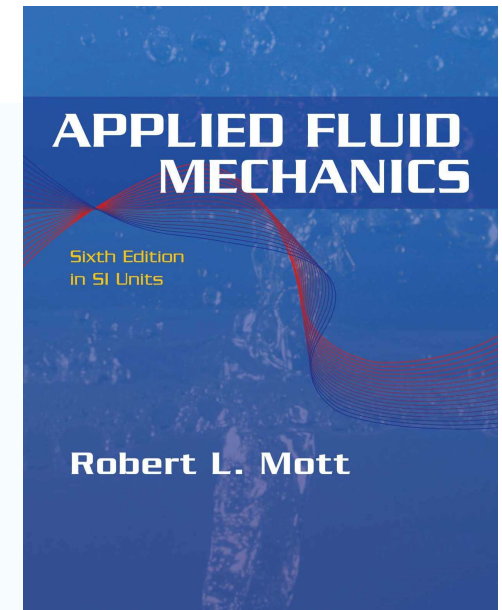


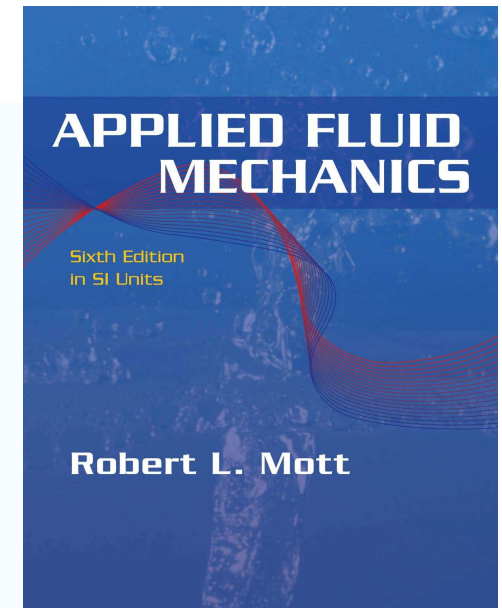
# Applied Fluid Mechanics

1. The Nature of Fluid and the Study of Fluid Mechanics
2. Viscosity of Fluid
3. Pressure Measurement
4. Forces Due to Static Fluid
5. Buoyancy and Stability
6. Flow of Fluid and Bernoulli's Equation
7. General Energy Equation
8. Reynolds Number, Laminar Flow, Turbulent Flow and Energy Losses Due to Friction



# Applied Fluid Mechanics

9. Velocity Profiles for Circular Sections and Flow in Noncircular Sections
10. Minor Losses
11. Series Pipeline Systems
12. Parallel Pipeline Systems
13. Pump Selection and Application
14. Open-Channel Flow
15. Flow Measurement
16. Forces Due to Fluids in Motion

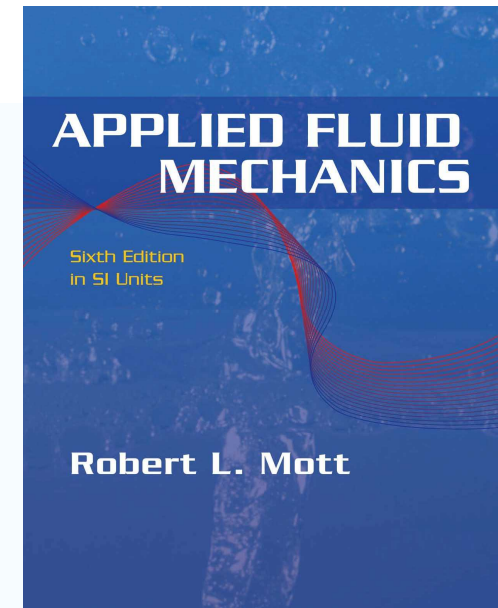


# Applied Fluid Mechanics

17. Drag and Lift

18. Fans, Blowers, Compressors  
and the Flow of Gases

19. Flow of Air in Ducts



## 3. Pressure Measurement

### Chapter Objectives

---

1. Define the relationship between *absolute pressure*, *gage pressure*, and *atmospheric pressure*.
2. Describe the degree of variation of atmospheric pressure near Earth's surface.
3. Describe the properties of air at standard atmospheric pressure.
4. Describe the properties of the atmosphere at elevations from sea level to 30 000 m.
5. Define the relationship between a change in elevation and the change in pressure in a fluid.

## 3. Pressure Measurement

### Chapter Objectives

---

6. Describe how a *manometer* works and how it is used to measure pressure.
7. Describe a U-tube manometer, a differential manometer, a well-type manometer, and an inclined well-type manometer.
8. Describe a *barometer* and how it indicates the value of the local atmospheric pressure.
9. Describe various types of pressure gages and pressure transducers.

## 3. Pressure Measurement

### Chapter Outline

---

1. Absolute and Gage Pressure
2. Relationship between Pressure and Elevation
3. Development of the Pressure-Elevation Relation
4. Pascal's Paradox
5. Manometers
6. Barometers
7. Pressure expressed as the Height of a Column of Liquid
8. Pressure Gages and Tranducers

## 3. Pressure Measurement

### 3.1 Absolute and Gage Pressure

---

- When making calculations involving pressure in a fluid, you must make the measurements relative to some reference pressure.
- Normally the reference pressure is that of the atmosphere, and the resulting measured pressure is called *gage pressure*.
- Pressure measured relative to a perfect vacuum is called *absolute pressure*.

## 3. Pressure Measurement

### 3.1 Absolute and Gage Pressure

---

- A simple equation relates the two pressure-measuring systems:

$$P_{abs} = P_{gage} + P_{atm} \quad (3-2)$$

where

$p_{abs}$  = Absolute pressure

$p_{gage}$  = Gage pressure

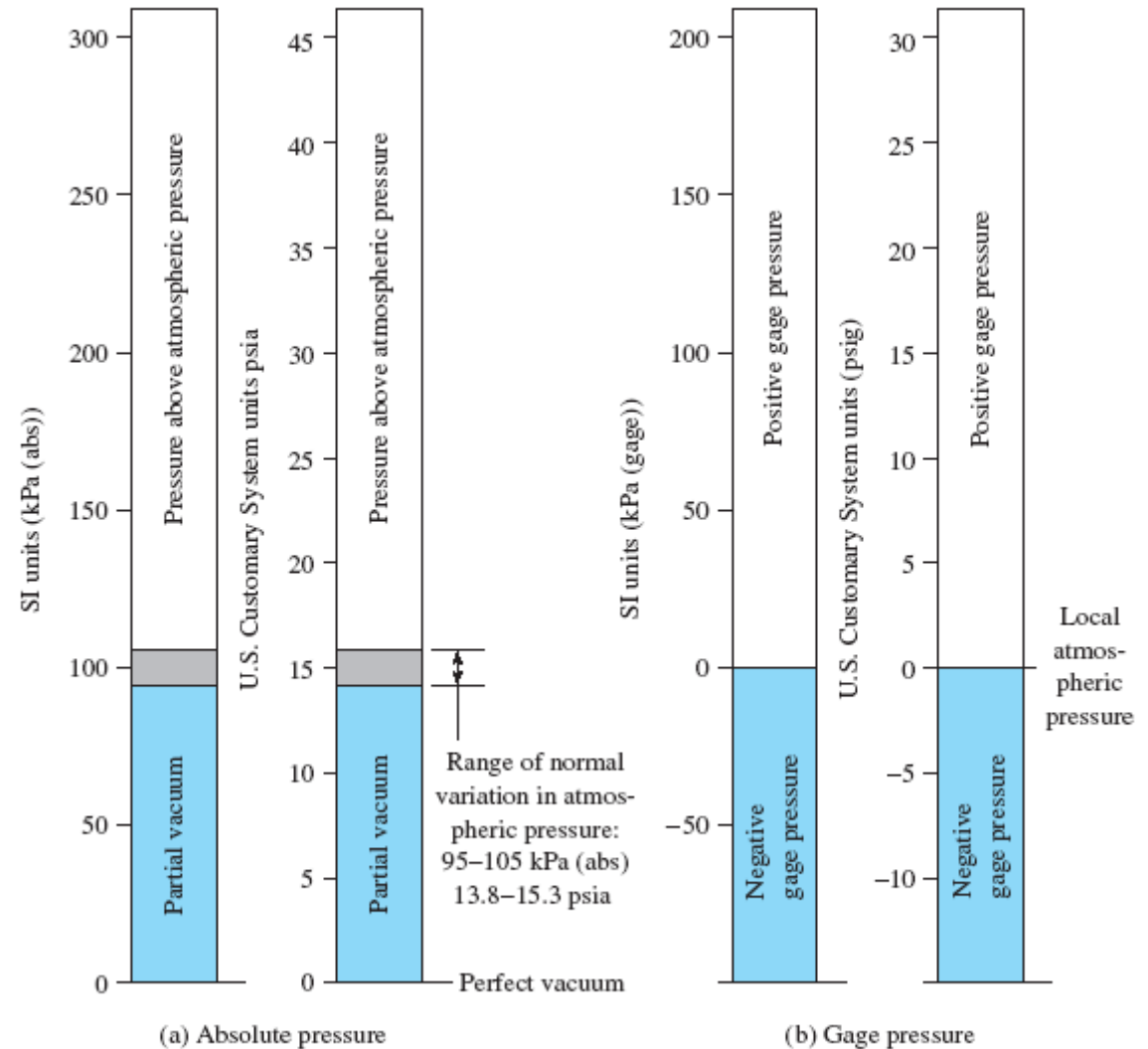
$p_{atm}$  = Atmospheric pressure



# 3. Pressure Measurement

## 3.1 Absolute and Gage Pressure

- Fig 3.1 shows the comparison between absolute and gage pressures.



