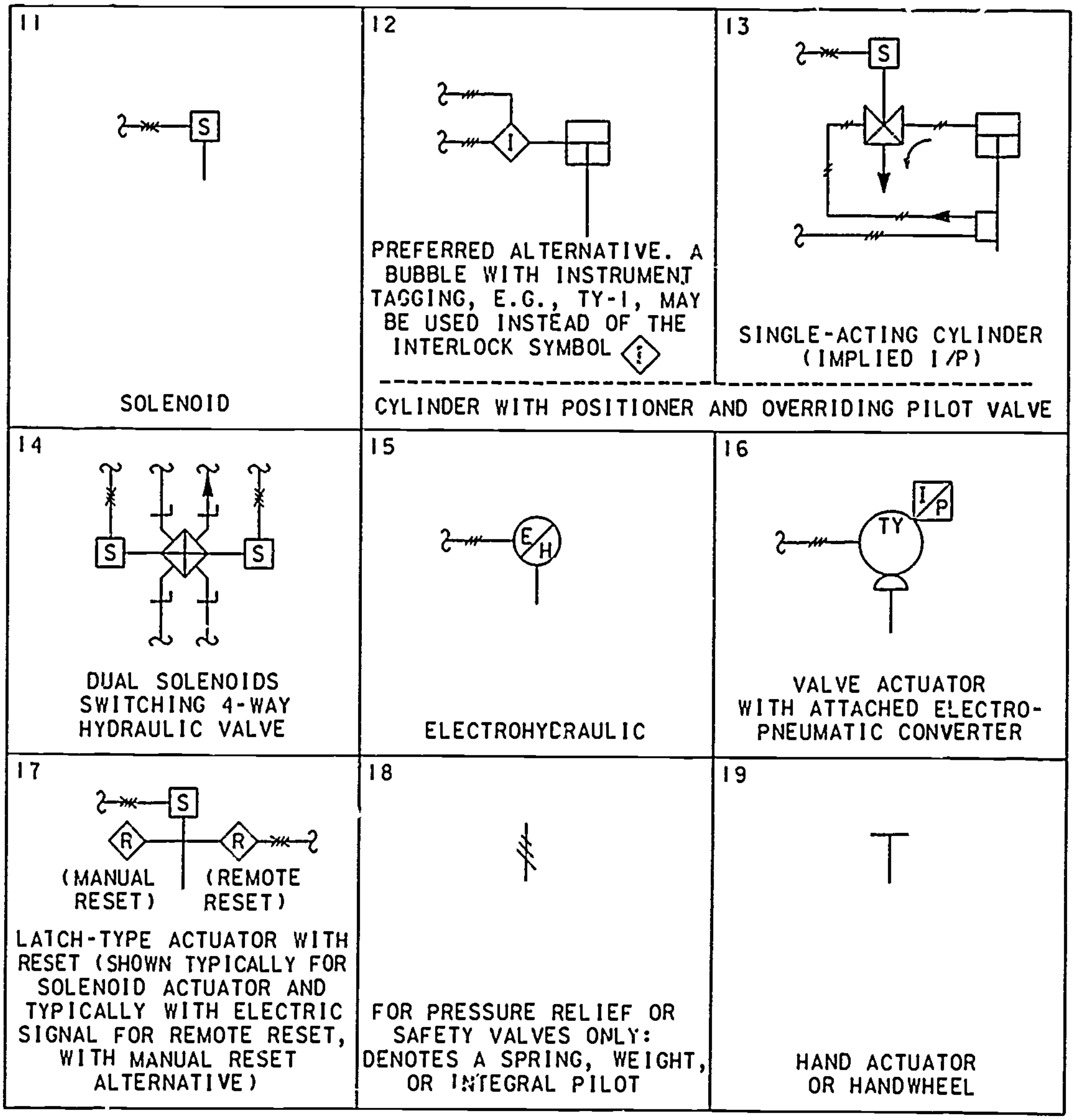



* Pilot may be positioner, solenoid valve, signal converter, etc.

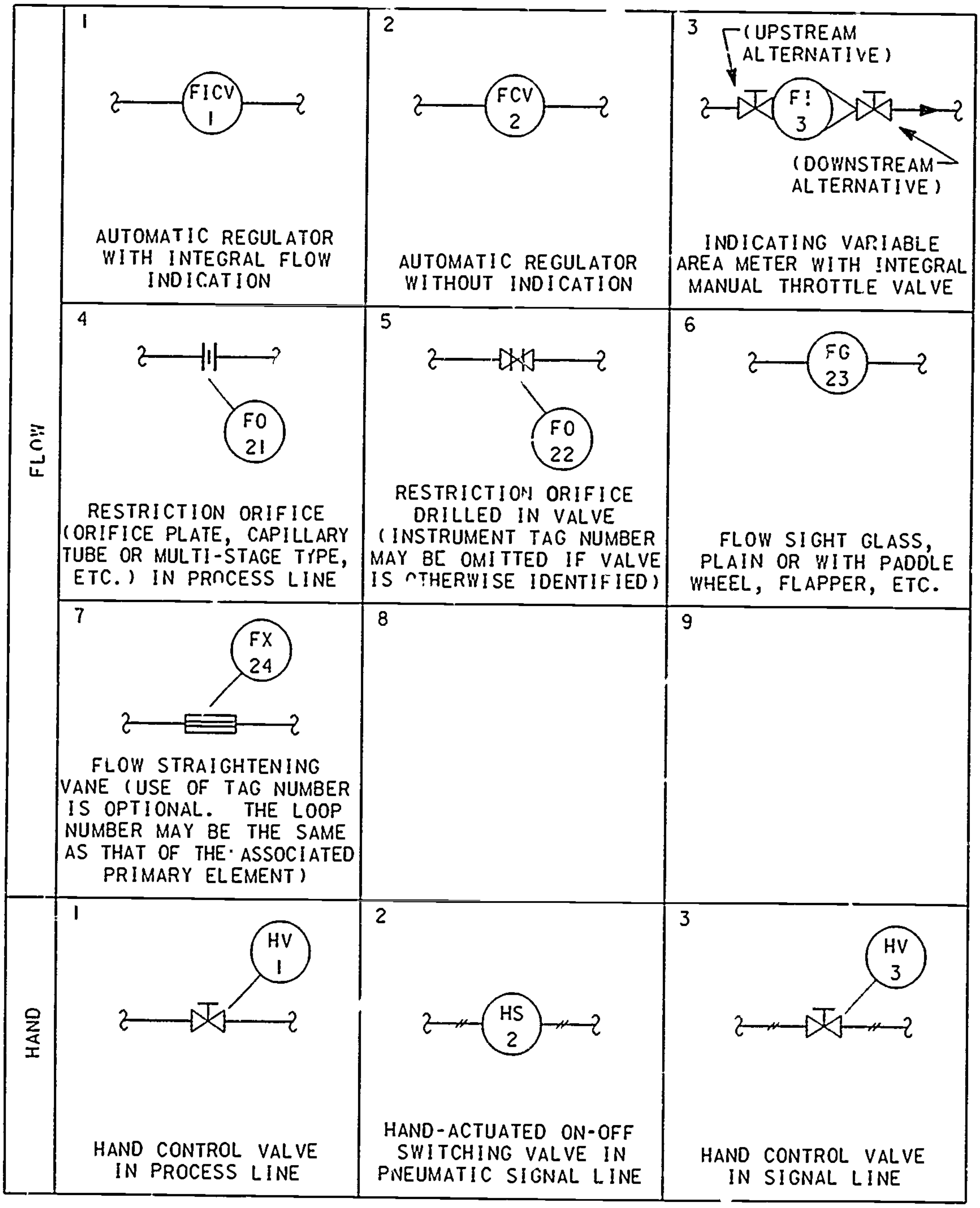
** The positioner need not be shown unless an intermediate device is on its output. The positioner tagging, ZC, need not be used even if the positioner is shown. The positioner symbol, a box drawn on the actuator shaft, is the same for all types of actuators. When the symbol is used, the type of instrument signal, i.e., pneumatic, electric, etc., is drawn as appropriate. If the positioner symbol is used and there is no intermediate device on its output, then the positioner output signal need not be shown.

*** The arrow represents the path from a common to a fail open port. It does not correspond necessarily to the direction of fluid flow.

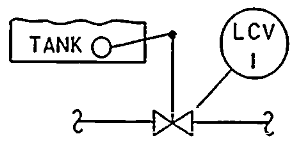
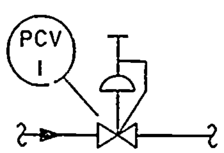
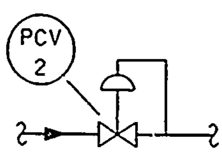
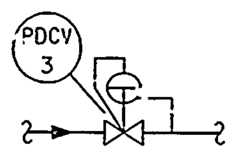
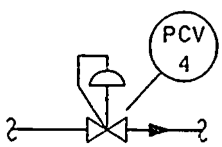
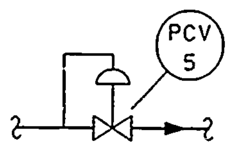
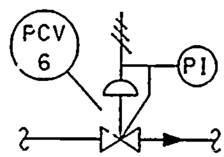
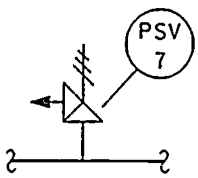
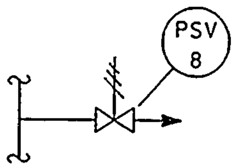
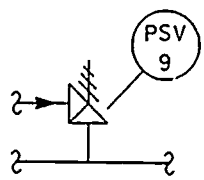
# Actuator Symbols (Continued)



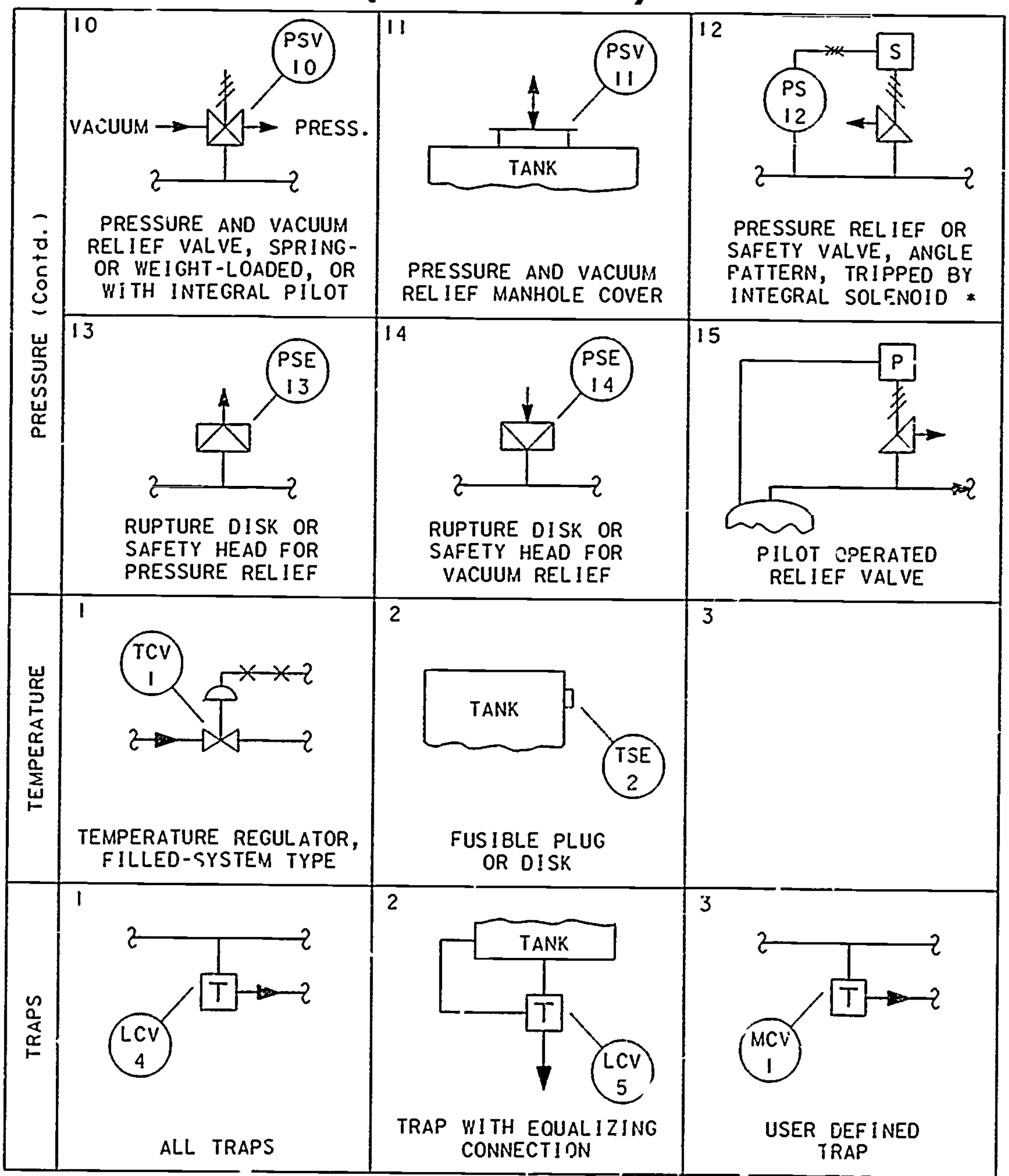
# Symbols for Self-Actuated Regulators, Valves, and Other Devices



# Symbols for Self-Actuated Regulators, Valves, and Other Devices (Continued)

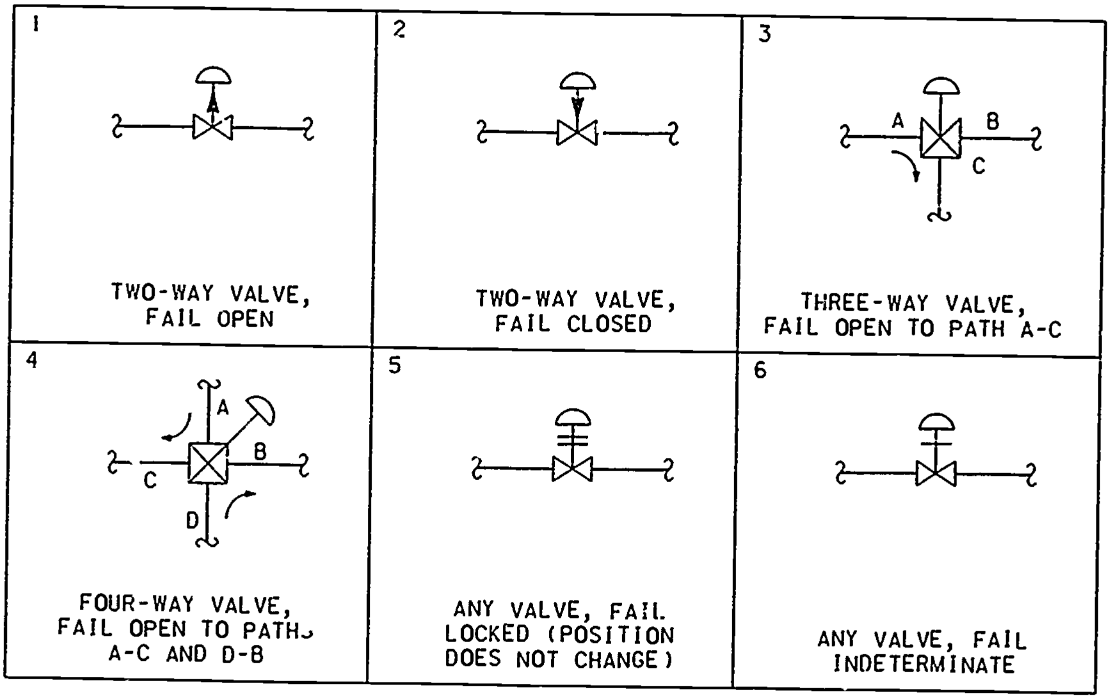
| | | | |
|---|---|---|---|
| LEVEL | 1   LEVEL REGULATOR WITH MECHANICAL LINKAGE | 2 | 3 |
| PRESSURE | 1   PRESSURE-REDUCING REGULATOR, SELF-CONTAINED, WITH HANDWHEEL ADJUSTABLE SET POINT | 2   PRESSURE-REDUCING REGULATOR WITH EXTERNAL PRESSURE TAP | 3   DIFFERENTIAL-PRESSURE-REDUCING REGULATOR WITH INTERNAL AND EXTERNAL PRESSURE TAPS |
| | 4   BACKPRESSURE REGULATOR, SELF-CONTAINED | 5   BACKPRESSURE REGULATOR WITH EXTERNAL PRESSURE TAP | 6   PRESSURE-REDUCING REGULATOR WITH INTEGRAL OUTLET PRESSURE RELIEF VALVE, AND OPTIONAL PRESSURE INDICATOR (TYPICAL AIR SET) |
| | 7   PRESSURE RELIEF OR SAFETY VALVE, GENERAL SYMBOL | 8   PRESSURE RELIEF OR SAFETY VALVE, STRAIGHT-THROUGH PATTERN, SPRING-OR WEIGHT-LOADED, OR WITH INTEGRAL PILOT | 9   VACUUM RELIEF VALVE, GENERAL SYMBOL |

# Symbols for Self-Actuated Regulators, Valves, and Other Devices (Continued)




* The solenoid-tripped pressure relief valve is one of the class of power-actuated relief valves and is grouped with the other types of relief valves even though it is not entirely a self-actuated device.

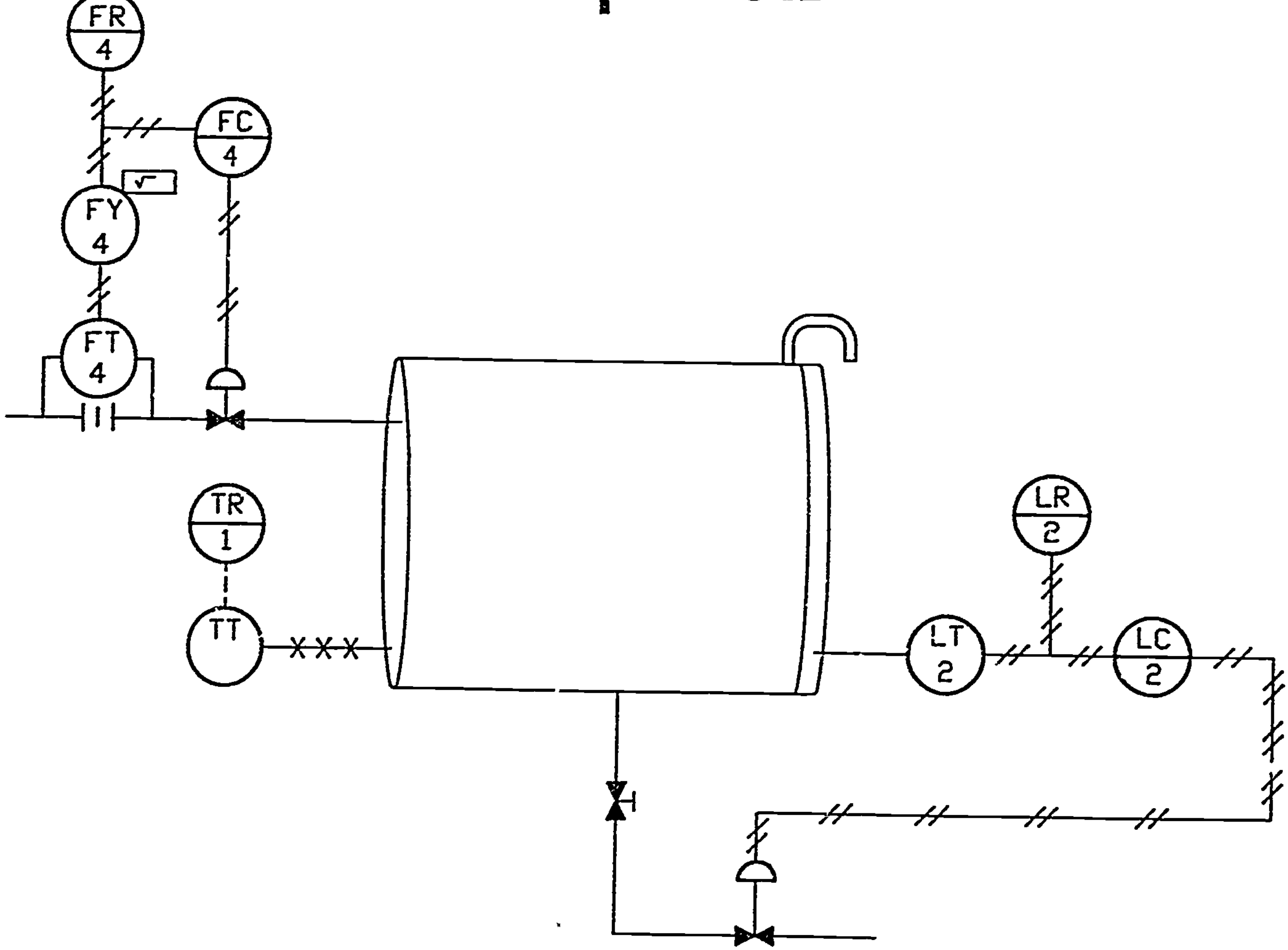
# Symbols for Actuator Action in Event of Actuator Power Failure




The failure modes indicated are those commonly defined by the term, "shelf-position". As an alternative to the arrows and bars, the following abbreviations may be employed:

FO - Fail Open
FC - Fail Closed
FL - Fail Locked (last position)
FI - Fail Indeterminate

# Sample P&ID



# SYSTEM COMPONENTS
# UNIT II

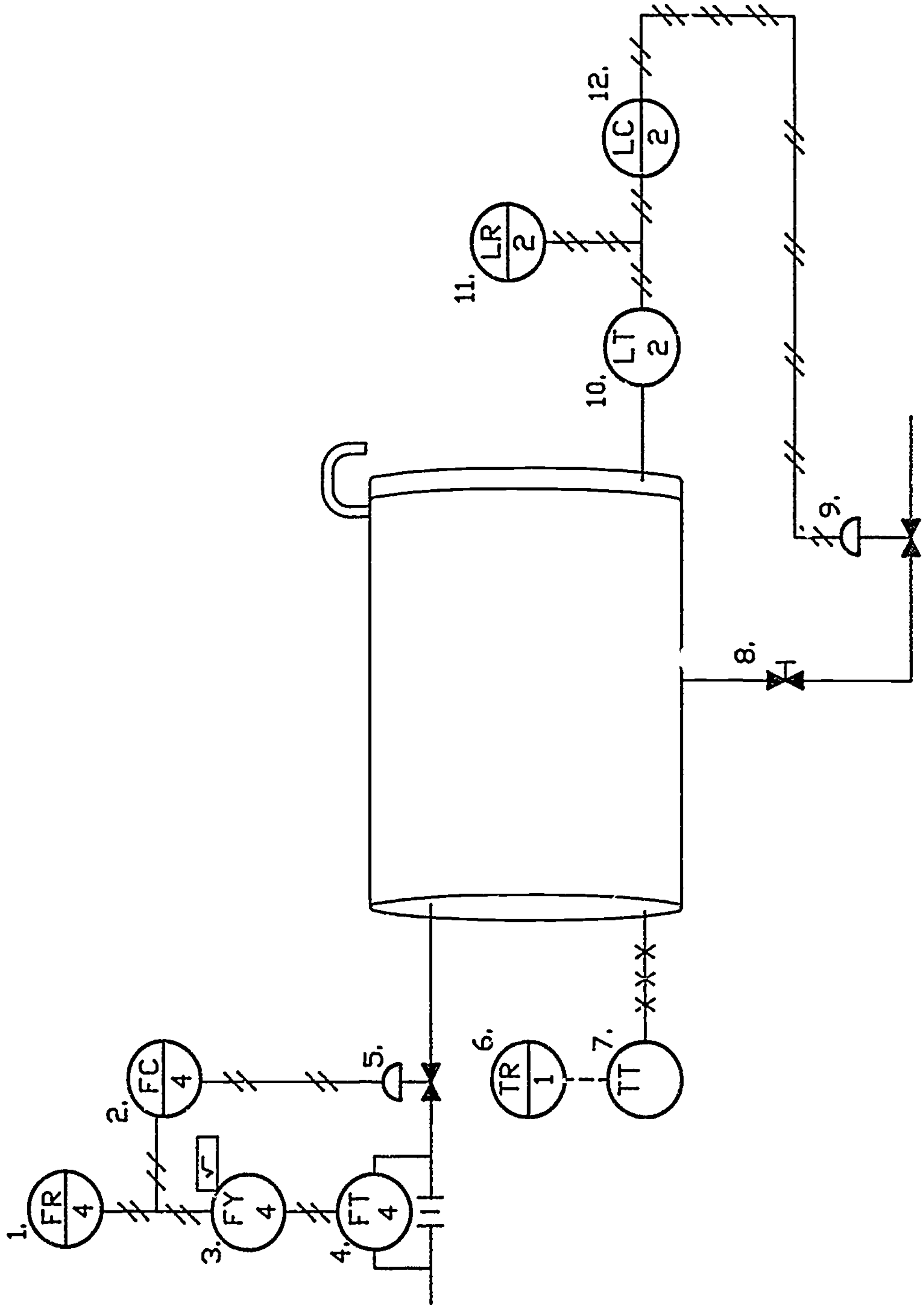
## ASSIGNMENT SHEET #1 — IDENTIFY INSTRUMENTS USED IN A SIMPLE PROCESS SYSTEM

Directions: Study the P&ID in Figure 1 that accompanies this assignment sheet, interpret the standard ISA symbols on the diagram, then write the name of the instrument or device beside its corresponding number below. Refer to the transparency masters as needed to complete your identification.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________
8. ______________________________
9. ______________________________
10. ______________________________
11. ______________________________
12. ______________________________

# ASSIGNMENT SHEET #1

FIGURE 1



# SYSTEM COMPONENTS
# UNIT II

## ANSWERS TO ASSIGNMENT SHEET

**Assignment Sheet #1**

1. Pneumatic flow recorder, loop #4
2. Pneumatic flow controller, loop #4
3. Pneumatic square root extractor, loop #4
4. Pneumatic flow transmitter, loop #4
5. Pneumatic control valve, loop #4
6. Electrical temperature recorder, loop #1
7. Electrical temperature transmitter (capillary tube element), loop #1
8. Hand operated valve, loop #2
9. Pneumatic control valve, loop #2
10. Pneumatic level transmitter, loop #2
11. Pneumatic level recorder, loop #2
12. Pneumatic level controller, loop #2

# SYSTEM COMPONENTS
# UNIT II

## TEST

NAME ______________________________ SCORE ______________

1. Match terms related to system components with their correct definitions.

| | | | |
|---|---|---|---|
| _____a. | A device for detecting or measuring a physical property or characteristic | 1. | Instrumentation |
| | | 2. | Local |
| _____b. | A device that detects information in one form and transforms it into another form or quantity | 3. | Transducer |
| | | 4. | Inferential |
| _____c. | A transducer which converts a measured variable into a standard transmission signal | 5. | Remote |
| _____d. | The making of a measurement or completion of an operation by an instrument that can function without having to open or enter the process being measured | 6. | Sensor |
| | | 7. | Piezoelectric |
| | | 8. | Ultrasonic |
| _____e. | Electrical generation produced when natural or manufactured crystals are subjected to pressure; some man-made crystals are very powerful in voltage output | 9. | Transmitter |
| | | 10. | Restrictor |
| _____f. | The equipment and software required to monitor energy levels and other variables in a process, and to control the energy exchanges required to complete the processing of raw materials | 11. | Non-invasive |
| | | 12. | Process variable |
| _____g. | An indirect method of measuring a variable by inferring a result such as inferring flow measurement from a pressure differential reading | | |
| _____h. | The media or condition in a process that is being measured and controlled | | |
| _____i. | A reduced section of pipe which causes a measurable pressure drop and permits measurement of flow through a line | | |
| _____j. | High frequency sound waves (200 KHz to 500 KHz) used to measure process variables | | |

# TEST

______k. A device such as a controller that is installed at the point of application

______l. Removed from the point of application such as readouts for sensing devices in hazardous environments

2. Select true statements concerning sensors used for measuring temperature by placing an "X" beside each statement that is true.

(NOTE: For a statement to be true, all parts of the statement must be true.)

______a. The most common device for measuring temperature is the thermistor.

______b. Sensors common in industrial temperature measuring include:

1. Thermistors.
2. RTD's (resistance temperature detectors).
3. Filled-thermal systems.
4. Linear IC (integrated chip) devices.
5. Bimetallic devices.
6. Thermometers and IR (infrared) thermometers.
7. Thermocouples.
8. Optical sensors.

______c. Because they are rugged, low cost, do not require a power source, and are available in a wide range of types, thermocouples are the most frequently used temperature measuring devices in industry.

3. Solve problems concerning sensors used for measuring pressure by circling the information that best completes each statement.

a. Because many pressure sensors are mechanical, it is necessary to transduce and transmit the pressure reading, so most pressure sensors are also **(recorders, transmitters)**.

b. Strain gauges and other newer types of pressure sensing devices cost less than traditional pressure sensing devices, and they are also **(more accurate, smaller)**.

# TEST

4. Complete statements concerning sensors used for measuring flow by circling the information that best completes each statement.

   a. Since flow in open vessels and streams does not lend itself to conventional measurement, flow sensing devices are mostly designed to measure flow through a pipe or (**a tube, a channel**).

   b. Measuring flow has always been a design challenge because measuring flow directly usually interferes with the (**flow of media, pressure**) through the pipe.

   c. The simplest method used to measure flow is to channel the flow into a (**tank, pipe**) and measure the quantity flowing into the (**tank, pipe**) in seconds, minutes, or hours.

   d. Some sensors such as turbines and displacement pistons measure flow by filling and dumping liquid, and recording the (**number of times per interval this occurs, weight per time interval**).

   e. Flow rate is often "inferred" by measuring another condition, and an orifice plate does this by measuring the (**pressure differential, speed of flow**) across a restricted area in a pipe.

   f. Vortex flow meters extend into a pipe and create swirling currents behind the projection, and the (**energy of the disturbance, weight of pressure**) can be measured to indicate the flow rate.

   g Vortex meters are relatively new and gaining in popularity because they do not create the (**energy loss, design problems**) experienced with other systems.

   h. Venturi tubes are used to measure flow, but they are (**very expensive, difficult to monitor**) and require a considerable length of pipe to be effective.

   i. Ultrasonic sensors are being developed to measure flow, and although they are non-invasive, they are (**very expensive, difficult to monitor**).

5. Select true statements concerning sensors used for measuring level by placing an "X" beside each statement that is true.

   _____a. One of the most common level measuring devices is a device that looks like an empty box covered with a diaphragm, and the device is placed at the bottom of a tank.

   _____b. As liquid presses on a level measuring diaphragm, it provides a measure of the amount of liquid in the tank above the diaphragm.

   _____c. A bubble tube is another level measuring device placed at the bottom of a tank, and air or gas is forced out of the tube to indicate the amount of pressure needed to overcome the weight of the liquid, and this is a measure of the amount of liquid above the bubble tube.

# TEST

_____d. Sight glasses are simple devices that permit visual monitoring of liquid level, and another simple procedure is to weight the vessel, and then determine the amount of liquid by subtracting the weight of the vessel, and dividing by the unit of weight of the liquid.

_____e. Ultrasonic sensors send a sound wave to the bottom of a tank and record the time it takes the signal to return to the top of the liquid, and this technique works on some solids too.

_____f. Another system of measuring the level of solids is to install a radioactive isotope source in the bottom of the storage, and then reading the amount of radioactivity at the top; the level of the solid is determined by the amount of signal loss from bottom to top.

_____g. Level sensors are selected according to the material being measured, and the location of the vessel, and for these reasons, level sensors may give direct measurement or "inferred" measurement as the process dictates.

6. Solve problems concerning other sensing devices by circling the information that best completes the following statements.

   a. In addition to pressure, temperature, flow, and level, there are other variables in process control such as (**hardness and elasticity, cost**).

   b. Sensor technology is so diverse that there are (**more than 50 different types of sensors, literally hundreds of different types of sensors**).

7. Match transmitter devices with their characteristics.

_____a. Since sensor signals may be buried in the noise of the process itself, these transmitters usually enhance the sensor signal which can be transmitted a long distance to a controller in a control room.

_____b. These are instruments that send air signals from a remote sensor or transducer to a receiver in a control system, and they are transmitted in a range of 3 to 15 psi to comply with ISA standards.

_____c. These devices send signals in a range from 4 to 20 mA to comply with ISA standards; since 4 mA represents the zero signal, an actual reading of zero indicates the system is down.

_____d. These transmitters reflect the move to miniturization because they combine a sensor and a transmitter in one unit, and they have the capacity to transmit information a relatively long distance.

1. Electrical transmitters
2. Pneumatic transmitters
3. Sensing transmitters
4. Process signal transmitters

# TEST

8. Complete statements concerning special transmitter designs by circling the information that best completes each statement.

   a. Many sensors/transducers produce an electrical output that can be changed to the 4 to 20 mA signal easily with minimum cost; ICs that are very reliable can serve transmitter needs at a much lower cost than pneumatic transmitters, and the electrical signal can be transmitted **(farther than, almost as far as)** a pneumatic signal.

   b. The wires that carry process variable signals sometimes **(diminish in strength, pick up undue electrical noise)** in certain process environments, and the designer is sometimes forced to use a pneumatic signal.

   c. A newer way around electrical noise is to transmit the signal on optical cables which are **(almost impervious, totally impervious)** to electrical noise.

   d. Process signals can also be transmitted as electrical voltages, and this is common when signals are digitized and sent by a digital transmission voltage standard such as **(RS-242 or IEEE-488, MS-DOS)**.

   e. In addition to sensor/transmitter single units, IC design permits the addition of intelligence in the form of a microcomputer, and this has produced a new breed of "smart" sensing transmitters that can perform local control tasks, gather and evaluate information, and send it on in **(digital, analog)** form to a master computer.

9. Match receiver devices with their characteristics.

| | |
|---|---|
| _____a. Show an operator the condition of a system at a moment in time | 1. Recorders |
| _____b. An extension of another receiver in that they have timer-driven charts attached so that a momentary reading can be recorded for reference at a late time by an operator. | 2. Controllers |
| _____c. Digital or analog systems that have the capability of sending back corrective signals to the system rather than passive monitoring of the process. | 3. Indicators |

10. Complete statements concerning indicators by circling the information that best completes each statement.

    a. A local indicator may or may not have separate indicator and sensor parts, but a **(sensing, remote)** indicator is always a two-part system, or sometimes more than two parts.

    b. A minimum system would consist of a sensor/transmitter or an indicator device that would respond **(directly, indirectly)** to the output of the transmitted signal.

    c. **(Many systems, Very few systems)** have sensors, transmitters, signal conditioners, and receivers ahead of the indicator device.

## TEST

11. Select true statements concerning recorders by placing an "X" beside each statement that is true.

_____a. A recorder receives an electrical or pneumatic input which is changed into mechanical motion which causes a pen or a stylus to write on a chart which is powered by some kind of clock.

_____b. Input into a recorder is usually electric.

_____c. When recorder input is electrical, it runs a meter movement device which converts current into pointer movement that swings in an arc and records on a chart.

_____d. Electrical input into a recorder can also activate a solenoid or motor which converts current into a linear motion that moves the stylus back and forth over the chart.

_____e. When a recorder input is pneumatic, air comes into a bourdon tube, a spiral tube, or a bellows where it is converted mechanically to swing the stylus in an arc or in a back and forth linear motion over the chart.

_____f. The recorder mechanical parts are simple devices that run a stylus.

_____g. The mechanical mechanism is normally used to make scale changes if the user decides to adapt the recorder to a new task.

_____h. The mechanical parts of the recorder must also fit the cases that hold the round or scroll charts, and the mechanical design may very considerably from large to small recorder boxes.

_____i. The clock that moves the chart may be a synchronous motor like an electric-clock motor, an air motor if electricity is not available, a battery-operated clock for remote units, and some older units still have wind-up clocks.

_____j. The timing mechanism of a recorder must operate in a time frame required by the process, and common reporting times are 24, 48, and 72 hours, long periods such as weeks or months at remote sites, and legal or governmental reports may have special reporting periods.

12. Solve problems concerning controllers by answering the following questions:

a. When a controller takes action, what does that action accomplish?

Answer: ______________________________

b. The receiver device on a controller may have to transform a signal, but why is this done to the signal?

Answer: ______________________________

# TEST

13. Select true statements concerning control elements by placing an "X" beside each statement that is true.

    (NOTE: For a statement to be true, all parts of the statement must be true.)

    _____a. Control elements are that part of a system that cause a change in the item or media being controlled, and the change may happen because of direct or indirect action of the control element.

    _____b. Control elements or final elements have two very important characteristics:

    1) Since they operate directly on the item or media being controlled, they must be capable of withstanding the environment of the process.

    2) The element must be capable of exercising considerable power over whatever is being controlled because it may have to close off flow to a process where considerable energy is expanded.

    _____c. The control element or final element is considered to be the brains in a control system.

14. Select true statements concerning valves and actuators by placing an "X" beside each statement that is true.

    (NOTE: For a statement to be true, all parts of the statement must be true.)

    _____a. The final element in a control process is usually a valve.

    _____b. Valves are operated by actuators which open and close valves.

    _____c. Actuators are required because t control signal must be converted to enough mechanical energy to open or close a valve, and actuators do this.

    _____d. Valves provide two basic kinds of control:

    1) On/off.

    2) High/low

    _____e. The part of the valve that changes the flow rate may be designed as a plug, gate, cock, butterfly, or it may control by "pinching off" the flow.

# TEST

15. Complete statements concerning servo devices by circling the information that best completes each statement.

    a. Servo devices, electrical or pneumatic, are (never, sometimes) used as actuators for control valves.

    b. **(Pneumatic, Electrical)** servos need a large area to run from instrument air, or they need an air-to-air amplifier or an air-over-oil system to provide the power necessary to move a valve.

    c. Electrical servo devices include **(AC, DC)** drive motors used mostly for smaller applications, and **(AC, DC)** drive motors used for larger, high torque applications.

    d. **(Stepper, Digital)** motors which can be driven by computer signals are becoming popular, but are found only in fractional horsepower sizes.

16. Select true statements concerning the P&ID by placing an "X" beside each statement that is true.

    _____a. Process and Instrumentation Diagrams, commonly called P&IDs, are used in designing systems, and afford technicians appropriate reference for monitoring, maintenance, and troubleshooting.

    _____b. P&IDs use letters, lines, and symbols that are taken from ISA-S5.1, which means Instrument Society of American, Standard 5.1.

    _____c. Loop diagrams are simplified P&IDs that isolate individual loops in a system.

    _____d. P&IDs use ISA identification letters, instrument line symbols, and device symbols designed to provide uniformity in the field of instrumentation, and technicians need to know ISA letters and symbols.

17. Interpret basic ISA symbols by answering the questions beside each of the following illustrations:

    a. 1) What does the upper part of the balloon identify?

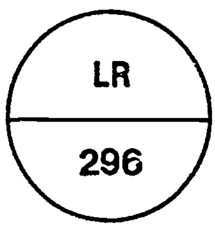
    Answer: ______________________________

    ______________________________

    2) What does the bottom part of the balloon identify?

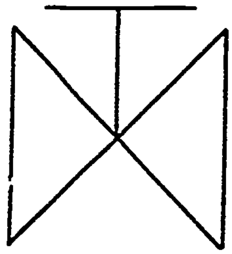
    Answer: ______________________________

    ______________________________



## TEST

b. What does the "T" in the valve symbol indicate?



Answer: ______________________

______________________

c. What does this special symbol indicate?

Answer: ______________________

18. Interpret ISA identification letters and symbols by properly identify the following letters and illustrations:

a. What does the letter F indicate in an initial position?

Answer: ______________________

b. What does the letter T indicate in an initial position?

Answer: ______________________

c. What does the letter P indicate in an initial position?

Answer: ______________________

d. What does the letter L indicate in an initial position?

Answer: ______________________

e. What do the letters TT indicate?

Answer: ______________________

f. What do the letters FC indicate?

Answer: ______________________

g. What does this symbol indicate?

Answer: ______________________

h. What does this symbol indicate?

Answer: ______________________

(NOTE: If the following activity has not been accomplished prior to the test, ask your instructor when it should be completed.)

19. Identify instruments used in a simple process systems. (Assignment Sheet #1)

# SYSTEM COMPONENTS
# UNIT II

## ANSWERS TO TEST

1.

| | | | | | |
|---|---|---|---|---|---|
| a. | 6 | e. | 7 | i. | 10 |
| b. | 3 | f. | 1 | j. | 8 |
| c. | 9 | g. | 4 | k. | 2 |
| d. | 11 | h. | 12 | l. | 5 |

2. b, c

3. a. Transmitters
   b. Smaller

4. a. A tube
   b. Flow of media
   c. Tank, tank
   d. Number of times per interval this occurs
   e. Pressure differential
   f. Energy of disturbance
   g. Energy loss
   h. Very expensive
   i. Very expensive

5. a, b, c, d, e, f, g

6. a. Hardness and elasticity
   b. Literally hundreds of different types of sensors

7. a. 4
   b. 2
   c. 1
   d. 3

8. a. Farther than
   b. Pick up undue electrical noise
   c. Almost impervious
   d. RS-242 or IEEE-488

9. a. 3
   b. 1
   c. 2

## ANSWERS TO TEST

10. a. Remote
    b. Directly
    c. Many systems

11. a, c, d, e, g, h, i, j

12. a. It corrects deviation from setpoint
    b. So it can be used by a control device

13. a, b

14. a, b, c, e

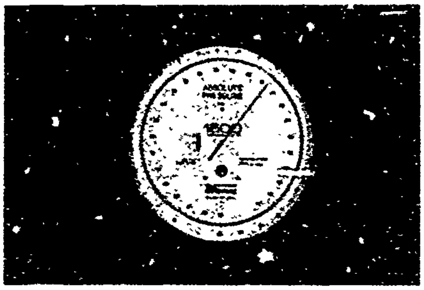
15. a. Sometimes
    b. Pneumatic
    c. AC, DC
    d. Stepper

16. a, b, c, d

17. a. 1) The variable and instrument function
       2) The loop number
    b. That the valve is hand operated
    c. A square root extractor

18. a. Flow
    b. Temperature
    c. Pressure or vacuum
    d. Level
    e. Temperature transmitter
    f. Flow controller
    g. Pneumatic signal
    h. Electric signal

19. Assignment Sheet #1 evaluated to the satisfaction of the instructor



# PRINCIPLES OF PRESSURE MEASUREMENT
## UNIT III

## UNIT OBJECTIVE

After completion of this unit, the student should be able to relate the basics of pressure measurement to the devices used to measure pressure. The student should also be able to discuss the operations of manometers, Bourdon tubes, diaphragms, capsules, bellows, and strain gauges, and select appropriate measuring devices for given applications. These competencies will be evidenced by correctly completing the procedures outlined in the assignment and job sheets, and by scoring a minimum of 85 percent on the unit test.

## SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to principles of pressure measurement with their correct definitions.
2. Select true statements concerning basics of pressure measurement.
3. Complete statements concerning units of pressure measurement.
4. Select true statements concerning other units of pressure measurement.
5. Select true statements concerning pressure and specific gravity.
6. Solve problems concerning measuring pressure with manometers.
7. Complete statements concerning U-tube manometers and their uses.
8. Select true statements concerning well manometers and their uses.
9. Solve problems concerning inclined tube manometers and their uses.
10. Select true statements concerning measuring pressure with Bourdon tubes.
11. Complete statements concerning measuring pressure with helix and spiral Bourdon tubes.
12. Select true statements concerning measuring pressure with diaphragms, capsules, and bellows.