## 3. Pressure Measurement

### Example 3.1

---

Express a pressure of 155 kPa (gage) as an absolute pressure. The local atmospheric pressure is 98 kPa(abs).

$$P_{abs} = P_{gage} + P_{atm}$$

$$P_{abs} = 155 \text{ kPa(gage)} + 98 \text{ kPa(abs)} = 253 \text{ kPa(abs)}$$

Notice that the units in this calculation are kilopascals (kPa) for each term and are consistent. The indication of gage or absolute is for convenience and clarity.

## 3. Pressure Measurement

### Example 3.2

---

Express a pressure of 225 kPa(abs) as a gage pressure. The local atmospheric pressure is 101 kPa(abs).

$$P_{\text{abs}} = P_{\text{gage}} + P_{\text{atm}}$$

Solving algebraically for  $p_{\text{gage}}$  gives

$$P_{\text{gage}} = P_{\text{abs}} - P_{\text{atm}}$$

$$P_{\text{gage}} = 225 \text{ kPa(abs)} - 101 \text{ kPa(abs)} = 124 \text{ kPa(gage)}$$

## 3. Pressure Measurement

### Example 3.3

Express a pressure of 75.2 kPa as a gage pressure. The local atmospheric pressure is 103.4 kPa.

$$P_{\text{abs}} = P_{\text{gage}} + P_{\text{atm}}$$

$$P_{\text{gage}} = P_{\text{abs}} - P_{\text{atm}}$$

$$P_{\text{gage}} = 75.2 \text{ kPa} - 103.4 \text{ kPa} = -28.2 \text{ kPa}$$

Notice that the result is negative. This can also be read “28.2 kPa below atmospheric pressure” or “28.2 kPa vacuum.”

## 3. Pressure Measurement

### Example 3.4

---

Express a pressure of  $-42.7$  kPa as an absolute pressure.

$$P_{\text{abs}} = P_{\text{gage}} + P_{\text{atm}}$$

Because no value was given for the atmospheric pressure, we will use  $p_{\text{atm}}=101$  kPa:

$$P_{\text{abs}} = -42.7 \text{ kPa} + 101 \text{ kPa} = 58.3 \text{ kPa}$$

## 3. Pressure Measurement

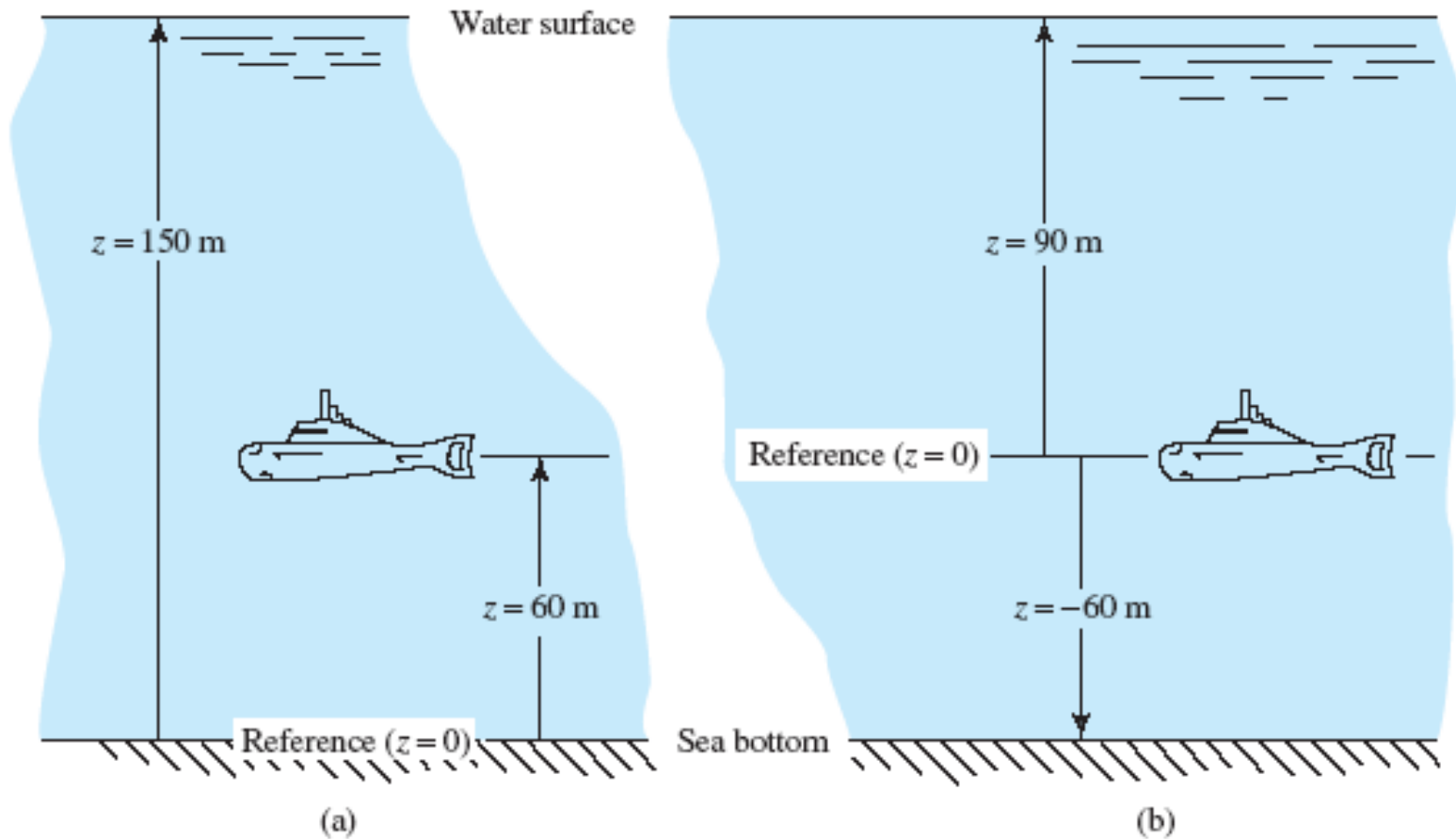
### 3.2 Relationship between Pressure and Elevation

---

- The term *elevation* means the vertical distance from some reference level to a point of interest and is called  $z$ .
- A *change* in elevation between two points is called  $h$ . Elevation will always be measured positively in the upward direction.
- In other words, a higher point has a larger elevation than a lower point.
- Fig 3.2 shows the illustration of reference level for elevation.

# 3. Pressure Measurement

## 3.2 Relationship between Pressure and Elevation



## 3. Pressure Measurement

### 3.2 Relationship between Pressure and Elevation

---

- The change in pressure in a homogeneous liquid at rest due to a change in elevation can be calculated from

$$\Delta p = \gamma h \quad (3-3)$$

where

$\Delta p$  = Change in pressure

$\gamma$  = Specific weight of liquid

$h$  = Change in elevation

- *In this book we assume that the pressure in a gas is uniform unless otherwise specified.*



## 3. Pressure Measurement

### Example 3.5

---

Calculate the change in water pressure from the surface to a depth of 5 m.

Use Eq. (3–3),

$$\Delta p = (9.81 \text{ kN/m}^3)(5.0 \text{ m}) = 49.05 \text{ kN/m}^2 = 49.05 \text{ kPa}$$

If the surface of the water is exposed to the atmosphere, the pressure there is 0 Pa(gage). Descending in the water (decreasing elevation) produces an increase in pressure. Therefore, at 5 m the pressure is 49.05 kPa(gage).

## 3. Pressure Measurement

### Example 3.6

---

Calculate the change in water pressure from the surface to a depth of 3.05 m.

Use Eq. (3–3),

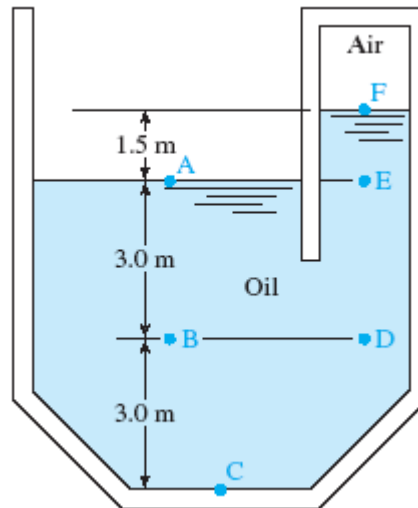
$$\Delta p = \frac{9.81 \text{ kN}}{\text{m}^3} \times 3.05 \text{ m} = 29.9 \text{ kPa}$$

If the surface of the water is exposed to the atmosphere, the pressure there is 0 Pa (gage). Descending in the water (decreasing elevation) produces an increase in pressure. Therefore, at 3.05 m the pressure is 29.9 kPa.

## 3. Pressure Measurement

### Example 3.7

Figure 3.3 shows a tank of oil with one side open to the atmosphere and the other side sealed with air above the oil. The oil has a specific gravity of 0.90. Calculate the gage pressure at points A, B, C, D, E, and F and the air pressure in the right side of the tank.



## 3. Pressure Measurement

### Example 3.7

---

*Point A* At this point, the oil is exposed to the atmosphere, and therefore

$$p_A = 0 \text{ Pa(gage)}$$

*Point B* The change in elevation between point A and point B is 3.0 m, with B lower than A. To use Eq. (3–3) we need the specific weight of the oil:

$$\gamma_{\text{oil}} = (\text{sg})_{\text{oil}}(9.81 \text{ kN/m}^3) = (0.90)(9.81 \text{ kN/m}^3) = 8.83 \text{ kN/m}^3$$

Then we have

$$\Delta p_{A-B} = \gamma h = (8.83 \text{ kN/m}^3)(3.0 \text{ m}) = 26.5 \text{ kN/m}^2 = 26.5 \text{ kPa}$$

## 3. Pressure Measurement

### Example 3.7

---

Now, the pressure at B is

$$p_B = p_A + \Delta p_{A-B} = 0 \text{ Pa(gage)} + 26.5 \text{ kPa} = 26.5 \text{ kPa(gage)}$$

*Point C* The change in elevation from point A to point C is 6.0 m, with C lower than A. Then, the pressure at point C is

$$\Delta p_{A-C} = \gamma h = (8.83 \text{ kN/m}^3)(6.0 \text{ m}) = 53.0 \text{ kN/m}^2 = 53.0 \text{ kPa}$$

$$p_C = p_A + \Delta p_{A-C} = 0 \text{ Pa(gage)} + 53.0 \text{ kPa} = 53.0 \text{ kPa(gage)}$$

*Point D* Because point D is at the same level as point B, the pressure is the same. That is, we have

$$p_D = p_B = 26.5 \text{ kPa(gage)}$$

## 3. Pressure Measurement

### Example 3.7

---

*Point E* Because point E is at the same level as point A, the pressure is the same. That is, we have

$$p_E = p_A = 0 \text{ Pa(gage)}$$

*Point F* The change in elevation between point A and point F is 1.5 m, with F higher than A. Then, the pressure at F is

$$\Delta p_{A-F} = -\gamma h = (-8.83 \text{ kN/m}^3)(1.5 \text{ m}) = -13.2 \text{ kN/m}^2 = -13.2 \text{ kPa}$$

$$p_F = p_A + \Delta p_{A-F} = 0 \text{ Pa(gage)} + (-13.2 \text{ kPa}) = -13.2 \text{ kPa}$$

## 3. Pressure Measurement

### Example 3.7

---

*Air Pressure* Because the air in the right side of the tank is exposed to the surface of the oil, where  $p_F = -13.2\text{kPa}$  the air pressure is also  $-13.2\text{kPa}$  or  $13.2\text{ kPa}$  below atmospheric pressure.

## 3. Pressure Measurement

### Summary of observations from Example 3.7

---

- The results from Problem 3.7 illustrate the general conclusions listed below Eq. (3–3):
- The pressure increases as the depth in the fluid increases. This result can be seen from  $p_C > p_B > p_A$ .
- Pressure varies linearly with a change in elevation; that is,  $p_C$  is two times greater than  $p_B$  and C is at twice the depth of B.
- Pressure on the same horizontal level is the same. Note that  $p_E = p_A$  and  $p_D = p_B$ .
- The decrease in pressure from E to F occurs because point F is at a higher elevation than point E. Note that  $p_F$  is negative; that is, it is below the atmospheric pressure that exists at A and E.



## 3. Pressure Measurement

### 3.3 Development of the Pressure-Elevation Relation

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- The relationship between a change in elevation in a liquid,  $h$ , and a change in pressure is

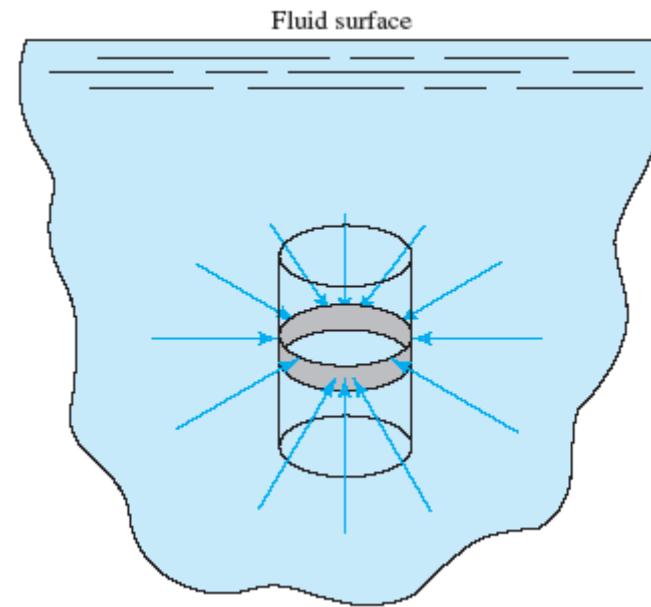
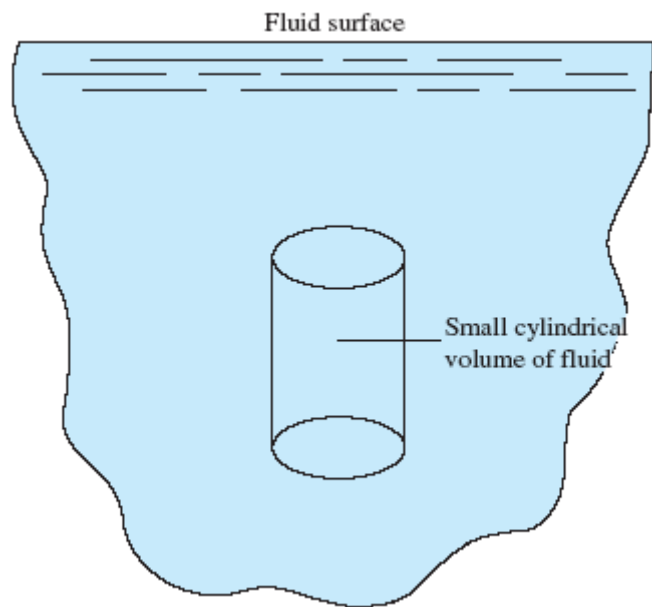
$$\Delta p = \gamma h \quad (3-3)$$

where  $\gamma$  is the specific weight of the liquid.

- Fig 3.4 shows the small volume of fluid within a body of static fluid.
- Fig 3.5 shows the pressure forces acting in a horizontal plane on a thin ring.