# OBJECTIVE SHEET

13. Complete statements concerning measuring pressure with strain gauges.

14. Select appropriate pressure measuring devices for given applications. (Assignment Sheet #1)

15. Use Pascal's law to calculate force, area, and pressure. (Assignment Sheet #2)

16. Make pressure readings from U-tube, well, and inclined tube manometers. (Assignment Sheet #3)

17. Demonstrate the ability to construct a test apparatus, make and record pressure measurements, and complete pressure measurement conversions. (Job Sheet #1)

# PRINCIPLES OF PRESSURE MEASUREMENT
# UNIT III

## SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information, assignment, and job sheets.

C. Make transparencies.

D. Discuss unit and specific objectives.

E. Discuss information sheet.

F. Discuss Assignment Sheet #1, and prepare examples of processes that use the measuring devices listed.

G. Discuss and demonstrate the procedures outlined in Job Sheet #1, and explain to students the importance of being able to properly make measurement conversions.

H. Review safety procedures for working with mercury-filled devices.

I. Have available as many pressure measuring devices as you can find so that students can examine them.

J. Invite local industrial supervisors to talk to the class about the types of pressure measuring controls used in manufacturing or production facilities in your area.

K. Give test

## REFERENCES USED IN DEVELOPING THIS UNIT

A. *Dwyer Controls and Gauges*. Michigan City, IN 46360: Dwyer Instruments, Inc., 1985.

B. *Dwyer Engineering and Product Applications Handbook*. Michigan City, IN 46300: Dwyer Instruments, Inc., 1986.

C. *Omega Complete Pressure and Strain Measurement Handbook and Encyclopedia*. Stamford, CT 06907: Omega Engineering, Inc., 1988.

D. Whalen, Bruce R. *Basic Instrumentation*. Third Edition. Austin, TX 78758: Petroleum Extension Service, University of Texas at Austin, 1983.

# PRINCIPLES OF PRESSURE MEASUREMENT
# UNIT III

## INFORMATION SHEET

I. Terms and definitions

A. Gauge — An instrument designed to measure physical characterics of a liquid, gas, or solid

(NOTE: Gauge is also spelled "gage" in much technical literature.)

B. Pressure — The measure of force per unit area where force is given in weight rather than mass, and the unit area is square inches or square meters

C. Notation — The abbreviations used in scientific and technical literature to express formulas or shorten long phrases frequently repeated

D. Meniscus - The curved surface that appears on the top of a column of liquid

E. Inches of water column — A measurement that references pressure as related to the height of water in a column; it is noted as "in W.C." or "in $H_2O$"

F. Inches of Mercury — A measurment that references pressure as related to the height of Mercury in a column; it is noted as in Hg

II. Basics of pressure measurement (Handout #1)

A. Pressure is force times unit area, and is expressed by the formula $P=\frac{F}{A}$.

B. Force is weight and measured in pounds (English) or newtons (metric).

C. Area is given in inches squared, feet squared, or meters squared.

D. An important concept concerning pressure is Pascal's law which states that the pressure induced in a vessel by a fluid is equal at all points in the vessel.

E. The importance of Pascal's law is that it established that the pressure created by a liquid in a vessel is the height of the liquid on some specific area squared.

EXAMPLE: If the same liquid were used to fill two vessels of the same height, and one vessel had an area of 2 square inches while the other vessel had an area of 50 square inches, the pressure in pounds per square inch would be the same.

# INFORMATION SHEET

III. Units of pressure measurement (Transparency 1)

A. PSI or pounds per square inch is the fundamental unit for measuring pressure, and is noted as $lb/in^2$.

B. The fundamental metric unit for measuring pressure is Pa or Pascals, but it is usually stated as kiloPascals and noted as kPa.

C. Atmospheric pressure is the pressure resulting from the weight of the earth's atmosphere which at sea level is equal to $14.69 lb/in^2$.

D. PSIA or pounds per square inch absolute is a pressure scale that references the complete absence of pressure as a zero point.

E. PSIG or pounds per square inch gage is a pressure scale that has its zero point equal to atmospheric pressure, and is used in instrumentation to avoid the problem of having to constantly convert from units referenced to absolute zero.

(NOTE: A reading of 10.2 psig at sea level would be equal to 24.9 psia because 10.2 + 14.7 is 24.9.)

F. PSID or pounds per square inch differential is the pressure difference between two points in a process.

G. A vacuum is any pressure less than atmospheric pressure, and zero on the psia scale indicates a perfect vacuum.

IV Other units of pressure measurement (Transparency 1)

A. Two other pressure measuring units date back to an early instrument called a manometer which can be used to measure pressure in inches of water or inches of Mercury.

B. Inches of water are used to measure processes that have very small pressures and may be noted as in W.C. or in $H_2O$.

C. Inches of Mercury are used to measure processes that have high pressures and is noted as in Hg.

D. Mercury is 13.6 times heavier than water, and it does not have to displace a high volume of liquid to make a measurement.

EXAMPLE: The 14.7 psi of atmospheric pressure on the earth's surface equates, in rounded figures, to 30 inches of Mercury or 406.8 inches of water, and that equates to 33.9 feet of water.

# INFORMATION SHEET

V. Pressure and specific gravity

A. Pressure and specific gravity are closely related, and it is important to know the specific gravity of a material if you need to calculate the pressure created by the material in a vessel, tank, or column.

B. Specific gravity is the ratio of the weight or mass of one material compared to the same volume of another material.

C. Ratios are found by comparison with standard materials; liquids are compared to water, and gases are compared to hydrogen.

D. In pressure measurement, materials such as water and Mercury are used to describe pressure in units called inches of water or inches of Mercury.

E. Since water is the standard for measuring liquids, it has a specific gravity of 1; however, Mercury weighs 13.6 times as much as water, so Mercury has a specific gravity of 13.6

VI. Measuring pressure with manometers (Handout #2)

A. Manometer comes from the Greek word "manos" which means "thin" or "rare", and in keeping with the name, manometers are used to measure "light" or small pressures.

B. Manometers are popular pressure measuring devices because they are inexpensive, very sensitive, and require little maintenance.

C. Manometers, on the other hand, are fragile, limited in pressure range, must sometimes be adjusted for barometric pressure, and require temperature compensation because the measuring liquid expands with temperature increase.

D. Although there are many variations of manometer types, there are three basic manometer designs:

1. U-tube manometers;
2. Well manometers;
3. Inclined tube manometers.

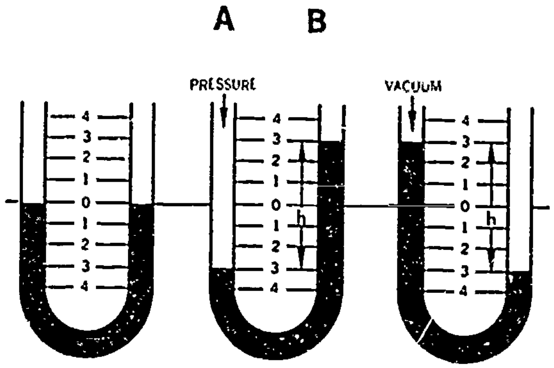
VII. U-tube manometers and their uses

A. The U-tube manometer gets its name from the fact that it is shaped like the letter U.

## INFORMATION SHEET

B. For the sake of reference, the legs of a U-tube manometer are usually labeled A and B. (Figure 1)

FIGURE 1




Courtesy Dwyer Instruments Inc.

C. If pressure is applied to leg A, the liquid in the tube will move down leg A and cause a proportionate rise in the liquid in leg B.

D. The difference between the height of legs A and B represents the amount of pressure applied to A, and the pressure will be the liquid displaced, in pounds, times the height of the column in inches, converted to pounds per square inch.

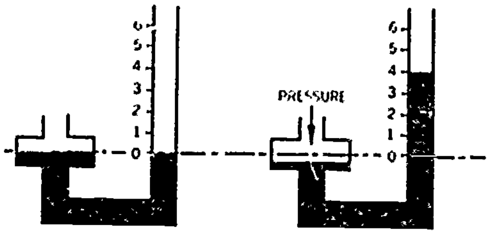
E. The versatile U-tube manometer can measure differences in pressure when pressure is applied to either end of the tube, or it can measure a vacuum which will move the liquid in the opposite direction of positivo pressure.

F. Pressure measurements from a U-tube manometer can be given in inches of water or inches of Mercury.

VIII. Well manometers and their uses

A. The well manometer looks something like a U-tube manometer that has had one of the legs replaced with a well that has a surface area much larger than the area inside the tube. (Figure 2)

FIGURE 2




Courtesy Dwyer Instruments Inc.

# INFORMATION SHEET

B. Shape is not a factor in pressure measurement (Pascal's law); however, the square area of the well is large enough to contain enough liquid to fill the tube with liquid, and since the area of the well is larger, pressure applied will move liquid in the tube in direct proportion to the area difference.

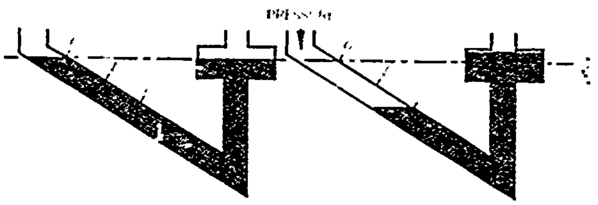
EXAMPLE: If the well were 10 times the area in the tube, and pressure applied to the well moved the liquid down in the well 1 inch, then the pressure would move the liquid up in the tube 10 inches.

C. Well manometers have a rugged design, and are used primarily in industrial applications.

## IX. Inclined tube manometers and their uses

A. An inclined tube manometer has a tube inclined at a shallow angle to create more horizontal movement than vertical movement so that a slight pressure change will cause a large change in movement along the horizontal length of the tube. (Figure 3)

FIGURE 3



Courtesy Dwyer Instruments Inc.

B. Slight pressure changes are difficult to detect on the vertical scale of a conventional U-tube manometer, but slight movement in an inclined manometer creates large, horizontal movement in the tube and makes it easier to observe small changes in pressure.

## X. Measuring pressure with bourdon tubes

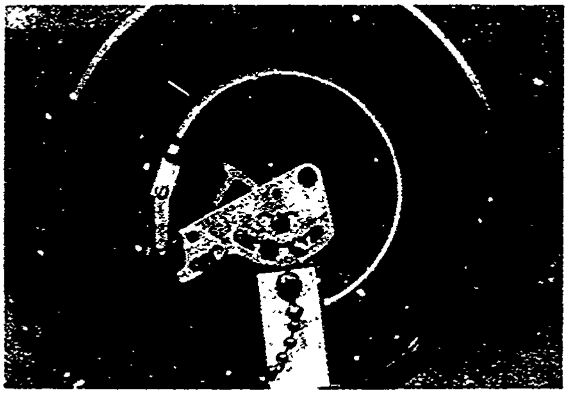
A. A bourdon tube is a round tube slightly flattened, rolled into a "C" shape, fastened into a socket on one end, and plugged on the other end.

B. When pressure is applied to the socketed end of a bourdon tube, the "C" tube straightens out in response to the pressure applied.

# INFORMATION SHEET

C. The plugged end of a practical bourdon tube has an attachment that operates a lever with a gear on one end to move a spindle which in turn moves a pointer in front of a scale set up in appropriate pressure units. (Figure 4)

FIGURE 4



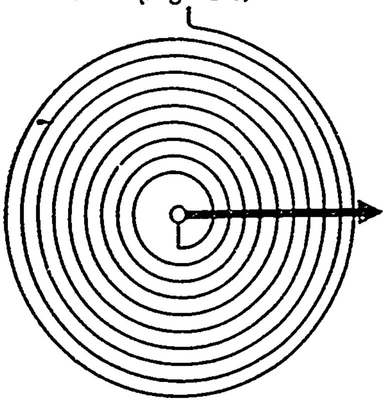
## XI. Measuring pressure with helix and spiral bourdon tubes

A. A conventional "C" shaped bourdon tube is approximately 270 degrees of a circle, and in order to expand tube motion for additional movement to drive mechanical instruments, helix and spiral bourdon tubes are used.

EXAMPLE: Both the helix and spiral tubes are extensions of the conventional bourdon tube, but they connect the equivalent of several 270 degree tubes together as if they were end to end to multiply motion; three turns are equal to 360 × 3, or 1,080 degrees which is the same as 4 × 270 degrees, and produces four times as much motion as a single bourdon tube gauge.

B. Spiral bourdon tubes have the turns laid out on top of each other so that each turn forms a larger diameter. (Figure 5)

FIGURE 5

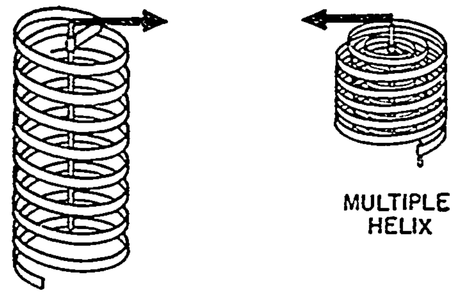


Courtesy Petroleum Extension Service (PETEX)
University of Texas at Austin

## INFORMATION SHEET

C. Helix bourdon tubes have the turns laid out in front of each other so that each turn maintains the same diameter. (Figure 6)

FIGURE 6




Courtesy Petroleum Extension Service (PETEX)
University of Texas at Austin

D. Space requirements dictate whether a spiral or helix tube should be used, and the spiral tube is used in instruments for shallow cases that have large surface areas, and the helix tubes are used in designs with deep cases and small surface areas.

E. Since spiral tubes are difficult to make out of heavy-gauge tubing, and helix tubes are easier to make out of heavy-gauge tubing, the helix tubes are used in high pressure applications where heavy-gauge tubing is necessary.

F. Regardless of type, bourdon tubes have to be springy enough to return to their original shapes after pressure is applied and released, and the tubes are usually made of phosphor bronze or stainless steel so they can withstand chemicals used in systems.

XII. Measuring pressure with diaphragms, capsules, and bellows

A. A diaphragm is a round sheet of metal or plastic, sealed around its circumference, and housed in a case that has a pressure inlet on one side and some type of attachment to the diaphragm in the center. (Figure 7)

FIGURE 7

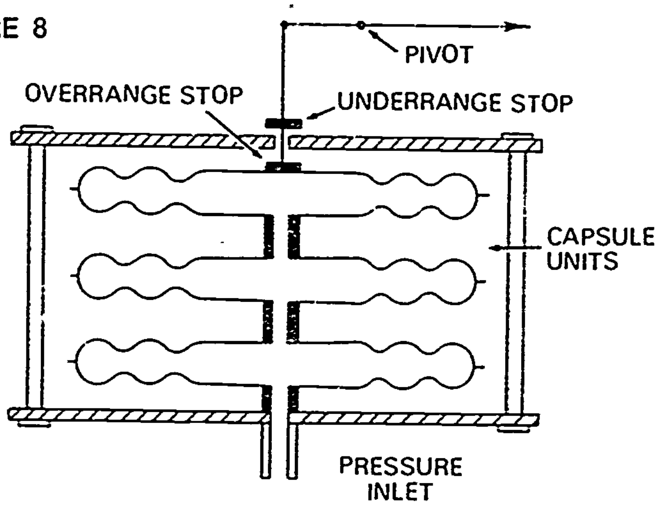
## INFORMATION SHEET

B. When pressure is applied to a diaphragm, the metal or plastic flexes away from the pressure source, and this movement is transferred to the mechanism to be driven.

C. It is common to form a diaphragm with concentric ripples in the surface so that the surface has greater area to move in response to applied pressure.

D. A capsule is two or more diaphragms fastened together around their circumferences so that pressure applied through the center of one diaphragm creates a total deflection directly proportional to the number of diaphragms in the capsule. (Figure 8)

FIGURE 8




**Courtesy Petroleum Extension Service (PETEX)**
**University of Texas at Austin**

E. If a capsule is slightly redesigned so that only the circumference portion is retained, and if several of these are fastened together, they form a new device called a bellows. (Figure 9)

FIGURE 9

## INFORMATION SHEET

G. Bellows are manufactured as sealed units that have single pressure inlets, and the action of the sum of all the capsules in the bellows determines the amount of bellows action.

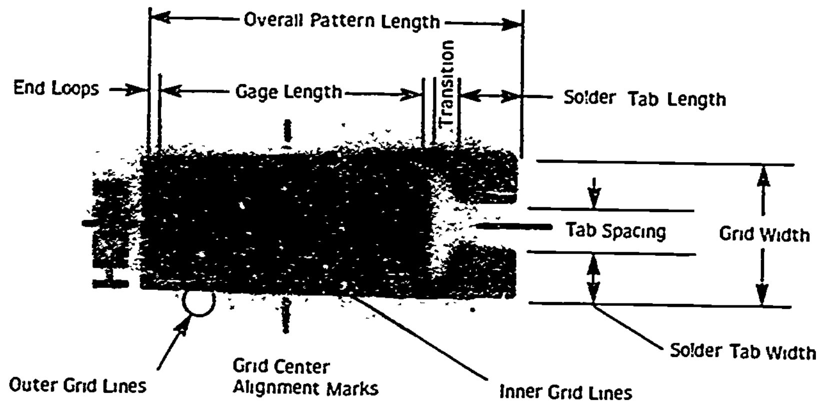
H. Bellows are generally made of the same materials used in bourdon tubes, and sometimes used interchangeably in instruments that use bourdon tubes.

XIII. Measuring pressure with strain gauges

A. In vessels, pipes, and tubes, strain gauges are used to measure pressure by detecting the expansion of the wall of the container to which pressure is applied.

B. Strain gauges are made of small metal wires inside a plastic sheet, or metal conductors placed on a sheet of plastic. (Figure 10)

FIGURE 10






C. When an object undergoes strain, the wires in the attached strain gauge stretch slightly and change the resistance of the conductors inside the gauge.

D. The slight change in the strain gauge resistance is detected by a bridge circuit which amplifies the signal and sends it to the measuring system in the form of current or voltage changes.

E. Since the pressure reading is changed to another energy form, strain gauges are classified as transducers, and like other transducers, change pressure readings to electrical or pneumatic signals.

# Altitude and Pressure Relationships

| Location | Georgraphical Characteristic | Altitude above or below sea level | PSIA | in Hg |
|---|---|---|---|---|
| Mt. Everest (Tibet) | Highest known point on earth | +29,028 ft. | 4.7 | 9.57 |
| Mt. McKinley (Alaska) | Highest point in North America | +20,320 ft. | 7.0 | 14.25 |
| Denver (Colorado) | Inland mountain | + 5,280 ft. | 12.1 | 24.63 |
| Oklahoma City (Oklahoma) | Inland plain | + 1,299 ft. | 14.1 | 28.70 |
| Los Angeles (California) | Coastal plain - sea level | ± 0 ft. | 14.7 | 29.92 |
| Death Valley (California & Nevada) | Lowest point in Western Hemi-sphere | − 282 ft. | 14.8 | 30.13 |

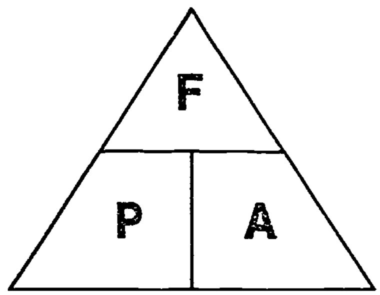
**NOTE: Figures at higher altitudes are approximate.**

# PRINCIPLES OF PRESSURE MEASUREMENT
# UNIT III

## HANDOUT #1 — FORMULAS FOR CALCULATING PRESSURE

### PURPOSE

Pressure readings are basic to almost all process systems, and a good technician needs to have a ready command of Pascal's law which is the fundamental equation used to measure pressure. In plain language, Pascal's law says that pressure equals force divided by the area over which the pressure is applied. The formula is expressed mathematically as $P = \frac{F}{A}$, and can also be expressed graphically:




F = Force measured in pounds (lbs)
A = Area measured in inches squared ($in^2$)
P = Pressure measured in pounds per square inch (PSI)

The pressure triangle provides good visual reinforcement for another important part of the fundamental equation: when any two quantities are known, the third or unknown quantity can be determined.

### APPLICATION

To use the pressure triangle, cover the unknown quantity, and then calculate the unknown quantity according to its position in the triangle.

To calculate force when pressure and area are known, multiply pressure times area so that $F = P \times A$.

Example: When $A = 5\ in^2$
When $P = 2$ psi
Then $F = 10$ lbs

To calculate pressure when force and area are known, divide force by area so that $P = \frac{F}{A}$.

Example: When $F = 10$ lbs
When $A = 5\ in^2$
Then $P = 2$ psi

# HANDOUT # 1

To calculate area when force and pressure are known, divide force by pressure so that $A = \frac{F}{P}$.

Example: When $F = 10$ lbs
When $P = 2$ psi
Then $A = 5\ in^2$

## PRACTICE

Assignment Sheet #1 provides a few problems in measuring pressure, and in using the pressure triangle to solve some really basic pressure applications.

# PRINCIPLES OF PRESSURE MEASUREMENT
# UNIT III

## HANDOUT #2 — MEASURING PRESSURE WITH MANOMETERS

(NOTE: The following materials and illustrations have been adapted from technical materials published by Dwyer Instruments, Inc., and are reprinted with permission of Dwyer Instruments, Inc.)

### PURPOSE

A knowledge of why manometers work the way they do will provide a technician with a good background for working with and calibrating instruments used to measure pressure. Accuracy in reading a manometer is another important part of calibrating pressure devices and instruments. Inaccurate measurements can be avoided by knowing how manometers are designed and constructed.

### DESIGN AND CONSTRUCTION

Whether a manometer is filled with water, Mercury, or special gage oil, the specific gravity of the fluid must be known. The fluid must also have good "wetting" characteristics, and be capable of forming a well-shaped "meniscus" in the indicating tube. The meniscus is the curved upper surface that appears on the surface of a column of liquid. Mercury creates a meniscus that curves outward (convex), and water creates a meniscus that curves inward (concave). Whether water, Mercury, or special gage oil, manometer fluid must form a consistant, well shaped meniscus in the indicating tube to facilitate accurate, repeatable readings. Some water manometers are furnished with fluorscein green concentrate to act as a wetting agent for the water, and to also serve as a dye to improve the consistency and visibility of the meniscus for easier, more accurate reading.

### PARALLAX ERROR

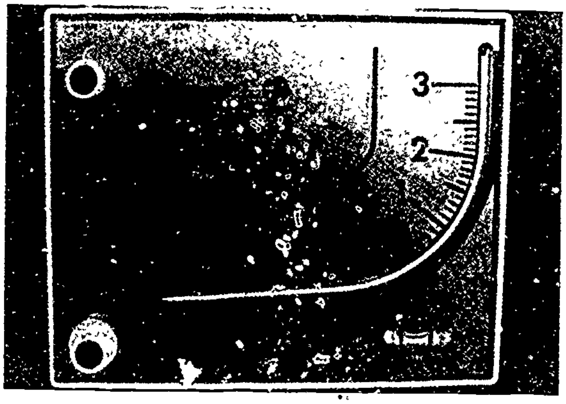
Parallax error is an observational error often associated with reading a sweep-needle pressure gauge or voltohmmeter. It is caused by the refraction of light through glass or plastic placed over a scale, plus the apparent change in position of an object as a person changes viewing position. It leads to inaccurate readings in various instruments. To avoid the parallax error in reading a manometer, it is essential to make readings with the line of sight perpendicular to the liquid column. Better manometers assure parallax-error-free readings by using a silk-screen scale on polished aluminum. The polished aluminum reflects the image of the meniscus, and when the meniscus and its reflection are aligned, the line of sight is perpendicular to the liquid column at the meniscus, and the reading is accurate and accurately repeatable. (Figure 1)

## HANDOUT #2

### LEVEL ERROR

With inclined and inclined-vertical manometers, accurate readings require that the inclined portion of the scale be at the exact design angle. Good manometers of these types have integrated, sensitive spirit levels to help avoid level error, and better manometers also have a screw-type leveling adjustment. (Figure 1)

FIGURE 1




### CONCLUSION

Manometers are useful instruments in testing and calibrating pressure devices of all kinds, but they must be selected carefully for the application, and they must be read with skill to assure accuracy and repeatability.

# PRINCIPLES OF PRESSURE MEASUREMENT
# UNIT III

## HANDOUT #3 — PRESSURE MEASURING/TEST INSTRUMENTS AND CONVERSIONS

### PURPOSE

To have a command of many troubleshooting procedures, a process technician will need to know how to properly connect and adjust common pressure measuring test instruments. First among these is the air pressure regulator which has numerous field applications. Other instruments frequently used include the PSI test gauge, the Mercury manometer, the bellows pressure gauge that measures pressure in PSI, and the bellows pressure gauge that measures pressure in inches of water.

### APPLICATION

Knowing how to properly connect and adjust a test instrument is equally as important as selecting the right instrument. Since a pressure bellows gauge has a high input and a low input, connecting an air supply to the low input side would cause the indicator to deflect opposite the direction desired. In other cases, a quick burst of improperly adjusted air could blow Mercury out of a manometer and create a safety hazard. In short, practice with test situations will give the potential technician a better command of selection, placement, and adjustment.

### CONVERSIONS

Refer to the Pressure Conversion Table that accompanies Job Sheet #1 of this unit as you read through the following.

It is common that a test reading will be in a form that requires conversion to another form. If a technician gets a measurement in inches of Mercury (in Hg) and wants to convert the reading to pounds per square inch (lb/in$^2$), the Hg reading has to be multiplied by .491, and the .491 is called the conversion multiplier. A good pressure conversion table includes conversion multipliers required for converting pressure measurements. The table will include inHg (inches of Mercury), mmHg (millimeters of Mercury), inH$_2$O (inches of water), and lb/in$^2$ (pounds per square inch) conversion multipliers required to obtain a form that a technician can compare with the unit of measure on the device being read or tested.

### PRACTICE

Job Sheet #1 outlines the procedure for selecting, connecting, and adjusting pressure measuring test instruments, and for properly making conversions.

# PRINCIPLES OF PRESSURE MEASUREMENT
# UNIT III

## ASSIGNMENT SHEET #1 — SELECT APPROPRIATE PRESSURE MEASURING DEVICES FOR GIVEN APPLICATIONS

Directions: Study the chart, and refer to it as needed to answer the questions that follow.

| Devices | Advantages | Limitations |
|---|---|---|
| Manometer | Simple principle, results reproducible without special parts, ie: glass tube and water. Low cost to manufacture. Very good for moderately low pressure applications. | Limited range and also sensitive to position. Not rugged enough or portable enough for many industrial applications. Must observe environmental restrictions if Mercury is used. |
| Bouraon Tube | Rugged and portable enough for most plant applications and excellent for high range pressure applications. Poor response near zero end of scale. Accessories are available for special type applications such as steam, pulsing pressures and chemicals. Variations such spiral and helical tube expand range. | Limited sensitivity and low range ability. Industrial grade instruments are expensive and require recalibration on a regular schedule. Gauges may be damaged by corrosive materials. Limited mechanical movement. |
| Diaphragm | Very simple construction, principle and operation. Commonly use as the pressure element inside transmitter units. | Limited drive capability, normally used in conjunction with other mechanical equipment. Limited pressure range. |
| Capsule | Extension of the diaphragm device with more sensitivity and drive. Used in simple freestanding instruments such as barometers. | Limited drive capability, but better over the diaphragm. Sensitive devices that require mechanical protection. |
| Bellows | Extension of capsule design with increased drive and sensitivity. Used as the pressure elements in many recorders and controller devices. | More costly to manufacture than other members of the diaphragm family. Require mechanical stops to prevent damage from over range inputs. |
| Strain Gauge | Produces electrical output compatible with transmission of signals to electronic instruments. | It is not a direct pressure reading device, requires host vessel, and bridge amplifier. An expensive system solution. |

## ASSIGNMENT SHEET #1

1. In an industrial application where noncorrosive media is used, and where high range pressures have to be measured, which device would most likely be present in a system, a manometer or a Bourdon tube?

   Answer ______________________________

2. If a capsule is an extension of a diaphragm device, what is a bellows an extension of?

   Answer ______________________________

3. In a situation where a capsule device would serve as well as a bellows device, which device would probably be selected, and why?

   Answer ______________________________

4. List a device from the chart that would provide a pressure reading by inferring.

   Answer ______________________________

5. Why should a Mercury manometer be used with extra special care?

   Answer ______________________________

6. What pressure measuring devices are fairly common parts of pressure transmitter devices?

   Answer ______________________________

# PRINCIPLES OF PRESSURE MEASUREMENT
# UNIT III

## ASSIGNMENT SHEET #2 — USE PASCAL'S LAW TO CALCULATE FORCE, AREA, AND PRESSURE

Directions: Read the following questions carefully, and visually call up the pressure triangle in your mind to help calculate the answer to each problem. Be sure to include the formula you used to solve each problem so that your instructor can properly evaluate your calculations.

1. If you applied 10 pounds of force to a bicycle pump with a 2-inch piston, how much air pressure would be produced? ____________

   Use this area as a workspace:

   Write the formula here: ____________

2. If a hydraulic jack creates a pressure of 2,000 psi, and the cylinder/piston is 5 square inches, how much weight (force) will the jack lift? ____________

   Write the formula here: ____________

3. If you had a pump that created 80 pounds per square inch, and it had to lift 200 pounds, what cylinder/piston area would be required to do the job? ____________

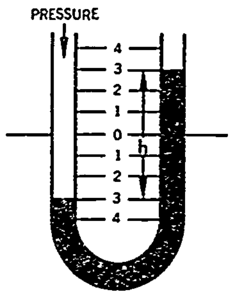
   Write the formula here: ____________

# PRINCIPLES OF PRESSURE MEASUREMENT
# UNIT III

## ASSIGNMENT SHEET #3 — MAKE PRESSURE READINGS FROM U-TUBE, WELL, AND INCLINED TUBE MANOMETERS

Directions: Read the following problems, examine the illustrations with each problem, and complete the answer in the appropriate units of measurement.

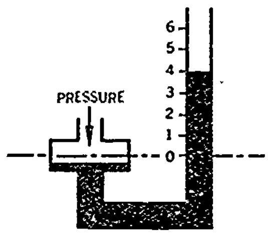
1. What is the pressure indicated in this manometer?




Courtesy Dwyer Instruments Inc.

Give your answer in inches of water:____________

2. What is the pressure indicated in this manometer?

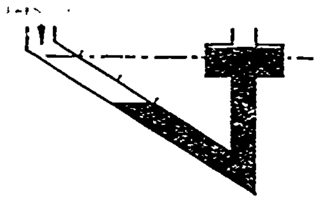



Courtesy Dwyer Instruments Inc.

Give your answer in inches of Mercury: ____________

## ASSIGNMENT SHEET #3

3. What is the pressure indicated in this manometer?



Courtesy Dwyer Instruments Inc.

Give your answer in inches of water column: ____________

# PRINCIPLES OF PRESSURE MEASUREMENT
# UNIT III

## ANSWERS TO ASSIGNMENT SHEETS

**Assignment Sheet #1**

1. Bourdon tube
2. A capsule
3. The capsule; because the bellows device would cost more
4. Strain gauge
5. Mercury-filled manometer; because if broken it poses a health hazard
6. Diaphragms and capsules

**Assignment Sheet #2**

1. 5 psi
2. 1,000 lbs.
3. 2.5 $in^2$

**Assignment Sheet #3**

1. 6 in $H_2O$
2. 4 in Hg
3. 2 in W.C.

# PRINCIPLES OF PRESSURE MEASUREMENT
# UNIT III

## JOB SHEET #1 — CONSTRUCT A TEST APPARATUS, MAKE AND RECORD PRESSURE MEASUREMENTS, AND COMPLETE PRESSURE MEASUREMENT CONVERSIONS

A. Equipment and materials

1. Safety glasses
2. Calculator
3. 1/4″ plastic hoses and fittings
4. Two 1/4″ needle valves
5. 0-40 psi air pressure regulator
6. 0-150″ water pressure gauge (bellows type)
7. 36″ U-tube Mercury manometer
8. 0-15 psi test gauge (bourdon tube)
9. 0-15 psi pressure gauge (bellows type)
10. Air supply
11. Pencil

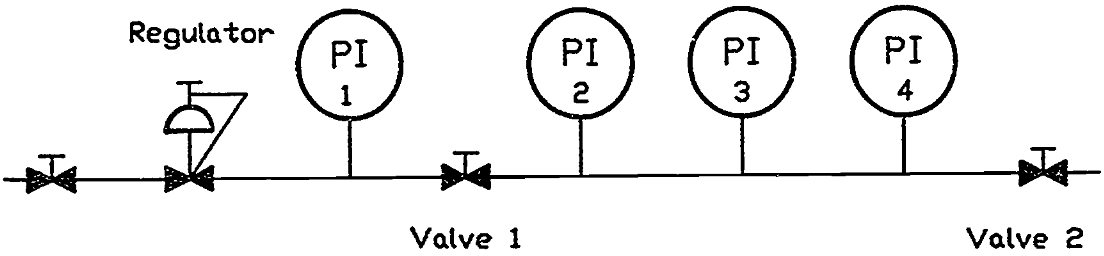
B. Routine #1 — Constructing the test apparatus

1. Put on safety glasses.
2. Place the 1/4″ plastic hose on a work area.

## JOB SHEET #1

3. Arrange the test instruments along the hose as shown in Figure 1.

FIGURE 1




4. Position the test instruments as follows:

   PI-1: 0-15 PSI test gauge

   PI-2: 0-150 in $H_2O$ bellows gauge

   PI-3: 0-36 inHg manometer

   PI-4: 0-15 PSI bellows gauge

5. Connect components with quick disconnect fittings designed for low pressure applications, or use suitable nylon or plastic fittings.

   ☐ Have your instructor check your testing apparatus.

C. Routine #2 — Making pressure measurements

1. Put on safety glasses.

2. Close valve 1 and open valve 2.

3. Make sure the air supply is off, and do not turn on the air supply until this routine directs you to do so.

   **(CAUTION: Check with your instructor for a quick review of safety procedures for working around Mercury-filled devices.)**

4. Set the regulator for "0" output by turning the knob fully counterclockwise.

5. Check to make sure that the arrow on the bottom of the regulator is pointing in the direction of air flow.

6. Turn on the air supply.

# JOB SHEET #1

7. Check PI-1 for a reading of "0".

8. Open valve 1, and close valve 2.

9. Adjust the air pressure regulator until a reading of .5 PSI is indicated on PI-1, and then read and record the pressures on PI-2, PI-3, and PI-4 on the Pressure Measurement Data Sheet that accompanies this job sheet.

10. Continue adjusting the air pressure regulator for PI-1 readings through 5, in .5 increments, and make all pressure entries required to complete the Pressure Measurement Data Sheet.

11. Continue as required to obtain readings for your data sheet, and then turn off air supply and open valve 2 to relieve pressure.

    ☐ Have your instructor check your pressure Measurement Data Sheet.

D. Routine #3 — Making pressure measurement conversions

1. Place your data sheet beside the Pressure Conversion Table that accompanies this job sheet, and record the appropriate conversion multiplier for PI-1 readings .5, 2.5, and 5 as indicated on the Pressure Measurement Data Sheet.

2. Use your calculator to make the appropriate conversions, and record those conversions in their appropriate places on your Pressure Measurement Data Sheet.

    ☐ Have your instructor check your conversions.

4. Disconnect the testing apparatus, and return equipment and materials to proper storage.

# JOB SHEET #1

## Pressure Measurement Data Sheet

| PI-1 Settings | PI-2 In $H_2O$ | | Conversion Multiplier | | In $H_2O$-Hg Conversion | PI-3 In Hg | | Conversion Multiplier | | In Hg-PSI Conversion | PI-4 PSI | | Conversion Multiplier | | PSI-In $H_2O$ Conversion |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .5 | ______ | × | ______ | = | ______ | ______ | × | ______ | = | ______ | ______ | × | ______ | = | ______ |
| 1.0 | ______ | | | | | ______ | | | | | ______ | | | | |
| 1.5 | ______ | | | | | ______ | | | | | ______ | | | | |
| 2.0 | ______ | | | | | ______ | | | | | ______ | | | | |
| 2.5 | ______ | × | ______ | = | ______ | ______ | × | ______ | = | ______ | ______ | × | ______ | = | ______ |
| 3.0 | ______ | | | | | ______ | | | | | ______ | | | | |
| 3.5 | ______ | | | | | ______ | | | | | ______ | | | | |
| 4.0 | ______ | | | | | ______ | | | | | ______ | | | | |
| 4.5 | ______ | | | | | ______ | | | | | ______ | | | | |
| 5.0 | ______ | × | ______ | = | ______ | ______ | × | ______ | = | ______ | ______ | × | ______ | = | ______ |

NOTE: Gravity and altitude affect pressure readings. A correction multiplier for your locale can be calculated or may be available from a local utility or architect. Since correction multipliers have to be calculated locally, they are not included in this text.

# JOB SHEET #1

## Pressure Conversion Table

| When measurement is in | To get | Multiply by |
|---|---|---|
| in Hg | $lb/in^2$ | .491 |
| in Hg | mmHg | 25.4 |
| $lb/in^2$ | in Hg | 2.036 |
| $lb/in^2$ | mmHg | 51.7 |
| mmHg | $lb/in^2$ | .0193 |
| mmHg | in Hg | 3.94 |
| in $H_2O$ | in Hg | .0735 |
| in Hg | in $H_2O$ | 13.6 |
| in $H_2O$ | $lb/in^2$ | .0361 |
| $lb/in^2$ | in $H_2O$ | 27.7 |

# PRINCIPLES OF PRESSURE MEASUREMENT
# UNIT III

## PRACTICAL TEST #1
## JOB SHEET #1 — CONSTRUCT A TEST APPARATUS, MAKE AND RECORD PRESSURE MEASUREMENTS, AND COMPLETE PRESSURE MEASUREMENT CONVERSIONS

**Student's name** ______________________________ **Date** ____________

**Evaluator's name** ______________________________ **Attempt no.** ______

Student instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

### PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

| The student: | | YES | NO |
|---|---|---|---|
| 1. Wore safety glasses. | 1. | ☐ | ☐ |
| 2. Handled equipment safely. | 2. | ☐ | ☐ |
| 3. Constructed testing apparatus properly. | 3. | ☐ | ☐ |
| 4. Made and recorded all pressure measurements. | 4. | ☐ | ☐ |
| 5. Entered proper conversion multipliers on data sheet. | 5. | ☐ | ☐ |
| 6. Made conversions properly. | 6. | ☐ | ☐ |
| 7. Disconnected testing apparatus safely. | 7. | ☐ | ☐ |
| 8. Returned equipment and materials to proper storage. | 8. | ☐ | ☐ |

Evaluator's comments: ________________________________________________

______________________________________________________________

______________________________________________________________

# JOB SHEET #1 PRACTICAL TEST

## PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

| Criteria: | | | | |
|---|---|---|---|---|
| Equipment and Materials | Properly selected and properly used<br>4 | Properly selected and acceptably used<br>3 | Poorly selected and/or used<br>2 | Improperly selected and/or used<br>1 |
| Testing Procedure | Well followed<br>4 | Acceptably followed<br>3 | Poorly followed<br>2 | Improperly followed<br>1 |
| Data Recording | All properly entered<br>4 | Almost all entered<br>3 | Too few entered<br>2 | Too few entered or improperly entered<br>1 |
| Safety | Carefully observed<br>4 | Acceptably observed<br>3 | Poorly observed<br>2 | Improperly observed<br>1 |

EVALUATOR'S COMMENTS: ______________________________

______________________________________________

### PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

# PRINCIPLES OF PRESSURE MEASUREMENT
# UNIT III

## TEST

NAME ______________________________ SCORE ______________

1. Match terms related to principles of pressure measurement with their correct definitions.

| | | |
|---|---|---|
| _____a. | An instrument designed to measure physical characteristics of a liquid, gas, or solid | 1. Notation |
| _____b. | The measure of force per unit area where force is given in weight rather than mass, and the unit area is square inches or square meters | 2. Inches of Mercury |
| _____c. | The abbreviations used in scientific and technical literature to express formulas or shorten long phrases frequently repeated | 3. Gauge |
| _____d. | The curved surface that appears on the top of a column of liquid | 4. Meniscus |
| _____e. | A measurement that references pressure as related to the height of water in a column; it is noted as "in W.C." or "in $H_2O$" | 5. Pressure |
| _____f. | A measurement that references pressure as related to the height of Mercury in a column; it is noted as in Hg | 6. Inches of water column |

2. Select true statements concerning basics of pressure measurement by placing an "X" beside each statement that is true.

_____a. Pressure is force times unit area, and is expressed by the formula P=

_____b. Force is weight and measured only in pounds.

_____c. Area is given in inches squared, feet squared, or meters squared.

_____d. An important concept concerning pressure is Pascals law which states that the pressure induced in a vessel by a fluid is equal at all points in the vessel.

_____e. The importance of Pascal's law is that it established that the pressure created by a liquid in a vessel is the height of the liquid on some specific area squared.

# TEST

3. Complete statements concerning units of pressure measurements by circling the information that best completes each statement.

   a. PSI or pounds per square inch is the fundamental unit for measuring pressure, and is noted as (**$lb/in^2$, $in/lb^2$**).

   b. The fundamental metric unit for measuring pressure is Pa or Pascals, but it is usually stated as kiloPascals and noted as (**kPa, KPA**).

   c. Atmospheric pressure is the pressure resulting from the weight of the earth's atmosphere which at sea level is equal to (**$14.69 lb/in^2$, $17.04 lb/in^2$**).

   d. PSIA or pounds per square inch absolute is a pressure scale that references (**the complete absence of pressure, any vacuum**) as a zero point.

   e. PSIG or pounds per square inch gauge is a pressure scale that has its zero point equal to atmospheric pressure, and is used in instrumentation to avoid the problem of having to constantly convert from units referenced to (**absolute zero, differential pressure**).

   f. PSID or pounds per square inch differential is the pressure difference between (**two points in a process, PSIA and PSIG**).

   g. A vacuum is any pressure less than atmospheric pressure, and zero on the (**psig, psia**) scale indicates a perfect vacuum.

4. Select true statements concerning other units of pressure measurement by placing an "X" beside each statement that is true.

   _____a. Two other pressure measuring units date back to an early instrument called a manometer which can be used to measure pressure in inches of water or inches of Mercury.

   _____b. Inches of water are used to measure processes that have high pressures and may be noted as in W.C. or in $H_2O$.

   _____c. Inches of Mercury are used to measure processes that have low pressures and is noted as in Hg.

   _____d. Mercury is 13.6 times heavier than water, and it does not have to displace a high volume of liquid to make a measurement.

# TEST

5. Select true statements concerning pressure and specific gravity by placing an "X" beside each statement that is true.

_____a. Pressure and specific gravity are closely related, and it is important to know the specific gravity of a material if you need to calculate the pressure created by the material in a vessel, tank, or column.

_____b. Specific gravity is the ratio of the weight or mass of one material compared to the same volume of another material.

_____c. Ratios are found by comparison with standard materials; liquids are compared to Mercury, and gases are compared to nitrogen.

_____d. In pressure measurement, materials such as water and Mercury are used to describe pressure in units called inches of water or inches of Mercury.

_____e. Since water is the standard for measuring liquids, it has a specific gravity of 1; however, Mercury weighs 13.6 times as much as water, so Mercury has a specific gravity of 13.6

6. Solve problems concerning measuring pressure with manometers by answering the following questions.

   a. Are manometers better for measuring high pressures or low pressures?