## 3. Pressure Measurement

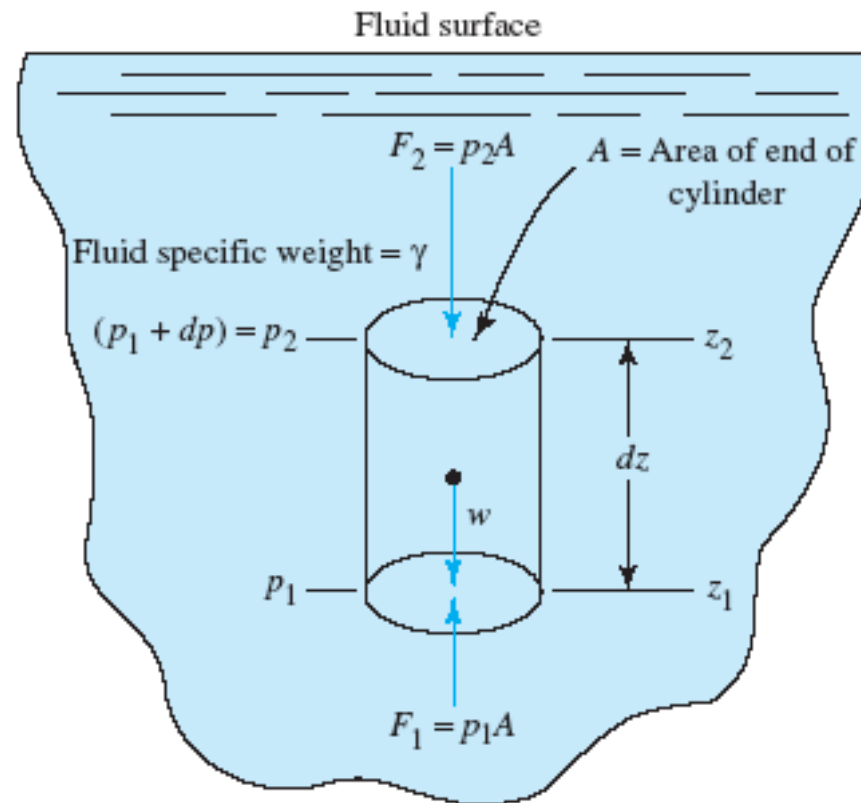
### 3.3 Development of the Pressure-Elevation Relation



## 3. Pressure Measurement

### 3.3 Development of the Pressure-Elevation Relation

- Fig 3.6 shows the forces acting in the vertical direction.



## 3. Pressure Measurement

### 3.3 Development of the Pressure-Elevation Relation

---

- The following concepts are illustrated in the figure:
  1. The fluid pressure at the level of the bottom of the cylinder is called  $p_1$ .
  2. The fluid pressure at the level of the top of the cylinder is called  $p_2$ .
  3. The elevation difference between the top and the bottom of the cylinder is called  $dz$ , where  $dz = z_2 - z_1$
  4. The pressure change that occurs in the fluid between the level of the bottom and the top of the cylinder is called  $dp$ . Therefore,  $p_2 = p_1 + dp$ .
  5. The area of the top and bottom of the cylinder is called  $A$ .

## 3. Pressure Measurement

### 3.3 Development of the Pressure-Elevation Relation

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6. The volume of the cylinder is the product of the area  $A$  and the height of the cylinder  $dz$ . That is,  $V=A(dz)$ .
7. The weight of the fluid within the cylinder is the product of the specific weight of the fluid and the volume of the cylinder. That is,  $w = V = A(dz)$ . The weight is a force acting on the cylinder in the downward direction through the centroid of the cylindrical volume.
8. The force acting on the bottom of the cylinder due to the fluid pressure  $p_1$  is the product of the pressure and the area  $A$ . That is,  $F_1 = p_1A$  This force acts vertically upward, perpendicular to the bottom of the cylinder.

## 3. Pressure Measurement

### 3.3 Development of the Pressure-Elevation Relation

---

- The force acting on the top of the cylinder due to the fluid pressure  $p_2$  is the product of the pressure and the area  $A$ . That is,  $F_2 = p_2 A$ . This force acts vertically downward, perpendicular to the top of the cylinder. Because  $p_2 = p_1 + dp$  another expression for the force  $F_2$  is

$$F_2 = (p_1 + dp)A \quad (3-4)$$

## 3. Pressure Measurement

### 3.3 Development of the Pressure-Elevation Relation

---

- Using upward forces as positive, we get

$$\Sigma F_v = 0 = F_1 - F_2 - w \quad (3-5)$$

- Substituting from Steps 7–9 gives

$$p_1 A - (p_1 + dp)A - \gamma(dz)A = 0 \quad (3-6)$$

- Notice that the area  $A$  appears in all terms on the left side of Eq. (3–6). It can be eliminated by dividing all terms by  $A$ . The resulting equation is

$$p_1 - p_1 - dp - \gamma(dz) = 0 \quad (3-7)$$

## 3. Pressure Measurement

### 3.3 Development of the Pressure-Elevation Relation

---

- Now the term  $p_1$  can be cancelled out. Solving for  $dp$  gives

$$dp = -\gamma(dz) \quad (3-8)$$

- The process of integration extends Eq. (3-8) to large changes in elevation, as follows:

$$\int_{p_1}^{p_2} dp = \int_{z_1}^{z_2} -\gamma(dz) \quad (3-9)$$

- Equation (3-9) develops differently for liquids and for gases because the specific weight is constant for liquids and it varies with changes in pressure for gases.



## 3. Pressure Measurement

### 3.3.1 Liquids

---

- A liquid is considered to be incompressible. Thus, its specific weight  $\gamma$  is a constant.
- This allows  $\gamma$  to be taken outside the integral sign in Eq. (3–9). Then,

$$\int_{p_1}^{p_2} dp = -\gamma \int_{z_1}^{z_2} (dz) \quad (3-10)$$

- Completing the integration process and applying the limits gives

$$p_2 - p_1 = -\gamma(z_2 - z_1) \quad (3-11)$$

## 3. Pressure Measurement

### 3.3.1 Liquids

---

- For convenience, we define  $p = p_2 - p_1$  and  $h = z_2 - z_1$ .
- Equation (3–11) becomes  $\Delta p = \gamma h$  which is identical to Eq. (3–3).

## 3. Pressure Measurement

### 3.3.2 Gases

---

- Because a gas is compressible, its specific weight changes as pressure changes.
- To complete the integration process called for in Eq. (3–9), you must know the relationship between the change in pressure and the change in specific weight.
- The relationship is different for different gases, but a complete discussion of those relationships is beyond the scope of this text and requires the study of thermodynamics.

## 3. Pressure Measurement

### 3.3.3 Standard Atmosphere

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- Appendix E describes the properties of air in the *standard atmosphere* as defined by the U.S. National Oceanic and Atmospheric Administration (NOAA).
- Tables E1 and E2 give the properties of air at standard atmospheric pressure as temperature varies.
- Table E3 and the graphs in Fig. E1 give the properties of the atmosphere as a function of elevation.