      Answer: ______________________________________________

   b. Two other phenomena affect manometer performance; what are they:

      Answer: ______________________________________________

7. Complete statements concerning U-tube manometers and their uses by circling the information that best completes each statement.

   a. The U-tube manometer gets its name from the fact that it is (**shaped like the letter U, in a tube**).

   b. For the sake of reference, the legs of a U-tube manometer are usually labeled (**A and B, 1 and 2**).

   c. If pressure is applied to leg A, the liquid in the tube will move (**up, down**) leg A and cause a proportionate (**rise, fall**) in the liquid in leg B.

   d. The difference between the height of legs A and B represents the amount of pressure applied to A, and the pressure will be the liquid displaced, in pounds, times the height of the column in inches, converted to (**pounds per square inch, in x h$^2$**).

   e. The versatile U-tube manometer can measure differences in pressure when pressure is applied to either end of the tube, or it can measure a vacuum which will move the liquid in the (**same, opposite**) direction of positive pressure.

   f. Pressure measurements from a U-tube manometer can be given in inches of water or inches of (**Mercury, Hydrogen**).

# TEST

8. Select true statements concerning well manometers and their uses by placing an "X" beside each statement that is true.

_____a. The well manometer looks something like a U-tube manometer that has had one of the legs replaced with a well that has a surface area much larger than the area inside the tube.

_____b. Shape is not a factor in pressure measurement; however, the square area of the well is large enough to contain enough liquid to fill the tube with liquid, and since the area of the well is larger, pressure applied will move liquid in the tube in direct proportion to the area difference.

_____c. Well manometers have a rugged design, and are used in all kinds of applications.

9. Solve problems concerning inclined tube manometers and their uses by answering the following questions.

a. An inclined tube manometer creates more horizontal movement than vertical movement or vise versa?

Answer: ________________________________________

b. What is the real value of an inclined tube manometer?

Answer: ________________________________________

10. Select true statements concerning measuring pressure with bourdon tubes by placing an "X" beside each statement that is true.

_____a. A bourdon tube is a round tube slightly flattened, rolled into a "C" shape, fastened into a socket on one end, and plugged on the other end.

_____b. When pressure is applied to the socketed end of a bourdon tube, the "C" tube straightens out in response to the pressure applied.

_____c. The plugged end of a practical bourdon tube has an attachment that operates a lever with a gear on one end to move a spindle which in turn moves a pointer in front of a scale set up in appropriate pressure units.

11. Complete statements concerning measuring pressure with helix and spiral bourdon tubes by circling the information that best completes each statement.

a. A conventional "C" shaped bourdon tube is approximately (180, 270) degrees of a circle, and in order to expand tube motion for additional movement to drive mechanical instruments, helix and spiral bourdon tubes are used.

b. Spiral bourdon tubes have the turns laid out on top of each other so that each turn forms a (smaller, larger) diameter.

## TEST

c. Helix bourdon tubes have the turns laid out in front of each other so that each turn **(maintains the same diameter, increases the diameter)**.

d. Space requirements dictate whether a spiral or helix tube should be used, and the spiral tube is used in instruments for shallow cases that have large surface areas, and the helix tubes are used in designs with deep cases and **(small, large)** surface areas.

e. Since spiral tubes are difficult to make out of heavy-gauge tubing, and helix tubes are easier to make out of heavy-gauge tubing, the helix tubes are used in **(high, medium)** pressure applications where heavy-gauge tubing is necessary.

f. Regardless of type, bourdon tubes have to be springy enough to return to their original shapes after pressure is applied and released, and the tubes are usually made of phosphore, bronze, or stainless steel so they can withstand **(chemicals, heat)** used in systems.

12. Select true statements concerning measuring pressure with diaphragms, capsules, and bellows by placing an "X" beside each statement that is true.

_____a. A diaphragm is a round sheet of metal or plastic, sealed around its circumference, and housed in a case that has a pressure inlet on one side and some type of attachment to the diaphragm in the center.

_____b. When pressure is applied to a diaphragm, the metal or plastic flexes away from the pressure source, and this movement is transferred to the mechanism to be driven.

_____c. It is common to form a diaphragm with concentric ripples in the surface so that the surface has greater area to move in response to applied pressure.

_____d. A capsule is two or more diaphragms fastened together around their circumferences so that pressure applied through the center of one diaphragm creates a total deflection directly proportional to the number of diaphragms in the capsule.

_____e. If a capsule is slightly redesigned so that only the circumference portion is retained, and if several of these are fastened together, they form a new device called a triple capsule.

_____f. Bellows are manufactured as sealed units that have single pressure inlets, and the action of the sum of all the capsules in the bellows determines the amount of bellows action.

_____g. Bellows are generally made of the same materials used in diaphragms, and sometimes used interchangeably in instruments that use manometers.

# TEST

13. Complete statements concerning measuring pressure with strain gauges by inserting the information that best completes each statement.

    a. In vessels, pipes, and tubes, strain gauges are used to measure pressure by detecting the ____________ of the wall of the container to which pressure is applied.

    b. Strain gauges are made of small ____________ wires inside a plastic sheet, or metal conductors placed on a sheet of plastic.

    c. When an object undergoes strain, the wires in the attached strain gauge stretch slightly and change the ____________ of the conductors inside the gauge.

    d. The slight change in the strain gauge ____________ is detected by a bridge circuit which amplifies the signal and sends it to the measuring system in the form of current or voltage changes.

    e. Since the pressure reading is changed to another energy form, strain gauges are classified as ____________ ,and like other ____________ ,change pressure readings to electrical or pneumatic signals.

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

14. Select appropriate pressure measuring devices for given applications. (Assignment Sheet #1)

15. Use Pascal's law to calculate force, area, and pressure. (Assignment Sheet #2)

16. Make pressure readings from U-tube, well, and inclined tube manometers. (Assignment Sheet #3)

17. Demonstrate the ability to construct a test apparatus, make and record pressure measurements, and complete measurement conversions. (Job Sheet #1)

# PRINCIPLES OF PRESSURE MEASUREMENT
# UNIT III

## ANSWERS TO TEST

1. a. 3 d. 4
   b. 5 e. 6
   c. 1 f. 2

2. a, c, d, e

3. a. $lb/in^2$
   b. kPa
   c. $14.69 lb/in^2$
   d. The complete absence of pressure
   e. Absolute zero
   f. Two points in a process
   g. psia

4. a, d

5. a, b, d, e

6. a. Low pressures
   b. Barometric pressure and temperature

7. a. Shaped like the letter U
   b. A and B
   c. Down, rise
   d. Pounds per square inch
   e. Opposite
   f. Mercury

8. a, b

9. a. More horizontal than vertical
   b. Small pressure changes are easier to observe

10. a, b, c

## ANSWERS TO TEST

11. a. 270
    b. Larger
    c. Maintains the same
    d. Small
    e. High
    f. Chemicals

12. a, b, c, d, f

13. a. Expansion
    b. Metal
    c. Resistance
    d. Resistance
    e. Transducers, transducers

14.-16. Evaluated to the satisfaction of the instructor

17. Job Sheet #1 evaluated according to the criteria in Practical Test #1

# PRINCIPLES OF LEVEL MEASUREMENT
## UNIT IV

## UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss the basics of level measurement, and differentiate between low-pressure and high-pressure level measuring methods. The student should also be able to relate capacitance, displacer, and conductance probes to their applications. The student should also be able to discuss newer methods of level measurement such as infrared, radioactive, and ultrasonic systems. These competencies will be evidenced by correctly completing the procedures in the assignment and job sheets, and by scoring a minimum of 85 percent on the unit test.

## SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to principles of level measurement with their correct definitions.
2. Select true statements concerning basics of level measurement.
3. Complete statements concerning measuring liquids in tanks.
4. Complete statements concerning measuring liquids with sight glasses.
5. Select true statements concerning measuring level with float devices.
6. Solve problems concerning measuring level with displacers.
7. Select true statements concerning measuring level with capacitance level sensors.
8. Complete statements concerning measuring level with bubbler systems.
9. Solve problems concerning measuring level with differential pressure.
10. Complete statements concerning measuring level with infrared systems.

# OBJECTIVE SHEET

11. Select true statements concerning measuring level with radioactive devices.

12. Solve problems concerning measuring level with ultrasonic techniques.

13. Complete statements concerning other methods of level measurement.

14. Select true statements concerning specific gravity and level measurement.

15. Complete statements concerning applications of level measurement.

16. Examine and interpret performance charts. (Assignment Sheet #1)

17. Make an emergency level measurment in a make-up water storage tank. (Assignment Sheet #2)

18. Demonstrate the ability to:

    a. Measure, cut, and bend copper tubing to specifications. (Job Sheet #1)

    b. Use a bubbler system to determine liquid level in a tank open to atmosphere. (Job Sheet #2)

# PRINCIPLES OF LEVEL MEASUREMENT
# UNIT IV

## SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information and assignment sheets.

C. Make transparencies.

D. Discuss unit and specific objectives.

E. Discuss information sheet.

F. Invite the supervisor of a local or area processing activity to talk to the class about the forms of level measurement used in an area industry.

G. Have available level measuring devices to show students as you discuss various devices in class.

H. Demonstrate the proper way to cut and bend copper tubing, and correlate the job sheets so that students can cut and bend the required tubing for Job Sheet #2 as they complete Job Sheet #1.

I. Review safety requirements for working with Mercury manometers, and the importance of slowly opening valves under pressure.

J. Give test

## REFERENCES USED IN DEVELOPING THIS UNIT

A. *Omega Complete Flow and Level Measurement Handbook and Encyclopedia*. Stamford, CT 06907: Omega Engineering, Inc., 1988.

B. Whalen, Bruce R. *Basic Instrumentation*. Third Edition. Austin, TX 78758: Petroleum Extension Service, University of Texas at Austin,1983.

C. *Dwyer Engineering and Product Applications Handbook*. Michigan City, IN 46360: Dwyer Instruments, Inc., 1986.

D. *Modulevel® EZ Series Electronic Level Transmitters*. Downers Grove, IL 60515-4499: Magnetrol International, 1984.

# PRINCIPLES OF LEVEL MEASUREMENT
# UNIT IV

## INFORMATION SHEET

I. Terms and definitions

A. Capacitance — The property of capacitors that enables them to store electrical charges as voltage, and release the charge back into a system when the circuit voltage drops

B. Displacers — Devices used to displace a fixed amount of liquid in a vessel to provide a level measurement

C. Ferrous — Containing or derived from iron, and often applied to ferro-magnetic materials like nickel and cobalt because they magnetize like iron

D. Float — A liquid level measuring device that works on Archimedes' principle that a floating body is buoyed up by a force equal to the weight of the liquid it displaces

E. IR (infrared) — The electro-magnetic radiation that lies in the spectrum above light and below microwave frequencies; a radiation of heat that can be measured by detection devices

F. LVDT (linear variable differential transformer) — A measuring device with a fixed primary coil and two secondary windings, connected in such a way that signals it produces will cancel if the core is centered between the secondary windings, but will indicate both movement and direction if the coil moves toward one end or the other

G. Static head — The pressure created by the weight of a liquid pressing down on the bottom of the vessel in which the liquid is contained

H. Ultrasonic — High frequency sound waves (200,000 to 500,000 KHz) that are beyond the range of human hearing, but travel well in air and in liquids

II. Basics of level measurement

A. Measuring sticks and float devices were the earliest forms of level measurement, and are still the most common forms used.

B. A measuring stick is still used by service stations to measure the level of fuel in their underground storage tanks, and early automobiles had measuring sticks attached to the gas caps.

# INFORMATION SHEET

C. Float gauges are still used in the water tanks of toilets to measure liquid level and control refilling.

D. Modern automobiles use dashboard fuel gauges or may have a computer display unit, but the fuel level measurement is still made by a metal float attached to a variable resistor so it can transmit an electrical signal to a gauge or computer.

III. **Measuring liquids in tanks** (Transparency 1)

A. The conventional float within a tank is suspended on a cable, and usually installed inside a metal tube known as a stilling well.

B. The stilling well/tube helps keep the float in proper vertical alignment in cases where pumping into or out of a tank would cause currents that would move the float horizontally, and cause a measurement error.

C. Since the level of the liquid cannot be seen inside the tank, there must be a way to determine the level of the float, and the level of the liquid it is floating in.

D. The simplest method of float control is to attach a cable or metal tape to the float, and roll the cable or tape up towards the top of the tank on a spool, and then count the rotations of the spool.

E. A related method of float control is to encode the tape with indentations or holes that can be read by some mechanical or optical device at the take-up spool, and level information transmitted on to a display or recorder.

F. In most cases, tanks are some distance from a control point, and transmitters are used to send level information to a central location.

IV. **Measuring liquids with sight glasses** (Transparency 2)

A. Sight glasses are common on low-pressure process vessels.

EXAMPLE: A large coffee urn usually employs a sight glass that reaches from the bottom to the top of the urn, and since the sight glass is parallel to the urn, the level in the sight glass is the true level of the coffee in the urn.

B. Sight glasses pose a problem in that an operator must be physically present to monitor the level.

C. Because of the need to read level at any time, or to review the record of level as needed, other methods of reading level have been devised.

# INFORMATION SHEET

V. **Measuring level with float devices** (Transparency 3)

A. For processes under pressure, metal vessels are used, and the level measuring floats, when they are used, are in metal or plastic piping where they cannot be seen.

B. When a non-ferrous metal or plastic tube is run parallel to a vessel, and a ferrous metal float is placed in the tube, level can be detected with an LVDT (linear variable differential transformer) or a magnetic reed switch.

C. An LVDT is a special transformer with a movable magnetic core, and is capable of an output electrical signal that can detect the amount of movement, and the direction of movement.

D. When the float of an LVDT is the movable core, and the rest of the transformer is attached around the tube containing the liquid from the process, then the resulting electrical signal is a level measurement.

E. A magnetic reed switch is a magnet attached to the float in a parallel tube so that when the level changes, and the float moves up and down, it passes the reed switches attached to the parallel tube, causing the reed switches to close and produce electrical signals.

EXAMPLE: If a reed switch were located at every inch of level movement, the switch signals would be summed to provide a level measurement.

VI. **Measuring level with displacers** (Transparency 3)

A. Displacers are similar to float-type level gauges, but instead of floating on top of a liquid, a displacer is submerged or partially submerged into the liquid it is measuring.

B. Since the displacer is submerged or partially submerged in the liquid, it is buoyed up or down by the liquid level.

C. When the level is low, the displacer is heavier compared to the buoyant force, and it pulls down on the force measuring system.

D. When the level is high, the displacer is lighter compared to the buoyant force, and it pushes up on the force measuring system.

E. Since displacers are normally submerged in a liquid, they are not subject to surface movement when liquid is pumped in or out.

F. Displacers are capable of a broader range of level control than float gauges, and are less affected by density than float gauges.

## INFORMATION SHEET

VII. Measuring level with capacitance level sensors

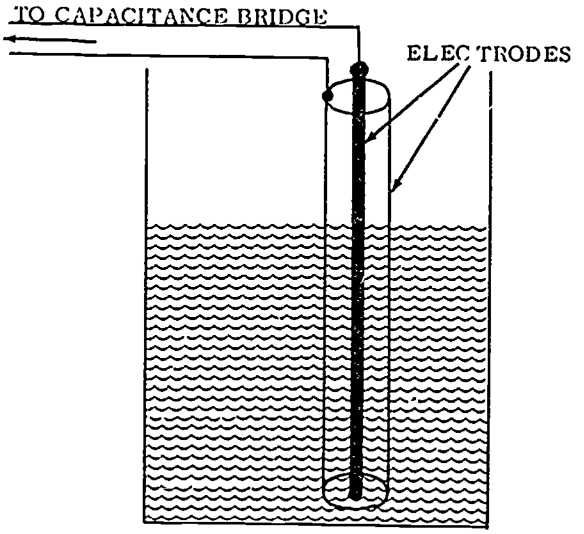
A. Capacitive sensors are used in electronic pressure and differential pressure transmitters.

B. The capacitive sensor has two plates separated by a thin insulating material called a dielectric.

C. A liquid pressure change causes a capacitance change in a capacitive sensor.

D. A change in capacitance is converted into a current or voltage output which corresponds to a differential pressure which is calibrated to correspond to level. (Figure 1)

FIGURE 1




**Courtesy Petroleum Extension Service (PETEX)**
**University of Texas at Austin**

VIII. Measuring level with bubbler systems

A. Static head measuring devices work on the principle that the weight of a liquid above some square area is a function of the specific gravity of the liquid, and the height of the liquid in a column.

B. The bubble tube is a common level measuring device and is used with a pressure or $\Delta P$ device.

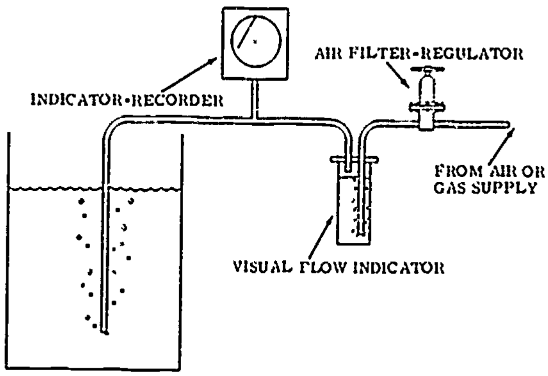
(NOTE: $\Delta P$ is the symbol for differential pressure, and a symbol that technicians run across frequently in instrumentation literature.)

# INFORMATION SHEET

C. In a bubble tube device, a tube runs to the bottom of a vessel, and air or gas pressure is applied until a stream of bubbles is produced. (Figure 2)

D. The stream of bubbles indicates that gas pressure applied is sufficient to overcome the static pressure of the head, and the pressure of the applied gas is measured and used to compute level from the pressure/height relationship.

FIGURE 2




Courtesy Petroleum Extension Service (PETEX)
University of Texas at Austin

IX. **Measuring level with differential pressure**

A. In closed or pressurized systems, ΔP measuring methods are used to determine level.

B. One ΔP gauge uses a manometer connected with the pressure leg to the bottom of the vessel, and the other leg connected to the top of the vessel.

C. The pressure in the system is cancelled because it is applied to each leg of the manometer while the weight of the liquid in the vessel is measured by the difference in height of the liquid in the manometer legs.

D. Manometers used in level measuring devices are usually made of metal to withstand pressure, and floats are sometimes added to follow and detect level in the manometer, and the float levels are then read mechanically or magnetically.

# INFORMATION SHEET

X. Measuring level with infrared systems

A. Infrared or optical level measuring systems are used for special applications where remote gauging of materials is desirable or necessary such as the level of molten metal in a furnace.

B. IR measuring devices are effective with materials that give off IR energy, and the level measuring device reads the distance of the radiation sources, and reports the level based on the relationship of sensor, liquid level of the IR source, and the bottom of the vessel.

C. Most IR sensors use radiation to compute distance, so the temperature which causes radiation from the material must be used in computing a correction for level measurement.

D. One compensation method is to have a dual sensor measuring intensity and distance, and to use the intensity reading to adjust the system.

E. IR equipment is used sparingly because it is costly, but with the advent of solid state IR sensors, the cost is dropping rapidly, and these systems will become more popular.

XI. Measuring level with radioactive devices

A. Radioactive or nuclear measuring devices are used in remote or difficult to access places, and also for level measurement of solid materials.

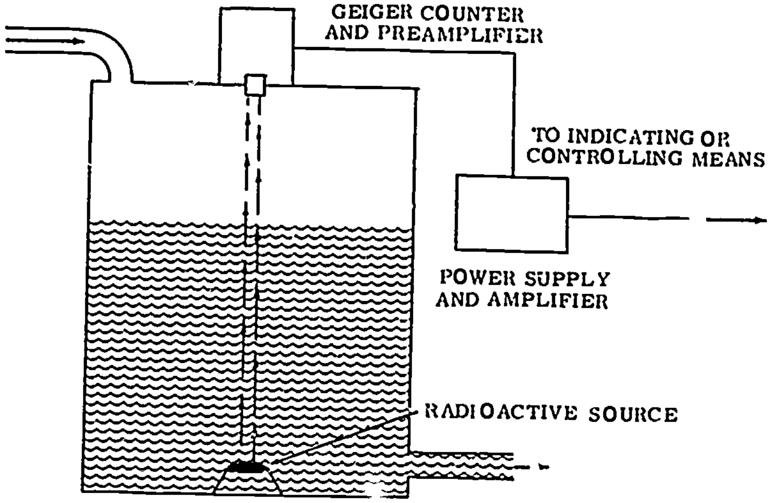
(NOTE: Radioactive systems pose a health hazard to operators working near them, and radioactive source materials are strictly controlled by the government.)

B. One level measurement system uses a radioactive isotope source with known radiation characteristics.

C. The isotopes are attached to the bottom of a vessel containing the material (liquid or solid) to be measured, while a Geiger counter is placed at the top of the vessel to make a reading that determines the amount of radiation passing through the material. (Figure 3)

# INFORMATION SHEET

FIGURE 3




**Courtesy Petroleum Extension Service (PETEX)**
**University of Texas at Austin**

D. The amount of radiation reaching the top is a function of the amount of material the radioactive particles had to pass through to reach the top, and the higher the level of the material, the lower the amount of radiation that will reach the Geiger-counter.

XII. **Measuring level with ultrasonic techniques**

A. Ultrasonic level measuring techniques are being used more and more because they can accomplish certain types of level measuring tasks that other systems cannot do with accuracy.

B. In a system, an ultrasonic transducer is placed in a vessel perpendicular to the level of the material, and then pulsed at a frequency of 200KHz to 500KHz.

C. The ultrasonic signals hit the top of the liquid and bounce back to the source transducer, and the time it takes the signal to travel back and forth to the level interface is computed, and the distance is calculated by the system to find the level.

D. There is also a secondary return signal that follows the first, and serves as a good reference with which to compare.

# INFORMATION SHEET

E. Ultrasonic level measuring systems compute level no matter what the composition of the material is, or even if the composition of the material is changing.

F. Ultrasonic systems are being used more and more to measure levels of sewage and cooling tower water because both of these materials require level monitoring, and are constantly changing in composition.

G. Measuring level ultrasonically permits facilities such as underground concrete sewage receptacles to be placed in remote sites.

XIII. **Other methods of level measurement**

A. A level measuring technique common to both solid and liquid levels is to weigh the vessel that contains the material to be measured.

B. In these level measuring systems, the vessels are mounted on load cells or strain gauges that track the weight of the vessel and the material inside.

C. Level is calculated by a system controller that subtracts the weight of the vessel and divides by the unit weight of the material to calculate the volume, and converts that to a level measurement.

XIV. **Specific gravity and level measurement**

A. Just as with other measurement forms, specific gravity or the density of a material affects level measuring equipment.

B. In a level measuring system that uses a float, the specific gravity of the liquid in which the float is placed becomes significant because the more dense the liquid, the less the float will sink in the liquid.

C. Measuring level with a displacement sensor depends on the amount of liquid displaced by the sensor, and how much liquid the sensor displaces is dependent on the specific gravity of the liquid.

D. Static head and differential pressure measuring techniques depend on the weight of the liquid on top of a sensor, and that weight will always vary with specific gravity of the liquid.

E. All level measuring techniques that depend on pressure or weight are subject to changes in readings when there is a change in specific gravity.

# INFORMATION SHEET

XV. Applications of level measurement

A. One of the most common applications in level measurement is determining the level of material in a storage tank, and although several methods are used, float devices are common.

B. In both food processing and brewing of beer, measurement and control of level in batch processing is critical to production of a quality product.

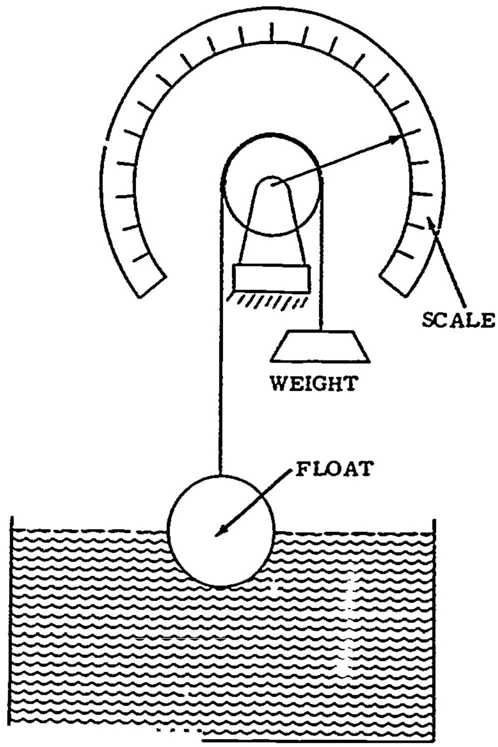
C. Level measurement of the contents of vessels is critical in petroleum and chemical processes because the vessels, in many cases, supply raw materials or semifinished product required for continued flow.

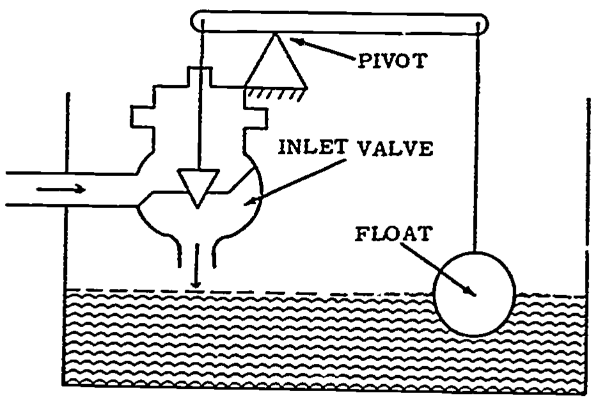
D. Measuring level in flow systems is different from batch systems because in flow systems, the vessels must be closed.

E. Measuring level in closed vessels used in flow systems requires capacitance sensors, IR, nuclear, ultrasonic, or pressure measuring systems.

F. Because of gains in integrated circuit and transducer technology, the newer systems of level measurement such as ultrasonic and IR will find more applications because the systems are small, lightweight, and portable, and offer versatile options such as easy interfacing with computers and other electronic devices.

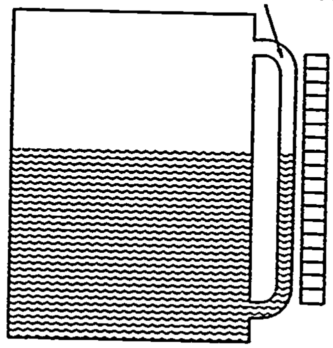
# Typical Float Gauges

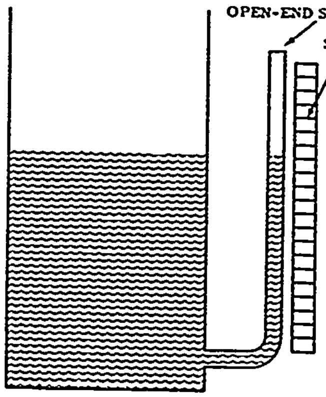



Courtesy Petroleum Extension Service (PETEX)
University of Texas at Austin

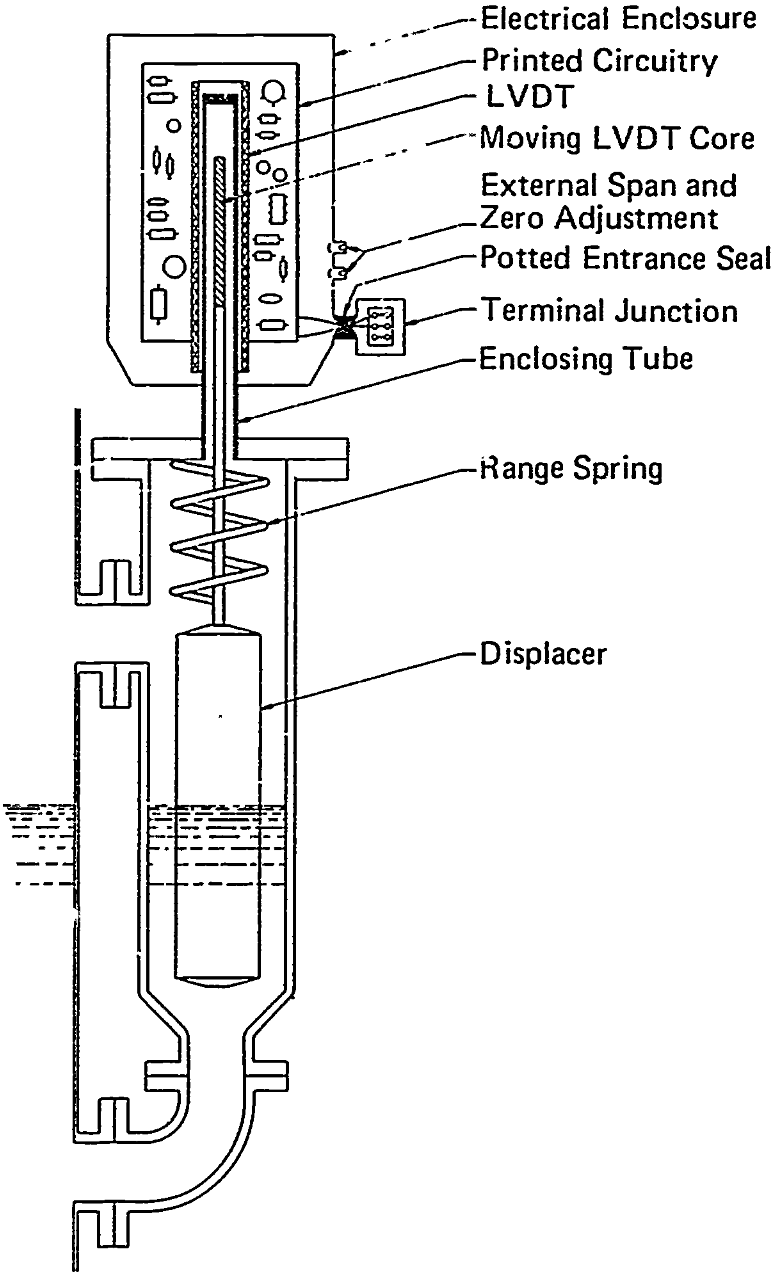
# Sight Glass Applications




Courtesy Petroleum Extension Service (PETEX)
University of Texas at Austin

# Linear Variable Differential Transformer




Courtesy Magnetrol International

# PRINCIPLES OF LEVEL MEASUREMENT
# UNIT IV

## HANDOUT #1 — WORKING WITH CHARTS

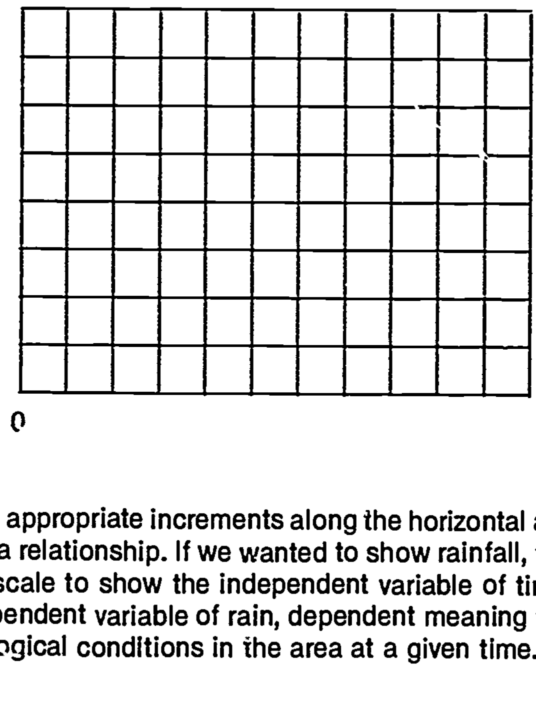
### PURPOSE

Materials presented graphically provide faster access to complex information, and convenient records for reference. In instrumentation, charts plotted on common graph paper provide technicians with a handy tool for helping calibrate instruments, and keeping track of system performance. Making a chart is not difficult, but knowing how charts are structured will make the task easier.

### APPLICATION

Charts are usually made on graph paper so that the chart presents an extension of two scales. One scale runs horizontally along the bottom of the graph from left to right, and the other scale is a vertical one that intersects the horizontal scale so that the two scales intersect at a zero point at lower left. When the scales are extended, they form a grid or a graph on which a chart can be plotted. (Figure 1)

FIGURE 1

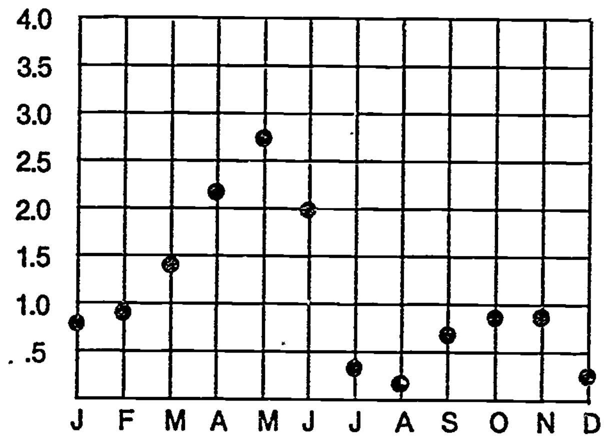



By adding variables in appropriate increments along the horizontal and vertical scales, we can use the graph to plot a relationship. If we wanted to show rainfall, the chart would be plotted along the horizontal scale to show the independent variable of time, and along the vertical scale to show the dependent variable of rain, dependent meaning that the amount of rainfall depends on meteorological conditions in the area at a given time. (Figure 2)

## HANDOUT # 1

FIGURE 2

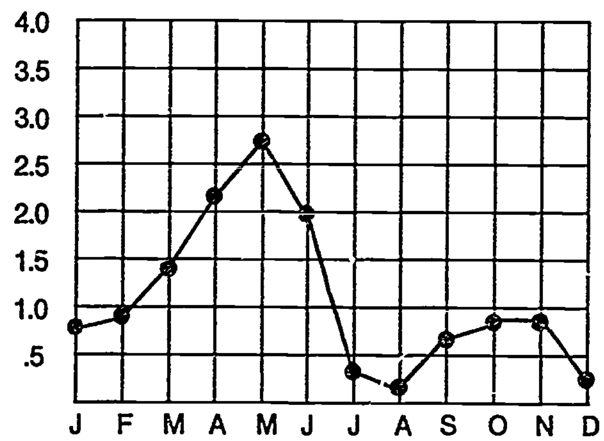
Monthly rainfall in inches




Dots may be used to plot the chart, but connecting the dots with a prominent line gives the chart a profile which provides greater visibility. It's easy to see in Figure 3 that rainfall peaked in May and declined to nearly nothing in August. But the profile created by connecting the dots does more than enhance graphic impact, as we will see later. (Figure 3)

FIGURE 3

Monthly rainfall in inches

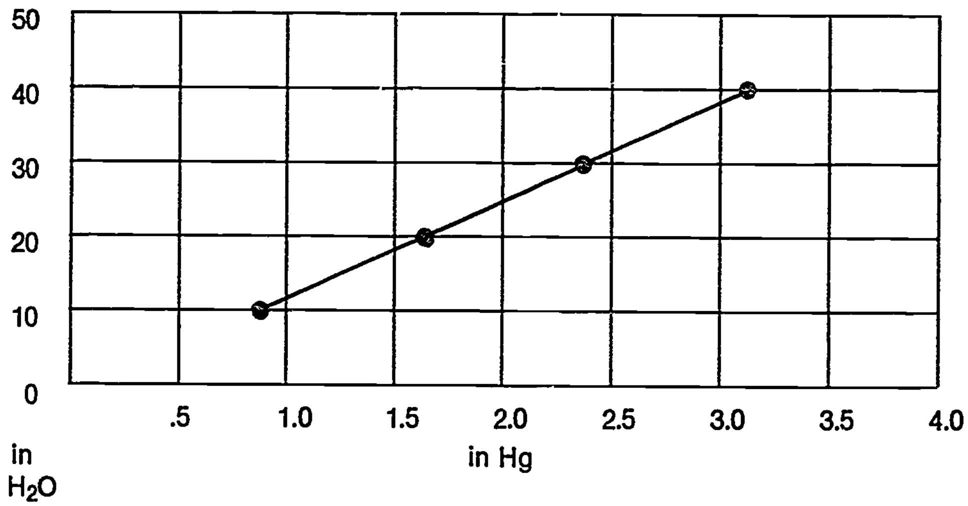


# HANDOUT #1

A few more words about the rainfall chart. There should be no difficulty in determining the months because they're in order from J(anuary) through D(ecember). That means the first J in the middle of the chart is June and the second J is July. By relating the initials to the months they represent, and because we know the order of the months, we see the order in the chart. This process of relating things in an order or relating them to known values is usu .ily called common sense, but it's also a form of interpolating. Let's look at another chart to better demonstrate how the profile of a chart can have significance.

The chart in Figure 4 shows the relationship between inches of Mercury (in Hg) and inches of water (in $H_2O$). But notice the profile made when the dots are connected—it's a straight line. When the connected points on a chart form a straight line, the chart is said to have linearity. In instrumentation, certain instruments function in such a way that when their performance is charted, it will approximate a straight line, and the closer the performance approximates a straight line, the greater the degree of linearity. When charted performance does not approximate a straight line, it is said to be non-linear. Since linear and non-linear are words used often in instrumentation, it's easier to remember them by the way they look on a chart because that's the way they are referenced in instrumentation. (Figure 4)

FIGURE 4




Determining the names of the months in the rainfall chart was called a form of interpolating, but in a stricter sense, interpolating means to be able to estimate an **unknown value** by referencing adjacent known values. Look again at the linearity of the water/Mercury chart. The chart doesn't show how many inches of water would be equal to 3.5 inches of Mercury, but the linear information makes it easy to interpolate: 3.5 in Hg = 47 in $H_2O$. The figure is approximate for the chart given, but on a chart with smaller increments, interpolation would give an exact figure.

# HANDOUT # 1

## CONCLUSION

Charts are valuable tools for instrumentation technicians because they provide information necessary for calibrating instruments, and checking system performance. Linearity and non-linearity become obvious when charted, and recorders and other instruments have both linear and non-linear scales. Charts themselves are not all square or rectangular, many clocking devices use circular charts. Charts may present more than one dependent variable, even two or three. Being able to make charts, read charts, and interpolate unknown values from the information charts provide are among the skills a good instrumentation technician needs to develop.

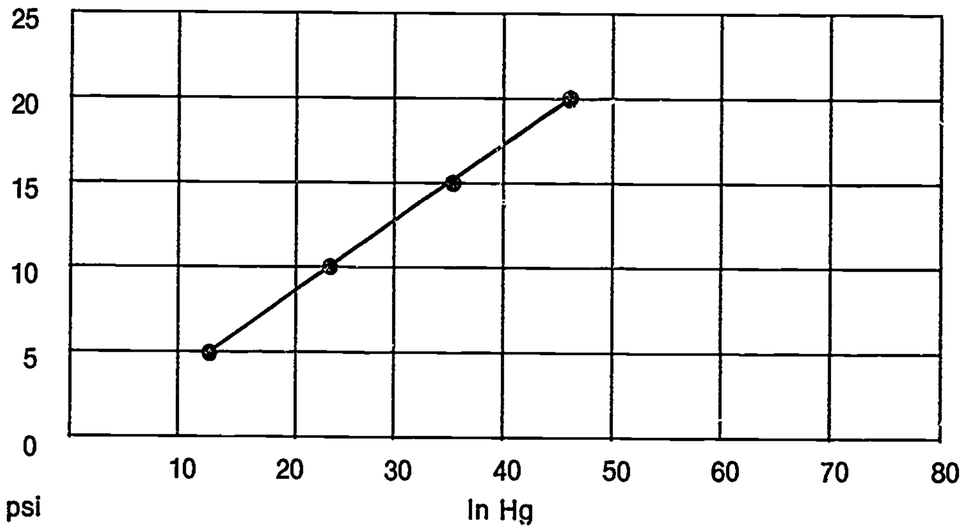
# PRINCIPLES OF LEVEL MEASUREMENT
# UNIT IV

## ASSIGNMENT SHEET #1 — EXAMINE AND INTERPRET PERFORMANCE CHARTS

Directions: Examine the following charts carefully and answer the questions that follow.

1.

psi/Inches of Mercury Chart




a. Is the information in the chart linear or non-linear?

Answer: ______________________________

b. Can the chart be used to interpolate other psi/in Hg relationship, or would you have to guess?

Answer: ______________________________

c. What is 12 psi approximately equal to in inches of Mercury?

Answer: ______________________________

d. What would be the approximate psi equivalent of 60 in Hg?

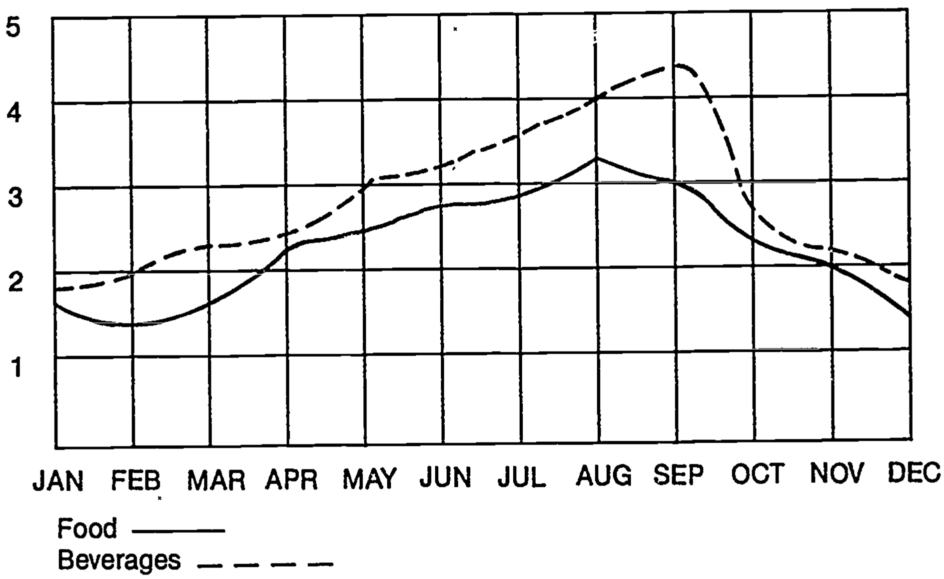
Answer: ______________________________

e. What would be the approximate in Hg equivalent of 2.5 psi?

Answer: ______________________________

## ASSIGNMENT SHEET #1

2. Joe's Place
Monthly Sales—Thousands of Units




a. Is the information about Joe's Place linear or non-linear?

Answer: ____________________

b. The legend at the lower left of the chart provides what information about food and beverages?

Answer: ____________________

c. In what three months did Joe sell the most beverages?

Answer: ____________________

d. What were the worst two months for Joe's food sales?

Answer: ____________________

# ASSIGNMENT SHEET #1

e. Joe started a 90-day advertising campaign with a local radio station just before the 4th of July. Study the chart carefully, and then select the answer that best reflects the information in the chart. Did the advertising help?

1) The advertising definitely helped.

2) People naturally drink more cold beverages during hot weather months, and beverages sales dropped significantly when cooler weather arrived, so no true evaluation of the advertising can be made.

3) The advertising did not help.

Answer: ____________________

f. What does your answer to e show about the relationship of non-linearity and interpolation? (Select the best answer)

1) There is absolutely no relationship.

2) It is difficult to interpolate from non-linear information.

3) Non-linear information is worthless.

Answer: ____________________

# PRINCIPLES OF LEVEL MEASUREMENT
# UNIT IV

## ASSIGNMENT SHEET #2 — MAKE AN EMERGENCY LEVEL MEASUREMENT IN A MAKE-UP WATER STORAGE TANK

Directions: Instrumentation technicians frequently have to execute emergency troubleshooting routines to avoid costly downtime in a system. Sometimes a device can be quickly replaced, repaired, or recalibrated, but at other times the technician has to improvise. Read the following situation carefully, consider all conditions given, and solve the problem in a simulated emergency.

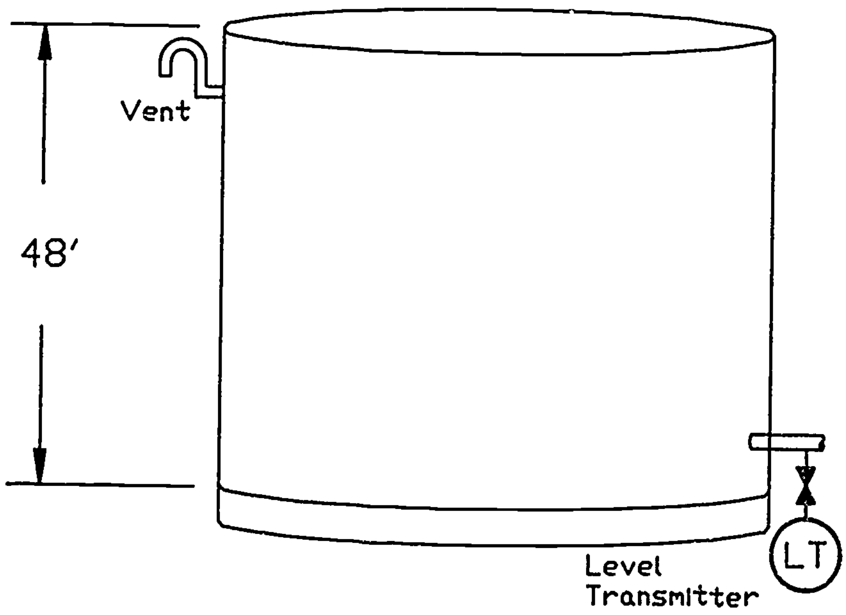
**Situation**

It's 2 o'clock in the morning. The shift supervisor at the City Electric Company power plant calls you to report that there is a potential problem with the level in the make-up water storage tank. Water has been used from the tank at a regular rate, but the control room operator has had no indication of water level in the tank for more than 3 hours, and is worried about running out of water.

You know the situation poses the possibility of a costly shutdown of the boiler and turbine generator, so you rush to the power plant and immediately determine that the level transmitter on the make-up tank is out of order. From previous experience, you know that you can repair the transmitter and have it back in normal operation in about 1.5 hours, and you confidently report the information to the supervisor. The supervisor tells you that an hour and a half is too long, and that a reliable calculation of water level in the tank must be made as soon as possible. To help with your troubleshooting, you have the following conditions on which to base your decisions:

1. From the P&ID, you check specifications for the tank.

FIGURE 1



## ASSIGNMENT SHEET #2

2. You make the following determinations:

    a. The tank is 48 feet high.

    b. The tank is vented to the atmosphere.

    c. There is no sight glass.

    d. There is no way to use a stick for measuring.

    e. The level transmitter uses static head to infer level.

    f. In the future, you will make it a point to get to bed earlier when you're on stand-by.

3. You decide to measure the static head on the tank by using the level transmitter connection, and immediately go to the I&C (Instrumentation and Control) shop to look for necessary equipment. You find 5 devices there that might serve your purpose, so mark YES if you can use the device, and mark NO if you cannot use the device.

| | | YES | NO |
|---|---|---|---|
| a. | 36" U-tube water manometer | ☐ | ☐ |
| b. | 36" U-tube mercury manometer | ☐ | ☐ |
| c. | 0-15 PSI test gauge | ☐ | ☐ |
| d. | 0-30 PSI test gauge | ☐ | ☐ |
| e. | 0-60 Hg well manometer | ☐ | ☐ |

4. You decide to measure the static head in pounds per square inch, and your gauge reads 10 PSI. This means the water level in the tank is (use your Pressure Conversion Table and then convert to feet):

    a. 13 feet

    b. 16 feet

    c. 23 feet

    d. 30 feet

5. You decide to measure the static head in inches of Mercury, and your manometer reads 19.4 in Hg. This means the water level in the tank is (use your Pressure Conversion Table and then convert to feet):

    a. 15 feet

    b. 17 feet

    c. 22 feet

    d. 33 feet

# ASSIGNMENT SHEET #2

6. As a passing thought, you wonder if an accurate level measurement could be made if the tank were pressurized.

   a. True

   b. False

7. Your supervisor requests that you explain the answer you gave to item 6.

   ______________________________________________

   ______________________________________________

   ______________________________________________

   ______________________________________________

☐ Have your instructor evaluate your work.

# ASSIGNMENT SHEET #2

## Pressure Conversion Table

| When measurement is in | To get | Multiply by |
|---|---|---|
| in Hg | $lb/in^2$ | .491 |
| in Hg | mmHg | 25.4 |
| $lb/in^2$ | in Hg | 2.036 |
| $lb/in^2$ | mmHg | 51.7 |
| mmHg | $lb/in^2$ | .0193 |
| mmHg | in Hg | 3.94 |
| in $H_2O$ | in Hg | .0735 |
| in Hg | in $H_2O$ | 13.6 |
| in $H_2O$ | $lb/in^2$ | .0361 |
| $lb/in^2$ | in $H_2O$ | 27.7 |

# PRINCIPLES OF LEVEL MEASUREMENT
# UNIT IV

## ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #1

1. a. Linear
   b. Chart can be used to interpolate
   c. 28 in Hg
   d. 25 psi
   e. 5 in Hg

2. a. Non-Linear
   b. Food is represented by a solid line, beverages a dotted line
   c. Jul, Aug, & Sep
   d. Jan & Feb
   e. 2
   f. 2

Assignment Sheet #2

3. a. No
   b. No
   c. No
   d. Yes
   e. Yes

4. 23 feet

5. 22 feet

6. False because there is no top access to establish $\Delta P$

7. Evaluated to the satisfaction of the instructor

# PRINCIPLES OF LEVEL MEASUREMENT
# UNIT IV

## JOB SHEET #1 — MEASURE, CUT, AND BEND COPPER TUBING TO SPECIFICATIONS

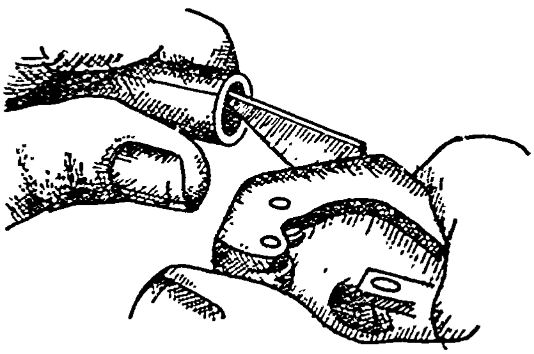
A. Tools and equipment

1. Tubing cutter
2. 1/4" level-type tubing bender w/graduated degree scale
3. Copper tubing, 1/4" OD
4. Tape measure
5. Marker
6. Safety glasses

B. Routine #1 — Making a 90° bend

1. Put on safety glasses.
2. Measure 17" on a straight piece of copper tubing.
3. Cut the tubing with a tubing cutter.
4. Ream the cut end of tubing lightly to remove burrs. (Figure 1)

FIGURE 1



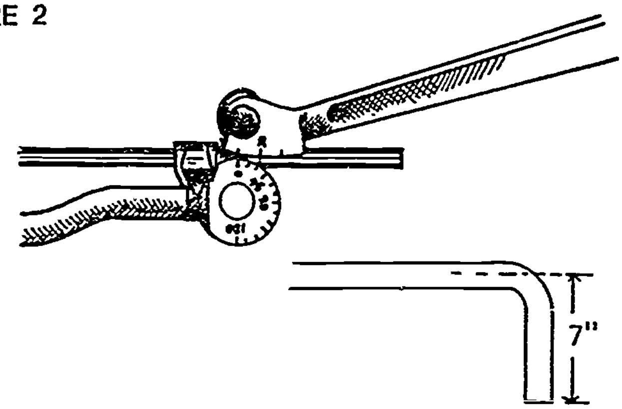
5. Meausre 7" on the piece you cut off, and mark it.

(NOTE: In lieu of the routines outlined, your instructor may direct you to complete the tubing requirements for the bubbler system that has to be constructed for Job Sheet #2)

# JOB SHEET #1

6. Fit the tubing bender over the copper as illustrated in Figure 2.

FIGURE 2




7. Align the "R" mark on the mark on the tubing.

8. Pull the lever until the "R" mark lines up with the 90° mark.

9. Remove the bender.

   ☐ Have your instructor check your work.

C. Routine #2 — Making a 180° bend

1. Put on safety glasses.

2. Measure and cut off a 12" piece of tubing.

3. Lightly ream the ends to remove burrs.

4. Measure and mark 6" on the tubing.

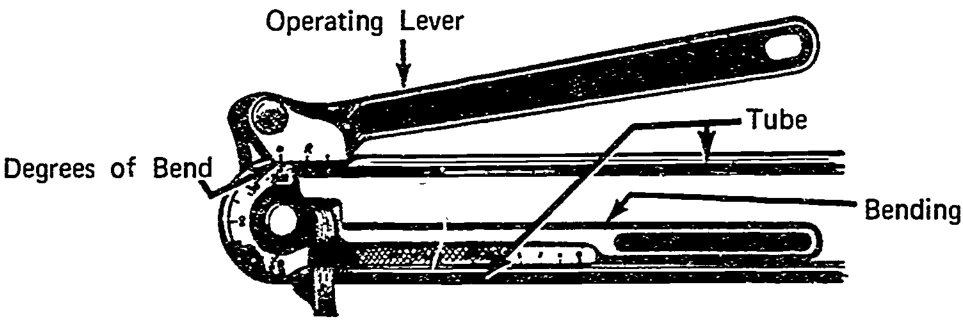
5. Fit the bender over the copper.

6. Align the "R" mark on the bender with the 6" mark on the tubing.

## JOB SHEET #1

7. Pull the lever until the "R" mark on the bender lines up with the 180° mark on the bender scale. (Figure 3)

FIGURE 3




8. Remove the bender.

☐ Have your instructor check your work.

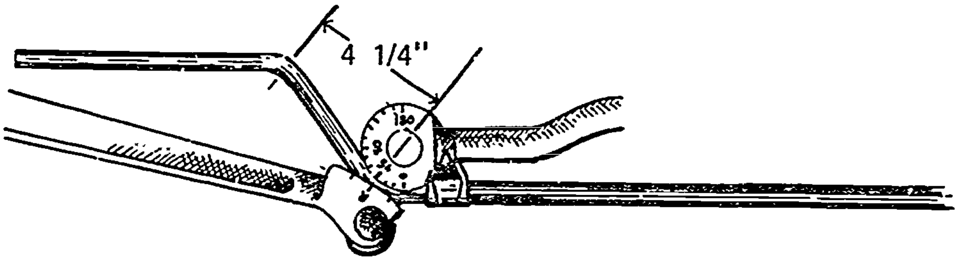
D. Routine #3 — Making a 45° offset bend

1. Put on safety glasses.
2. Measure and cut off a 17" piece of tubing, and ream the ends.
3. Measure and mark 6" on the tubing.
4. Fit the bender over the copper.
5. Align the "R" mark on the bender with the 6" mark on the tubing.
6. Pull the lever until the "R" mark on the bender lines up with the 45° mark on the bender scale.
7. Remove the bender.
8. Measure 4 1/4" from the first mark, and make another mark.
9. Fit the bender over the copper so that it is on the opposite side of the tubing where you made the first bend.
10. Align the "R" mark on the bender with the 4 1/4" mark on the tubing.

## JOB SHEET #1

11. Pull the lever until the "R" mark on the bender lines up with the 45° mark on the bender scale. (Figure 4)

FIGURE 4




12. Measure the offset to make sure it is 4 1/4" from the center of one bend to the cther.

☐ Have your instructor check your work.

13. Clean area and return tools and equipment to proper storage.

# PRINCIPLES OF LEVEL MEASUREMENT
# UNIT IV

## JOB SHEET #2 — USE A BUBBLER SYSTEM TO DETERMINE LIQUID LEVEL IN A TANK OPEN TO ATMOSPHERE

A. Tools and materials

1. Clear 30" to 60" high water tank with a bottom spigot drain
2. 0-100 in $H_2O$ Magnahelic bellows pressure gauge
3. Air pressure regulator
4. Instrument air supply
5. 1/4" copper tubing with cutting and bending tools
6. 1/4" tee
7. 1/4" plastic tubing and appropriate connectors
8. Hand held calculator
9. Pencil and paper
10. Safety glasses

B. Routine #1 — Assembling the bubbler system

1. Put on safety glasses.
2. Measure and cut copper tubing as required to reach from 1" above the bottom of the tank inside, up over the rim of the tank, and down the outside of the tank to the instrument air connection.

   (NOTE: If you require help with cutting, bending, or connecting copper tubing, ask your instructor for assistance, and be sure to use Figure 1 that accompanies this job sheet as a guideline to help get this activity properly set up.)

3. Connect the air pressure regulator to the air supply, and make sure it is turned fully COUNTERCLOCKWISE to the OFF position.
4. Connect the output of the air pressure regulator to the 1/4" tee at the bubbler tube.
5. Connect the manometer to the tee with plastic tubing and secure with proper connections.

# JOB SHEET #2

6. Check all fittings for tightness, and be sure the bubbler tube itself is securely in place so that it will not move under pressure.

   ☐ Have your instructor check your work.

C. Routine #2 — Measuring level with the bubbler system

1. Fill the tank with water to a point you choose to reference as 100% full.

2. Measure and record in inches the distance of the liquid level (from bottom to top) when the tank is full, and enter the figure on the Bubbler Data Sheet that accompanies this job sheet.

   **(CAUTION: As you turn the air pressure regulator on in Step 4, be certain to do it very slowly to avoid exceeding the maximum range of the Magnahelic gauge.)**

3. Turn on the air supply to the regulator.

4. Turn the air regulator slowly CLOCKWISE as you watch the bubbler pipe.

5. Continue to slowly increase air pressure until you see bubbles rising from the bubbler tube.

6. Adjust the air pressure to the minimum pressure required to maintain the slowest stream of bubbles possible.

7. Read the in $H_2O$ on the gauge, and record the figure on your data sheet beside the level entry for full.

   ☐ Have your instructor check your work.

   (NOTE: Your in $H_2O$ reading for a full tank should be very close to the height of the level in your tank. In other words, if you have 30" of water in the tank, the gauge reading should be close to 30 in $H_2O$.)

D. Routine #3 — Measuring falling level

1. Drain the water level in the tank until the tank is 3/4 full.

2. Measure the 3/4 full mark in inches and record it on your data sheet.

3. Read the in $H_2O$ and record the figure on your data sheet beside the level entry for 3/4 full.

4. Drain the water level in the tank until the tank is 1/2 full, and record the level and in $H_2O$ measurements on your data sheet.

5. Drain the water level in the tank until the tank is 1/4 full, and record level and in $H_2O$ readings on your data sheet.

   ☐ Have your instructor check your work.

## JOB SHEET #

E. Routine #4 — Preparing a bubbler data chart

1. Go to your data chart, and make a prominent dot at points that correlate liquid level to in $H_2O$ for the tank 100% full, 75% full, 50% full, and 25% full.

2. Join the dots on your chart by connecting them with a line.

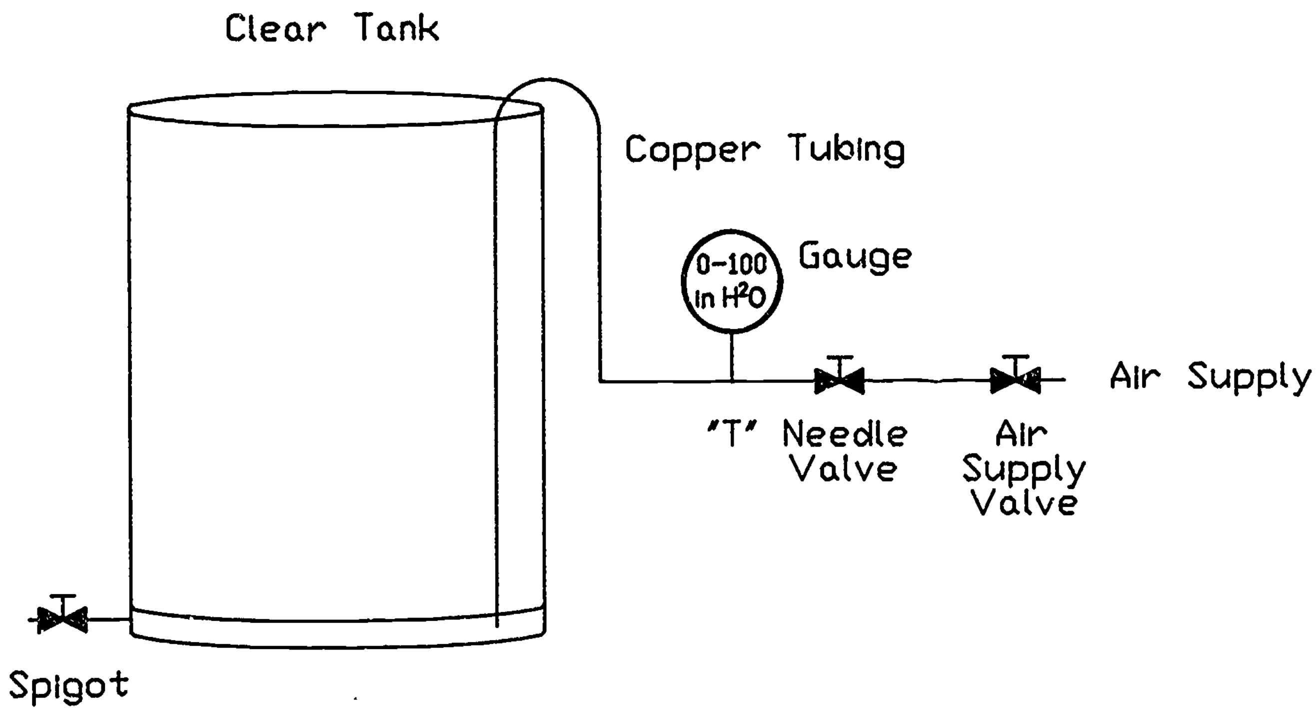
   ☐ Have your instructor check your work.

3. Discuss with your instructor the linearity of your information, and how your chart can be used to interpolate other relationships for level/in $H_2O$.

4. Turn off air supply, disassemble the bubbler tank, and return tools and equipment to proper storage.

JOB SHEET #2

FIGURE 1







75

# JOB SHEET #2

## Bubbler Data Sheet

| | Level: In Inches | Pressure: in $H_2O$ |
|---|---|---|
| Full: | ____________ | ____________ |
| 3/4 Full: | ____________ | ____________ |
| 1/2 Full: | ____________ | ____________ |
| 1/4 Full: | ____________ | ____________ |

## Bubbler Data Chart

100% (Full) ______

75% ______

50% ______

25% ______

0

% of Level in Tank

Actual Inches of Water in Tank

25% ______ 50% ______ 75% ______ 100% ______

______ in $H_2O$ on gauge

# PRINCIPLES OF LEVEL MEASUREMENT
# UNIT IV

## PRACTICAL TEST #1
## JOB SHEET #1 — MEASURE, CUT, AND BEND COPPER TUBING TO SPECIFICATIONS

Student's name ______________________________ Date ____________

Evaluator's name ______________________________ Attempt no. ______

Student instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

### PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:

| | | | YES | NO |
|---|---|---|---|---|
| 1. | Wore safety glasses. | 1. | ☐ | ☐ |
| 2. | Measured and cut tubing properly. | 2. | ☐ | ☐ |
| 3. | Made a 90° bend properly. | 3. | ☐ | ☐ |
| 4. | Made a 180° bend properly. | 4. | ☐ | ☐ |
| 5. | Made a 45° offset bend properly. | 5. | ☐ | ☐ |
| 6. | Had proper on center measurement of offset. | 6. | ☐ | ☐ |
| 7. | Cleaned area and returned equipment to storage. | 7. | ☐ | ☐ |

Evaluator's comments: ________________________________________________

______________________________________________________________

______________________________________________________________

# JOB SHEET #1 PRACTICAL TEST

## PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

| Criteria: | | | | |
|---|---|---|---|---|
| Equipment and Materials | Properly selected and properly used<br>4 | Properly selected and acceptably used<br>3 | Poorly selected and/or used<br>2 | Improperly selected and/or used<br>1 |
| Procedure | Well followed<br>4 | Acceptably followed<br>3 | Poorly followed<br>2 | Improperly followed<br>1 |
| Product | Excellent<br>4 | Good<br>3 | Fair<br>2 | Poor<br>1 |
| Safety | Carefully observed<br>4 | Acceptably observed<br>3 | Poorly observed<br>2 | Improperly observed<br>1 |

EVALUATOR'S COMMENTS: ____________________________________________

______________________________________________________________

**PERFORMANCE EVALUATION KEY**

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

# PRINCIPLES OF LEVEL MEASUREMENT
# UNIT IV

## PRACTICAL TEST #2
## JOB SHEET #2 — USE A BUBBLER SYSTEM TO DETERMINE LIQUID LEVEL IN A TANK OPEN TO ATMOSPHERE

Student's name ______________________________ Date ____________

Evaluator's name ____________________________ Attempt no. ______

Student instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

### PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

The student:

| | | | YES | NO |
|---|---|---|---|---|
| 1. | Wore safety glasses. | 1. | ☐ | ☐ |
| 2. | Prepared and assembled bubbler properly. | 2. | ☐ | ☐ |
| 3. | Assembled valves and manometer safely. | 3. | ☐ | ☐ |
| 4. | Made water level entries on data sheet. | 4. | ☐ | ☐ |
| 5. | Made gauge reading entries on data sheet. | 5. | ☐ | ☐ |
| 6. | Completed Bubbler Data Chart Properly. | 6. | ☐ | ☐ |
| 7. | Disassembled bubbler safely. | 7. | ☐ | ☐ |
| 8. | Returned tools and equipment to storage. | 8. | ☐ | ☐ |

Evaluator's comments: _______________________________________________

_____________________________________________________________________

_____________________________________________________________________

# JOB SHEET #2 PRACTICAL TEST

## PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

| Criteria: | | | | |
|---|---|---|---|---|
| Equipment and Materials | Properly selected and properly used 4 | Properly selected and acceptably used 3 | Poorly selected and/or used 2 | Improperly selected and/or used 1 |
| Bubbler Assembly Procedure | Well followed 4 | Acceptably followed 3 | Poorly followed 2 | Improperly followed 1 |
| Data Sheet and Chart Entries | All properly entered 4 | Almost all entered 3 | Too few entered 2 | Too few entered or improperly entered 1 |
| Safety | Carefully observed 4 | Acceptably observed 3 | Poorly observed 2 | Improperly observed 1 |

EVALUATOR'S COMMENTS: ______________________________

______________________________

| PERFORMANCE EVALUATION KEY |
|---|
| 4 — Skilled — Can perform job with no additional training.<br>3 — Moderately skilled — Has performed job during training program; limited additional training may be required.<br>2 — Limited skill — Has performed job during training program; additional training is required to develop skill.<br>1 — Unskilled — Is familiar with process, but is unable to perform job. |

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

# PRINCIPLES OF LEVEL MEASUREMENT
# UNIT IV

## TEST

NAME ______________________________ SCORE ______________

1. Match the terms on the right with their correct definitions.

| | | |
|---|---|---|
| _____a. | The property of capacitors that enables them to store electrical charges as voltage, and release the charge back into a system when the circuit voltage drops | 1. Static head |
| | | 2. Float |
| | | 3. IR |
| _____b. | Devices used to displace a fixed amount of liquid in a vessel to provide a level measurement | 4. Ultrasonic |
| | | 5. Capacitance |
| _____c. | Containing or derived from iron, and often applied to ferro-magnetic materials like nickel and cobalt because they magnetize like iron | 6. LVDT |
| | | 7. Ferrous |
| _____d. | A liquid level measuring device that works on Archimedes' principle that a floating body is buoyed up by a force equal to the weight of the liquid it displaces | 8. Displacers |
| _____e. | The electro-magnetic radiation that lies in the spectrum above light and below micro-wave frequencies; a radiation of heat that can be measured by detection devices | |
| _____f. | A measuring device with a fixed primary coil and two secondary windings, connected in such a way that signals it produces will cancel if the core is centered between the secondary windings, but will indicate both movement and direction if the coil moves toward one end or the other | |
| _____g. | The pressure created by the weight of a liquid pressing down on the bottom of the vessel in which the liquid is contained | |
| _____h. | High frequency sound waves that are beyond the range of human hearing, but travel well in air and in liquids | |

## TEST

2. Select true statements concerning the basics of level measurement by placing an "X" beside each statement that is true.

_____a. Measuring sticks and float devices were the earliest forms of level measurement but are rarely used today.

_____b. A measuring stick is still used by service stations to measure the level of fuel in their underground storage tanks, and early automobiles had measuring sticks attached to the gas caps.

_____c. Float gauges are still used in the water tanks of toilets to measure liquid level and control refilling.

_____d. Modern automobiles use dashboard fuel gauges or may have a computer display unit, but the fuel level measurement is still made by a metal float attached to a variable resistor so it can transmit an electrical signal to a gauge or computer.

3. Complete statements concerning measuring liquids in tanks by circling the item that best completes each statement.

   a. The conventional float within a tank is suspended on a cable, and usually installed inside a **(metal tube, protective box)** known as a stilling well.

   b. The stilling well/tube helps keep the float in proper **(vertical, horizontal)** alignment in cases where pumping into or out of a tank would cause currents that would move the float horizontally, and cause a measurement error.

   c. Since the level of the liquid cannot be seen inside the tank, there must be a way to determine the level of the float, and the level of the **(liquid, stilling well)** it is floating in.

   d. The **(simplest, most complex)** method of float control is to attach a cable or metal tape to the float, and roll the cable or tape up towards the top of the tank on a spool, and then count the rotations of the spool.

   e. A related method of float control is to encode the tape with indentations or holes that can be read by some mechanical or optical device at the take-up spool, and level information transmitted on to **(a display or recorder, an alarm)**.

   f. In most cases, tanks are some distance from a control point, and **(transmitters, mechanical linkages)** are used to send level information to a central location.

# TEST

4. Complete statements concerning measuring liquids with sight glasses by circling the item that best completes each statement.

   a. Sight glasses are common on (low-pressure, high pressure) process vessels.

   b. Sight glasses pose a problem in that (an operator must be physically present to monitor the level, they have to be cleaned often).

   c. Because of the need to read level at any time, or to review the record of level as needed, (other methods of reading level have been devised, sight glasses have been greatly improved).

5. Select true statements concerning measuring level with float devices by placing an "X" beside each statement that is true.

   _____a. For processes under pressure, metal vessels are used, and the level measuring floats, when they are used, are in metal or plastic piping where they can be seen.

   _____b. When a non-ferrous metal or plastic tube is run parallel to a vessel, and a ferrous metal float is placed in the tube, level can be detected with an LVDT or a sight glass.

   _____c. An LVDT is a special transformer with a movable magnetic core, and is capable of an output electrical signal that can tell instrumentation the amount of movement, and the direction of movement.

   _____d. When the float of an LVDT is the movable core, and the rest of the transformer is attached around the tube containing the liquid from the process, then the resulting electrical signal is a level measurement.

   _____e. A magnetic reed switch is a magnet attached to the float in a parallel tube so that when the level changes, and the float moves up and down, it passes the reed switches attached to the parallel tube, causing the reed switches to close and produce electrical signals.

6. Solve the following problems concerning measuring level with displacers by selecting the appropriate answer.

   a. Since a displacer is buoyed up and down by the liquid level it is measuring, what effect would low level have on the force measuring system; would it pull down on the force measuring system or push up on the force measuring system?

      Answer: ______________________________

   b. Compared to float gauges, displacers are capable of what range of level control, broader or more restricted?

      Answer: ______________________________

## TEST

7. Select true statements concerning measuring level with capacitance level sensors by placing an "X" beside each statement that is true.

_____a. Capacitance sensors are used in electronic pressure and differential pressure transmitters.

_____b. The capacitance sensor has two plates separated by a thin insulating material called an insulator.

_____c. A liquid pressure change causes a capacitance change in a capacitive sensor.

_____d. A change in capacitance is converted into a current or voltage output which corresponds to a differential pressure which is calibrated to correspond to level.

8. Complete statements concerning measuring level with bubbler systems by circling the items that best complete each statement.

   a. **(Static head, Float gauge)** measuring devices work on the principle that the weight of a liquid above some square area is a function of the specific gravity of the liquid, and the height of the liquid in a column.

   b. The **(bubble tube, sight glass)** is a common level measuring device and is used with a pressure or $\Delta P$ device.

   c. In a bubble tube device, a tube runs to the **(bottom, top)** of a vessel, and air or gas pressure is applied until a stream of bubbles is produced.

   d. The stream of bubbles indicates that gas pressure applied is sufficient to overcome the static pressure of the head, and the pressure of the applied gas is measured and used to compute level from the **(pressure/height relationship, measured speed of the bubble movement)**.

9. Solve the following problems concerning measuring level with differential pressure by selecting the appropriate answer.

   a. When a manometer is used to measure $\Delta P$, what does the difference in height of the liquid in the manometer legs indicate, the weight of the liquid in the vessel or the height of the liquid in the vessel?

   Answer: ______________________________

   b. When floats are used to detect level in a manometer, are float levels read mechanically or magnetically, or are float levels monitored visually?

   Answer: ______________________________

# TEST

10. Complete statements concerning measuring level with infrared systems by circling the items that best complete each statement.

    a. Infrared or optical level measuring systems are used for special applications where (**remote, instant**) gauging of materials is desirable or necessary such as the level of molten metal in a furnace.

    b. IR measuring devices are effective with materials that give off IR energy, and the level measuring device reads the distance of the radiation sources, and reports the level based on the relationship of sensor, liquid level of the IR source, and the (**bottom, top**) of the vessel.

    c. Most IR sensors use radiation to compute (**distance, time**) so the temperature which causes radiation from the material must be used in computing a correction for level measurement.

    d. One compensation method is to have a dual sensor measuring (**intensity, temperature**) and distance, and to use the intensity reading to adjust the system.

    e. IR equipment is used sparingly because it is (**costly, dangerous**) but with the advent of solid state IR sensors, the cost is dropping rapidly, and these systems will become more popular.

11. Select true statements concerning measuring level with radioactive devices by placing an "X" beside each statement that is true.

    _____a. Radioactive or nuclear measuring devices are used in remote or difficult to access places, and also for level measurement of gases.

    _____b. One level measurement system uses a radioactive isotope source with random radiation characteristics.

    _____c. The isotopes are attached to the bottom of a vessel containing the material to be measured, while a Geiger counter is placed at the top of the vessel to make a reading that determines the amount of radiation passing through the material.

    _____d. The amount of radiation reaching the top is a function of the amount of material the radioactive particles had to pass through to reach the top, and the higher the level of the material, the lower the amount of radiation that will reach the Geiger counter.

    _____e. To calibrate an IR system requires knowledge of the characteristics of the radiation source, the modulation ability of the material in the vessel, and the effect of distance of the detector from the source because radioactivity diminishes in relation to the square of the distance.

    _____f. Another nuclear-based level measuring system uses multiple radioactive sources spaced vertically along the inner lining of a vessel.

    _____g. On the opposite wall of the vessel is a detector capable of averaging the outputs of the radiation sources.

    _____h. Radioactive signals rise in proportion to the level increase in the vessel, and the signal is converted to a level reading at a display unit.

## TEST

12. Solve the following problems concerning measuring level with ultrasonic techniques by selecting the appropriate answer.

    a. Radar works by bouncing a signal off an object and calculating the time it takes for the signal to return to the sending source. Could ultrasonic level measuring techniques be compared to radar or it is the comparison unjustified?

    Answer: ______________________________

    b. Ultrasonic level measuring systems can compute level no matter what the composition of the material is, but can an ultrasonic system compute level when the composition of the material is changing?

    Answer: ______________________________

13. Complete statements concerning other methods of level measurement by circling the items that best complete each statement.

    a. A level measuring technique common to both solid and liquid levels is to (measure, weigh) the vessel that contains the material to be measured.

    b. In these level measuring systems, the vessels are mounted on load cells or strain gauges that track the weight of the vessel (and the material inside, with no material inside).

    c. Level is calculated by a (system controller, scale) that subtracts the weight of the vessel and divides by the unit weight of the material to calculate the volume, and converts that to a level measurement.

14. Select true statements concerning specific gravity and level measurement by placing an "X" beside each statement that is true.

    ______a. Just as with other measurement forms, specific gravity or the density of a material affects level measuring equipment.

    ______b. In a level measuring system that uses a float, the specific gravity of the liquid in which the float is placed becomes significant because the more dense the liquid, the less the float will sink in the liquid.

    ______c. Measuring level with a displacement sensor depends on the amount of liquid displaced by the sensor, and how much liquid the sensor displaces is dependent on the specific gravity of the liquid.

    ______d. Static head and differential pressure measuring techniques depend on the weight of the liquid on top of a sensor, and that weight will always vary with specific gravity of the liquid.

    ______e. All level measuring techniques that depend on pressure or weight are subject to changes in readings when there is a change in specific gravity.

# TEST

15. Complete statements concerning applications of level measurement by circling the items that best complete each statement.

    a. One of the most common applications in level measurement is determining the level of material in a storage tank, and although several methods are used, **(float devices, sight glasses)** are common.

    b. In both food processing and brewing of beer, measurement and control of level in **(batch processing, flow control)** is critical to production of a quality product.

    c. Level measurement of the contents of vessels is critical in petroleum and chemical processes because the vessels, in many cases, supply **(pressure, raw materials)** or semifinished product required for continued flow.

    d. Measuring level in flow systems is different from batch systems because in flow systems, the vessels must be **(closed, open to atmosphere)**.

    e. Measuring level in closed vessels used in flow systems requires capacitance sensors, IR, nuclear, ultrasonic, or **(pressure measuring systems, remote sensing)**.

    f. Because of gains in integrated circuit and transducer technology, the newer systems of level measurement such as **(float gauge, ultrasonic)** and IR will find more applications because the systems are small, lightweight, and portable, and offer versatile options such as easy interfacing with computers and other electronic devices.

(NOTE: If the following activities have not been accomplished prior to the test, ask your instructor when they should be completed.)

16. Examine and interpret performance charts. (Assignment Sheet #1)

17. Make an emergency level measurement in a make-up water storage tank. (Assignment Sheet #2)

18. Demonstrate the ability to:

    a. Measure, cut, and bend copper tubing to specifications. (Job Sheet #1)

    b. Use a bubbler system to determine liquid level in a tank open to atmosphere. (Job Sheet #2)

# PRINCIPLES OF LEVEL MEASUREMENT
# UNIT IV

## ANSWERS TO TEST

1. a. 5
   b. 8
   c. 7
   d. 2
   e. 3
   f. 6
   g. 1
   h. 4

2. b, c, d

3. a. Metal tube
   b. Vertical
   c. Liquid
   d Simplest
   e. A display or recorder
   f. Transmitters

4. a. Low-pressure
   b. An operator must be physically present to monitor the level
   .c Other methods of reading level have been devised

5. c, d, e

6. a. ., would pull down on the force measuring system
   b. Broader

7. a, c, d

8. a. Static head
   b. Bubble tube
   c. Bottom
   d. Pressure/height relationship

9. a. The weight of the liquid in the vessel
   b. Mechanically or magnetically

## ANSWERS TO TEST

10. a. Remote
    b. Bottom
    c. Distance
    d. Intensity
    e. Costly

11. c, d, e, f, g

12. a. Ultrasonic level measuring techniques can be compared to radar
    b. Yes

13. a. Weigh
    b. And the material inside
    c. System controller

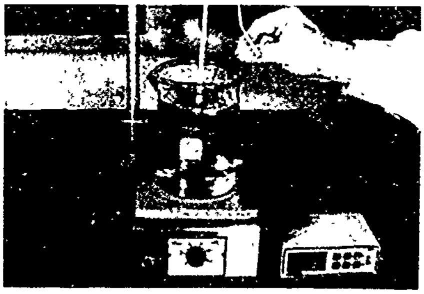
14. a, b, c, d, e

15. a. Float devices
    b. Batch processing
    c. Raw materials
    d. Closed
    e. Pressure measuring systems
    f. Ultrasonic

16. Evaluated to the instructor's satisfaction

17. Evaluated to the instructor's satisfaction

18. Evaluated according to criteria in practical tests



# PRINCIPLES OF TEMPERATURE MEASUREMENT
## UNIT V

## UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss the principles of temperature measurement, and list the units of temperature measurement. The student should also be able to relate thermocouples, resistance temperature detectors, thermistors, filled thermal systems, bimetallic, and infrared sensors to their applications in temperature measuring systems. These competencies will be evidenced by correctly completing the procedures in the job sheet, and by scoring a minimum of 85 percent on the unit test.

## SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to principles of temperature measurement with their correct definitions.
2. Complete statements concerning units of temperature measurement.
3. Select true statements concerning measuring temperature with thermometers.
4. Solve problems concerning measuring temperature with thermocouples.
5. Select true statements concerning measuring temperature with RTDs (Resistance Temperature Detectors).
6. Solve problems concerning measuring temperature with thermistors.
7. Select true statements concerning measuring temperature with FTSs (Filled Thermal Systems.)
8. Complete statements concerning classes and applications of FTSs.
9. Complete statements concerning measuring temperature with bimetallic devices.
10. Solve problems concerning measuring temperature with infrared devices.
11. Complete statements concerning measuring temperature with LICS (Linear Integrated Circuit Sensors).
12. Select true statements concerning digital and analog readouts.

## OBJECTIVE SHEET

13. Solve problems concerning temperature scale conversions.

14. Select true statements concerning applications of temperature measurement.

15. Demonstrate the ability to use steam and ice baths and a potentiometer to confirm temperature output at the hot junction of a thermocouple. (Job Sheet #1)

# PRINCIPLES OF TEMPERATURE MEASUREMENT
# UNIT V

## SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information sheet.

C. Make transparencies.

D. Discuss unit and specific objectives.

E. Discuss information sheet.

F. Display thermometers, thermocouples, thermistors, or whatever temperature sensing devices you find so that students can examine them.

G. Invite a local production supervisor to talk to the class about temperature measurement and the devices used for measuring and recording temperature at a local or area production facility.

H. Read Job Sheet #1 with care, and prepare thermocouples as required. Review safety requirements for working with a hot plate and boiling water and the need to handle thermometers with care.

I. Give test

## REFERENCES USED IN DEVELOPING THIS UNIT


A. Johnson, Curtis D. *Process Control Instrumentation Technology*. New York, NY: John Wiley & Sons, 1982.

B. Tyson, Forrest. *Industrial Instrumentation*. Englewood Cliffs, NJ: Prentice-Hall Book Co., 1980.

C. Hall, Ronald P. *Automated Process Control Systems (Concepts and Hardware)*. Englewood Cliffs, NJ: Prentice-Hall Book Co., 1981.

D. Potvin, John. *Applied Process Control Instrumentation*. Reston, VA: Reston Publishing Co., 1983.

E. *Omega Complete Temperature Measurement Handbook and Encyclopedia*. Stamford, CT 06907: Omega Engineering, Inc., 1988.

F. *Airco Industrial Gases Data Book*. Murray Hill, NJ 07974: Airco, 1986.

# PRINCIPLES OF TEMPERATURE MEASUREMENT
# UNIT V

## INFORMATION SHEET

I. Terms and definitions

A. Alumel — An alloy of 95% nickel and 5% aluminum, manganese, and silicon used in the manufacture of thermocouples

B. Chromel — An alloy of 90% nickel and 10% chromium used in the manufacture of thermocouples

C. Constantan — An alloy of tin and copper used in the manufacture of thermocouples

D. Seebeck effect — A principle discovered in 1821, that became the theoretical basis for thermocouples because it states that when two different metal objects are connected together at each end, and a temperature difference exists between the two junctions, a potential will exist, and current will flow

E. SAMA (Scientific Apparatus Maker Association) — An organization of instrument manufacturers that sets standards for measuring equipment

F. Temperature — The measure in degrees of the presence of, or the transfer of heat energy in a system

II. Units of temperature measurement

A. The unit of relative temperature in the English system is Fahrenheit; in this system, water freezes at 32° and boils at 212°, and the scale may run as far below zero as is necessary.

(NOTE: The name Fahrenheit honors G. D. Fahrenheit who invented the liquid in glass thermometer in the early 1700s.)

B. The unit of relative temperature in the metric system is Celsius; in this system, water freezes at 0° and boils at 100°.

(NOTE: Celsius was adopted over the name Centigrade when the metric system was standardized by the International Standards Organization (ISO), and the units of 10 in the Celsius system are much easier to deal with than the 32 to 212 Fahrenheit scale which has 180 divisions, and does not begin at zero.)

# INFORMATION SHEET

C. The metric absolute temperature measuring scale is Kelvin; in this system, water boils at 373.18°, and the absolute scale goes 273.18° below 0° Celsius to the point where no molecular motion exists.

(NOTE: Kelvin comes from British Lord Kelvin who helped establish early temperature measurement standards. and rather than express temperature in negative units, absolute temperature scales are used in many process instruments.)

D. The absolute measuring scale for English units is the Rankine scale where absolute zero is 459.7° below zero Fahrenheit.

(NOTE: The scientific community deals mostly with absolute temperatures, and since they use the metric system, the Rankine scale is not well known.)

E. A BTU (British Thermal Unit) is a unit of heat frequently used in rating heat transfer equipment, and a BTU is the amount of heat required to raise a pound of water one degree in temperature.

(NOTE: Specifically, a single BTU is required to raise the temperature of a pound of water from 62° to 63°F.)

III. Measuring temperature with thermometers

A. There are a number of devices that can be called thermometers, and all of them function pretty much the same; they have a tube with a container on one end that holds a liquid that expands and contracts inside a sealed tube to indicate temperature.

B. Industrial grade thermometers are made of special heat-treated glass that has been carefully marked to provide highly accurate scales.

C. Industrial thermometers are mounted in rugged cases with the scale around the tube well marked so it can be read at a distance.

D. Physicist Daniel Fahrenheit who invented the temperature scale named for him also did early research on thermometers.

IV. Measuring temperature with thermocouples (Transparency 1)

A. Thermocouples are made of two dissimilar metal wires which may be separated from each other by ceramic or other insulating devices that can with stand temperature extremes.

B. Thermocouples are fastened together on the end where measurement is taken, the other end is attached to instrumentation, and the entire assembly is housed in a case called a thermowell to protect it from the process environment.

# INFORMATION SHEET

C. Thermocouples develop an electrical potential in millivolts, and each millivolt corresponds to a specific temperature.

(NOTE: See the Type J Thermocouple mV/Temperature Conversion Chart that accompanies Job Sheet #1 of this unit.)

D. Thermocouples are designed for specific applications and are identified by letter type. (Transparency 1)

Example: A type J thermocouple, made of iron and constantan wires welded together, will cover a temperature range from −210 to 760°C, but for temperatures below or beyond that range, a type J thermocouple would not be practical, nor would a type J be practical in a corrosive atmosphere.

E. In cases where the thermocouple signal must be transmitted for some distance, each type thermocouple has matching extension wires designed for that specific thermocouple.