## 3. Pressure Measurement

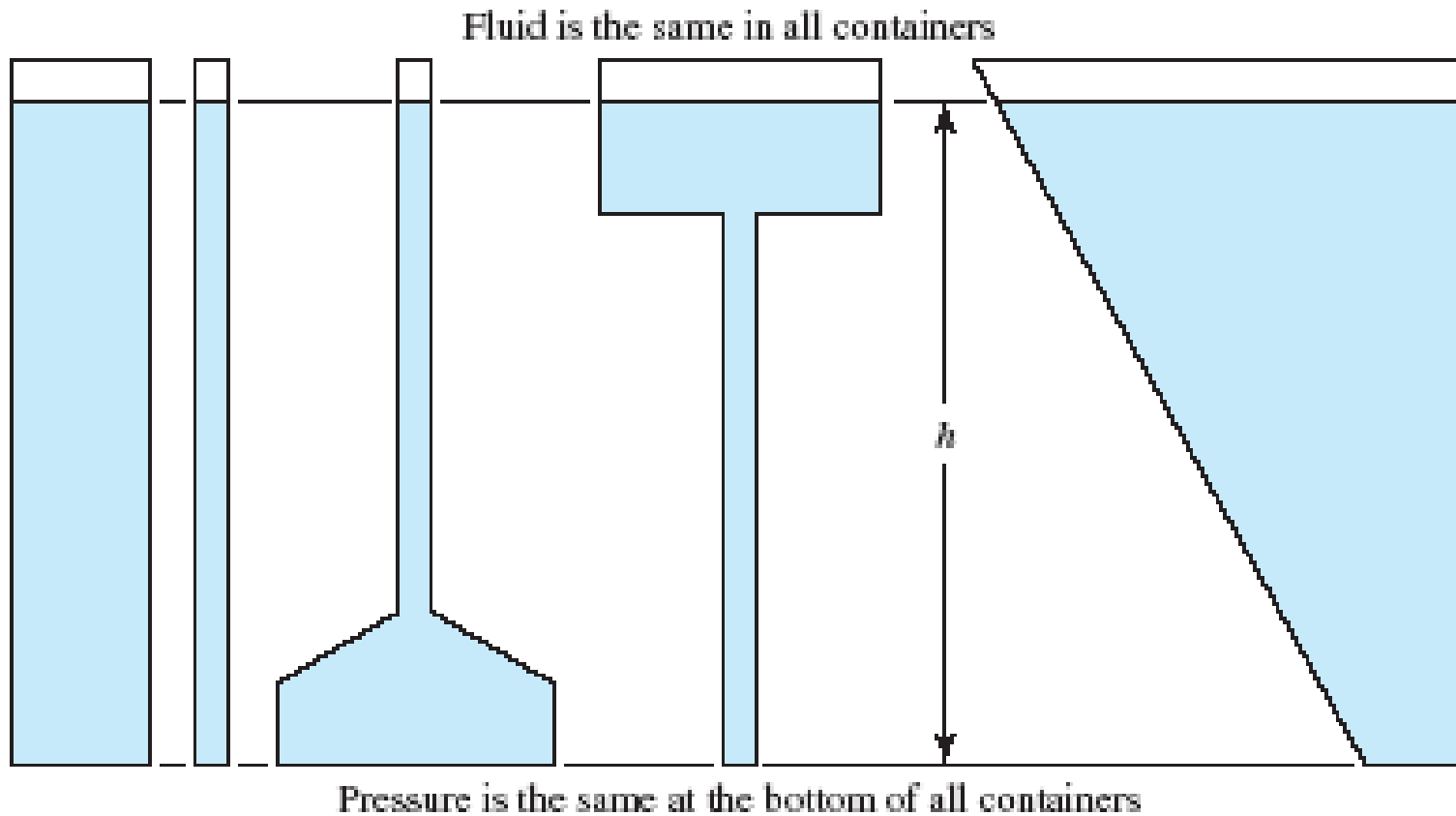
### 3.4 Pascal's Paradox

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- In the development of the relationship  $p = \rho h$  the size of the small volume of fluid does not affect the result.
- The change in pressure depends only on the change in elevation and the type of fluid, not on the size of the fluid container.
- Fig 3.7 shows the illustration of Pascal's paradox.
- This phenomenon is useful when a consistently high pressure must be produced on a system of interconnected pipes and tanks.

## 3. Pressure Measurement

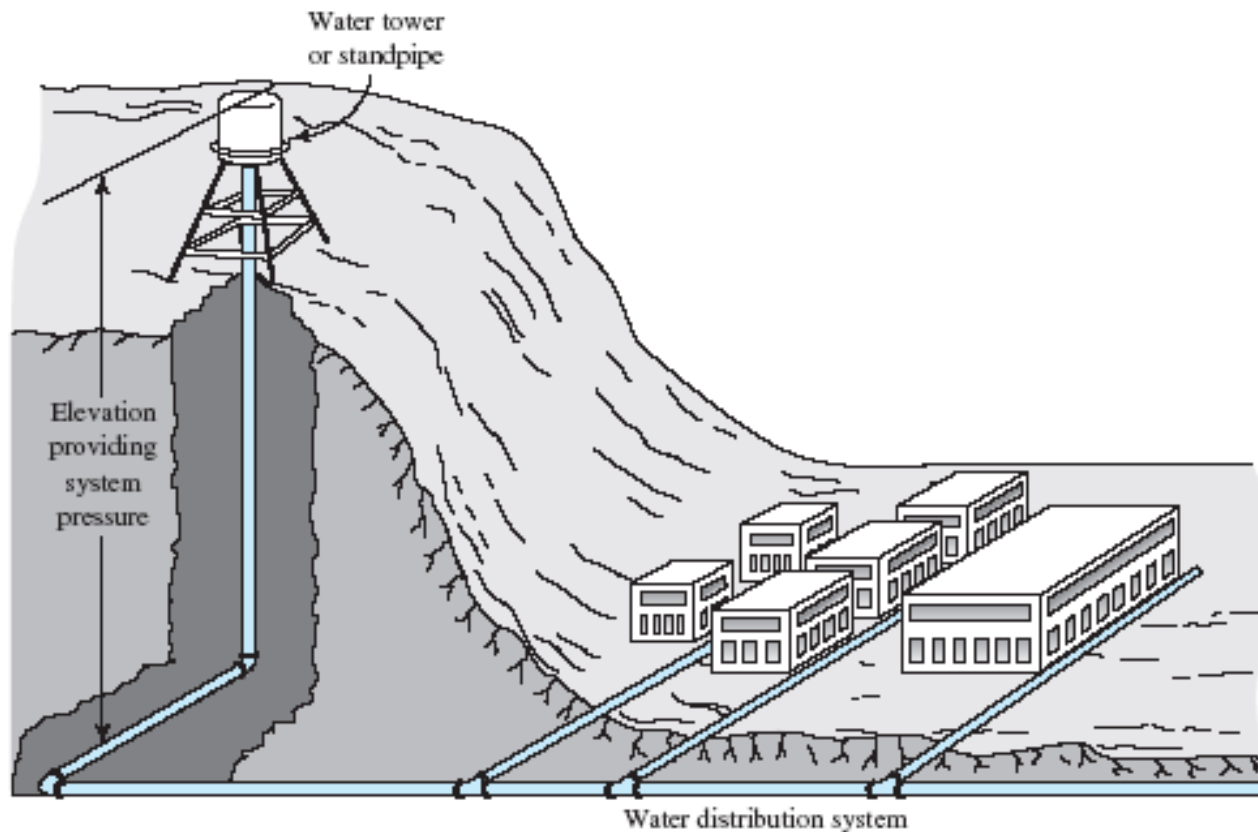
### 3.4 Pascal's Paradox



## 3. Pressure Measurement

### 3.4 Pascal's Paradox

- Fig 3.8 shows the use of a water tower or a standpipe to maintain water system pressure.



## 3. Pressure Measurement

### 3.4 Pascal's Paradox

---

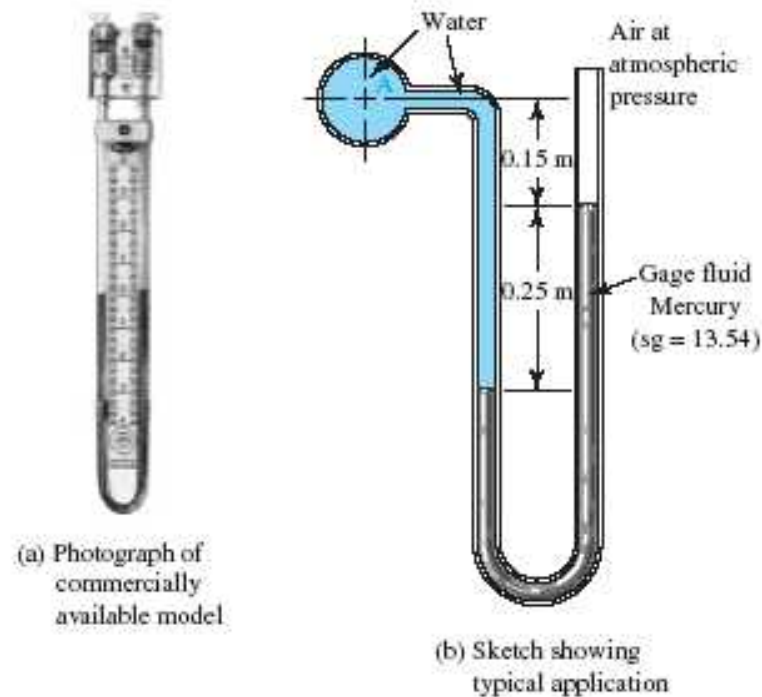
- Besides providing a reserve supply of water, the primary purpose of such tanks is to maintain a sufficiently high pressure in the water system for satisfactory delivery of the water to residential, commercial, and industrial users.



## 3. Pressure Measurement

### 3.5 Manometers

- *Manometer* uses the relationship between a change in pressure and a change in elevation in a static fluid.
- Fig 3.9 shows the U-tube manometer.



## 3. Pressure Measurement

### 3.5 Manometers

---

- Because the fluids in the manometer are at rest, the equation  $p = \rho h$  can be used to write expressions for the changes in pressure that occur throughout the manometer.
- These expressions can then be combined and solved algebraically for the desired pressure.

## 3. Pressure Measurement

### 3.5 Manometers

---

- Below are the procedure for writing the equation for a manometer:
  1. Start from one end of the manometer and express the pressure there in symbol form (e.g.,  $p_A$  refers to the pressure at point A). If one end is open as shown in Fig. 3.9, the pressure is atmospheric pressure, taken to be zero gage pressure.
  2. Add terms representing changes in pressure using  $p = \rho h$  proceeding from the starting point and including each column of each fluid separately.

## 3. Pressure Measurement

### 3.5 Manometers

---

3. When the movement from one point to another is downward, the pressure increases and the value of  $p$  is added. Conversely, when the movement from one point to the next is upward, the pressure decreases and  $p$  is subtracted.
4. Continue this process until the other end point is reached. The result is an expression for the pressure at that end point. Equate this expression to the symbol for the pressure at the final point, giving a complete equation for the manometer.

## 3. Pressure Measurement

### 3.5 Manometers

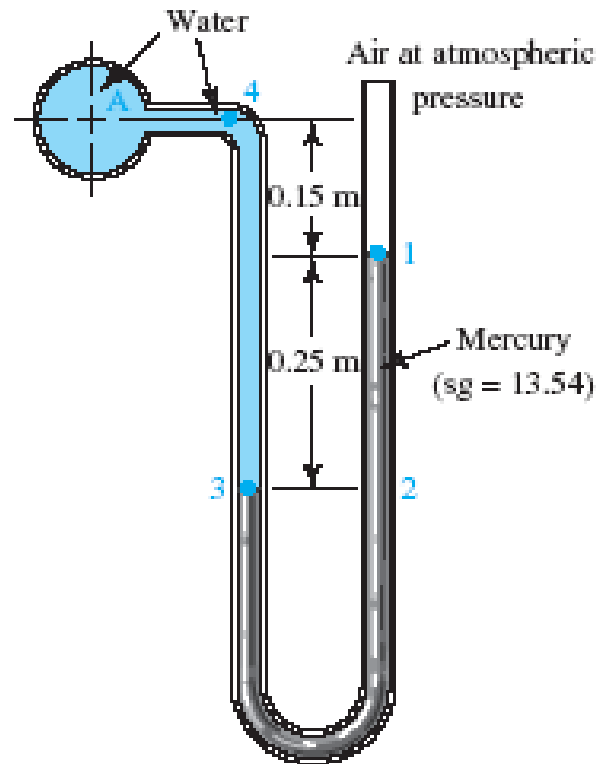
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5. Solve the equation algebraically for the desired pressure at a given point or the difference in pressure between two points of interest.
6. Enter known data and solve for the desired pressure.

## 3. Pressure Measurement

### Example 3.8

Using Fig. 3.9, calculate the pressure at point A. Perform Step 1 of the procedure before going to the next panel.



## 3. Pressure Measurement

### Example 3.8

---

The only point for which the pressure is known is the surface of the mercury in the right leg of the manometer, point 1. Now, how can an expression be written for the pressure that exists within the mercury, 0.25 m below this surface at point 2?

The expression is

$$p_1 + \gamma_m(0.25 \text{ m})$$

The term  $\gamma_m(0.25\text{m})$  is the change in pressure between points 1 and 2 due to a change in elevation, where  $\gamma_m$  is the specific weight of mercury, the gage fluid. This pressure  $p_1$  change is added to because there is an increase in pressure as we descend in a fluid.

## 3. Pressure Measurement

### Example 3.8

---

So far we have an expression for the pressure at point 2 in the right leg of the manometer. Now write the expression for the pressure at point 3 in the left leg.

Because points 2 and 3 are on the same level in the same fluid at rest, their pressures are equal.

Continue and write the expression for the pressure at point 4.



## 3. Pressure Measurement

### Example 3.8

---

$$p_1 + \gamma_m(0.25 \text{ m}) - \gamma_w(0.40 \text{ m})$$

where  $\gamma_w$  is the specific weight of water. Remember, there is a decrease in pressure between points 3 and 4, so this last term must be subtracted from our previous expression.

What must you do to get an expression for the pressure at point A?

Nothing. Because points A and 4 are on the same level, their pressures are equal. Now perform Step 4 of the procedure.

## 3. Pressure Measurement

### Example 3.8

---

You should now have

$$p_1 + \gamma_m(0.25 \text{ m}) - \gamma_w(0.40 \text{ m}) = p_A$$

$$p_A = p_1 + \gamma_m(0.25 \text{ m}) - \gamma_w(0.40 \text{ m})$$

Be sure to write the complete equation for the pressure at point A. Now do Steps 5 and 6. Several calculations are required here:

$$p_1 = p_{\text{atm}} = 0 \text{ Pa (gage)}$$

$$\gamma_m = (\text{sg})_m(9.81 \text{ kN/m}^3) = (13.54)(9.81 \text{ kN/m}^3) = 132.8 \text{ kN/m}^3$$

$$\gamma_w = 9.81 \text{ kN/m}^3$$

## 3. Pressure Measurement

### Example 3.8

---

Then, we have

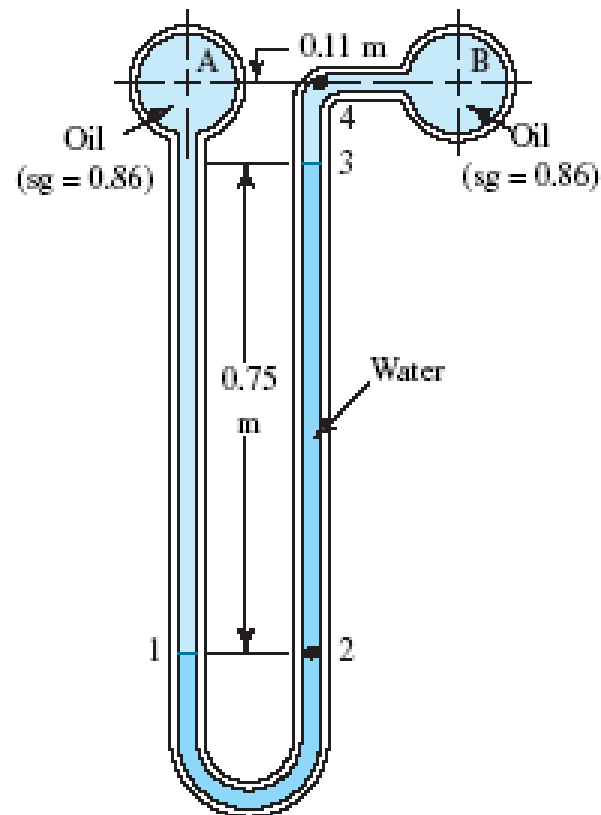
$$\begin{aligned} p_A &= p_1 + \gamma_m(0.25 \text{ m}) - \gamma_w(0.40 \text{ m}) \\ &= 0 \text{ Pa(gage)} + (132.8 \text{ kN/m}^3)(0.25 \text{ m}) - (9.81 \text{ kN/m}^3)(0.40 \text{ m}) \\ &= 0 \text{ Pa(gage)} + 33.20 \text{ kN/m}^2 - 3.92 \text{ kN/m}^2 \\ p_A &= 29.28 \text{ kN/m}^2 = 29.28 \text{ kPa(gage)} \end{aligned}$$

Remember to include the units in your calculations.  
Review this problem to be sure you understand every step before going to the next panel for another problem.

### 3. Pressure Measurement

#### Example 3.9

Calculate the difference in pressure between points A and B in Fig. 3.11 and express it as  $p_B - p_A$ .



## 3. Pressure Measurement

### Example 3.9

---

This type of manometer is called a *differential manometer* because it indicates the difference between the pressure at two points but not the actual value of either one. Do Step 1 of the procedure to write the equation for the manometer.

We could start either at point A or point B. Let's start at A and call the pressure  $p_A$  there. Now write the expression for the pressure at point 1 in the left leg of the manometer.

$$p_A + \gamma_o(0.86 \text{ m})$$

where  $\gamma_o$  is the specific weight of the oil.

## 3. Pressure Measurement

### Example 3.9

---

What is the pressure at point 2? It is the same as the pressure at point 1 because the two points are on the same level.

Go on to point 3 in the manometer.

$$p_A + \gamma_o(0.86 \text{ m}) - \gamma_w(0.75 \text{ m})$$

Now write the expression for the pressure at point 4.

$$p_A + \gamma_o(0.86 \text{ m}) - \gamma_w(0.75 \text{ m}) - \gamma_o(0.11 \text{ m})$$

## 3. Pressure Measurement

### Example 3.9

Our final expression should be the complete manometer equation,

$$p_A + \gamma_o(0.86 \text{ m}) - \gamma_w(0.75 \text{ m}) - \gamma_o(0.11 \text{ m}) = p_B$$

$$p_B - p_A = \gamma_o(0.86 \text{ m}) - \gamma_w(0.75 \text{ m}) - \gamma_o(0.11 \text{ m})$$

$$\gamma_o = (\text{sg})_o(9.81 \text{ kN/m}^3) = (0.86)(9.81 \text{ kN/m}^3) = 8.44 \text{ kN/m}^3$$

$$\gamma_w = 9.81 \text{ kN/m}^3$$

In this case it may help to simplify the expression before substituting known values. Because two terms are multiplied by  $\gamma_o$  they can be combined as follows:

$$p_B - p_A = \gamma_o(0.75 \text{ m}) - \gamma_w(0.75 \text{ m})$$

$$p_B - p_A = (0.75 \text{ m})(\gamma_o - \gamma_w)$$

## 3. Pressure Measurement

### Example 3.9

---

The pressure at B, then, is

$$\begin{aligned} p_B - p_A &= (0.75 \text{ m})(8.44 - 9.81) \frac{\text{kN}}{\text{m}^3} \\ &= (0.75)(-1.37) \frac{\text{kN}}{\text{m}^2} \\ p_B - p_A &= -1.03 \text{ kN/m}^2 \end{aligned}$$

The negative sign indicates that the magnitude of  $p_A$  is greater than that of  $p_B$ . Notice that using a gage fluid with a specific weight very close to that of the fluid in the system makes the manometer very sensitive. A large displacement of the column of gage fluid is caused by a small differential pressure and this allows a very accurate reading.