F. Thermocouples are the most frequently used temperature measuring devices for several reasons:

1. They are relatively inexpensive.
2. They generate their own power and need no external power source.
3. They can be constructed in the field.

V. Measuring temperature with RTDs (Resistance Temperature Detectors)

A. RTDs are commonly used transducers that, unlike thermocouples, will not generate their own signals.

B. The RTD requires a power source, and associated wiring, which may be a slight disadvantage, but is a very linear device that requires little or no compensation for output to an instrumentation package.

C. An RTD is made of a very fine resistance wire, usually platinum, wound on a core and packaged in a variety of forms ranging from embedded devices to long probes or flat packs that can be attached or cemented to a machine surface.

D. Because of its very stable relationship between temperature and resistance, platinum is used often in RTDs.

(NOTE: Platinum is the international standard measured between the triple point of hydrogen, the point at which it can be solid, liquid, or gas, 13.81 degrees Kelvin, to the freezing point of antimony at 630.75 degrees Celsius.)

# INFORMATION SHEET

E. Other metals used in RTDs include nickle which can be used over a temperature range of −70 to +150 degrees Celsius, and copper which is good in the −200 to +150 degrees Celsius range.

F. Newer RTD designs use a thin film of platinum to help lower cost, and provide smaller sizes and new flat shapes for surface mounting.

G. Industrial RTDs are very linear compared to thermocouples and thermistors, and platinum RTDs are more linear than nickel or copper.

H. For industrial applications in wheatstone bridge measuring circuits, RTDs come packaged in two, three, or four lead configurations.

I. The additional leads form compensation networks for the elimination of lead length errors:

1. The two-wire lead has no compensation.
2. The three-lead units eliminate almost all errors.
3. The four-lead units completely eliminate errors and are used in critical applications.

VI. Measuring temperature with thermistors

A. Like RTDs, thermistors are thermal-resistant devices, but the similarity ends there because a thermistor is a non-linear, solid-state device.

B. Thermistors are made from oxides of cobalt, copper, iron, manganese, nickel, tin, titanium, and zinc, or combinations of these materials that are shaped as a powder, and then heat treated to form a crystalline material.

C. Thermistors come in many shapes such as beads, disks, rods, probes, and washers, and in sizes ranging from beads that will pass through the eye of a needle to washers that fit under bolts of almost all sizes.

D. Thermistor output is not very linear, so the output must be compensated by the system, or ignored as in the case where a user is interested in certain fixed points, rather than continuous readings over some range of temperature.

E. Thermistors find applications in consumer electronics as well as in instrumentation because of their low cost and flexibility in shape, but their lack of linearity limits their use in precision instruments.

F. Industrial use of thermistors is growing because better manufacturing methods are producing more consistent resistance devices, and outputs can be made with positive or negative resistance characteristics to further increase application potential.

# INFORMATION SHEET

VII. Measuring temperature with FTSs (Filled Thermal Systems)

A. Filled thermal systems were once the mainstay of temperature measuring systems, but they have been replaced by newer electrical devices because they are bulky and don't fit well into modern equipment design.

B. FTSs are limited in the distance they can transmit a signal, and they will not interface directly to electronic or digital equipment.

C. A filled thermal system has three main parts:

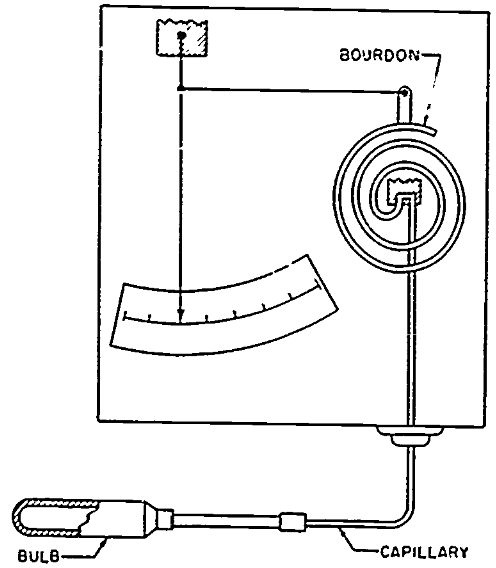
1. A bulb;

2. A capillary;

3. A pressure sensing element, usually a bourdon tube.

D. The bulb is located at the heat source to be measured, the pressure measuring element is at the display, recorder, or controller, and the capillary connects the two parts. (Figure 1)

FIGURE 1




Courtesy Petroleum Extension Service (PETEX)
University of Texas at Austin

VIII. Classes and applications of FTSs (Transparency 2)

A. Capillary compensation can be used in classes I, III, and V; however, compensation is used normally in I and V only.

# INFORMATION SHEET

B. Compensation is accomplished by running a second capillary to a second pressure element that cancels the effect of temperature input along the capillary tube, and this can also be accomplished with liquid filled fully compensated, or liquid filled case compensated capillary design.

C. The Class V, Mercury filled systems have a very high mechanical drive ability because of large expansion characteristic of Mercury, and the Class V systems drive devices such as recorders and small valves.

D. In the Class II systems, a liquid turns a vapor at a hot spot, and drives the pressure element at the readout end of the system, and since the hot spot can occur at any place in the system, including the capillary, these systems cannot be compensated, and are designed for specific applications. (Transparency 3)

E. The Class III systems have excellent low temperature characteristics, can effectively operate at a distance of 200 feet, and are very common in refrigeration systems.

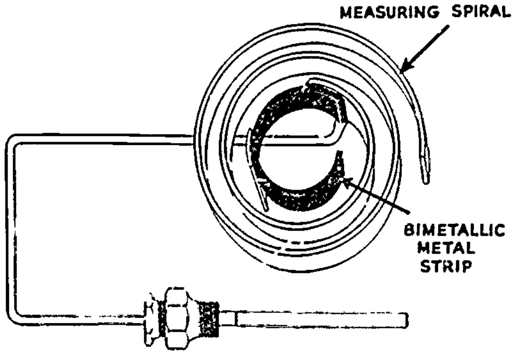
F. The subclasses of A, B, C, and D in the type II systems are popular because they are low cost, uncomplicated devices that can be tailored to the measuring situation.

IX. **Measuring temperature with bimetallic devices**

A. Bimetallic devices are simple, and commonly used where mechanical output is necessary to drive purely mechanical or electromechanical systems.

B. A bimetallic mechanism consists of two metals with dissimilar thermal expansion characteristics, fused together so that a change in temperature will cause the different expansion rates to distort the combined metallic device. (Figure 2)

FIGURE 2




**Courtesy Petroleum Extension Services (PETEX)**
**University of Texas at Austin**

# INFORMATION SHEET

C. Bimetallic devices may be made in many forms including the common spiral spring used to operate household thermostats, the helical spring used to operate rotary mechanical switches, and the flat spring used in industrial pneumatic thermostats.

D. Another common bimetallic application is the small metal disc overload switch used to trip off an electric motor when motor temperature exceeds normal limits.

## X. Measuring temperature with infrared devices

A. Infrared temperature measuring is complex, expensive, and confined to situations where no other type of temperature measuring system could function.

B. IR temperature measuring is based on Planck's formula which states (in simplified terms): the temperature of an object can be measured by reading the IR radiation from the source, if you know the distance and the wavelength of the radiation.

C. Applications of radiation thermometry that other systems cannot manage include:

1. Measuring the temperature of moving materials;
2. Measuring extremely high temperatures such as molten metals;
3. Measuring large temperature areas such as the surface of a planet or star;
4. Measuring temperatures inside vessels with high or low pressures (vacuums), or even inside transparent or semi-transparent objects

D. IR temperature measuring devices have three outstanding advantages over other systems:

1. They can measure temperature without contacting the object;
2. They can produce rapid, accurate measurements;
3. They can read the temperature of an object even if it is among other heat sources.

# INFORMATION SHEET

XI. Measuring temperature with LICS (Linear Integrated Circuit Sensors)

A. The increase in temperature associated with the increase in current through a semiconductor is a phenomena that plagued early designers of semiconductor devices.

B. By relating the change in output current with changes in temperature, designers matched and linearized the output currents to a temperature scale, and the IC temperature sensor was created.

C. LICS promise to impact the marketplace because they can be made very small, they are low cost, they are very linear, and they are capable of impedance matching almost any electronic system.

XII. Digital and analog readouts

A. Temperature measuring devices have traditionally used an analog meter or an analog recording device to provide a readout.

B. Digital readouts are rapidly replacing analog devices in instrumentation to provide temperature readings that are printed on a piece of paper or screened on a monitor.

C. The reporting of temperature in digital form makes it easy to perform mathematical control calculations, and other operational calculations.

D. Digital readout devices are increasing in popularity because of the diminishing cost of microprocessor based computer equipment, the low cost of analog to digital conversion ICs, and the low cost of digital readout devices.

XIII. Temperature scale conversions (Transparency 4)

A. Earlier equipment, and much current equipment, uses Fahrenheit readings, and since most new equipment uses Celsius readings, technicians need to know how to quickly and accurately make temperature scale conversions from Fahrenheit to Celsius, and from Celsius to Fahrenheit.

B. Scientific applications also require conversion to and from the Kelvin scale, so technicians need to be able to make scale conversions.

C. Converting from Fahrenheit to Celsius is the most common requirement, and the formula is: degrees Celsius equal degrees Fahrenheit minus 32, times $^5/_9$, or $C^\circ = {^5/_9}\,(^\circ F - 32^\circ)$.

EXAMPLE:

$98.6^\circ F - 32^\circ \times .555 = 36.96^\circ C$

(NOTE: .555 is the decimal equivalent of $^5/_9$.)

# INFORMATION SHEET

D. Converting from Celsius to Fahrenheit formula is: degrees Fahrenheit equal degrees Celsius × 9/5 + 32, or F° = 32° + (°C × 9/5).

EXAMPLE:

37°C × 1.8 + 32° = 98.6°F

(NOTE: 1.8 is the decimal equivalent of 9/5 .)

E. Converting from Celsius to Kelvin formula is: degrees Kelvin equal degrees Celsius plus 273.15, or K = C° + 273.15.

EXAMPLE:

37°C + 273.15 = 310.15K

(NOTE: There is no degree symbol used with the Kelvin scale.)

F. To convert Fahrenheit to Kelvin, first convert Fahrenheit to Celsius, and then convert Celsius to Kelvin.

EXAMPLE:

98.6°F = 37°C + 273.15 = 310.15K

G. If you ever have to convert the Rankine scale, first convert Fahrenheit by subtracting 459.7, and then convert to Celsius or Kelvin as notation demands.

EXAMPLE:

558.27°R − 459.67 = 98.6°F

XIV. **Applications of temperature measurement**

A. Some temperature measuring devices are common in the home; heat and air-conditioning are controlled by a bimetallic coil in a thermostat.

B. Industrial applications of temperature measurement are mostly to measure and feedback control parameters to a controller.

C. Industrial applications include common thermocouples by the millions, RTDs, and advanced IR thermometers that measure such diverse applications as the temperature of molten steel in a blast furnace to the temperature of stars far distant in space.

D. Temperature measuring devices range in size from large filled thermal systems with bulbs the size of melons to thermistors embedded in tiny instruments placed in catheters to be threaded into the veins of human patients.

E. The cost of temperature sensing devices ranges from common thermistors selling for a few pennies to platinum RTDs and IR thermometers that cost thousands of dollars.

# THERMOCOUPLE TYPES

| Type of Thermocouple | Composition | Temperature Range |
|---|---|---|
| B | Platinum/Rhodium, 30%, and Platinum/Rhodium 6% Wire | 0 to 1820 Degrees Celsius |
| E | Nickel/Chromium, 10%, and Constantan Wire | −270 to 1000 Degrees Celsius |
| J | Iron and Constantan Wire | −210 to 760 Degrees Celsius |
| K | Alumel and Chromel Wire | −270 to 1372 Degrees Celsius |
| R | Platinum/Rhodium 13% and Platinum Wire | −50 to 1768 Degrees Celsius |
| S | Platinum/Rhodium 10% and Platinum Wire | −50 to 1768 Degrees Celsius |
| T | Copper and Constantan Wire | −270 to 400 Degrees Celsius |

Type S is the international standard.

Type J is most popular because of cost and range.

Type E is popular because of resistance to corrosion, and high output voltage.

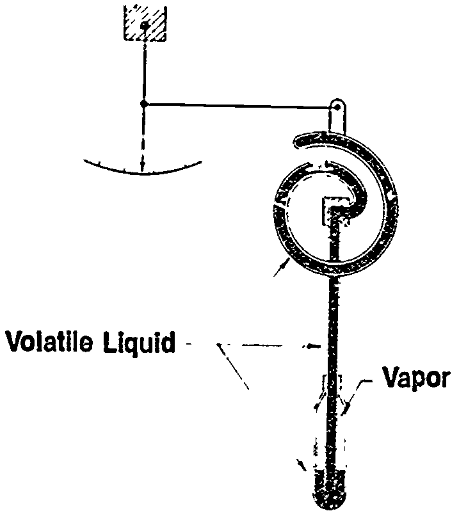
Type T is most popular in below zero applications.

Newer types using tungsten and rhenium are standardized, and more detailed information on thermocouples may be found in the ISA publication, *American National Standard TEMPERATURE MEASUREMENT THERMOCOUPLES MC96.1.*

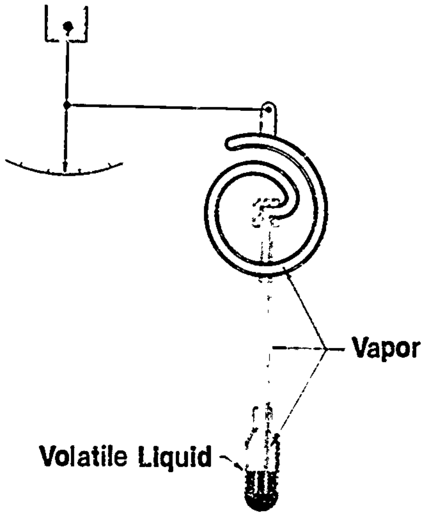
# FILLED THERMAL SYSTEMS

| Class | Structure | Temperature Range | Operating Characteristics |
|---|---|---|---|
| I | Liquid filled (other than Mercury) | −87 to +316° C | Maximum capillary of 200 feet if not compensated, 15 feet, if compensated |
| IA | Liquid filled (other than Mercury) | −87 to +316° C | Fully compensated |
| IB | Liquid filled (other than Mercury) | −87 to +316° C | Case compensated |
| II | Vapor filled | −40 to +316° C | Maximum capillary of 200 feet |
| IIA | Vapor filled | −40 to +316° C | Operates with the bulb at a temperature above the rest of the system |
| IIB | Vapor filled | −40 to +316° C | Operates with the bulb at a temperature below the rest of the system |
| IIC | Vapor filled | −40 to +316° C | Operates with the bulb above or below but not equal to the rest of the system |
| IID | Vapor filled | −40 to +316° C | Operates with the bulb at temperatures above, below, and equal to the rest of the system |
| III | Gas filled | −268 to +639° C | Maximum capillary of 200 feet |
| V | Mercury filled | −39 to +650° C | Capillary of 200 feet uncompensated, or 15 feet compensated |

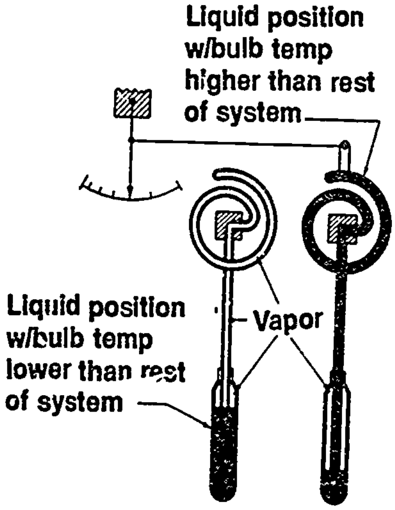
# CLASS II FILLED THERMAL SYSTEMS



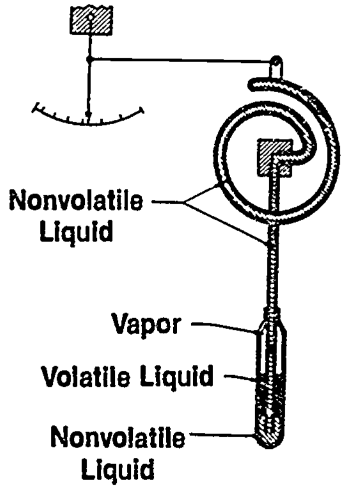

Operates with the bulb at a temperature above the rest of the system




Operates with the bulb at a temperature below the rest of the system




Bulb above or below but not equal to rest of system




Bulb at temperatures above, below, and equal to the rest of the system

Courtesy Petroleum Extension Service (PETEX)
University of Texas at Austin

# TEMPERATURE CONVERSION CHART

| | KELVIN K | CELSIUS °C | FAHRENHEIT °F | RANKIN °R |
|---|---|---|---|---|
| WATER BOILS | 373.15 | 100° | 212° | 671.67° |
| HUMAN BODY | 310.15 | 37° | 98.6° | 558.27° |
| WATER FREEZES | 273.15 | 0° | 32° | 491.67° |
| FAHRENHEIT ZERO | 255.37 | -17.78° | 0° | 459.67° |
| CELSIUS = FAHRENHEIT | 233.15 | -40° | -40° | 419.67° |
| BITTER COLD WEATHER | 227.59 | -45.56° | -50° | 409.67° |
| $CO_2$ SUBLIMES | 194.68 | -78.47° | -109.25° | 350.42° |
| COLDEST ON EARTH | 180.38 | -92.77° | -135° | 324.67° |
| XENON BOILS | 165.04 | -108.11° | -162.59° | 297.08° |
| KRYPTON BOILS | 119.81 | -153.34° | -244.01° | 215.66° |
| OXYGEN BOILS | 90.18 | -182.97° | -297.35° | 162.32° |
| ARGON BOILS | 87.28 | -185.87° | -302.57° | 157.10° |
| NITROGEN BOILS | 77.36 | -195.79° | -320.42° | 139.25° |
| CRYOGENIC REGION | $K = °C + 273.15$ | $°C = \frac{5}{9}(°F - 32°)$ | $°F = 32° + (°C \times \frac{9}{5})$ | $°R = °F + 459.67$ |
| NEON BOILS | 27.09 | -246.06° | -410.[illegible]° | 48.77° |
| HYDROGEN BOILS | 20.27 | -252.88° | -423.19° | 36.48° |
| HELIUM IV BOILS | 4.22 | -268.93° | -452.08° | 7.59° |
| ABSOLUTE ZERO | 0 | -273.15 | -459.67 | 0° |

TRIPLE POINT OF WATER = +.01°C OR = +32.02°F

Reprinted with permission: AIRCO Industrial Gases Data Book, 1982.

# PRINCIPLES OF TEMPERATURE MEASUREMENT
# UNIT V

## HANDOUT #1 — THERMOCOUPLE CHARACTERISTICS

### PURPOSE

Since thermocouples are temperature measuring devices that instrument technicians will frequently have to troubleshoot, technicians need to know how thermocouples are made, why they function as they do, how their structure affects the ways they can be used, and why testing a thermocouple with a digital VOM requires a special procedure. A potentiometer would probably be used to accomplish this task in the field, but knowing how to do it with a VOM will give a technician valuable knowledge about thermocouples.

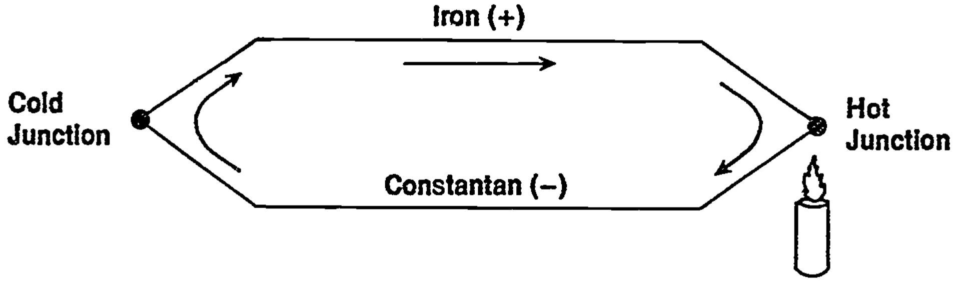
### BACKGROUND

In 1826, German physicist, T.J. Seebeck discovered that when the junction of two dissimilar metals is subjected to heat, it will cause an electrical potential change (EMF), and set up a current in a circuit. The phenomena is known as the Seebeck effect, and is the basis of all thermocouple operation.

### STRUCTURE

A thermocouple junction is made by welding two dissimilar wires together, but to close a circuit so current will flow, two junctions are required. One junction is called the hot junction, where heat is applied, and the other junction is called the cold junction or reference junction. Note how the two dissimilar wires of iron and constantan (copper-nickel alloy) form the hot and cold junctions in a Type J thermocouple.

FIGURE 1



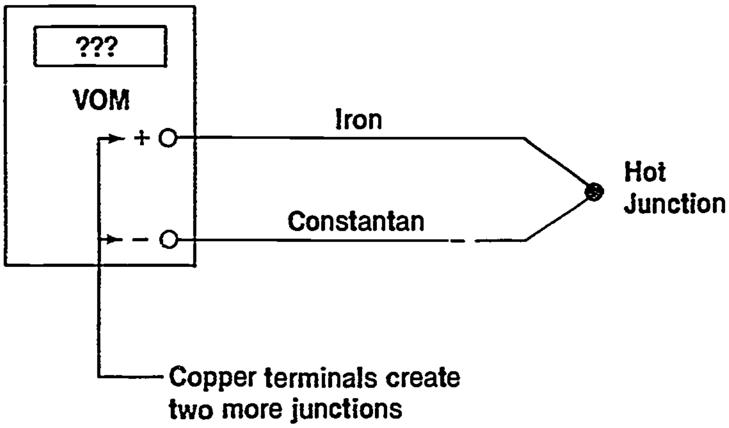

Type J Thermocouple

# HANDOUT #1

QUESTION: Why can't the cold junction be connected to a digital VOM to obtain a voltage reading that corresponds to the temperature of the hot junction?

ANSWER: Remember the Seebeck effect. The hot junction connections to a VOM would create two more junctions of dissimilar metals, and the temperature at these junctions would create an error in the reading.

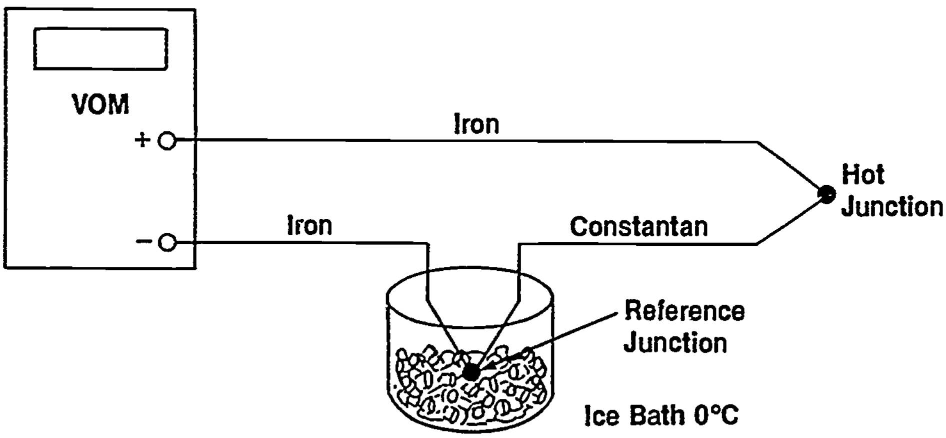
FIGURE 2




### PROBLEMS AND SOLUTIONS

To obtain a proper hot junction voltage reading requires knowing the temperature of the reference junction, and this is accomplished by using an ice bath that will maintain the reference junction at 0°C (32°F). With an ice bath properly set up, another problem is solved because both leads to the VOM are iron, and although there are still two junctions at the VOM, they are copper-iron and will cancel each other if both leads are the same temperature.

FIGURE 3



# HANDOUT #1

## CONCLUSION

Knowing the temperature of the reference point, and the cancelling effect of the copper-iron junctions at the VOM provides conditions that will give a millivolt reading on the digital VOM that will correspond to the temperature of the hot junction. The voltage reading on the VOM can be converted to temperature by using a temperature conversion table that corresponds with the thermocouple type being used.

(NOTE: Complete Job Sheet #1 that follows this handout. The job sheet uses a type J thermocouple, and has a type J conversion chart to help you better understand thermocouples and how to properly test them.)

# PRINCIPLES OF TEMPERATURE MEASUREMENT
# UNIT V

## JOB SHEET #1 — USE STEAM AND ICE BATHS AND A POTENTIOMETER TO CONFIRM TEMPERATURE OUTPUT AT THE HOT JUNCTION ON A THERMOCOUPLE

A. Equipment and materials

1. Safety glasses
2. Potentiometer
3. Two 1000 mL pyrex beakers
4. °C thermometer, −1 to 101°C (°F thermometer may be used)
5. Hot plate
6. Water
7. Ice cubes
8. Hot pads
9. Type J thermocouple
10. Pencil
11. Calculator
12. Instrument tripod with thermocouple clip

B. Routine #1 — Setting up the steam bath

1. Put on safety glasses.
2. Fill a 1000 mL beaker with tap water.
3. Place the beaker on the hot plate.
4. Turn the hot plate control to maximum.

   **(CAUTION: Keep hot pads handy, and use appropriate safety procedures when working with hot or boiling water.)**

5. Lower the hot plate heat control when water starts to boil.
6. Position the °C thermometer in the tripod clip, and center it at least 3 inches deep into the steam bath.

   ☐ Have your instructor check your work.

# JOB SHEET #1

C. Routine #2 — Setting up the ice bath

1. Put on safety glasses.
2. Fill a 1000 mL pyrex beaker with ice cubes.
3. Add just enough tap water to fill the gaps between the ice cubes.
4. Check to see if the ice cubes float, and if they do, drain some of the water and add more ice cubes.

☐ Have your instructor check your work.

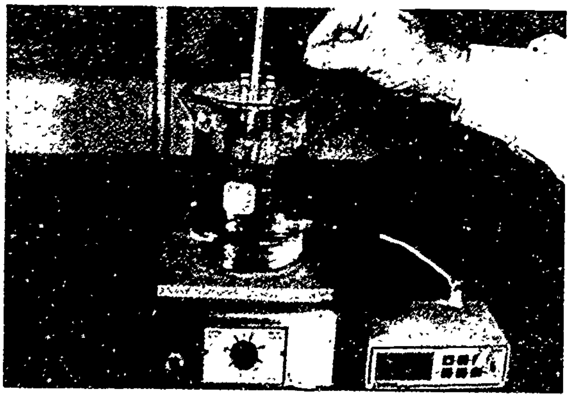
D. Routine #3 — Measuring thermocouple output with the steam bath

1. Put on safety glasses.
2. Put the thermocouple into, or connect the thermocouple to the potentiometer. (Figure 1)

FIGURE 1

3. Make sure that the water is boiling so that bubbles are evident on the surface of the water.
4. Insert the thermocouple measuring junction into the steam bath near the bottom point of the °C thermometer so that it is centered in the steam bath. (Figure 2)

FIGURE 2



## JOB SHEET #1

5. Observe and record the mV reading on the potentiometer.

   Steam bath mV reading: ____________ mV

6. Observe and record the °C thermometer reading.

   Steam bath °C reading: ____________ °C

   ☐ Have your instructor check your work.

E. Routine #4 — Measuring thermocouple output with the ice bath

1. Put on safety glasses.

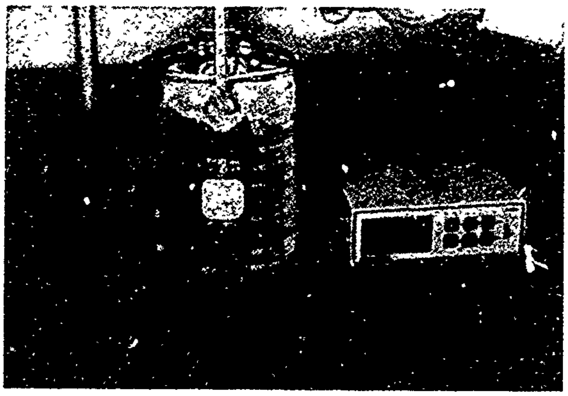
2. Raise the thermometer, move the tripod to an area over the ice bath, and permit the thermometer to cool.

   (NOTE: Your instructor may direct you to complete the first part of Routine #5 as you are waiting.)

3. Position the °C thermometer in the tripod clip, and center it at least 3 inches deep in the ice bath.

4. Insert the thermocouple measuring junction into the ice bath near the bottom point of the °C thermometer so that it is centered in the ice bath. (Figure 3)

   FIGURE 3



5. Observe and record the mV reading on the potentiometer.

   Ice batch mV reading: ____________ mV.

6. Observe and record the °C thermometer reading.

   Ice bath °C reading: ____________ °C.

   ☐ Have your instructor check your work.

# JOB SHEET #1

F. Routine #5 — Making mV and temperature conversions

1. Put on safety glasses.

2. Turn off hot plate and permit the steam bath to cool off as you continue.

3. Use your Type J Thermocouple mV/Temperature Conversion Chart that accompanies this job sheet to make the following conversions:

   Steam bath mV: ____________ converted to °C ____________.

   Steam bath °C readings: ____________ converted to °F ____________.

   Ice bath mV: ____________ converted to °C ____________

   Ice bath °C ____________ converted to °F ____________.

   ☐ Have your instructor check your work.

4. Make sure the steam bath beaker, tripod, and clamps are cool, and return equipment and materials to proper storage.

# JOB SHEET #1

## Type J Thermocouple mV/Temperature Conversion Chart

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| −40 | −1.960 | −2.008 | −2.055 | −2.102 | −2.150 | −2.197 | −2.244 | −2.291 | −2.338 | −2.384 | −2.431 |
| −30 | −1.481 | −1.530 | −1.578 | −1.626 | −1.674 | −1.722 | −1.770 | −1.818 | −1.865 | −1.913 | −1.960 |
| −20 | −0.995 | −1.044 | −1.093 | −1.141 | −1.190 | −1.239 | −1.288 | −1.336 | −1.385 | −1.433 | −1.481 |
| −10 | −0.501 | −0.550 | −0.600 | −0.650 | −0.699 | −0.748 | −0.798 | −0.847 | −0.896 | −0.945 | −0.995 |
| 0 | 0.000 | −0.050 | −0.101 | −0.151 | −0.201 | −0.251 | −0.301 | −0.351 | −0.401 | −0.451 | −0.501 |

| DEG C | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.000 | 0.050 | 0.101 | 0.151 | 0.202 | 0.253 | 0.303 | 0.354 | 0.405 | 0.456 | 0.507 |
| 10 | 0.507 | 0.558 | 0.609 | 0.660 | 0.711 | 0.762 | 0.813 | 0.865 | 0.916 | 0.967 | 1.019 |
| 20 | 1.019 | 1.070 | 1.122 | 1.174 | 1.225 | 1.277 | 1.329 | 1.381 | 1.432 | 1.484 | 1.536 |
| 30 | 1.536 | 1.588 | 1.640 | 1.693 | 1.745 | 1.797 | 1.849 | 1.901 | 1.954 | 2.006 | 2.058 |
| 40 | 2.058 | 2.111 | 2.163 | 2.216 | 2.268 | 2.321 | 2.374 | 2.426 | 2.479 | 2.532 | 2.585 |
| 50 | 2.585 | 2.638 | 2.691 | 2.743 | 2.796 | 2.849 | 2.902 | 2.956 | 3.009 | 3.062 | 3.115 |
| 60 | 3.115 | 3.168 | 3.221 | 3.275 | 3.328 | 3.381 | 3.435 | 3.488 | 3.542 | 3.595 | 3.649 |
| 70 | 3.649 | 3.702 | 3.756 | 3.809 | 3.863 | 3.917 | 3.971 | 4.024 | 4.078 | 4.132 | 4.186 |
| 80 | 4.186 | 4.239 | 4.293 | 4.347 | 4.401 | 4.455 | 4.509 | 4.563 | 4.617 | 4.671 | 4.725 |
| 90 | 4.725 | 4.780 | 4.834 | 4.888 | 4.942 | 4.996 | 5.050 | 5.105 | 5.159 | 5.213 | 5.268 |
| 100 | 5.268 | 5.322 | 5.376 | 5.431 | 5.485 | 5.540 | 5.594 | 5.649 | 5.703 | 5.758 | 5.812 |
| 110 | 5.812 | 5.867 | 5.921 | 5.976 | 6.031 | 6.085 | 6.140 | 6.195 | 6.249 | 6.304 | 6.359 |
| 120 | 6.359 | 6.414 | 6.468 | 6.523 | 6.578 | 6.633 | 6.888 | 6.742 | 6.797 | 6.852 | 6.907 |
| 130 | 6.907 | 6.962 | 7.017 | 7.072 | 7.127 | 7.182 | 7.237 | 7.292 | 7.347 | 7.402 | 7.457 |
| 140 | 7.457 | 7.512 | 7.567 | 7.622 | 7.677 | 7.732 | 7.787 | 7.843 | 7.898 | 7.953 | 8.008 |
| 150 | 8.008 | 8.063 | 8.118 | 8.174 | 8.229 | 8.284 | 8.339 | 8.394 | 8.450 | 8.505 | 8.560 |
| 160 | 8.560 | 8.616 | 8.671 | 8.726 | 8.781 | 8.837 | 8.892 | 8.947 | 9.003 | 9.058 | 9.113 |
| 170 | 9.113 | 9.169 | 9.224 | 9.279 | 9.335 | 9.390 | 9.446 | 9.501 | 9.556 | 9.612 | 9.667 |
| 180 | 9.667 | 9.723 | 9.778 | 9.834 | 9.889 | [illegible] | 10.000 | 10.055 | 10.111 | 10.166 | 10.222 |
| 190 | 10.222 | 10.277 | 10.333 | 10.388 | 10.444 | 10.499 | 10.555 | 10.610 | 10.666 | 10.721 | 10.777 |
| 200 | 10.777 | 10.832 | 10.888 | 10.943 | 10.999 | 11.054 | 11.110 | 11.165 | 11.221 | 11.276 | 11.332 |
| 210 | 11.332 | 11.387 | 11.443 | 11.498 | 11.554 | 11.609 | 11.665 | 11.720 | 11.776 | 11.831 | 11.887 |
| 220 | 11.887 | 11.943 | 11.998 | 12.054 | 12.109 | 12.165 | 12.220 | 12.276 | 12.331 | 12.387 | 12.442 |
| 230 | 12.442 | 12.498 | 12.553 | 12.609 | 12.664 | 12.720 | 12.776 | 12.831 | 12.887 | 12.942 | 12.998 |
| 240 | 12.998 | 13.053 | 13.109 | 13.164 | 13.220 | 13.275 | 13.331 | 13.386 | 13.442 | 13.497 | 13.553 |
| 250 | 13.553 | 13.608 | 13.664 | 13.719 | 13.775 | 13.830 | 13.886 | 13.941 | 13.997 | 14.052 | 14.108 |
| 260 | 14.108 | 14.163 | 14.219 | 14.274 | 14.330 | 14.385 | 14.441 | 14.496 | 14.552 | 14.607 | 14.663 |
| 270 | 14.663 | 14.718 | 14.774 | 14.829 | 14.885 | 14.940 | 14.995 | 15.051 | 15.106 | 15.162 | 15.217 |
| 280 | 15.217 | 15.273 | 15.328 | 15.383 | 15.439 | 15.494 | 15.550 | 15.605 | 15.661 | 15.716 | 15.771 |
| 290 | 15.771 | 15.827 | 15.882 | 15.938 | 15.993 | 16.048 | 16.104 | 16.159 | 16.214 | 16.270 | 16.325 |
| 300 | 16.325 | 16.380 | 16.436 | 16.491 | 16.547 | 16.602 | 16.657 | 16.713 | 16.768 | 16.823 | 16.879 |
| 310 | 16.879 | 16.934 | 16.989 | 17.044 | 17.100 | 17.155 | 17.210 | 17.266 | 17.321 | 17.376 | 17.432 |
| 320 | 17.432 | 17.487 | 17.542 | 17.597 | 17.653 | 17.708 | 17.763 | 17.818 | 17.874 | 17.929 | 17.984 |
| 330 | 17.984 | 18.039 | 18.095 | 18.150 | 18.205 | 18.260 | 18.316 | 18.371 | 18.426 | 18.481 | 18.537 |
| 340 | 18.537 | 18.592 | 18.647 | 18.702 | 18.757 | 18.813 | 18.868 | 18.923 | 18.978 | 19.033 | 19.089 |
| 350 | 19.089 | 19.144 | 19.199 | 19.254 | 19.309 | 19.364 | 19.420 | 19.475 | 19.530 | 19.585 | 19.640 |
| 360 | 19.640 | 19.695 | 19.751 | 19.806 | 19.861 | 19.916 | 19.971 | 20.026 | 20.081 | 20.137 | 20.192 |
| 370 | 20.192 | 20.247 | 20.302 | 20.357 | 20.412 | 20.467 | 20.523 | 20.578 | 20.633 | 20.688 | 20.743 |
| 380 | 20.743 | 20.798 | 20.853 | 20.909 | 20.964 | 21.019 | 21.074 | 21.129 | 21.184 | 21.239 | 21.295 |
| 390 | 21.295 | 21.350 | 21.405 | 21.460 | 21.515 | 21.570 | 21.625 | 21.680 | 21.736 | 21.791 | 21.846 |

Thermoelectric voltage in absolute millivolts

# PRINCIPLES OF TEMPERATURE MEASUREMENT
# UNIT V

## PRACTICAL TEST #1
## JOB SHEET #1 — USE A STEAM BATH, AN ICE BATH, AND A DIGITAL VOM TO CONFIRM THE TEMPERATURE OUTPUT OF THE HOT JUNCTION ON A THERMOCOUPLE

**Student's name** ______________________________ **Date** ____________

**Evaluator's name** ______________________________ **Attempt no.** ______

Student instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

### PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

| The student: | | YES | NO |
|---|---|---|---|
| 1. Wore safety glasses. | 1. | ☐ | ☐ |
| 2. Constructed testing apparatus properly and safely. | 2. | ☐ | ☐ |
| 3. Made and recorded all temperature measurements. | 3. | ☐ | ☐ |
| 4. Made conversions correctly. | 4. | ☐ | ☐ |
| 5. Disconnected testing apparatus safely. | 5. | ☐ | ☐ |
| 6. Returned equipment and materials to proper storage. | 6. | ☐ | ☐ |

Evaluator's comments: ______________________________________________

______________________________________________

______________________________________________

# JOB SHEET #1 PRACTICAL TEST

## PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

| Criteria: | | | | |
|---|---|---|---|---|
| Equipment and Materials | Properly selected and properly used 4 | Properly selected and acceptably used 3 | Poorly selected and/or used 2 | Improperly selected and/or used 1 |
| Testing Procedure | Well followed 4 | Acceptably followed 3 | Poorly followed 2 | Improperly followed 1 |
| Data Recording | All properly entered 4 | Almost all entered 3 | Too few entered 2 | Too few entered or improperly entered 1 |
| Safety | Carefully observed 4 | Acceptably observed 3 | Poorly observed 2 | Improperly observed 1 |

EVALUATOR'S COMMENTS: ______________________________

______________________________

### PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

# PRINCIPLES OF TEMPERATURE MEASUREMENT
# UNIT V

## TEST

NAME_______________________________________ SCORE_______________

1. Match the terms on the right with their correct definitions.

| | | |
|---|---|---|
| ______a. | An alloy of 95% nickel and 5% aluminum, manganese, and silicon used in the manufacture of thermocouples | 1. SAMA |
| | | 2. Chromel |
| ______b. | An alloy of 90% nickel and 10% chromium used in the manufacture of thermocouples | 3. Temperature |
| | | 4. Alumel |
| ______c. | An alloy of tin and copper used in the manufacture of thermocouples | 5. Seebeck effect |
| ______d. | A principle discovered in 1821, that became the theoretical basis for thermocouples because it states that when two different metal objects are connected together at each end, and a temperature difference exists between the two junctions, a potential will exist, and current will flow | 6. Constantan |
| ______e. | An organization of instrument manufacturers that sets standards for measuring equipment | |
| ______f. | The measure in degrees of the presence of, or the transfer of heat energy in a system | |

2. Complete statements concerning units of temperature measurement by circling the items that best complete each statement.

   a. The unit of relative temperature in the **(metric, English)** system is Fahrenheit; in this system, water freezes at 32° and boils at 212°, and the scale may run as far below zero as is necessary.

   b. The unit of relative temperature in the **(metric, English)** system is Celsius; in this system, water freezes at 0° and boils at 100°.

   c. The metric absolute temperature measuring scale is **(Rankine, Kelvin)**; in this system, water boils at 373.18°, and the absolute scale goes 273.18° below 0° Celsius to the point where no molecular motion exists.

## TEST

d. The absolute measuring scale for English units is the (Rankine, Kelvin) scale where absolute zero is 459.7° below zero Fahrenheit.

e. A BTU (British Thermal Unit) is a unit of heat frequently used in rating heat transfer equipment, and a BTU is the amount of heat required to raise a pound of water (ten degrees, one degree) in temperature.

3. Select true statements concerning measuring temperature with thermometers by placing an "X" beside each statement that is true.

_____a. There are a number of devices that can be called thermometers, and all of them function pretty much the same; they have a tube with a container on one end that holds a liquid that expands and contracts inside a sealed tube to indicate temperature.

_____b. Industrial grade thermometers are made of special heat-treated glass that has been carefully marked to provide highly accurate scales.

_____c. Industrial thermometers are mounted in rugged cases with the scale around the tube well marked so it can be read at a distance.

_____d. Physicist Lord Kelvin who invented the temperature scale named for him also did early research on thermometers.

4. Solve the following problems concerning measuring temperature with thermocouples.

a. How are thermocouples identified?

Answer: ____________________________________________

b. If a thermocouple had to be constructed in the field, could it be done?

Answer: ____________________________________________

c. What condition concerning a power source makes thermocouples attractive as temperature measuring devices?

Answer: ____________________________________________

# TEST

5. Select true statements concerning measuring temperature with RTDs by placing an "X" beside each statement that is true.

   (NOTE: For a statement to be true, all parts of the statement must be true.)

   _____a. RTDs are commonly used transducers that, unlike thermocouples, will not generate their own signals.

   _____b. The RTD requires a power source, and associated wiring, which may be a slight disadvantage, but is a very linear device that requires little or no compensation for output to an instrumentation package.

   _____c. An RTD is made of a very fine resistance wire, usually gold, wound on a core and packaged in a variety of forms ranging from embedded devices to long probes or flat packs that can be attached or cemented to a machine surface.

   _____d. Because of its very stable relationship between temperature and resistance, gold is used often in RTDs.

   _____e. Other metals used in RTDs include nickle which can be used over a temperature range of −70 to +150 degrees Celsius, and copper which is good in the −200 to +150 degrees Celsius range.

   _____f. Newer RTD designs use a thin film of platinum to help lower cost, and provide smaller sizes and new flat shapes for surface mounting.

   _____g. Industrial RTDs are very linear compared to thermocouples and thermistors, and platinum RTDs are more linear than nickel or copper.

   _____h. For industrial applications in wheatstone bridge measuring circuits, RTDs come packaged in two, three, or four lead configurations.

   _____i. The additional leads form compensation networks for the elimination of lead length errors:

      1) The two-wire lead has no compensation.

      2) The three-lead units eliminate almost all errors.

      3) The four-lead units completely eliminate errors and are used in critical applications.