## 3. Pressure Measurement

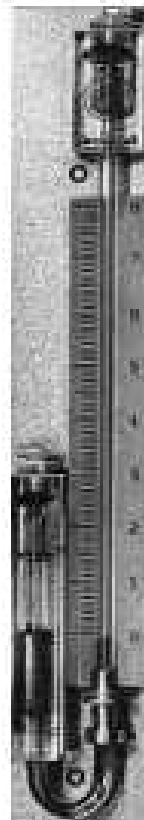
### 3.5 Manometers

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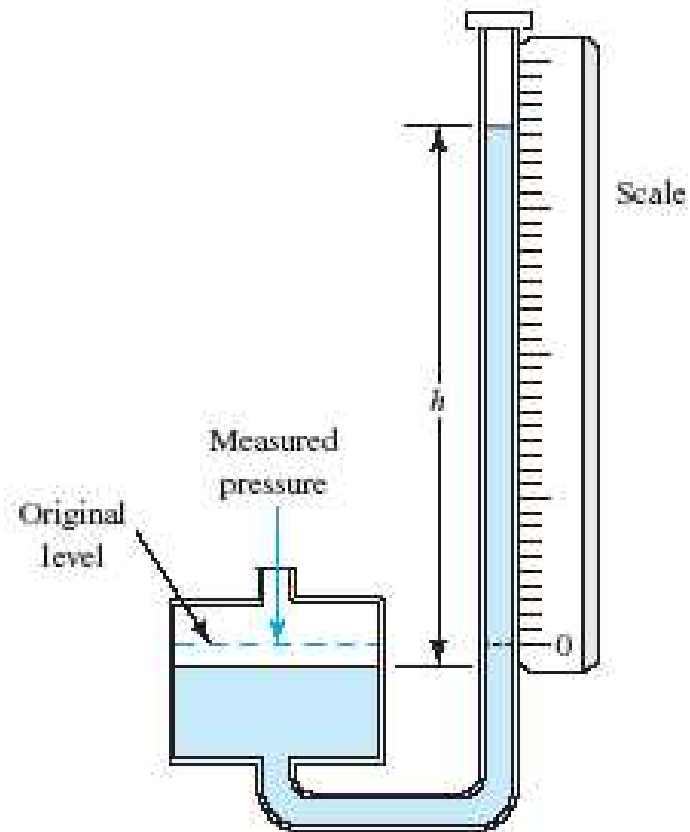
- Fig 3.12 shows the Well-type manometer.
- When a pressure is applied to a well-type manometer, the fluid level in the well drops a small amount while the level in the right leg rises a larger amount in proportion to the ratio of the areas of the well and the tube.
- A scale is placed alongside the tube so that the deflection can be read directly.
- The scale is calibrated to account for the small drop in the well level.

# 3. Pressure Measurement

## 3.5 Manometers



(a)



(b)

## 3. Pressure Measurement

### 3.5 Manometers

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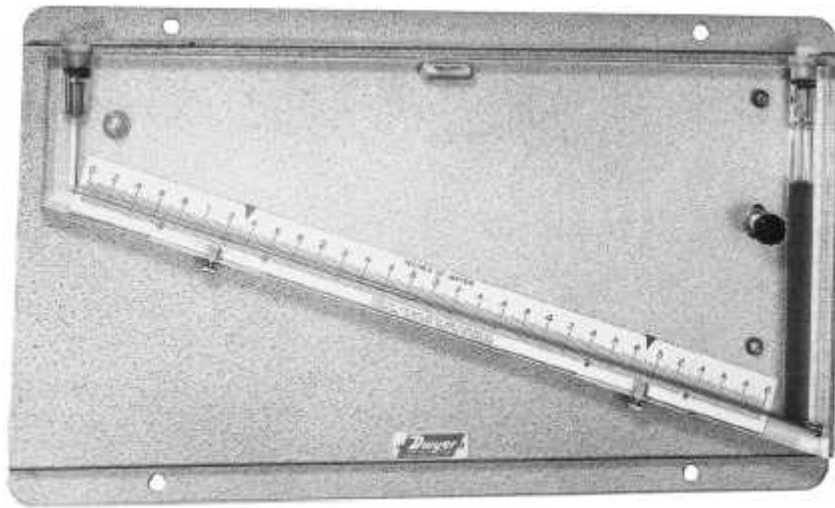
- Fig 3.13 shows the Inclined well-type manometer.
- It has the same features as the well-type manometer but offers a greater sensitivity by placing the scale along the inclined tube.
- The scale length is increased as a function of the angle of inclination of the tube,  $\theta$ .

$$\frac{h}{L} = \sin \theta$$

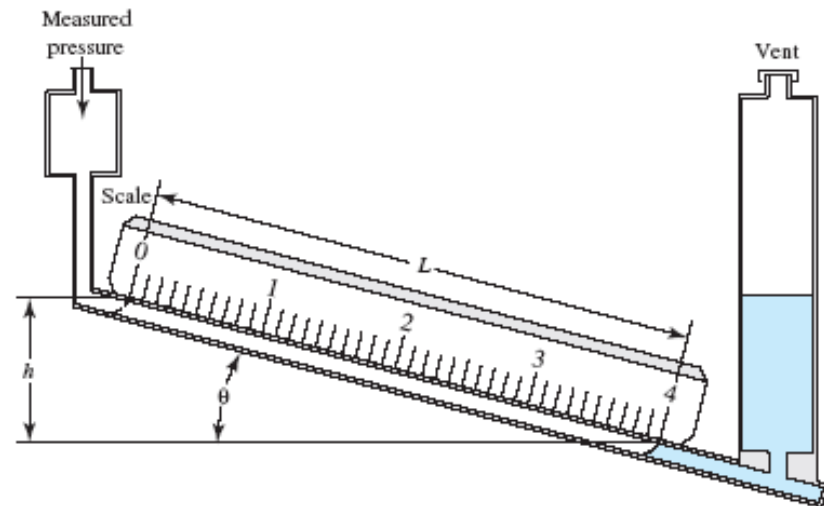
where  $L$  is the scale length and  $h$  is the manometer deflection

# 3. Pressure Measurement

## 3.5 Manometers



(a)



(b)

## 3. Pressure Measurement

### 3.6 Barometers

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- Fig 3.14 shows the barometers.
- It consists of a long tube closed at one end that is initially filled completely with mercury.
- By starting at this point and writing an equation similar to those for manometers, we get

$$0 + \gamma_m h = p_{\text{atm}}$$

$$P_{\text{atm}} = \gamma_m h \quad (3-12)$$

## 3. Pressure Measurement

### Example 3.10

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A news broadcaster reports that the barometric pressure is 772 mm of mercury. Calculate the atmospheric pressure in kPa(abs).

In Eq. (3–12),

$$p_{\text{atm}} = \gamma_{\text{m}} h$$

$$\gamma_{\text{m}} = 132.8 \text{ kN/m}^3$$

$$h = 0.772 \text{ m}$$

$$p_{\text{atm}} = (132.8 \text{ kN/m}^3)(0.772 \text{ m}) = 102.5 \text{ kN/m}^2 = 102.5 \text{ kN/m}^2(\text{abs})$$

## 3. Pressure Measurement

### Example 3.11

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The standard atmospheric pressure is 101.3 kPa. Calculate the height of a mercury column equivalent to this pressure.

We begin with Eq. (3–12),

$$h = \frac{P_{\text{atm}}}{\gamma_m} = \frac{101.3 \times 10^3 \text{ N}}{\text{m}^2} \times \frac{\text{m}^3}{132.8 \times 10^3 \text{ N}} = 0.76 \text{ m} = 760 \text{ mm}$$