6. Solve the following problems concerning measuring temperature with thermistors.

   a. Thermistors, like RTDs, are thermal-resistant devices, but what makes a thermistor different from an RTD?

      Answer: ____________________

   b. Is output from a thermistor linear or non-linear?

      Answer: ____________________

## TEST

7. Select true statements concerning measuring temperature with FTSs by placing an "X" beside each statement that is true.

   (NOTE: For a statement to be true, all parts of the statement must be true.)

   _____a. Filled thermal systems were once the mainstay of temperature measuring systems, but they have been replaced by newer electrical devices because they are bulky and don't fit well into modern equipment design.

   _____b. FTSs are limited in the distance they can transmit a signal, and they will not interface directly to electronic or digital equipment.

   _____c. A filled thermal system has three main parts:

   1) A bulb;

   2) A capillary;

   3) A pressure sensing element, usually a thermometer.

   _____d. The bulb is located at the heat source to be measured, the pressure measuring element is at the display, recorder, or controller, and the capillary connects to a transmitter.

8. Complete statements concerning classes and applications of FTSs by circling the items that best complete each statement.

   a. Capillary compensation can be used in classes I, III, and V; however, compensation is used normally in I and **(V, III)** only.

   b. Compensation is accomplished by running a **(second, single)** capillary to a second pressure element that cancels the effect of temperature input along the capillary tube, and this can also be accomplished with liquid filled fully compensated, or liquid filled case compensated capillary design.

   c. The Class V, **(Mercury, water)** filled systems have a very high mechanical drive ability because of large expansion characteristic of **(Mercury, water)**, and the Class V systems drive devices such as recorders and small valves.

   d. In the Class **(II, V)** systems, a liquid turns a vapor at a hot spot, and drives the pressure element at the readout end of the system, and since the hot spot can occur at any place in the system, including the capillary, these systems cannot be compensated, and are designed for specific applications.

   e. The Class III systems have excellent low temperature characteristics, can effectively operate at a distance of 200 feet, and are very common in **(refrigeration systems, general industrial applications)**.

   f. The subclasses of A, B, C, and D in the type II systems are popular because they are **(low cost, medium priced)**, uncomplicated devices that can be tailored to the measuring situation.

# TEST

9. Complete statements concerning measuring temperature with bimetallic devices by circling the items that best complete each statement.

   a. Bimetallic devices are simple, and commonly used where **(electrical, mechanical)** output is necessary to drive purely mechanical or electromechanical systems.

   b. A bimetallic mechanism consists of two metals with **(dissimilar, similar)** thermal expansion characteristics, fused together so that a change in temperature will cause the different expansion rates to distort the combined metallic device.

   c. Bimetallic devices may be made in **(only three, many forms)** including the common spiral spring used to operate household thermostats, the helical spring used to operate rotary mechanical switches, and the flat spring used in industrial pneumatic thermostats.

   d. Another common bimetallic application is the small metal disc overload switch used to trip :ff an electric motor wher motor **(temperature, speed)** exceeds nor-mal limits.

10. Solve the following problems concerning measuring temperature with infrared devices.

    a. In what situations are infrared measuring devices used?

       Answer: ______________________________

    b. Is IR temperature measurement based on Planck's formula or Kelvin's principle?

       Answer: ______________________________

    c. IR measuring devices are rapid and accurate. List at least one other outstanding quality of IR devices.

       Answer: ______________________________

       ______________________________

11. Complete statements concerning measuring temperature with LICs by circling the items that best complete each statement.

    a. The **(increase, decrease)** in temperature associated with the increase in current through a semiconductor is a phenomena that plagued early designers of semiconductor devices.

    b. By relating the change in output current with changes in **(amplitude, temperature)**, designers matched and linearized the output currents to a temperature scale, and the IC temperature sensor was created.

    c. LICS promise to impact the marketplace because they can be made very small, **(they are medium priced, they are low cost)**, they are very linear, and they are capable of impedance matching almost any electronic system.

# TEST

12. Select true statements concerning digital and analog readouts by placing an "X" beside each statement that is true.

_____a. Temperature measuring devices have traditionally used an analog meter or an analog recording device to provide a readout.

_____b. Digital readouts are rapidly replacing analog devices in instrumentation to provide temperature readings that are printed on a piece of paper or screened on a monitor.

_____c. The reporting of temperature in digital form makes it easy to perform mathematical control calculations, and other operational calculations.

_____d. Digital readout devices are increasing in popularity because of the diminishing cost of microprocessor based computer equipment, the low cost of analog to digital conversion ICs, and the low cost of digital readout devices.

13. Solve the following problems concerning temperature scale conversions.

a. What are the two most common temperature conversions a technician in process instrumentation will have to make?

Answer: ________________________________________

b. Given the formula C° = 5/9 (°F − 32°), what would 98.6 °F be in C°?

Answer: ________________________________________

14. Select true statements concerning applications of temperature measurement by placing an "X" beside each statement that is true.

_____a. Some temperature measuring devices are common in the home; heat and air-conditioning are controlled by a bimetallic coil in a thermostat.

_____b. Industrial applications of temperature measurement are mostly to measure and feedback control parameters to a controller.

_____c. Industrial applications include common thermocouples by the millions, RTDs, and advanced IR thermometers that measure such diverse applications as the temperature of molten steel in a blast furnace to the temperature of stars far distant in space.

_____d. Temperature measuring devices range in size from large filled thermal systems with bulbs the size of melons to thermistors embedded in tiny instruments placed in catheters to be threaded into the veins of human patients.

_____e. The cost of temperature sensing devices ranges from common thermistors selling for a few pennies to platinum RTDs and IR thermometers that cost thousands of dollars.

# TEST

(NOTE: If the following activity has not been accomplished prior to the test, ask your instructor when it should be completed.)

15. Demonstrate the ability to use steam and ice baths and a potentiometer to confirm temperature output at the hot junction of a thermocouple. (Job Sheet #1)

# PRINCIPLES OF TEMPERATURE MEASUREMENT
# UNIT V

## ANSWERS TO TEST

1. a. 4
   b. 2
   c. 6
   d. 5
   e. 1
   f. 3

2. a. English
   b. Metric
   c. Kelvin
   d. Rankine
   e. One degree

3. a, b, c

4. a. By letter type
   b. Yes
   c. Thermocouples generate their own power

5. a, b, e, f, g, h, i

6. a. Thermistors are non-linear, solid-state devices
   b. Non-linear

7. a, b

8. a. V
   b. Second
   c. Mercury, Mercury
   d. II
   e. Refrigeration systems
   f. Low cost

9. a. Mechanical
   b. Dissimilar
   c. Many
   d. Temperature

## ANSWERS TO TEST

10. a. Where no other type of measuring system could function
    b. Planck's formula
    c. They can measure temperature without contact with the object, or they can read the temperature of an object even if it is among other heat sources

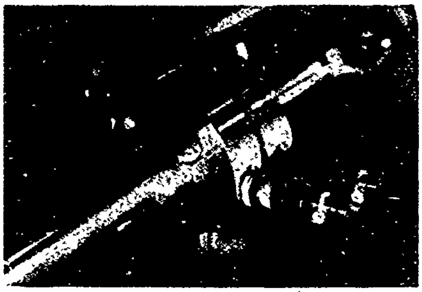
11. a. Increase
    b. Temperature
    c. They are low cost

12. a, b, c, d

13. a. Fahrenheit to Celsius and Celsius to Fahrenheit
    b. 36.96° C (or rounded off, 37°C)

14. a, b, c, d, e

15. Job Sheet #1 evaluated according to the criteria in Practical Test #1



# PRINCIPLES OF FLOW MEASUREMENT
## UNIT VI

## UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss the basics of flow measurement, differentiate between methods of flow measurement, and relate flow measuring devices to their flow measuring applications. The student should also be able to construct a test apparatus and measure flow. These competencies will be evidenced by correctly completing the procedures outlined in the job sheet, and by scoring a minimum of 85 percent on the unit test.

## SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to principles of flow measurement with their correct definitions.
2. Solve problems concerning basics of flow measurement.
3. Select true statements concerning units of flow measurement.
4. Differentiate between methods of flow measurement.
5. Complete statements concerning measuring flow with differential pressure devices.
6. Select true statements concerning measuring flow with differential pressure transmitters.
7. Complete statements concerning measuring flow with orifice plates.
8. Complete statements concerning measuring flow with venturi tubes.
9. Match venturi tube variations with their characteristics.
10. Select true statements concerning measuring flow with pitot tubes.
11. Solve problems concerning measuring flow with elbow meters.
12. Complete statements concerning measuring flow with vortex shedding.
13. Select true statements concerning measuring flow with rotameters.

## OBJECTIVE SHEET

14. Complete statements concerning measuring flow with turbine meters.
15. Solve problems concerning measuring flow with positive displacement meters.
16. Solve problems concerning methods of non invasive flow measurement.
17. Complete statements concerning measuring flow with Doppler effect flowmeters.
18. Select true statements concerning measuring flow with time-of-travel flowmeters.
19. Solve problems concerning measuring flow with magnetic flowmeters.
20. Complete statements concerning measuring flow with mass flow instruments.
21. Select true statements concerning the square root conversion.
22. Demonstrate the ability to construct a flow control apparatus, and use a Mercury manometer and a rotameter to measure flow in a system. (Job Sheet #1)

# PRINCIPLES OF FLOW MEASUREMENT
# UNIT VI

## SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information and assignment sheets.

C. Make transparencies.

D. Discuss unit and specific objectives.

E. Discuss information sheet.

F. Invite the supervisor of a local or area processing activity to talk to the class about the forms of flow measurement used in an area industry.

G. Have available flow measuring devices to show students as you discuss various devices in class.

H. Give test

## REFERENCES USED IN DEVELOPING THIS UNIT

A. Whalen, Bruce R. *Basic Instrumentation*. Third Edition. Austin, TX 78758: Petroleum Extension Service, University of Texas at Austin, 1983.

B. *Omega Complete Flow and Level Measurement Handbook and Encyclopedia*. Stamford, CT 06907: Omega Engineering, Inc., 1988.

C. *Instruction Book 2358*. Foxboro, MA 02035: The Foxboro Company, 1983.

D. *Dwyer Controls and Gauges*. Michigan City, IN 46360: Dwyer Instruments, Inc., 1985.

# PRINCIPLES OF FLOW MEASUREMENT
# UNIT VI

## INFORMATION SHEET

I. Terms and definitions

A. Inferential — The measurement of a variable such as flow in terms of another variable, and using the output or readout as if it were the original

B. Laminar — A term used in flow to indicate that the flow of material inside a pipe is smooth or streamlined

C. Reynolds Number — A system of numbers used to indicate the amount of turbulence in a pipe or tube

D. Slurry — A mixture of two materials that form a nonhomogenous mixture

E. Viscosity — The property of a liquid that indicates its ability to flow, sometimes expressed as the liquid's resistance to shearing displacement

II. Basics of flow measurement

A. An early method of measuring flow was to accumulate liquid in a container for a short period of time, and then use weight or volume and time to determine flow rate.

B. In modern applications, flow rate is expressed in units of mass or volume per period of time.

(NOTE: It would be the equivalent of being able to watch a point in a pipe, and then determine the volume of a liquid or gas that passed the point in a second, minute, or other time period.)

C. Other modern applications measure flow rate by inference, and this entails measuring some other parameter such as pressure drop, and inferring the rate of flow.

III. Units of flow measurement

A. Several industries, but especially the petroleum and petro-chemical industries, measure flow in barrels per hour.

(NOTE: The ordinary barrel may be 31.5 or 55 U.S. gallons, and the British use 36 imperial gallons, but dry materials and food stuffs use a different size barrel.)

# INFORMATION SHEET

B. Another common unit of flow measurement is gallons per hour, and in this unit, 1 U.S. gallon equals 0.003785 cubic meters, and if the British imperial gallon is used, it is equal to 1.20095 U.S. gallons.

(NOTE: Because of the ambiguity between the units, and the need to create confusion-free international markets, an attempt is underway to convert to the metric liter which is 0.2642 U.S. gallons.)

C. Measuring higher flow rates over shorter time spans is accomplished with a newer volume unit of liters per minute.

D. Viscosity is the unit that measures the resistance of a liquid to flow through a pipe or tube.

E. Volume is another unit of flow measurement for materials flowing through pipes or tubes, and is related to the physical state of the material:

1. The volume of a gas is measured in the older unit of cubic feet, or in liters or cubic meters.

2. Units used to measure the volume of a liquid varies with the applications and could be gallons, barrels, liters, or cubic meters.

F. When velocity is used to measure flow, it always means that a higher rate of flow will have a higher velocity: (Transparency 1)

1. Laminar flow is flow that moves parallel with the tube or pipe, and is considered to be "streamlined."

2. Turbulent flow has eddy currents or other nonparallel elements, and this phenomena is classified by a Reynolds number where 4,000 and up is considered turbulent.

## IV. Methods of flow measurement

A. Methods of measuring flow fall into two major categories:

1. Invasive

2. Non-invasive

B. An invasive measurement device includes anything that projects into a pipe or tube that carries material, and invasive methods are still used more often than noninvasive methods.

# INFORMATION SHEET

C. Non-invasive measurement devices do not enter the pipe or tube that carries material, and because they are outside, these devices must measure by inference, using some property of the material that can be detected outside, or producing an output signal to which the material inside the pipe can react.

V. **Measuring flow with differential pressure devices**

A. There are several types of differential pressure devices, and they all have primary and secondary elements:

1. The primary element disturbs the flow by restricting it in some fashion.

2. The secondary element reads the pressure differential created by the primary element.

B. Differential pressure devices work on the Bernoulli principle which states that the sum of energies in a flowing closed system, such as a pipe or tube, is constant.

C. The energies in a closed system include pressure, motion, and position, and by altering the motion with some kind of restriction, it will cause pressure to change in direct relation to motion or flow in the system, and since position does not change, the energies retain their constant.

EXAMPLE: When you press your thumb on the open end of a flowing garden hose, the pressure increases, and the stream of water shoots out from the end of the hose, but once you remove your thumb, the pressure is gone, and water flow through the hose returns to normal.

VI. **Measuring flow with differential pressure transmitters** (Transparency 2)

A. Differential pressure transmitters have the capacity to transmit a small pressure difference as a pneumatic or electrical signal for a great distance.

B. Differential pressure transmitters, or DP cells, are commonly used with orifice plates because the pressures produced across an orifice are small by design, and flow measurements are frequently made in places remote and hard to reach.

C. Creating high pressure drops to measure flow rate requires expensive devices, and with soaring production costs, differential pressure transmitters are contributing to cost-saving ways to do business.

## INFORMATION SHEET

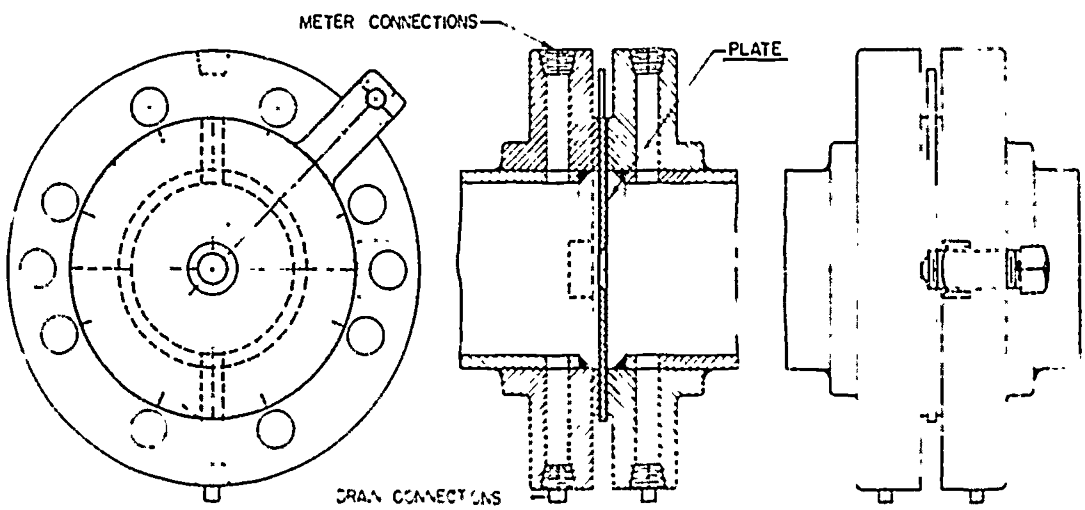
VII. Measuring flow with orifice plates (Transparency 3)

A. The simplest and most commonly used primary invasive device is the orifice plate.

B. An orifice plate is a metal plate with a hole smaller than the inside diameter of the pipes on which it is installed.

C. The orifice plate is bolted between two flanges in the pipe, and the pressure is tapped for measurement on both sides of the plate. (Figure 1)

FIGURE 1




Courtesy Petroleum Extension Service (PETEX)
The University of Texas at Austin

D. The pressure on the upstream side (where flow is coming from) is higher than pressure on the downstream side:

1. When flow rate increases, the pressure difference increases.

2. When flow rate decreases, the pressure difference will decrease in proportion.

E. The orifice plate is a simplistic device, but in design it is highly engineered, and the plates are designed for specific applications.

(NOTE: The orifice may be centered or offset, as the process requires, and the upstream side of the orifice is usually knife-sharp to minimize turbulence.)

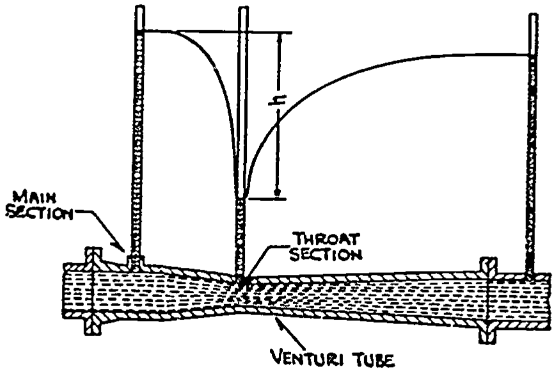
# INFORMATION SHEET

VIII. **Measuring flow with venturi tubes**

A. A venturi tube is designed with a restriction for reducing the inside diameter of a pipe, like an orifice plate, but yet the venturi tube is much better at conserving energy because it recovers pressure drop downstream from the restriction.

B. The sloped area leading up to the restriction in a venturi tube is called the approach area, the restriction is called the throat, and the tube following the throat is called the recovery area. (Figure 2)

FIGURE 2




**Courtesy Petroleum Extension Service (PETEX)**
**The University of Texas at Austin**

C. The throat usually contains one of the pressure measuring pickup points, and because of the long slope behind the restriction, most of the pressure drop is recovered, and a venturi tube is considered highly efficient in terms of conserving energy.

D. Venturi tubes are used mostly on special applications because special piping considerations make them expensive.

IX. **Venturi tube variations and their characteristics**

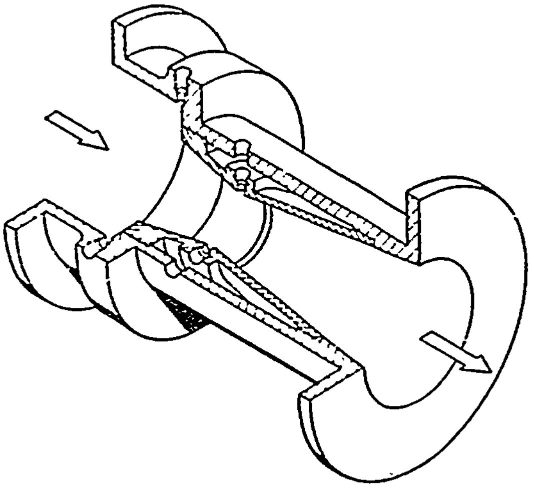
A. Long venturi — A venturi tube usually used to handle high flow volumes with almost all liquids, a highly efficient flow measuring device.

B. Short venturi — A venturi tube that has been shortened so that it will fit into shorter pipe runs; it costs less, but does not have the efficiency of a long venturi.

## INFORMATION SHEET

C. Dall tube — A device with the inner dimensions of a venturi tube, designed to fit inside a pipe and give results similar to a venturi. (Figure 3)

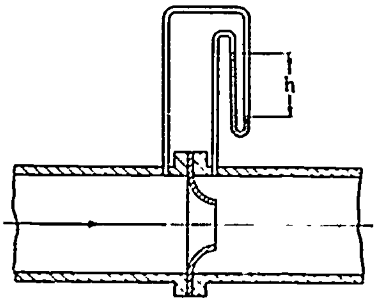
FIGURE 3



Courtesy Petroleum Extension Service (PETEX)
The University of Texas at Austin

D. Flow nozzle — A device that fits between the flanges of a pipe with a nozzle projecting into the pipe in the direction of flow; it contains the approach and throat equivalents of a venturi without the recovery part, and is more efficient than an orifice plate, but not as efficient as a long venturi. (Figure 4)

FIGURE 4




Courtesy Petroleum Extension Service (PETEX)
The University of Texas at Austin

# INFORMATION SHEET

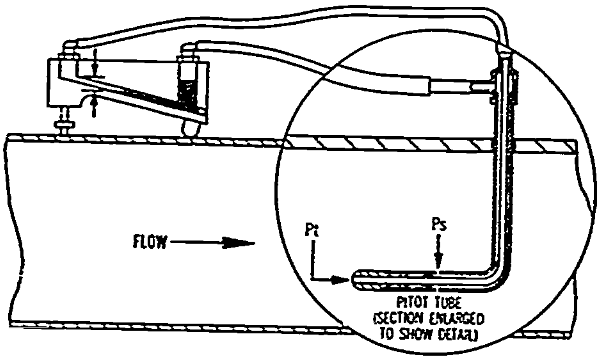
X. Measuring flow with Pitot tubes

A. A pitot tube is a double tube with a ninety degree bend on the end that projects into a pipe.

B. The inner tube of a pitot tube projects out of the second tube on the end that faces the flow, and is open to flow while the outer tube is closed to flow, and has a static hole on the backside facing away from flow.

C. Flow pressure strikes the impact end of the Pitot tube while the static hole at the backside of the tube remains in a lower pressure area away from the flow. (Figure 5)

FIGURE 1




Courtesy Dwyer Instruments, Inc.

D. The difference in pressure from impact to static hole increases as flow increases, and the pressure differential decreases as flow decreases.

E. Flow rate is determined by measuring the pressure difference between the inner and outer tubes.

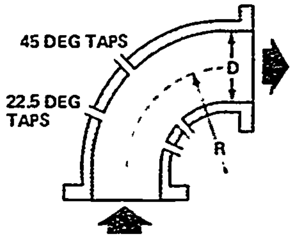
# INFORMATION SHEET

XI. Measuring flow with elbow meters

A. When liquid flows through a pipe albow, it creates a force on the interior surface of the elbow, and this force can be used to infer flow.

B. Two holes are placed in the elbow to permit the attachment of pressure sensing piezometer taps to make the required measurements. (Figure 6)

FIGURE 6





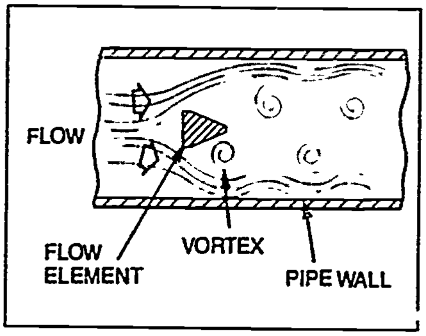

C. Almost any 90° elbow can be used as a flowmeter as long as the taps are placed at proper angles.

XII. Measuring flow with vortex shedding

A. Vortex shedding is sometimes called a wedge flow meter because of the shape of the wedge or shedder that is projected inside a section of short pipe.

B. The shedder disrupts flow, creates vortices, and the vortices in turn shed energy in the form of differential pressure. (Figure 7)

FIGURE 7



## INFORMATION SHEET

C. The differential pressure pulses are usually converted to electrical pulses by a transducer in the area of the vortex shedding action.

D. The signal from the vortex unit may be AC or the pulse amplitude (height) can be averaged to produce a 4-20 mA DC output signal, or the pulses can be counted by a computer.

E. The concept behind vortex shedding is complex, but in simple terms, vortex shedding is proportional to flow rate.

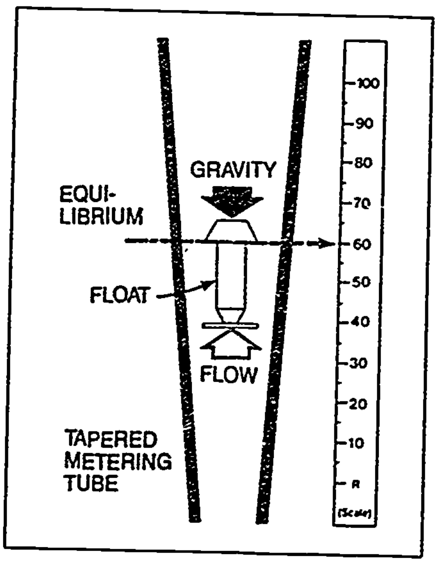
XIII. Measuring flow with rotameters

A. A rotameter works on the same principle as an orifice plate or a venturi tube where pressure drop across a restriction is used to measure flow.

B. A rotameter has a float housed in a metal tube that has a restriction where the float can rest when there is no fluid flowing in a system.

C. The float in a rotameter will rise or fall as more or less flow occurs in the system, and since a change in flow causes the restriction area to vary, the device is classified as a variable area flow meter. (Figure 8)

FIGURE 8




**REPRODUCED WITH THE PERMISSION OF OMEGA ENGINEERING, INC.**


D. The amount of flow is usually indicated by the height of the float in a glass or clear plastic housing with flow rate indicators clearly marked for monitoring.

E. For working with other than transparent or translucent liquids, some rotameters have mechanical or magnetic coupling to the float to provide a readout.

# INFORMATION SHEET

XIV. **Measuring flow with turbine meters** (Transparency 4)

A. A turbine meter works like the blades on a fan, and is fitted precisely into a section of pipe so that the blades of the turbine are filled with and emptied of fluid to provide a measure of volume passing a given point in a pipe.

B. The turbine rotor is mechanically connected to a mechanical readout device or to an electrical transducer that gives revolutions as flow rate.

C. If there is no mechanical connection to the rotor, some turbine meters have magnetic pickup transducers that count the blades as they turn, and the readout indicates flow rate.

(NOTE: Because turbine motors measure the filling and dumping of fluid over the blades, they are sometimes called volumetric flow meters.)

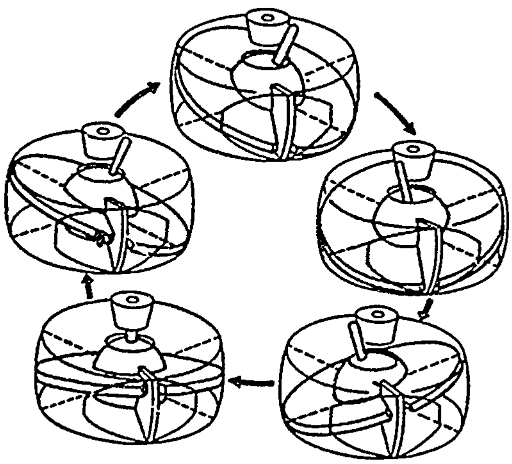
XV. **Measuring flow with positive displacement meters**

A. Positive displacement meters are used by gas and water utility companies to measure the amount of gas or water used by a homeowner or a business.

B. Positive displacement meters do not infer flow as other devices do, but instead they measure flow by separating the liquid or gas into portions that are counted by the system to give volume per time units.

C. The most popular positive displacement meter for measuring gas and water use is the nutating-disk meter which gets its name from its use of a round disk that is mounted on a ball bearing so that the disk tips and turns. (Figure 9)

FIGURE 9



**Courtesy Petroleum Extension Service (PETEX)**
**The University of Texas at Austin**

# INFORMATION SHEET

D. The nutating-disk meter has a cam follower that trips a mechanical counter to keep track of total volume, and send it on to an indicator or controller.

E. In addition to the nutating-disk meter, other positive displacement devices include piston meters, gear meters, fluted rotor meters, and impeller flowmeters.

XVI. **Methods of non-invasive flow measurement**

A. Non-invasive devices are located outside of the pipe or tube that carries the flow, and because these devices are outside, they must all measure by inference.

B. Measuring by inference requires the use of some property in flow material that can be detected outside the pipe, or the use of an instrument to which the flow can react in a fashion that implies the rate of flow.

C. Methods of non-invasive flow measurment include:

1. Doppler effect flowmeters;
2. Ultrasonic flowmeters;
3. Magnetic flowmeters;
4. Mass flowmeters.

XVII. **Measuring flow with Doppler effect flowmeters** (Transparency 5)

A. The Doppler effect states that the frequencies of sound signals received by an individual or an instrument are dependent on the position of the receiver, relative to the source of the sound.

B. Another way of stating the Doppler effect is to say that if you hear sound output from a moving source, or if you are moving relative to the sound source, the frequency of what you hear will appear to change with relative motion.

EXAMPLE: An example frequently given to demonstrate the Doppler effect is that of listening to a fast moving train that is sounding a whistle; the listener at a set point of observation will hear an increase in the pitch of the whistle as the train approaches and a decrease as the train moves on.

C. The Doppler effect is applied in flow measurement by using ultrasonic sound generators to transmit a signal through the wall of a pipe.

D. As long as the liquid has particles or air bubbles which will reflect the sound, the resulting shift in frequency will be proportional to the rate of flow.

# INFORMATION SHEET

E. The signal may be transmitted with or against the flow:

1. If transmitted waves oppose the flow, they return lower frequencies to the receiver.

2. If the transmitted waves travel in the direction of flow, they return higher frequencies to the receiver.

F. Doppler flowmeter systems may use two transducers located on either side of a pipe, or two on the same side of the pipe, with one unit transmitting and the other receiving the ultrasonic signal.

G. Electronic circuits control the transmission, and compare the received signal to produce flow rate information.

XVIII. **Measuring flow with time-of-travel flowmeters**

A. Time-of-travel flowmeters have transducers mounted on each side of a pipe, but instead of using a reflected signal like Doppler meters, they measure in two directions, against the flow and with the flow.

B. By measuring the time it takes ultrasonic waves to move from transducer to transducer against the flow, and then with the flow, the meters set up a time-differential relationship that is proportional to flow.

C. Unlike Doppler flow meters, the time-of-travel flowmeters do not require particles or bubbles in the flow material, and this permits the measurement of clear liquids and gases.

XIX. **Measuring flow with electromagnetic flowmeters** (Transparency 6)

A. Electromagnetic flowmeters work on Faraday's principle of electromagnetic generation which generally states that the voltage generated in a fixed length of conductor is a function of the velocity of the conductor through a magnetic field of known intensity.

B. Another way of expressing Faraday's principle is to say that if you move a specific length of conductor through a known magnetic field, the voltage output generated by the conductor is determined by the velocity of the conductor.

C. In an electro magnetic flowmeter, the liquid electrolyte is the conductor, the magnetic field is supplied by an electromagnet, and the flow of the fluid is the velocity carrying the conductor through the magnetic field.

D. An electromagnetic flowmeter is a section of stainless steel pipe lined with a special plastic, and two electrodes on opposite ends of the pipe.

# INFORMATION SHEET

E. As the conductive liquid flows through the pipe, a voltage is generated perpendicular to the magnetic field, and this voltage is picked up by the electrodes and transmitted to the measuring system.

F. The flow rate in the pipe produces an electrical voltage change as flow changes, and because electromagnetic flowmeters perform complicated functions, the electronic circuitry used with these meters is sophisticated.

XX. **Measuring flow with mass flow instruments** (Transparency 7)

A. Mass flow measuring devices are used to measure the weight or mass of the flowing material rather than the rate of flow.

B. Early systems measured mass by measuring the volume, and then using the density and other parameters of the material to compute mass.

C. Modern mass flow is measured directly by several super-sophisticated systems which use the principles of the Coriolis effect, gamma radiation based density measurement, and the gyroscopic action of mass flowing in a pipe loop.

D. The French scientist, Coriolis, discovered the principle of the Coriolis effect: an object traveling above the surface of the earth at a constant velocity will be deflected in a predictable fashion by the rotating earth.

EXAMPLE: Water draining from a bathtub in the northern hemisphere rotates counterclockwise, but water draining from a bathtub in the southern hemisphere rotates clockwise.

E. The mass flowmeter using the Coriolis effect is a U-shaped tube through which material flows.

F. As the material moves through the tube, the tube will twist in response to the movement of the mass in space above the earth (the Corolius effect), and the greater the mass flow, the more the tube will twist.

G. Sensitive magnetic sensors record U-tube movement, and send the signal to an electronics system which records or controls as necessary the amount of mass flowing in the system.

XXI. **The square root conversion**

A. All systems that use differential pressure to infer flow depend on the same relationship between flow in the pipe and pressure drop across some restriction.

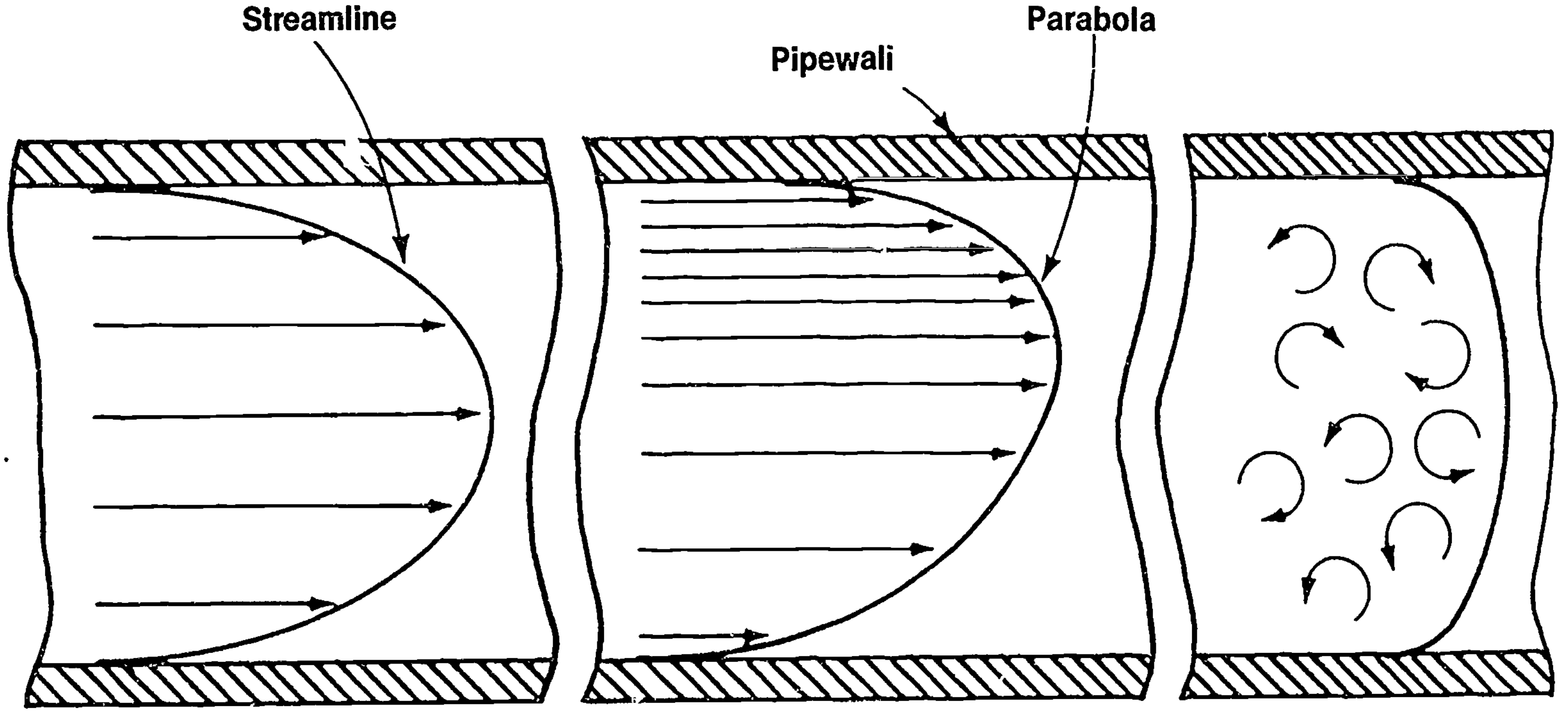
B. Since the output of the primary element is a squared function, the secondary element that reads it must extract the square root of the signal to determine true flow.

# INFORMATION SHEET

C. In older systems, several mechanical schemes were used to square the signal, modern computer devices now provide a low cost system for making the square root conversion.

EXAMPLE: A popular mechanical device for the square root conversion was the LeDoux Bell which was a special float placed inside a U-tube manometer filled with Mercury. The float was so shaped that its movement up and down in the Mercury was a square root function so that when the level of the manometer changed because of pressure drop in the primary flow element, the float woula automatically seek a new level, and thus compensate for the square root output of the differential pressure across the primary element.

# Laminar and Turbulent Flow



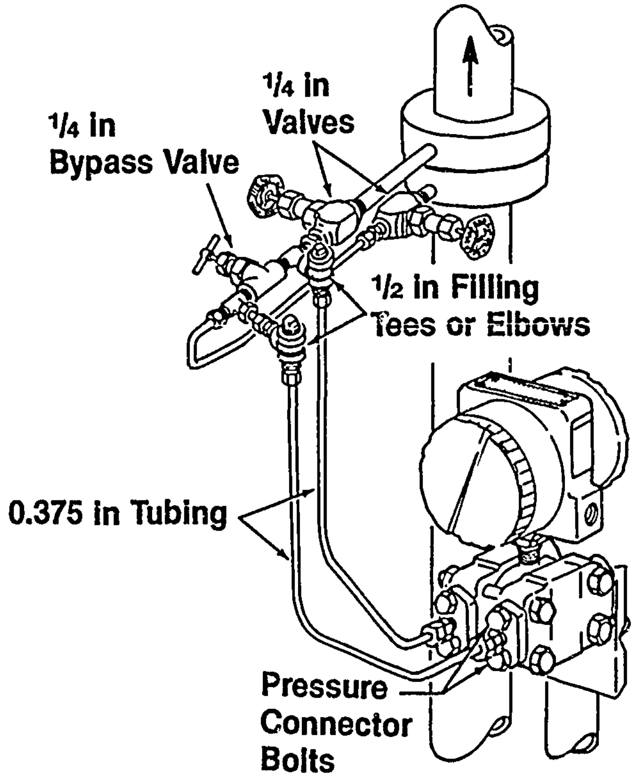

Laminar Flow
Uniform

Laminar Flow
Non-Uniform

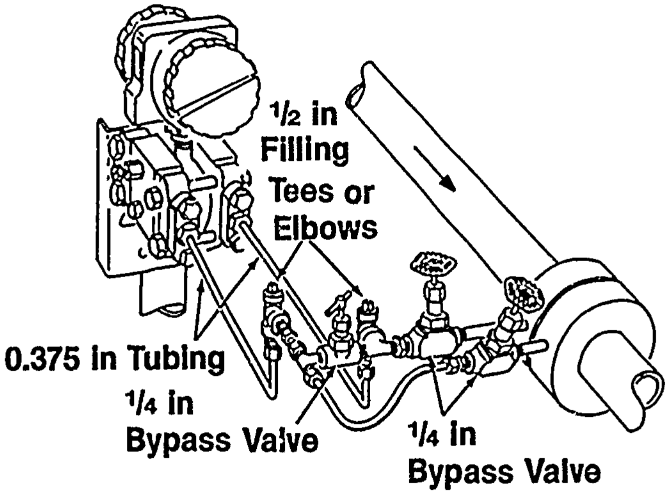
Turbulent
Flow

# Differential Pressure Transmitter

Vertical Line

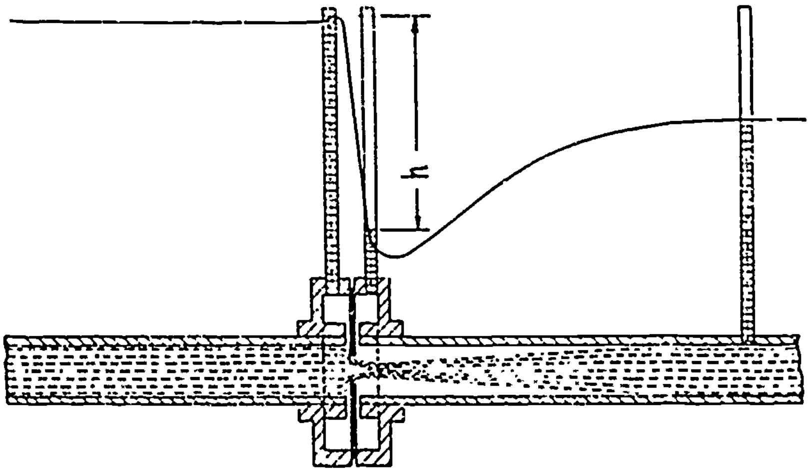



Horizontal Line

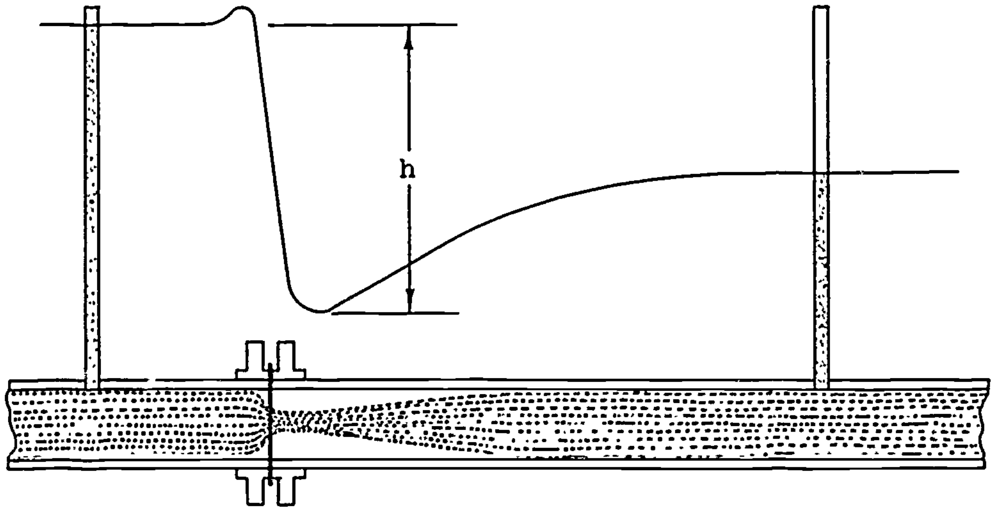



Courtesy The Foxboro Company

# Differential Pressure Transmitter



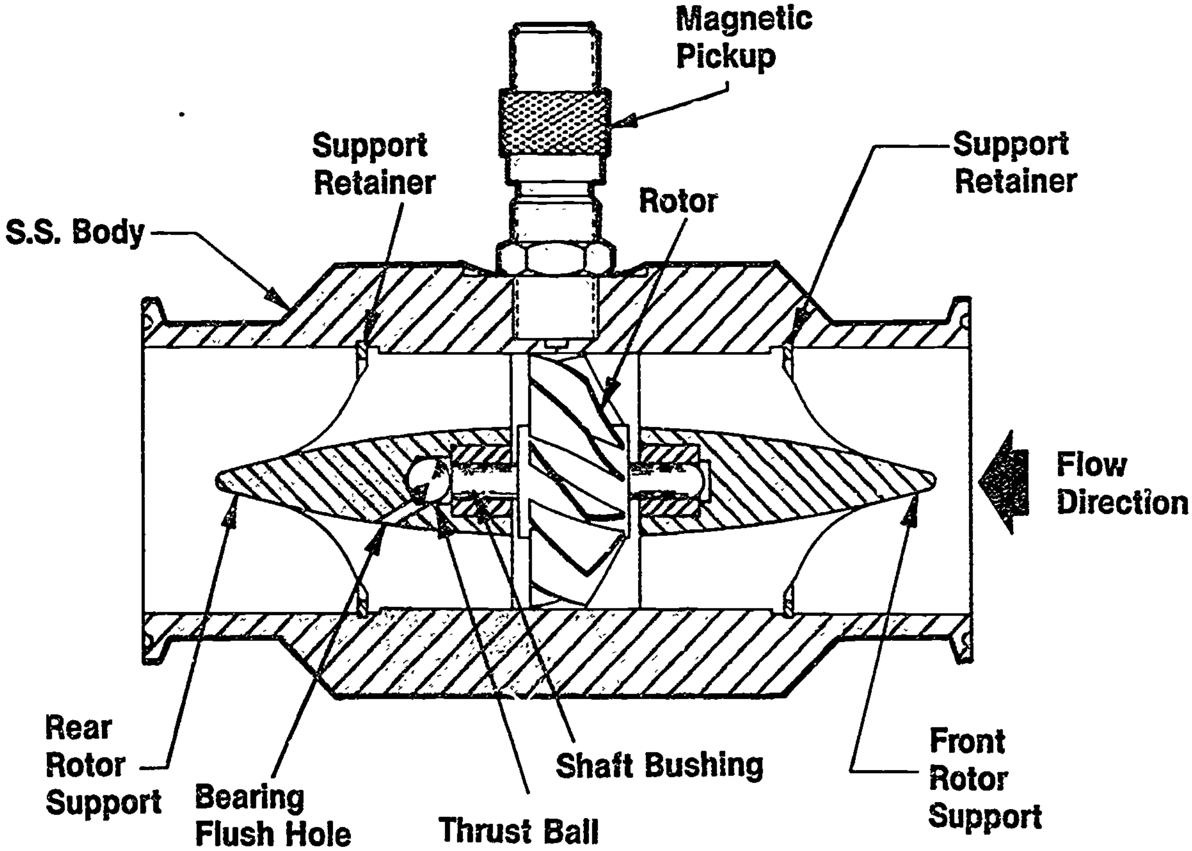

**Orifice plate with corner taps**



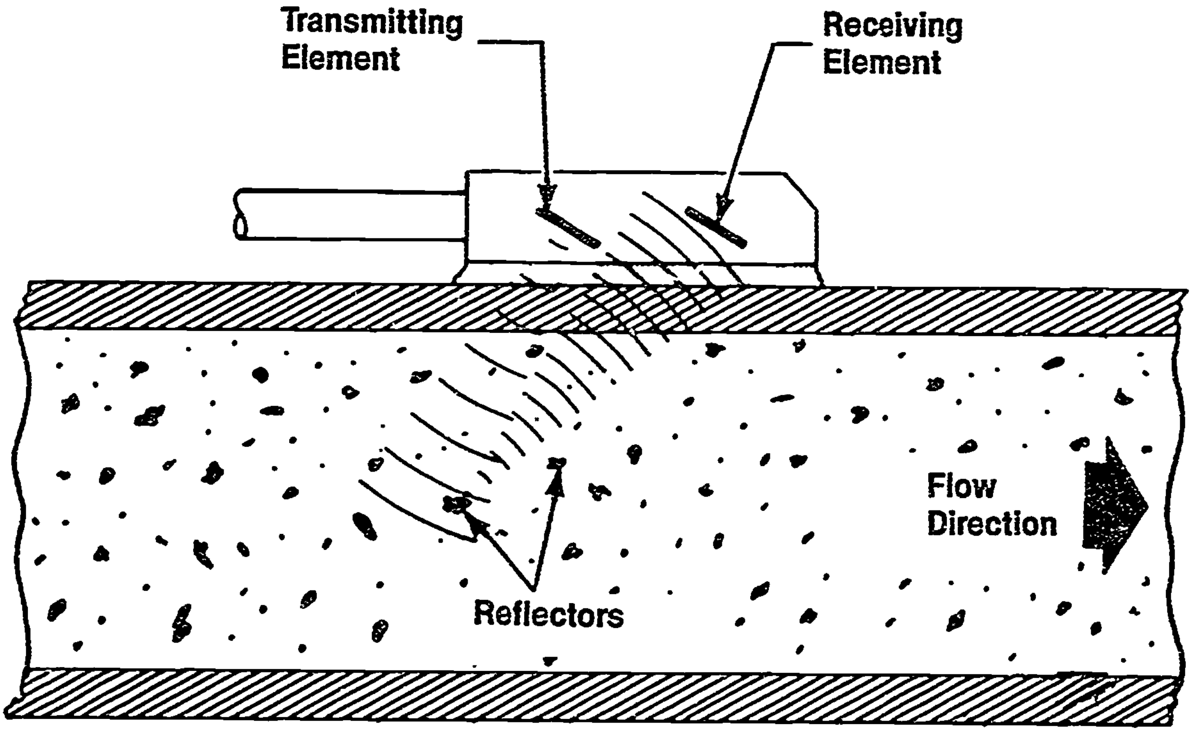

**Orifice plate with pipe taps**

**Courtesy Petroleum Extension Service (PETEX)**
**University of Texas at Austin**

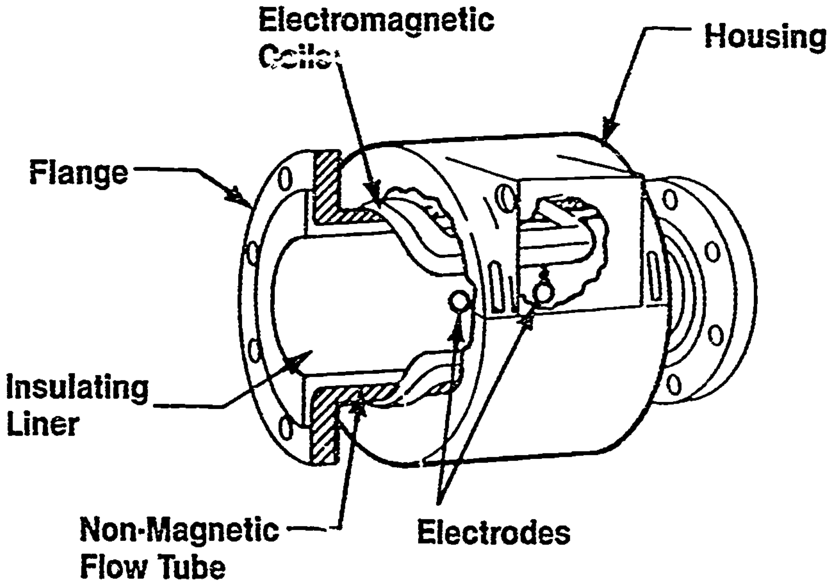
# Turbine Flowmeter



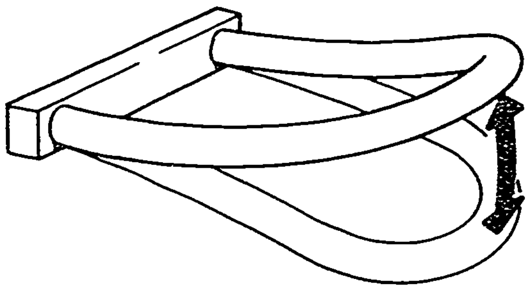
# Doppler Flowmeter



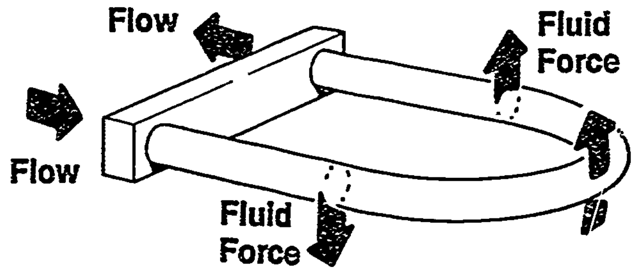
# Electromagnetic Flowmeter



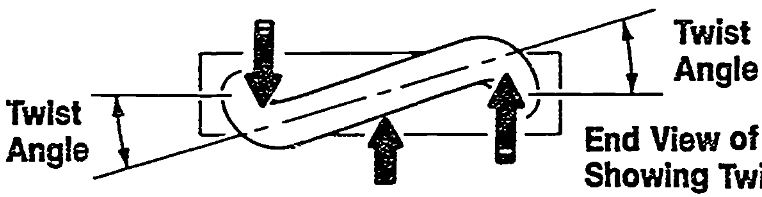
# Coriolis Mass Flowmeter



Vibrating Flow Tube




Fluid Forces Reacting to Vibration of Flow Tube




End View of Flow Tube Showing Twist

# PRINCIPLES OF FLOW MEASUREMENT
# UNIT VI

## HANDOUT #1 — THE SQUARE ROOT CONVERSION

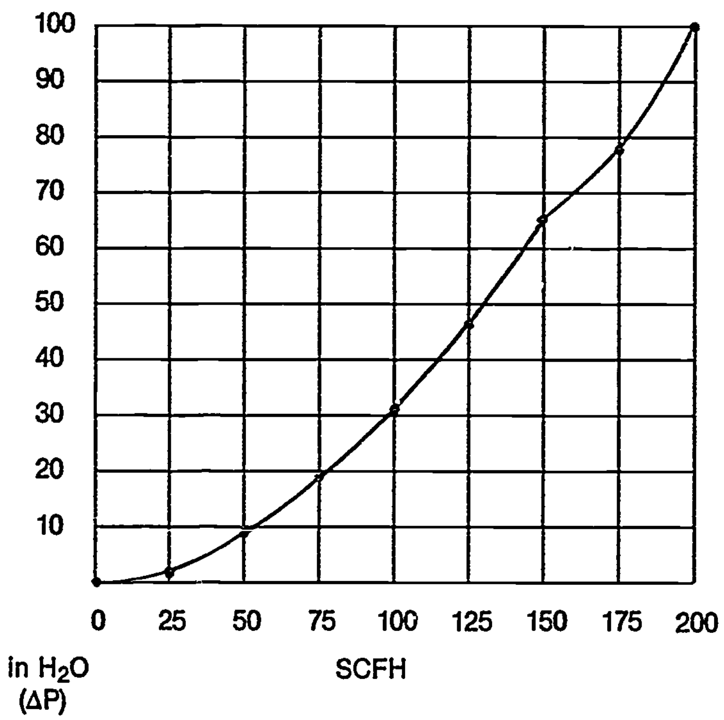
### Purpose

Because recorders and indicators are almost always linear devices, non-linear signals have to be converted to linear signals. The device used to make the non-linear/linear conversion is a square root extractor. A technician who understands the principle of the square root conversion will be able to spot conversion problems faster and be a better troubleshooter. The square root conversion is a simple process that can be accomplished quickly with a proper calculator, and the conversion can be easily demonstrated on a chart.

### ΔP Flow Chart

Observe in the following chart how ΔP in relation to flow (SCFH) gives a non-linear profile.

ΔP Flow Chart



# HANDOUT # 1

**The Square Root Conversion**

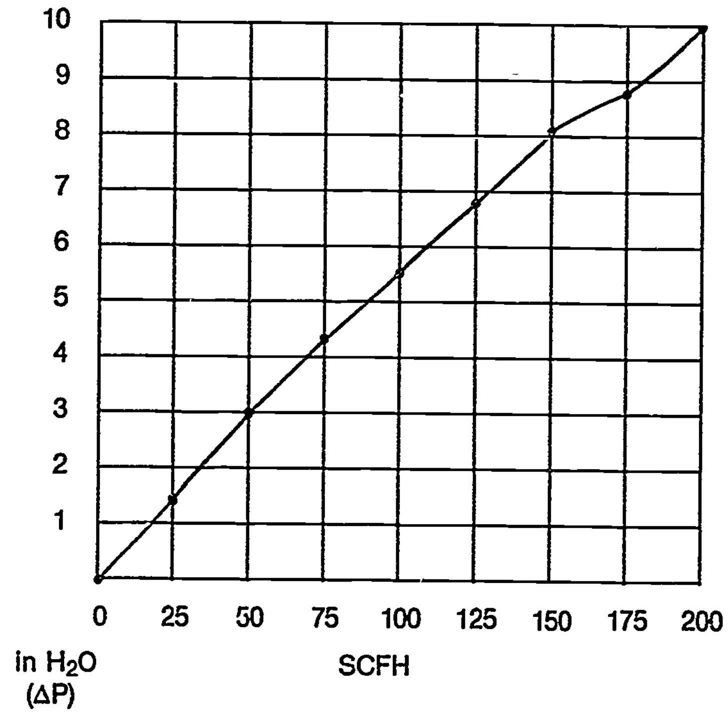
Observe in the following chart how the conversion of the ΔP readings converts the non-linear data into linear data. By using a calculator with a square root function, the conversion is simple. Take the lowest ΔP reading of 2 and find the square root. Mark the appropriate point on the square root chart, which in this case is 1.414. The next ΔP reading is 9 and the square root of 9 is (this is too easy) 3. By continuing with each ascending ΔP reading the non-linear/linear conversion is easy to complete. When the dots on the square root chart are connected by a line, the profile is almost linear, but not perfectly linear. Since all measurement instruments are subject to some error, the conversion will never be perfect, but the conversion provides a usable signal, and that is what we are after.

**Flow Measurement Data Sheet**

| Rotometer | Manometer in $H_2O$ | | Square Root Conversion |
|---|---|---|---|
| 0 SCFH | 0 | = | 0 |
| 25 SCFH | 2 | = | 1.414 |
| 50 SCFH | 9 | = | 3 |
| 75 SCFH | 19 | = | 4.35 |
| 100 SCFH | 31 | = | 5.567 |
| 125 SCFH | 47 | = | 6.855 |
| 150 SCFH | 66 | = | 8.124 |
| 175 SCFH | 78 | = | 8.831 |
| 200 SCFH | 100 | = | 10 |

## HANDOUT #1

**Square Root Conversion Chart**




**Conclusion**

Since $\Delta P$ is the most common way to measure flow, a square root extractor is necessary in flow measuring control loops. A square root extractor provides an efficient, low-cost method of making the non-linear/linear conversion. Knowing how a square root extractor accomplishes the conversion to a usable linear signal will provide a technician with better troubleshooting skills.

# PRINCIPLES OF FLOW MEASUREMENT
# UNIT VI

## JOB SHEET #1 — CONSTRUCT A FLOW CONTROL TEST APPARATUS, AND USE A MERCURY MANOMETER AND A ROTAMETER TO MEASURE FLOW IN A SYSTEM

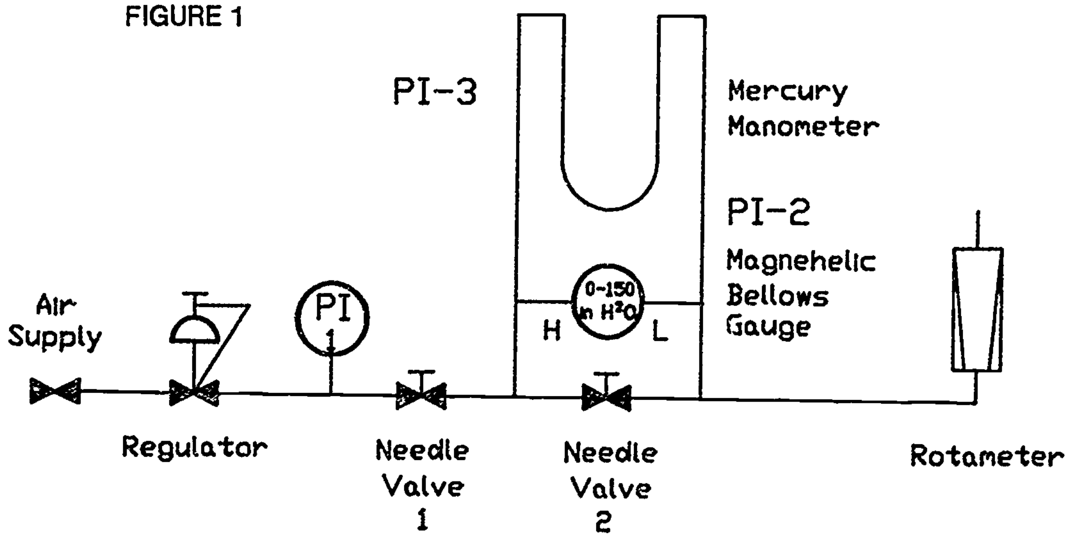
A. Equipment and materials

1. Safety glasses
2. Length of 1/4" plastic hose and fittings
3. 0-40 PSI air pressure regulator
4. Two 1/4" needle valves
5. 36" Hg manometer
6. 0-150" in $H_2O$ bellows gauge
7. Calculator with square root function
8. Air supply
9. 0-200 SCFH rotameter
10. 0-30 PSI test gauge
11. Pencil

B. Routine #1 — Constructing a flow control device

1. Put on safety glasses.
2. Place the 1/4" plastic hose on an appropriate work area.
3. Arrange test instruments along the hose as shown in Figure 1.

FIGURE 1



# JOB SHEET #1

4. Connect components with quick connect fittings or use suitable nylon or plastic fittings.

☐ Have your instructor check your testing apparatus.

C. Routine #2 — Using differential pressure to measure flow

1. Put on safety glasses.

2. Remember not to turn on the air supply until you are instructed to do so by this procedure..

**(CAUTION: Observe all safety rules for working around Mercury manometers under pressure.)**

3. Adjust the PI-1 pressure gauge for zero output by turning the adjustment handle fully counterclockwise.

4. Close needle valve 1 by turning it fully clockwise.

5. Open needle valve 2 by turning it fully counterclockwise.

**(CAUTION: Needle valve 2 should NEVER be fully closed during this exercise.)**

6. Turn on the air supply, and make sure the PI-1 pressure gauge reads zero.

7. Open needle valve 1 slowly while watching the reading on the PI-2 bellows pressure gauge.

**(CAUTION: An abrupt change of pressure can blow the mercury out of the manometer.)**

8. Turn the air regulator knob slowly clockwise until the rotameter reads 200 SCFH.

9. Adjust needle valve 2 slowly until 100 in $H_2O$ is indicated on the bellows pressure gauge, and approximately 7.35 in hg are indicated on the Mercury manometer.

(NOTE: You may have to turn back and forth to adjust the regulator and needle valve 2, but keep making the adjustments slowly until you get a differential pressure of 100 in $H_2O$, and a flow of 200 SCFH.)

☐ Have your instructor check your differential pressure measurement.

D. Routine #3 — Making flow measurement conversions

1. Put on safety glasses.

2. Decrease pressure on the PI-1 gauge to zero.

# JOB SHEET #1

3. Adjust the pressure regulator to obtain the rotameter SCFH flow rates indicated in the far left column of the Flow Measurement Data Sheet that accompanies this procedure.

4. Record the corresponding readings from the mercury manometer and the $H_2O$ gauge as you increase the SCFH readings in the increments shown on the data sheet.

5. Complete all readings as indicated.

   ☐ Have your instructor check your Flow Measurement Data Sheet.

E. Routine #4 — Making flow measurement conversions

1. Place your data sheet beside the Pressure Conversion Table that accompanies this procedure, and record the appropriate conversion multiplier to convert the manometer readings to PSI.

2. Use your calculator to make appropriate conversions, and record those conversions on your Flow Measurement Data Sheet.

3. Chart the in $H_2O$ readings with the appropriate SCFH by making dots on the chart at points where the two readings intersect.

4. Connect the dots with a line to give the chart a profile.

5. Answer the following questions:

   a. Is the relationship between P and SCFH linear or non-linear?

      Answer: ______________________________

   b. Does the rotameter measure pressure or flow?

      Answer: ______________________________

   c. Can P be used to infer flow?

      Answer: ______________________________

   d. If the flow measurement information were linear, what would be the P for 100 SCFH?

      Answer: ______________________________

   ☐ Have your instructor check your conversions and your graph.

# JOB SHEET #1

F. Routine #5 — Making and plotting the square root conversion

1. Go to the Square root Data Sheet that accompanies this job sheet, and transfer your in $H_2O$ readings to the appropriate column.

2. use your calculator to determine the square root conversion for all in $H_2O$ readings.

3. Enter your square root conversions at the appropriate points on the Square Root Conversion Chart, being sure to make a prominent dot at each in $H_2O$/SCFH point.

4. Connect the dots with a line so that they form a profile.

5. Compare your Square Root Conversion Chart with your Flow Measurement Chart to make sure you have accomplished a non-linear/linear conversion.

   ☐ Have your instructor check your work.

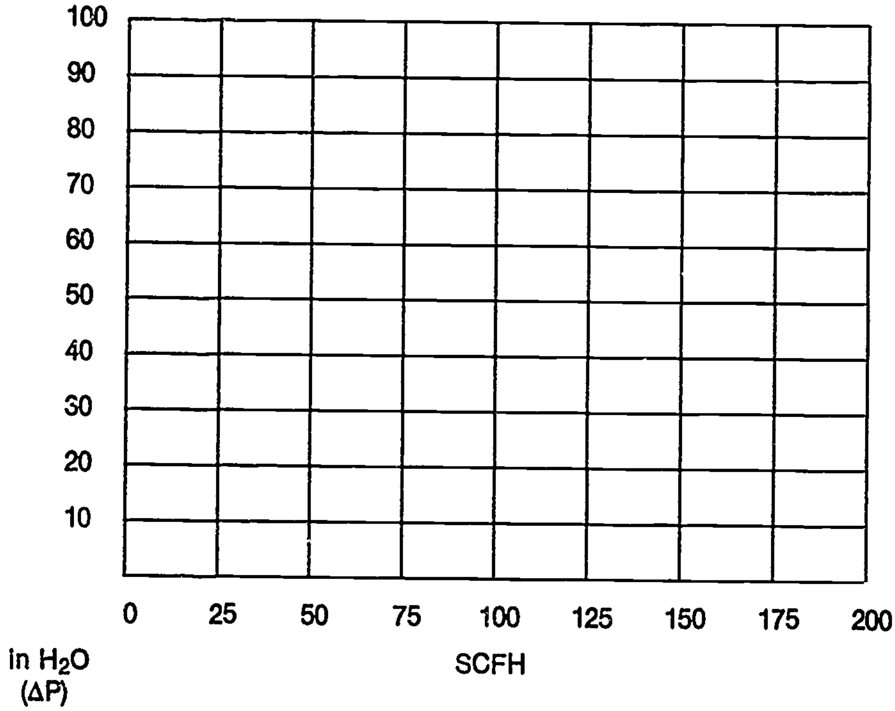
6. Turn off air supply, disconnect testing apparatus, and return equipment and materials to proper storage.

# JOB SHEET #1

## Flow Measurement Data Sheet

| Rotometer | Manometer in Hg | | Conversion Multiplier | | PSI | Bellows Gauge in $H_2O$ |
|---|---|---|---|---|---|---|
| 0 SCFH | ____________ | × | ____________ | = | ____________ | ____________ |
| 25 SCFH | ____________ | × | ____________ | = | ____________ | ____________ |
| 50 SCFH | ____________ | × | ____________ | = | ____________ | ____________ |
| 75 SCFH | ____________ | × | ____________ | = | ____________ | ____________ |
| 100 SCFH | ____________ | × | ____________ | = | ____________ | ____________ |
| 125 SCFH | ____________ | × | ____________ | = | ____________ | ____________ |
| 150 SCFH | ____________ | × | ____________ | = | ____________ | ____________ |
| 175 SCFH | ____________ | × | ____________ | = | ____________ | ____________ |
| 200 SCFH | ____________ | × | ____________ | = | ____________ | ____________ |

## Flow Measurement Chart



## JOB SHEET #1

### Pressure Conversion Table

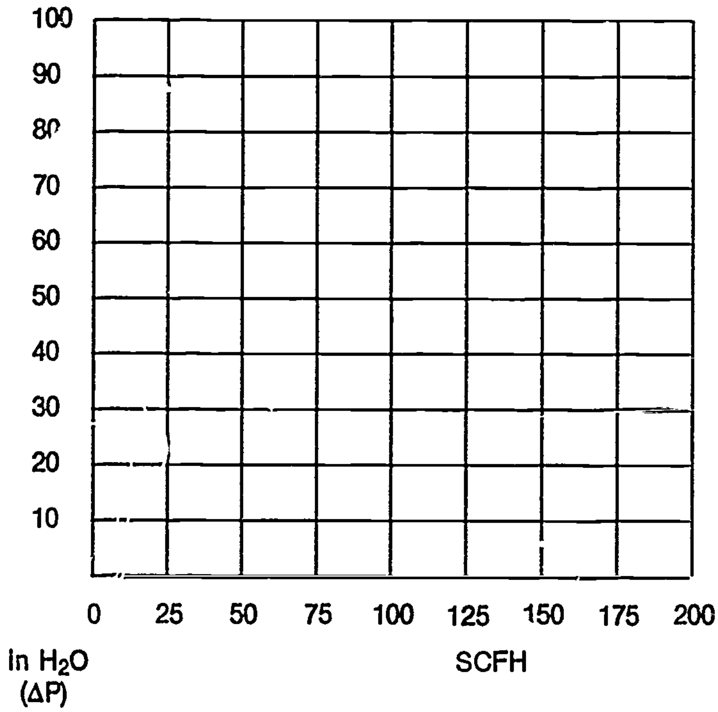
| When measurement is in | To get | Multiply by |
|---|---|---|
| in Hg | $lb/in^2$ | .491 |
| in Hg | mmHg | 25.4 |
| $lb/in^2$ | in Hg | 2.036 |
| $lb/in^2$ | mmHg | 51.7 |
| mmHg | $lb/in^2$ | .0193 |
| mmHg | in Hg | 3.94 |
| in $H_2O$ | in Hg | .0735 |
| in Hg | in $H_2O$ | 13.6 |
| in $H_2O$ | $lb/in^2$ | .0361 |
| $lb/in^2$ | in $H_2O$ | 27.7 |

# JOB SHEET #1

## Square Root Data Sheet

| Rotometer | Bellows Gauge in $H_2O$ | | Square Root Conversion |
|---|---|---|---|
| 0 SCFH | ________ | = | ________ |
| 25 SCFH | ________ | = | ________ |
| 50 SCFH | ________ | = | ________ |
| 75 SCFH | ________ | = | ________ |
| 100 SCFH | ________ | = | ________ |
| 125 SCFH | ________ | = | ________ |
| 150 SCFH | ________ | = | ________ |
| 175 SCFH | ________ | = | ________ |
| 200 SCFH | ________ | = | ________ |

## Square Root Conversion Chart



# PRINCIPLES OF FLOW MEASUREMENT
# UNIT VI

## PRACTICAL TEST #1
## JOB SHEET #1 — CONSTRUCT A FLOW CONTROL TEST APPARATUS, AND USE A MERCURY MANOMETER AND A ROTAMETER TO MEASURE FLOW IN A SYSTEM

**Student's name** ______________________ **Date** __________

**Evaluator's name** ______________________ **Attempt no.** ______

> Student instructions: When you are ready to perform this task, ask your instructor to observe the procedure and complete this form. All items listed under "Process Evaluation" must receive a "Yes" for you to receive an overall performance evaluation.

### PROCESS EVALUATION

(EVALUATOR NOTE: Place a check mark in the "Yes" or "No" blanks to designate whether or not the student has satisfactorily achieved each step in this procedure. If the student is unable to achieve this competency, have the student review the materials and try again.)

| The student: | | YES | NO |
|---|---|---|---|
| 1. Wore safety glasses. | 1. | ☐ | ☐ |
| 2. Constructed testing apparatus properly and safely. | 2. | ☐ | ☐ |
| 3. Made and recorded all flow measurements. | 3. | ☐ | ☐ |
| 4. Made conversions correctly. | 4. | ☐ | ☐ |
| 5. Graphed figures correctly. | 5. | ☐ | ☐ |
| 6. Disconnected testing apparatus safely. | 6. | ☐ | ☐ |
| 7. Returned equipment and materials to proper storage. | 7. | ☐ | ☐ |

Evaluator's comments: ________________________________________________

______________________________________________________________

______________________________________________________________

# JOB SHEET #1 PRACTICAL TEST

## PRODUCT EVALUATION

(EVALUATOR NOTE: Rate the student on the following criteria by circling the appropriate numbers. Each item must be rated at least a "3" for mastery to be demonstrated. (See performance evaluation key below.) If the student is unable to demonstrate mastery, student materials should be reviewed and another test procedure must be submitted for evaluation.)

| Criteria: | | | | |
|---|---|---|---|---|
| Equipment and Materials | Properly selected and properly used 4 | Properly selected and acceptably used 3 | Poorly selected and/or used 2 | Improperly selected and/or used 1 |
| Flow Measuring Procedure | Well followed 4 | Acceptably followed 3 | Poorly followed 2 | Improperly followed 1 |
| Data Recording and Graphing | All properly entered 4 | Almost all entered 3 | Too few entered 2 | Too few entered or improperly entered 1 |
| Safety | Carefully observed 4 | Acceptably observed 3 | Poorly observed 2 | Improperly observed 1 |

EVALUATOR'S COMMENTS: ______________________________

______________________________

### PERFORMANCE EVALUATION KEY

4 — Skilled — Can perform job with no additional training.
3 — Moderately skilled — Has performed job during training program; limited additional training may be required.
2 — Limited skill — Has performed job during training program; additional training is required to develop skill.
1 — Unskilled — Is familiar with process, but is unable to perform job.

(EVALUATOR NOTE: If an average score is needed to coincide with a competency profile, total the designated points in "Product Evaluation" and divide by the total number of criteria.)

# PRINCIPLES OF FLOW MEASUREMENT
# UNIT VI

## TEST

NAME ______________________ SCORE ____________

1. Match the terms on the right with their correct definitions.

| | | |
|---|---|---|
| _____a. | The measurement of a variable such as flow in terms of another variable, and using the output or readout as if it were the original | 1. Reynolds number |
| | | 2. Inferential |
| _____b. | A term used in flow to indicate that the flow of material inside a pipe is smooth or streamlined | 3. Viscosity |
| | | 4. Laminar |
| _____c. | A system of numbers used to indicate the amount of turbulence in a pipe or tube | 5. Slurry |
| _____d. | A mixture of two materials that form a non-homogenous mixture | |
| _____e. | The property of a liquid that indicates its ability to flow, sometimes expressed as the liquid's resistance to shearing displacement | |

2. Solve the following problems concerning basics of flow measurement by selecting the appropriate answer.

   a. Modern flow measuring systems express units of mass or volume in relation to what, weight or a period of time?

   Answer: ______________________

   b. When inference is used to measure flow, does it mean that some other parameter is measured first or that the rate of flow always infers volume?

   Answer: ______________________

## TEST

3. Select true statements concerning units of flow measurement by placing an "X" beside each statement that is true.

(NOTE: For a statement to be true, all parts of the statement must be true.)

______a. Several industries, but especially the petroleum and petro-chemical industries, measure flow in gallons per hour.

______b. Another common unit of flow measurement is gallons per minute, and in this unit, 1 U.S. gallon equals 0.003785 cubic meters, and if the British imperial gallon is used, it is equal to 1.20095 U.S. gallons.

______c. Measuring higher flow rates over shorter time spans is accomplished with a newer volume unit of liters per minute.

______d. Viscosity is the unit that measures the resistance of a liquid to flow through a pipe or tube.

______e. Volume is another unit of flow measurement for materials flowing through pipes or tubes, and is related to the physical state of the material:

1) The volume of a gas is measured in the older unit of cubic feet, or in liters or cubic meters.

2) Units used to measure the volume of a liquid varies with the applications and could be gallons, barrels, liters, or cubic meters.

______f. When velocity is used to measure flow, it always means that a higher rate of flow will have a higher velocity:

1) Laminar flow is flow that moves parallel with the tube or pipe, and is considered to be "streamlined."

2) Turbulent flow has eddy currents or other nonparallel elements, and this phenomena is classified by a Reynolds number where 4,000 and up is considered turbulent.

4. Differentiate between methods of flow measurement by placing an "X" beside the definition of "invasive" flow measurement.

______a. These measurement devices include anything that projects into a pipe or tube that carries material.

______b. These measurement devices do not enter the pipe or tube that carries material, and because they are outside, these devices must measure by inference.

# TEST

5. Complete statements concerning measuring flow with differential pressure devices by circling the items that best complete each statement.

   a. There are several types of differential pressure devices, and they all have primary and secondary elements:

      1) The primary element disturbs the flow by (redirecting, restricting) it in some fashion.

      2) The secondary element reads the (pressure differential, new flow rate) created by the primary element.

   b. Differential pressure devices work on the (Bernoulli, Pascal) principle which states that the sum of energies in a flowing closed system, such as a pipe or tube, is constant.

   c. The energies in a closed system include pressure, motion, and position, and by altering the motion with some kind of restriction, it will cause pressure to change in direct relation to motion or flow in the system, and since position does not change, the energies (retain their constant, vary with pressure).

6. Select true statements concerning measuring flow with differential pressure transmitters by placing an "X" beside each statement that is true.

   _____a. Differential pressure transmitters have the capacity to transmit a small pressure difference as a pneumatic or electrical signal for only a short distance.

   _____b. Differential pressure transmitters, or DP cells, are commonly used with orifice plates because the pressures produced across an orifice are small by design, and flow measurements are frequently made in places remote and hard to reach.

   _____c. Creating high pressure drops to measure flow rate requires expensive devices, and with soaring production costs, differential pressure transmitters are contributing to cost-saving ways to do business.

7. Complete statements concerning measuring flow with orifice plates by circling the items that best complete each statement.

   a. The simplest and most commonly used primary (non-invasive, invasive) device is the orifice plate.

   b. An orifice plate is a metal plate with (a hole, a series of holes) smaller than the inside diameter of the pipes on which it is installed.

   c. The orifice plate is bolted between two flanges in the pipe, and the pressure is tapped for measurement on (both sides of the plate, the lower side of the plate).

## TEST

d. The pressure on the upstream side is (higher, lower) than pressure on the downstream side:

   1) When flow rate increases, the pressure difference (increases, decreases).

   2) When flow rate decreases, the pressure difference will (increase, decrease) in proportion.

e. The orifice plate is a simplistic device, but in design it is highly engineered, and the plates are designed for (general, specific) applications.

8. Complete statements concerning measuring flow with venturi tubes by circling the items that best complete each statement.

   a. A venturi tube is designed with a restriction for reducing the inside diameter of a pipe, like an orifice plate, but yet the venturi tube is much better at (accelerating, conserving) energy because it recovers pressure drop downstream from the restriction.

   b. The sloped area leading up to the restriction in a venturi tube is called the approach area, the restriction is called the throat, and the tube following the throat is called the (recovery, downstream) area.

   c. The throat usually contains one of the pressure measuring pickup points, and because of the long slope behind the restriction, most of the pressure drop is recovered, and a venturi tube is considered highly efficient in terms of (conserving, measuring) energy.

   d. Venturi tubes are used mostly on special applications because special piping considerations make them (expensive, easy to install).

9. Match venturi tube variations with their characteristics.

| | | |
|---|---|---|
| _____a. | A venturi tube usually used to handle high flow volumes with almost all liquids, a highly efficient flow measuring device. | 1. Dall tube<br>2. Long venturi |
| _____b. | A venturi tube that has been shortened so that it will fit into shorter pipe runs; it costs less, but does not have the efficiency of a long venturi. | 3. Flow nozzle<br>4. Short venturi |
| _____c. | A device with the inner dimensions of a venturi tube, designed to fit inside a pipe and give results similar to a venturi. | |
| _____d. | A device that fits between the flanges of a pipe with a nozzle projecting into the pipe in the direction of flow; it contains the approach and throat equivalents of a venturi without the recovery part, and is more efficient than an orifice plate, but not as efficient as a long venturi. | |

# TEST

10. Select true statements concerning measuring flow with pitot tubes by placing an "X" beside each statement that is true.

    _____a. A pitot tube is a double tube with a 45 degree bend on the end that projects into a pipe.

    _____b. The inner tube of a pitot tube projects out of the second tube on the end that faces the flow, and is open to flow while the outer tube is closed to flow, and has a static hole on the backside facing away from flow.

    _____c. Flow pressure strikes the impact end of the pitot tube while the static hole at the backside of the tube remains in a lower pressure area away from the flow.

    _____d. The difference in pressure from impact to static hole increases as flow increases, and the pressure differential decreases as flow decreases.

    _____e. Flow rate is determined by measuring the pressure difference between the inner and outer tubes.

11. Solve the following problems concerning measuring flow with elbow meters by selecting the appropriate answer.

    a. When liquid flows through a pipe albow, it creates a force. Can this force be used to measure flow directly or to infer flow?

       Answer: ______________________________

    b. An elbow meter requires what, a special elbow or almost any 90° elbow?

       Answer: ______________________________

12. Complete statements concerning measuring flow with vortex shedding by circling the items that best complete each statement.

    a. Vortex shedding is sometimes called a wedge (**flow meter, orifice plate**) because of the shape of the wedge or shedder that is projected inside a section of short pipe.

    b. The shedder disrupts flow, creates vortices, and the vortices in turn shed energy in the form of (**differential pressure, accelerated flow**).

    c. The (**differential pressure, accelerated flow**) pulses are usually converted to electrical pulses by a transducer in the area of the vortex shedding action.

    d. The signal from the vortex unit may be AC or the pulse amplitude can be averaged to produce a 4-20 mA DC output signal, or the pulses can be counted (**by a computer, mechanically**).

    e. The concept behind vortex shedding is complex, but in simple terms, vortex shedding is proportional to (**flow rate, flow volume**).

# TEST

13. Complete statements concerning measuring flow with rotameters by circling the items that best complete each statement.

    a. A rotameter works on the same principle as an orifice plate or a venturi tube where pressure (**drop, increase**) across a restriction is used to measure flow.

    b. A rotameter has a float housed in a metal tube that has a restriction where the float can rest when there is no (**fluid flowing, pressure**) in a system.

    c. The float in a rotameter will rise or fall as more or less flow occurs in the system, and since a change in flow causes the restriction area to vary, the device is classified as a (**multiple, variable**) area flow meter.

    d. The amount of flow is usually indicated by the (**depth, height**) of the float in a glass or clear plastic housing with flow rate indicators clearly marked for monitoring.

    e. For working with other than transparent or translucent liquids, some rotameters have (**mechanical, digital**) or magnetic coupling to the float to provide a readout.

14. Complete statements concerning measuring flow with turbine meters by circling the items that best complete each statement.

    a. A turbine meter works like the blades on a fan, and is fitted precisely into a section of pipe so that the blades of the turbine are filled with and emptied of fluid to provide a measure of volume passing a (**long section, given point**) in a pipe.

    b. The turbine rotor is mechanically connected to a mechanical readout device or to an electrical transducer that gives (**revolutions, acceleration**) as flow rate.

    c. If there is no mechanical connection to the rotor, some turbine meters have magnetic pickup transducers that (**count the blades as they turn, measure RPM**), and the readout indicates flow rate.

15. Solve the following problems concerning measuring flow with positive displacement meters by selecting the appropriate answer.

    a. Where are positive displacement meters most frequently used, by petroleum refiners or by gas and water utility companies?

       Answer: ______________________________

    b. The most popular positive displacement meter is what, a fluted rotor meter or a nutating-disk meter?

       Answer: ______________________________

# TEST

16. Solve the following problems concerning methods of non-invasive flow measurement by selecting the appropriate answer.

    a. Measuring flow by inference requires what property in the flow material, a property that can be detected outside a pipe or a fluid of high density?

       Answer: ______________________________

    b. Methods of non-invasive flow measurement include doppler effect flowmeters and ultrasonic flowmeters, but can magnetic flowmeters also be considered non-invasive?

       Answer: ______________________________

17. Complete statements concerning measuring flow with Doppler effect flowmeters by circling the items that best complete each statement.

    a. The Doppler effect states that the **(frequencies, loudness)** of sound signals received by an individual or an instrument are dependent on the position of the receiver, relative to the source of the sound.

    b. Another way of stating the Doppler effect is to say that if you hear sound output from a moving source, or if you are moving relative to the sound source, the frequency of what you hear will appear to **(change, increase)** with relative motion.

    c. The Doppler effect is applied in flow measurement by using **(ultrasonic, AC)** sound generators to transmit a signal through the wall of a pipe.

    d. As long as the liquid has particles or air bubbles which will **(reflect, absorb)** the sound, the resulting shift in frequency will be proportional to the rate of flow.

    e. The signal may be transmitted with or against the flow:

       1) If transmitted waves oppose the flow, they return **(lower, higher)** frequencies to the receiver.

       2) If the transmitted waves travel in the direction of flow, they return **(higher, lower)** frequencies to the receiver.

    f. Doppler flowmeter systems may use two transducers located on either side of a pipe, or two on the same side of the pipe, with one unit transmitting and the other receiving the **(ultrasonic, AC)** signal.

    g. Electronic circuits control the transmission, and compare the received signal to produce **(flow rate information, differential pressure)**.

# TEST

18. Select true statements concerning measuring flow with time-of travel flowmeters by placing an "X" beside each statement that is true.

_____a. Time-of-travel flowmeters have transducers mounted on each side of a pipe, but instead of using a reflected signal like Doppler meters, they measure in two directions, against the flow and with the flow.

_____b. By measuring the time it takes ultrasonic waves to move from transducer to transducer against the flow, and then with the flow, the meters set up a time-differential relationship that is proportional to flow.

_____c. Like Doppler flow meters, the time-of-travel flowmeters do require particles or bubbles in the flow material, and this permits the measurement of clear liquids and gases.

19. Solve the following problems concerning measuring flow with electromagnetic flowmeters by selecting the appropriate answer.

a. Electromagnetic flowmeters operate on what, Faraday's principle or the law of the conservation of energy?

Answer: ______________________________

b. Moving a specific length conductor throughout a magnetic field causes a voltage output related to what, the orientation of the conductor or the velocity of the conductor?

Answer: ______________________________

c. How is voltage generated in an electromagnetic flowmeter, by charged electrodes or by conductive liquid flowing through a pipe?

Answer: ______________________________

20. Complete statements concerning measuring flow with mass flow instruments by circling the items that best complete each statement.

a. Mass flow measuring devices are used to measure the (**pressure, weight or mass**) of the flowing material rather than the rate of flow.

b. Early systems measured mass by measuring the (**density, volume**), and then using the (**density, volume**) and other parameters of the material to compute mass.

c. Modern mass flow is measured directly by several (**advanced, super-sophisticated**) systems which use the principles of the Coriolis effect, gamma radiation based density measurement, and the gyroscopic action of mass flowing in a pipe loop.

# TEST

d. The French scientist, Coriolis, discovered the principle of the Coriolis effect: an object traveling above the surface of the earth at a constant velocity will be deflected in a predictable fashion by (**the rotating earth, its speed**).

e. The mass flowmeter using the Coriolis effect is a U-shaped tube (**through, over**) which material flows.

f. As the material moves (**over, through**) the tube, the tube will twist in response to the movement of the mass in space above the earth, and the greater the mass flow, the more the tube will twist.

g. Sensitive magnetic sensors record U-tube movement, and send the signal to an electronics system which records or controls as necessary the (**amount of mass flowing in the system, flow rate**).

21. Select true statements concerning the square root conversion by placing an "X" beside each statement that is true.

_____a. All systems that use differential pressure to infer flow depend on the same relationship between flow in the pipe and pressure drop across some restriction.

_____b. Since the output of the primary element is a squared function, the secondary element that reads it must extract the square root of the signal to determine true flow.