## 3. Pressure Measurement

### 3.7 Pressure expressed as the Height of a Column of Liquid

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- When measuring pressures in some fluid flow systems, such as air flow in heating ducts, the magnitude of the pressure reading is often small.
- To convert from such units to those needed in calculations, the pressure– elevation relationship must be used.
- For example,

$$p = \gamma h$$

$$p = \frac{9.81 \text{ kN}}{\text{m}^3} (1 \text{ m}) = 9.81 \text{ kN/m}^2$$



## 3. Pressure Measurement

### 3.7 Pressure expressed as the Height of a Column of Liquid

---

- Then we can use this as a conversion factor,

$$1.0 \text{ mH}_2\text{O} = 9.81 \text{ kN/m}^2$$

$$1.0 \text{ mH}_2\text{O} = 9.81 \text{ kPa}$$

## 3. Pressure Measurement

### 3.8 Pressure Gages and Transducers

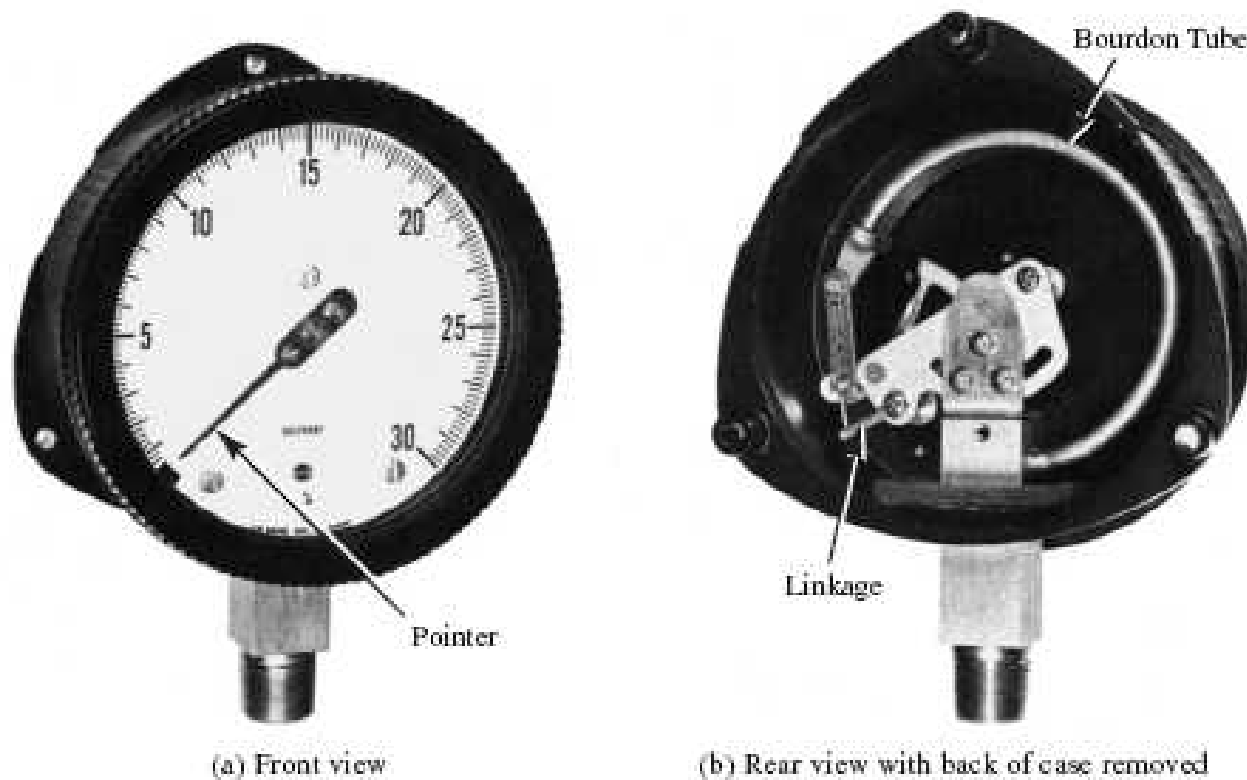
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- For those situations where only a visual indication is needed at the site where the pressure is being measured, a *pressure gage* is used.
- In other cases there is a need to measure pressure at one point and display the value at another.
- The general term for such a device is *pressure transducer*, meaning that the sensed pressure causes an electrical signal to be generated that can be transmitted to a remote location such as a central control station where it is displayed digitally.

## 3. Pressure Measurement

### 3.8.1 Pressure Gages

- Fig 3.15 shows the Bourdon tube pressure gage.



## 3. Pressure Measurement

### 3.8.1 Pressure Gages

---

- The pressure to be measured is applied to the inside of a flattened tube, which is normally shaped as a segment of a circle or a spiral.
- The increased pressure inside the tube causes it to be straightened somewhat.
- The movement of the end of the tube is transmitted through a linkage that causes a pointer to rotate.

## 3. Pressure Measurement

### 3.8.1 Pressure Gages

- Figure 3.16 shows a pressure gage using an actuation means called *Magnehelic pressure gage*.



(a)



(b)



(c)

## 3. Pressure Measurement

### 3.8.2 Strain Gage Pressure Transducer

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- Fig 3.17 shows the strain gage pressure transducer and indicator.
- The pressure to be measured is introduced through the pressure port and acts on a diaphragm to which foil strain gages are bonded.
- As the strain gages sense the deformation of the diaphragm, their resistance changes.
- The readout device is typically a digital voltmeter, calibrated in pressure units.

## 3. Pressure Measurement

### 3.8.2 Strain Gage Pressure Transducer



(a) Strain gage pressure transducer



(b) Digital electronic amplifier/indicator

## 3. Pressure Measurement

### 3.8.3 LVST-Type Pressure Transducer

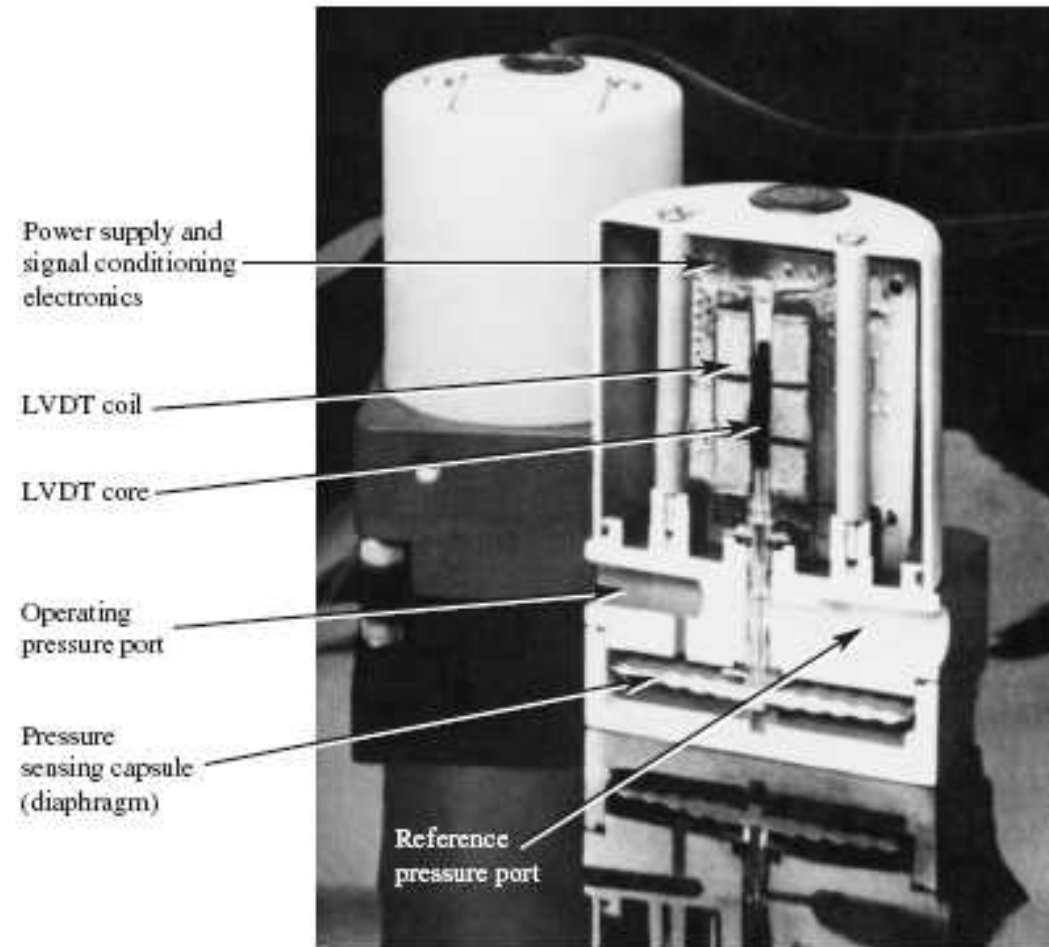
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- A *linear variable differential transformer* (LVDT) is composed of a cylindrical electric coil with a movable rod-shaped core.
- As the core moves along the axis of the coil, a voltage change occurs in relation to the position of the core.
- This type of transducer is applied to pressure measurement by attaching the core rod to a flexible diaphragm.
- Fig 3.18 shows the Linear variable differential transformer (LVDT)-type pressure transducer.



## 3. Pressure Measurement

### 3.8.3 LVST-Type Pressure Transducer



## 3. Pressure Measurement

### 3.8.4 Piezoelectric Pressure Transducer

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- Certain crystals, such as quartz and barium titanate, exhibit a *piezoelectric effect*, in which the electrical charge across the crystal varies with stress in the crystal.
- Causing a pressure to exert a force, either directly or indirectly, on the crystal leads to a voltage change related to the pressure change.
- Fig 3.19 shows the digital pressure gage.

## 3. Pressure Measurement

### 3.8.4 Piezoelectric Pressure Transducer



Pressure port