_____c. In older systems, several mechanical schemes were used to square the signal, modern computer devices now provide a low cost system for making the square root conversion.

(NOTE: If the following activity has not been accomplished prior to the test, ask your instructor when it should be completed.)

22. Demonstrate the ability to construct a flow control apparatus, and use a Mercury manometer and a rotameter to measure flow in a system. (Job Sheet #1)

# PRINCIPLES OF FLOW MEASUREMENT
# UNIT VI

## ANSWERS TO TEST

1. a. 2
   b. 4
   c. 1
   d. 5
   e. 3

2. a. A period of time
   b. Some other parameter is measured first

3. c, d, e, f

4. a

5. a. 1) Restricting
      2) Pressure differential
   b. Bernouilli
   c. Retain their constant

6. b, c

7. a. Invasive
   b. A hole
   c. Both sides of the plate
   d. Higher
   e. 1) Increases
      2) Decrease
   e. Specific

8. a. Conserving
   b. Recovery
   c. Conserving
   d. Expensive

9. a. 2
   b. 4
   c. 1
   d. 3

## ANSWERS TO TEST

10. b, c, d, e

11. a. To infer flow
    b. Almost any 90° elbow

12. a. Flow meter
    b. Differential pressure
    c. Differential pressure
    d. By a computer
    e. Flow rate

13. a. Drop
    b. Fluid flowing
    c. Variable
    d. Height
    e. Mechanical

14. a. A given point
    b. Revolutions
    c. Count the blades as they turn

15. a. By gas and water utility companies
    b. A nutating-disk meter

16. a. A property that can be detected outside a pipe
    b. Yes

17. a. Frequencies
    b. Change
    c. Ultrasonic
    d. Reflect
    e. 1) Lower
       2) Higher
    f. Ultrasonic
    g. Flow rate information

18. a, b

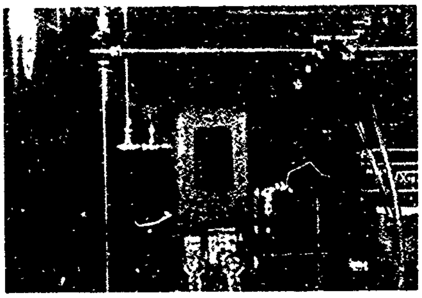
19. a. Faraday's principle
    b. The velocity of the conductor
    c. By conductive fluid flowing through a pipe

## ANSWERS TO TEST

20. a. Weight or mass
    b. Volume, density
    c. Super-sophisticated
    d. The rotating earth
    e. Through
    f. Through
    g. Amount of mass flowing in the system

21. a, b, c

22. Evaluated according to criteria in the practical test.



# PROCESS SYSTEMS
## UNIT VII

## UNIT OBJECTIVE

After completion of this unit, the student should be able to discuss signal transmission systems, and the standards for pneumatic and electrical transmissions. The student should also be able to relate other transmission schemes and devices to their applications, and identify and explain the function of instrument loops in a typical industrial application. These competencies will be evidenced by correctly performing the procedures outlined in the assignment sheet, and by scoring a minimum of 85 percent on the unit test.

## SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to the process systems with their correct definitions.
2. Solve problems concerning basics of signal transmission systems.
3. Select true statements concerning methods of signal transmission.
4. Solve problems concerning pneumatic transmission
5. Complete statements concerning standards for pneumatic transmission.
6. Select true statements concerning electrical transmission.
7. Select true statements concerning important elements in a current transmitted signal.
8. Match standards for electrical transmission with their characteristics.
9. Complete statements concerning frequency transmission.
10. Select true statements concerning pulse width or duration transmission.
11. Complete statements concerning digital pulse code transmission.
12. Solve problems concerning bit transmission formats.
13. Identify and explain the function of the instrument loops in a typical industrial application. (Assignment Sheet #1)

# PROCESS SYSTEMS
# UNIT VII

## SUGGESTED ACTIVITIES

A. Provide students with objective sheet.

B. Provide students with information and assignment sheets.

C. Make transparencies.

D. Discuss unit and specific objectives.

E. Discuss information sheet.

F. Discuss the assignment sheet with care, and be sure to use the accompanying P&ID to help students appreciate system design.

G. Arrange to have copies of P&IDs from local industry, and invite a technician or supervisor to discuss the system design with students.

H. Give test

## REFERENCES USED IN DEVELOPING THIS UNIT

A. *Instrumentation Basics Module D, Instrumentation Diagrams and Symbols*. Research Triangle Park, NC: 27709: Instrument Society of America, 1981.

B. Gillum, Donald R. *Control Loop Systems*. Austin, TX 78713: Extension Instruction and Materials Center, University of Texas at Austin, 1984.

C. Whalen, Bruce R. *Basic Instrumentation*. Third Edition. Austin, TX 78758: Petroleum Extension Service, University of Texas at Austin, 1983.

# PROCESS SYSTEMS
# UNIT VII

## INFORMATION SHEET

I. Terms and definitions

A. Asynchronous — A method of sending data when it is ready without referencing a timing signal or waiting for a signal from a receiver

B. Baud rate — The speed of data transmission as expressed in bits per second

EXAMPLE: 600 baud = 600 bits per second.

C. Bit — A shortening of "binary digit" which is the smallest unit of computer information, stated as binary 0 or binary 1

D. Byte — The combination of eight bits that form a binary character

E. Distributed process control — A control system in which local control modules and slave modules are interfaced with a central microcomputer/controller where total process activities can be displayed on a monitor for evaluation by an operator

F. EIA (Electronics Industry Association) — A national organization of equipmentmanufacturers and large service firms who set standards and coordinate smooth interaction of the electronics industry with the market place

G. IEEE (Institute of Electrical and Electronic Engineers) — A national organization of professionals in electricity and electronics who set standards for electrical and electronic equipment

H. Parallel transmission — The sending of all data bits simultaneously on separate lines, a transmission mode designed for short distances or where high speed transmission rates are desired

I. Serial transmission — the sending of data bits one at a time on a single line, a transmission mode designed for long distance communications where slower transmission speeds are acceptable

J. Synchronous — A method of sending data in serial form so that the bit by bit transmission is in step with a timing signal

II. Basics of signal transmission systems

A. Signal transmissions permit the use of one central controller for a number of processes, conserves space, money, and operators.

# INFORMATION SHEET

B. Transmission systems permit the placement of fragile and expensive control equipment in a central location safe from the process environment.

C. By separating receiving and control units from transducers in the field, and connecting them via a transmission system, it is easier to standardize instrument controllers.

D. In recent years, the users of process equipment have tried to standardize equipment because standardization permits streamline design, makes maintenance easier, and allows cost-saving quantity purchases of equipment.

## III. Methods of signal transmission

A. The two most common standard methods of signal transmission are:

1. The pneumatic 3-15 PSI standard;
2. The electrical 4-20 mA standard.

B. The pneumatic and electrical standards are well established, and there are thousands of installations in industry.

C. The rapid growth of computer and microprocessor applications has created a need for high speed data communications in industrial instrumentation, and particularly in the area of distributed process control.

D. Use of distributed process controls continues to increase because of the speed and convenience of having the control of part of a process done on location, and reported back to the next level of computer where supervisory control is handled.

## IV. Pneumatic transmission

A. Transmitting signals from the field or process unit to the controller or control room is often accomplished with air or pneumatic signals.

B. Pneumatic systems have several advantages because they can be used in hazardous areas where potential for explosion exists, and they have enough power to run the air control valves that are commonly used as final elements.

C. Most air supply systems consist of a compressor and an air tank to provide air for control if the electrical power is interrupted.

D. The major disadvantage of pneumatic tubing is that it is considered to have a true distributed lag, and this may cause signal loss along the length of the tubing.

# INFORMATION SHEET

E. The standard pneumatic signal with a range of 12 PSI can overcome signal loss, and prevent noise from masking the signal if transmission line length is under 1,000 feet.

(NOTE: Pneumatic signals can function at distances over 1,000 feet, but the time lag is too long for most processes.)

V. **Standards for pneumatic transmission**

A. The most common pneumatic standard is 3-15 PSI or 20-100 kPa, a pressure that represents 0% to 100% of the range of the variable being transmitted, or it is 0% to 100% of the valve stroke in final elements.

B. With a range of 3-15 PSI, the 9 PSI pressure is the central operating point that is set when a system needs to swing both positive and negative to control a process within a system.

C. The 3 PSI at 0% is referred to as a "live zero", which means that when you calibrate to the zero point, you can go below it, and you can approach the calibrated point from either direction.

D. Another advantage of live zero is in the troubleshooting and maintenance of the system because a troubleshooter can clearly distinguish between a failure and the zero control point.

VI. **Electrical transmission**

A. Electrical transmissions have become more common over the past 30 years because electrical systems have developed into reliable tools, and more technicians have been trained for electrical troubleshooting.

B. Electrical transmission has advantages over pneumatic systems; electrical systems cost less and can transmit signals farther.

C. In an electrical transmission system, the length of the current transmitted signal is determined by the total system resistance including wiring and loads, but the signal can be transmitted several miles.

VII. **Important elements in a current transmitted signal**

A. A series electrical transmission current delivery system is simple because it is a series electrical circuit that has a single path for current, and requires only two wires for supply and return of the current.

B. Loads can be attached anywhere in a current delivery system because a true series circuit supplies the same current anywhere in the circuit.

(NOTE: In practice, the 4-20 mA system can supply current into systems with resistances near 0 to 1,000 ohms.)

# INFORMATION SHEET

C. Because a current delivery system is so simple and tolerant of different loads, it is readily interchangeable in terms of equipment on the supply or the load end of the system.

VIII. Standards for electrical transmission and their characteristics

A. IEEE-488 — A parallel transmission standard.

B. IEEE-583, 595, and 596 — A computer automation standard.

C. EIA RS-232-C, RS-422, and RS-449 — Bit synchronous or asynchronous serial standards.

D. ISA 4-20 mA — An analog signal sent on two wires; it is essentially a real time signal.

E. 10-50 mA — A two wire analog signal, not common, but used where more drive is needed than the 4-20 mA can supply.

F. Standard analog signal — Similar to the 3-15 PSI pneumatic signals since they do not go to zero current, and can be calibrated for live zero from either direction.

(NOTE: Just like the 3-15 PSI pneumatic signal, the standard analog signal makes it easier to troubleshoot because the technician can tell a zero fault from a 4mA live zero signal level.)

G. 0 - 5v logic signals — Used in transmitting signals from TTL logic circuits, and IC transducers use the natural voltage range of the logic, 0 - 5v DC, where the actual zero signal is from 0 to .7 of a volt, and the logic one signal is 2.4 to 5v DC.

H. Two wire transmission systems — Many current transmitting systems are two wire twisted pair which can be used reliably by both analog and serial systems.

(NOTE: When noise creates a problem, the pair of wires is shielded, and in severe cases the wires are replaced with fiber optic cables.)

IX. Frequency transmission

A. Frequency transmission systems convert a source signal into an AC or pulse signal that has one frequency for the zero level source signal, and a second frequency for the maximum level source signal.

B. In a frequency transmission system, the AC or pulse signal is transmitted to a receiver where it is converted back to its original form.

EXAMPLE: A 4-20 mA range converted to a 5-15 Hertz pulse range.

# INFORMATION SHEET

C. AC or pulse transmissions are superior to the DC transmissions with respect to noise interference, and have more stability with temperature influence.

X. **Pulse width or duration transmission**

A. In a pulse width system, the source signal is a pulse that has a time duration (width) proportional to zero input at the signal source, and a different pulse width for the maximum source signal.

B. In a pulse width system, the 4-20 mA signal might be converted to pulse durations between 4 ms (milliseconds) and 20 ms.

C. When the signals in a pulse width system reach a receiver, they are decoded back to the 4-20 mA standard.

XI. **Digital pulse code transmission**

A. In a digital pulse code system, the source signal is converted into binary code, and transmitted to a receiver.

B. A common number of bits required to represent one character is eight, and the bits can be transmitted one after the other as serial information, or they can all go at the same time on separate lines as parallel information.

XII. **Bit transmission formats**

A. Bits of information are transmitted in a serial or parallel format, and both forms of bit transmission have their advantages.

B. Parallel transmission is faster because all bits travel synchronously on their own line, but you must have a line for each, and some extra common lines.

C. Serial transmissions can travel on only three lines, two signal lines and a common, but serial transmission is much slower because each bit travels separately within its own time cycle.

D. Some serial codes have parity bits which check to see if the signal arrives at its destination without error.

# PROCESS SYSTEMS
# UNIT VII

## HANDOUT #1 — BUILDING A FLOW CONTROL LOOP

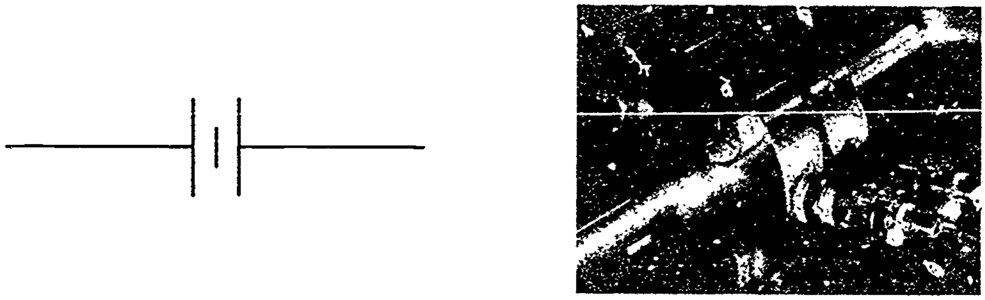
### Background

To understand how a process system is controlled, it is necessary to know the function each system component performs. In previous units, the functions of sensors, transmitters, controllers, and final elements have been discussed. Building a flow control loop with these components will show how these components are tied together to form the loop, the importance of standard signals in transmitting information between components in the loop, and the devices that serve the technicians who monitor systems to make sure they are performing to design standards.

### The flow sensor

An orifice plate is the primary element in many flow control loops. As the flow rate increases or decreases across the orifice, the differential pressure ($\Delta P$) created by the orifice will increase or decrease in proportion. The output signal from the orifice plate is a squared value, and therefore not linear with flow. Figure 1 shows the symbol for an orifice plate along with a photograph of a typical application.

FIGURE 1

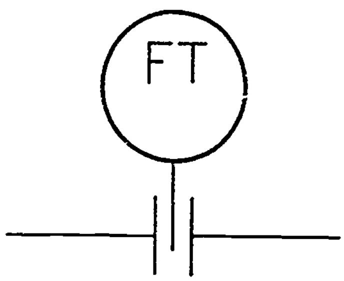


# HANDOUT # 1

## The flow transmitter

The non-linear output signal from the sensor (orifice plate) goes to a flow transmitter where the ΔP signal is converted into a signal form that can be transmitted. Since the flow transmitter is pneumatic, the transmitter output will be somewhere in the range of the 3 to 15 psi standard signal. When depicted in a symbol, the flow transmitter appears in a balloon with the letters FT, and in an application might look like the photograph in Figure 2.

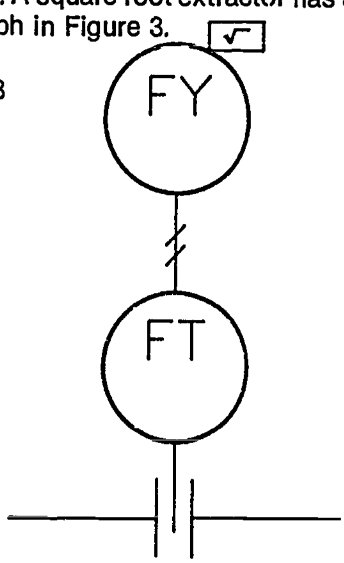
FIGURE 2

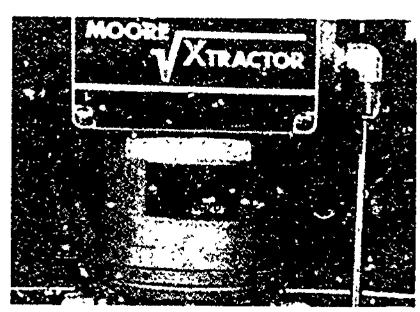



## The square root extractor

Since the output of the orifice plate sensor is a squared value, the flow transmitter cannot send its signal directly to the flow controller. Rather, the transmitter signal goes to a square root extractor which converts the non-linear signal to a linear signal that can be used by the controller. A square root extractor has a special symbol, and in application could look like the photograph in Figure 3.

FIGURE 3



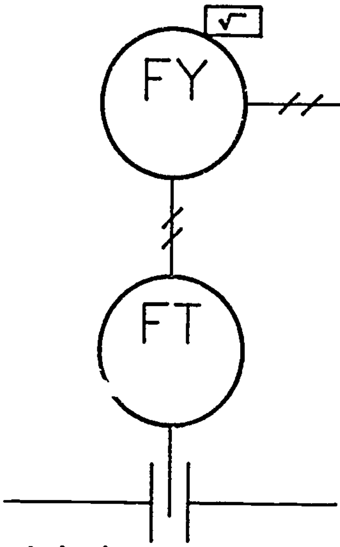



# HANDOUT #1

## The flow controller

The linear output signal from the square root extractor is sent to the pneumatic flow controller. Flow rate information is used by the controller to make a "decision." To make a decision, the controller compares the input from the sensor to "setpoint." Setpoint is what the flow rate should be, but if a difference in flow rate has been indicated by sensor information, the controller will recognize the difference, and this is called "deviation." On a P&ID, a flow controller appears in a balloon with appropriate letters, FC, and in application a flow controller could look like the controller in the Figure 4 photograph.

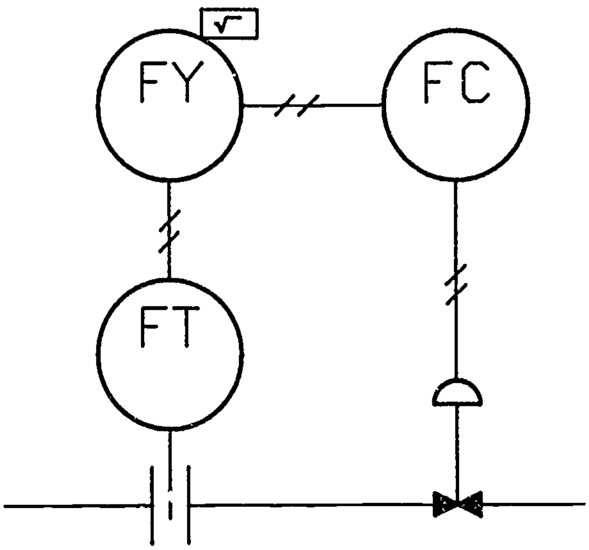
FIGURE 4

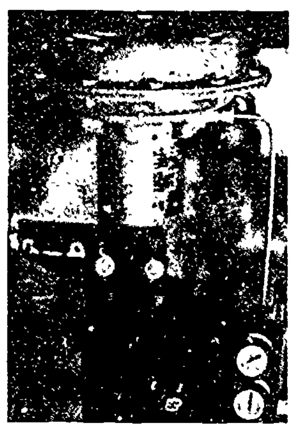



## The flow control valve

The decision made by the flow controller becomes an output signal to the flow control valve or final element. If controller setpoint is for a flow rate of 50 GPM (gallons per minute), and the sensor measures 45 GPM, the controller will make the decision that the control valve needs to open more to compensate for the deviation. If the sensor measures 55 GPM, the decision would be for the control valve to close an appropriate amount, and if sensor flow rate and setpoint are the same, the decision would be to leave the control valve at its present setting. A control valve has its own symbol, and is frequently shown with the actuator that activates it; the photograph in Figure 5 shows a typical application.

FIGURE 5



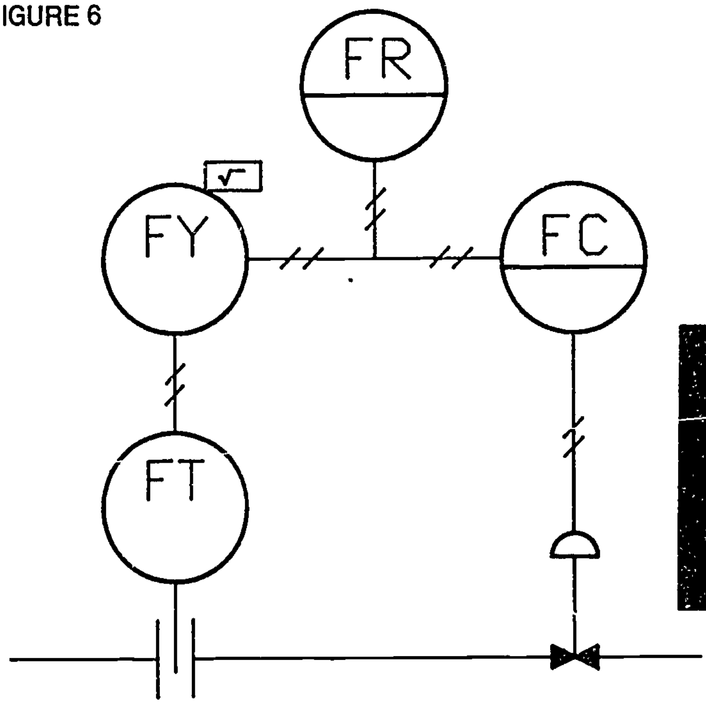



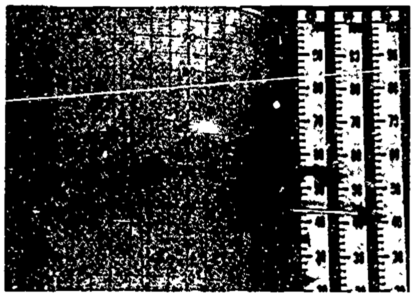
## HANDOUT # 1

**Observations**

Figure 5 shows a complete flow control loop. In fact, it's a closed loop with feedback. Feedback means that via the transmitter and square root extractor, the flow controller is continuously receiving flow rate information from the sensor. Flow controller output opens and closes the final control valve to maintain the setpoint value of the controller. But there are other control elements in process systems, and to best examine those other elements, a recorder needs to be added to the system. Note the recorder symbol, FR, and typical application in Figure 6.

FIGURE 6



**Modes of control**

The recorder added to the loop not only provides a continuous record of flow through the orifice, it records flow changes on chart paper to provide a permanent copy, and it also keeps track of the time everything happens. In fact, the recorder chart is an excellent way to explain the four modes of control:

1. Two-position control (On/Off);
2. Proportional control (Gain);
3. Reset control (Integral);
4. Rate control (derivative).

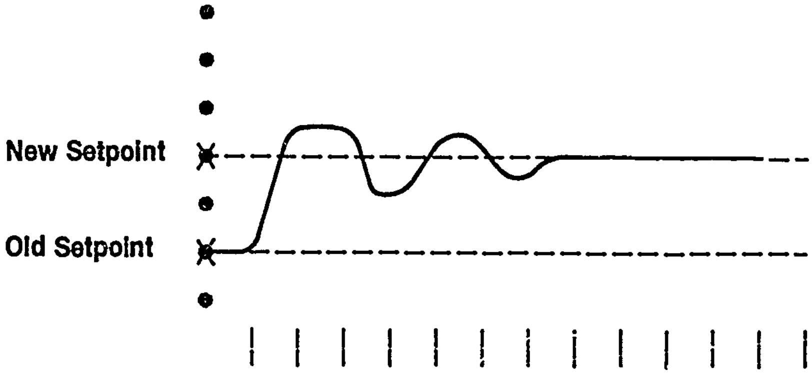
Two-position controls are seldom used in control loops, and the derivative mode is used in very slow control loops to anticipate a deviation. However, the proportional (gain) and reset (integral) modes can be well demonstrated with information from a recorder chart.

# HANDOUT #1

**Proportional control**

The best way to demonstrate how proportional control works is to change the setpoint on the controller, and then check the recorder chart which could look like the one in Figure 7.

FIGURE 7



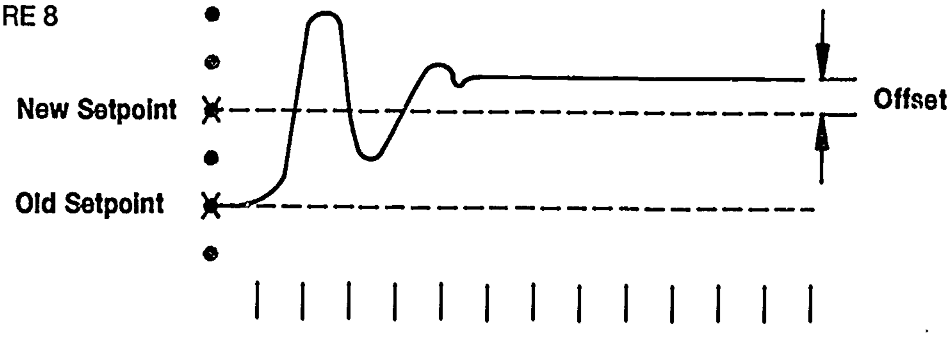

**Proportional Control**

Note how the recorder information in Figure 7 shows that immediately after setpoint change, flow increased above the new setpoint, then decreased below the new setpoint, and after a while, balanced on the new setpoint. The curve drawn by the recorder in Figure 7 represents a control mode working almost ideally. Still, because of flow loop characteristics, it is necessary to "tune" the loop. Tuning is accomplished by adjusting the "proportional band," which is the input change required to produce a full range change in output due to proportional control action.

**Reset control**

Most loops have characteristics that prevent the proportional control from returning to setpoint after a change in setpoint, or a disturbance. When this happens, it produces a difference between setpoint and actual flow, and this difference is called "offset" as illustrated in Figure 8.

FIGURE 8

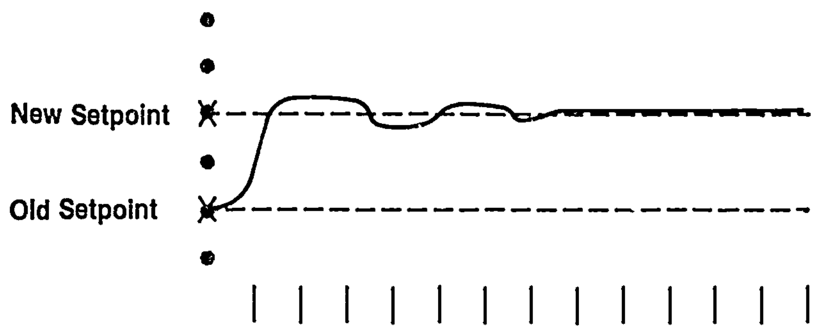



**Proportional Control**

## HANDOUT # 1

In many loops, offset is undesirable, and has to be corrected by using a controller with a reset mode (also referred to as integral). When proportional and integral control (PI) are used together, the response to a new setpoint or disturbance is both faster and smoother, and on a recorder chart the curve may look more like the curve in Figure 9.

FIGURE 9




**Proportional Plus Reset Control**

### Conclusions

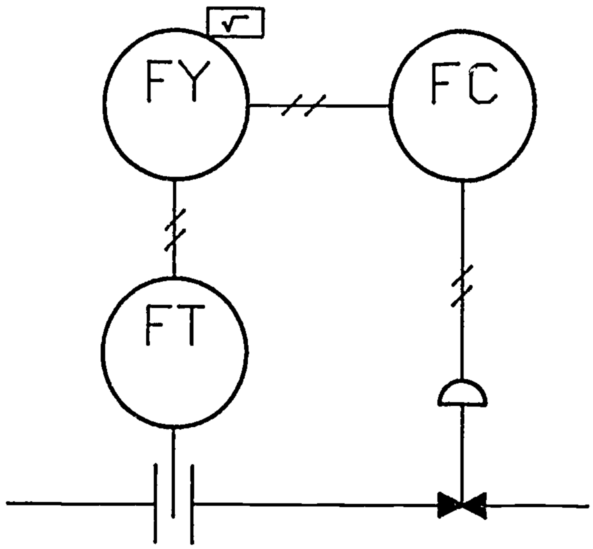
Process systems are complex, and control loops within systems must contribute to the total control objective. The combination of components, the transmission of information by standard signals, and a control mode capable of the design objective are all required to make a control loop or a complete process system work.

# PROCESS SYSTEMS
# UNIT VII

## ASSIGNMENT SHEET #1 — IDENTIFY COMPONENTS AND THEIR FUNCTIONS IN SELECTED CONTROL LOOPS

Directions: The diagrams in this assignment sheet are extracted from P&IDs for complete control systems, but each diagram is a control loop with components that perform to make the loop function within a total process system. Refer to the symbols from Unit II as often as you need to, study the diagrams carefully, and select the correct answer from the choices listed after each diagram.

**Diagram 1**




1. The control loop in Diagram 1 controls:

   _____a. Temperature

   _____b. Flow

   _____c. Level

   _____d. Pressure

2. The output of FT in Diagram 1 is:

   _____a. Pneumatic

   _____b. Hydraulic

   _____c. Electrical

   _____d. Capillary tubing

## ASSIGNMENT SHEET #1

3. The symbol FY in Diagram 1 represents:

_____a. A computer software link

_____b. A multiplier transducer

_____c. A square root extractor transducer

_____d. A flow controller

4. The flow control element in Diagram 1 is:

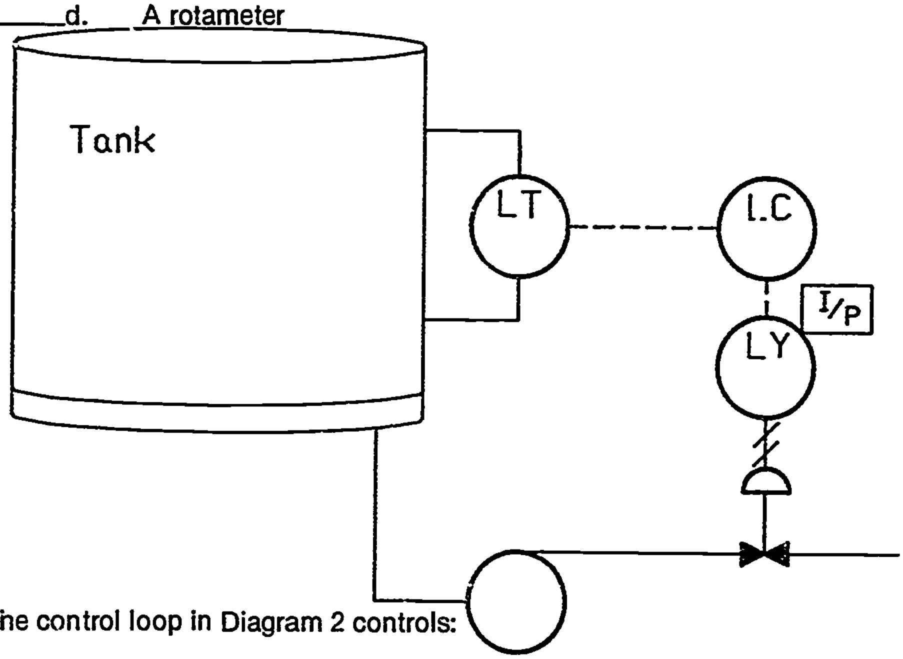
_____a. An orifice plate

_____b. A pitot tube

_____c. A venturi tube

_____d. A rotameter

Diagram 2




5. The control loop in Diagram 2 controls:

_____a. Temperature

_____b. Flow

_____c. Level

_____d. Pressure

## ASSIGNMENT SHEET #1

6. The output of LT in Diagram 2 is:

   _____a. Electrical

   _____b. Pneumatic

   _____c. Mechanical

   _____d. Binary

7. LY in Diagram 2 converts:

   _____a. Voltage to current

   _____b. Current to pressure

   _____c. Voltage to pressure

   _____d. Digital to analog

8. The setpoint adjustment in Diagram 2 is located on:

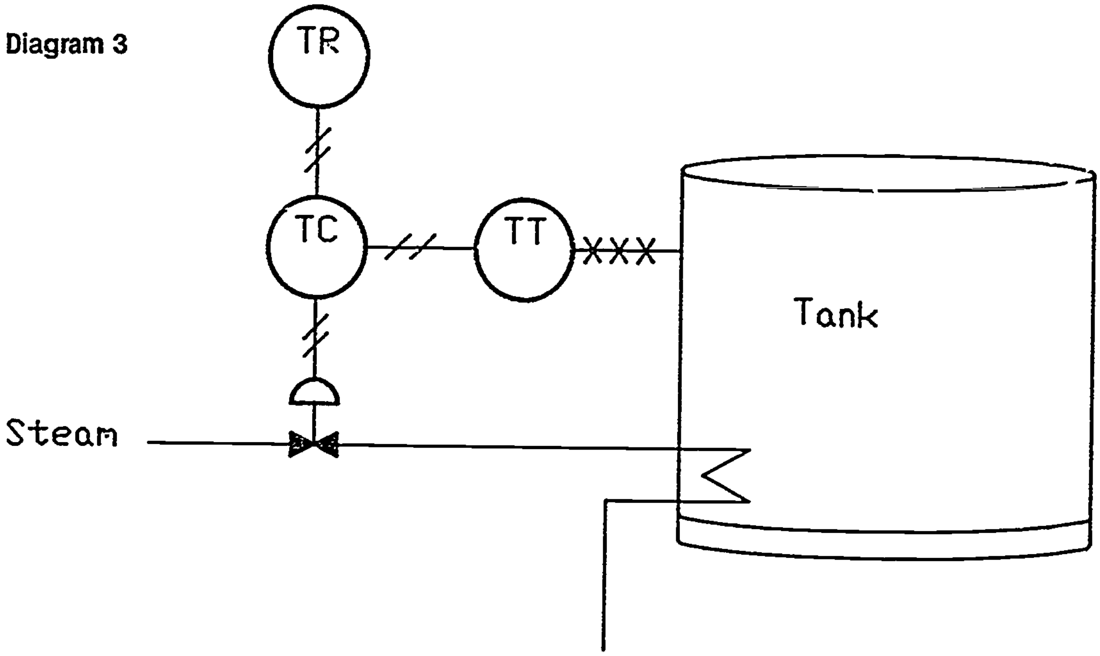
   _____a. LT

   _____b. LC

   _____c. LY

   _____d. Control panel

Diagram 3



## ASSIGNMENT SHEET #1

9. The control loop in Diagram 3 controls:

_____a. Flow

_____b. Level

_____c. Pressure

_____d. Temperature

10. The input to TT in Diagram 3 is:

_____a. Capillary tubing

_____b. Electrical

_____c. Pneumatic

_____d. Undefined

11. The liquid in the tank in Diagram 3 is heated by:

_____a. A pneumatic device

_____b. An electrical device

_____c. Steam

_____d. Water

12. If the liquid in the tank in Diagram 3 is controlled by steam, then the liquid is:

_____a. The controlled variable

_____b. The manipulated variable

13. The steam being controlled by the temperature loop in Diagram 3 is:

_____a. The controlled variable

_____b. The manipulated variable

14. The output of TT in Diagram 3 is:

_____a. Pneumatic

_____b. Electrical

_____c. Capillary tubing

_____d. Undefined

# PROCESS SYSTEMS
# UNIT VII

## ANSWERS TO ASSIGNMENT SHEET

Assignment Sheet #1

1. b
2. a
3. c
4. a
5. c
6. a
7. b
8. b
9. d
10. a
11. c
12 a
13. b
14. a

# PROCESS SYSTEMS
# UNIT VII

## TEST

NAME ______________________________ SCORE ______________

1. Match the terms on the right with their correct definitions.

| | | |
|---|---|---|
| _____a. | A method of sending data when it is ready without referencing a timing signal or waiting for a signal from a receiver | 1. Distributed process control |
| _____b. | The speed of data transmission as expressed in bits per second | 2. Serial transmission |
| _____c. | A shortening of "binary digit" which is the smallest unit of computer information, stated as binary 0 or binary 1 | 3. Byte |
| _____d. | The combination of eight bits that form a binary character | 4. Parallel transmission |
| _____e. | A control system in which local control modules and slave modules are interfaced with a central microcomputer/controller where total process activities can be displayed on a monitor for evaluation by an operator | 5. Bit |
| _____f. | A national organization of equipment manufacturers and large service firms who set standards and coordinate smooth interaction of the electronics industry with the market place | 6. Synchronous |
| _____g. | A national organization of professionals in electricity and electronics who set standards for electrical and electronic equipment | 7 Baud rate |
| _____h. | The sending of all data bits simultaneously on separate lines, a transmission mode designed for short distances or where high speed transmission rates are desired | 8. IEEE |
| _____i. | The sending of data bits one at a time on a single line, a transmission mode designed for long distance communications where slower transmission speeds are acceptable | 9. Asynchronous |
| _____j. | A method of sending data in serial form so that the bit by bit transmission is in step with a timing signal | 10. EIA |

## TEST

2. Solve the following problems concerning the basics of signal transmission systems by selecting the appropriate answer.

   a. By separating receiving and control units from transducers in the field, does it make the control units easier to monitor or does it make it easier to standardize instrument controllers?

      Answer: ______________________________

   b. Signal transmission systems are really significant because they do what—speed transmission or permit placement of equipment in a location safe from the process environment?

      Answer: ______________________________

3. Select true statements concerning methods of signal transmission by placing an "X" beside each statement that is true.

   (NOTE: For a statement to be true, all parts of the statement must be true.)

   _____a. The two most common standard methods of signal transmission are:

   1) The pneumatic 3-15 PSI standard;

   2) The electrical 4-20 mA standard.

   _____b. The pneumatic and electrical standards are not well established, because there are thousands of private installations in industry.

   _____c. The rapid growth of computer and microprocessor applications has created a need for high speed data communications in industrial instrumentation, and particularly in the area of distributed process control.

   _____d. Use of distributed process controls continues to increase because of the speed and convenience of having the control of part of a process done on location, and reported back to the next level of computer where supervisory control is handled.

4. Solve the following problems concerning pneumatic transmission by selecting the appropriate answer.

   a. Pneumatic transmission systems have several advantages, and one of them is what—that the systems are inexpensive or that they can be used in hazardous areas?

      Answer: ______________________________

   b. Pneumatic tubing has a distributed lag that may cause signal loss, but pneumatic lines are usually effective at distances up to 500 feet or 1,000 feet?

      Answer: ______________________________

# TEST

5. Complete statements concerning standards for pneumatic transmission by circling the Items that best complete each statement.

   a. The most common pneumatic standard is **(4-20PSI, 3-15 PSI)** or 20-100 kPa, a pressure that represents 0% to 100% of the range of the variable being transmitted, or it is 0% to 100% of the valve stroke in final elements.

   b. With a range of 3-15 PSI, the **(9 PSI, 7 PSI)** pressure is the central operating point that is set when a system needs to swing both positive and negative to control a process within a system.

   c. The 3 PSI at 0% is referred to as a **(live zero, negative zero)**, which means that when you calibrate to the zero point, you can go below it, and you can approach the calibrated point from either direction.

   d. Another advantage of **(negative zero, live zero)** is in the troubleshooting and maintenance of the system because a troubleshooter can clearly distinguish between a failure and the zero control point.

6. Select true statements concerning electrical transmission by placing an "X" beside each statement that is true.

   ______a. Electrical transmissions have become more common over the past 30 years because electrical systems have developed into reliable tools, and more technicians have been trained for electrical troubleshooting.

   ______b. Electrical transmission has few advantages over pneumatic systems; electrical systems cost more and cannot transmit signals as far.

   ______c. In an electrical transmission system, the length of the current transmitted signal is determined by the total system resistance including wiring and loads, but the signal can be transmitted several miles.

7. Select true statements concerning important elements in current transmitted signals by placing an "X" beside each statement that is true.

   ______a. A series electrical transmission current delivery system is simple because it is a series electrical circuit that has a single path for current, and requires only two wires for supply and return of the current.

   ______b. Loads can be attached anywhere in a current delivery system because a true series circuit supplies the same current anywhere in the circuit.

   ______c. Because a current delivery system is so simple and tolerant of different loads, it is readily interchangeable in terms of equipment on the supply or the load end of the system.

# TEST

8. Match standards for electrical transmission with their characteristics.

_____a. A parallel transmission standard.

_____b. A computer automation standard.

_____c. Bit synchronous or asynchronous serial standards.

_____d. An analog signal sent on two wires; it is essentially a real time signal.

_____e. A two wire analog signal, not common, but used where more drive is needed than the 4-20 mA can supply.

_____f. Similar to the 3-15 PSI pneumatic signals since they do not go to zero current, and can be calibrated for live zero from either direction.

_____g. Used in transmitting signals from TTL logic circuits, and IC transducers use the natural voltage range of the logic, 0 - 5v DC, where the actual zero signal is from 0 to .7 of a volt, and the logic one signal is 2.4 to 5v DC.

_____h. Many current transmitting systems are two wire twisted pair which can be used reliably by both analog and serial systems.

1. Standard analog signal
2. Two-wire transmission systems
3. IEEE 583, 595, and 596
4. 10-50 mA
5. IEEE 488
6. 0-5v logic signals
7. ISA 4-20 mA
8. EIA RS-231-C, RS-422, and RS-449

9. Select true statements concerning frequency transmission by placing an "X" beside each statement that is true.

_____a. Frequency transmission systems convert a source signal into an AC or pulse signal that has one frequency for the zero level source signal, and a second frequency for a medium level signal, and a third frequency for a maximum level.

_____b. In a frequency transmission system, the AC or pulse signal is transmitted to a receiver where it is converted back to its original form.

_____c. AC or pulse transmissions are superior to the DC transmissions with respect to noise interference, and have more stability with temperature influence.

# TEST

10. Select true statements concerning pulse width or duration transmission by placing an "X" beside each statement that is true.

_____a. In a pulse width system, the source signal is a pulse that has a time duration proportional to zero input at the signal source, and a different pulse width for the maximum source signal.

_____b. In a pulse width system, the 4-20 mA signal might be converted to pulse durations between 4 ms and 20 ms.

_____c. When the signals in a pulse width system reach a receiver, they are decoded back to the 4-20 mA standard.

11. Select true statements concerning digital pulse code transmission by placing an "X" beside each statement that is true.

_____a. In a digital pulse code system, the source signal is converted into binary code, and then converted to analog.

_____b. A common number of bits required to represent one character is eight, and the bits can be transmitted one after the other as serial information, or they can all go at the same time on separate lines as parallel information.

12. Solve the following problems concerning bit transmission formats by selecting the appropriate answer.

a. Bit transmission is accomplished in serial or parallel format, and which format is faster, parallel or serial?

Answer: ______________________________

b. Certain kinds of bits are used to assure that a signal arrives at its destination without error, and these bits are called source-code bits or parity bits?

Answer: ______________________________

(NOTE: If the following activity has not been accomplished prior to the test, ask your instructor when it should be completed.)

13. Identify and explain the function of the instrument loops in a typical industrial application. (Assignment Sheet #1)

# PROCESS SYSTEMS
# UNIT VII

## ANSWERS TO TEST

1. a. 9
   b. 7
   c. 5
   d. 3
   e. 1
   f. 10
   g. 8
   h. 4
   i. 2
   j. 6

2. a. Easier to standardize instrument controllers
   b. Permit placement of equipment in a location safe from the process environment

3. a, c, d

4. a. They can be used in hazardous areas
   b. 1,000 feet

5. a. 3-15 PSI
   b. 9 PSI
   c. Live ze...
   d. Live zero

6. a, c

7. a, b, c

8. a. 5
   b. 3
   c. 8
   d. 7
   e. 4
   f. 1
   g. 6
   h. 2

## ANSWERS TO TEST

9. b, c

10. a, b, c

11. b

12. a. Parallel
    b. Parity bits

13. Evaluated to the satisfaction of the instructor