Pressure Hulls and Canisters 1
Cornerstone Electronics Technology and Robotics III
(Notes primarily from "Underwater Robotics – Science Design and Fabrication", an excellent book for the design, fabrication, and operation of Remotely Operated Vehicles ROVs)

- **Administration:**
  - Prayer
- **Basics of Pressure:**
  - Fluid - A substance that has no fixed shape and yields easily to external pressure; a gas or a liquid.
  - Pressure – the force per unit area applied in a direction perpendicular to the surface of an object.
  - Pushing a fluid (gas of liquid) into a confined space results in pressurizing the fluid.

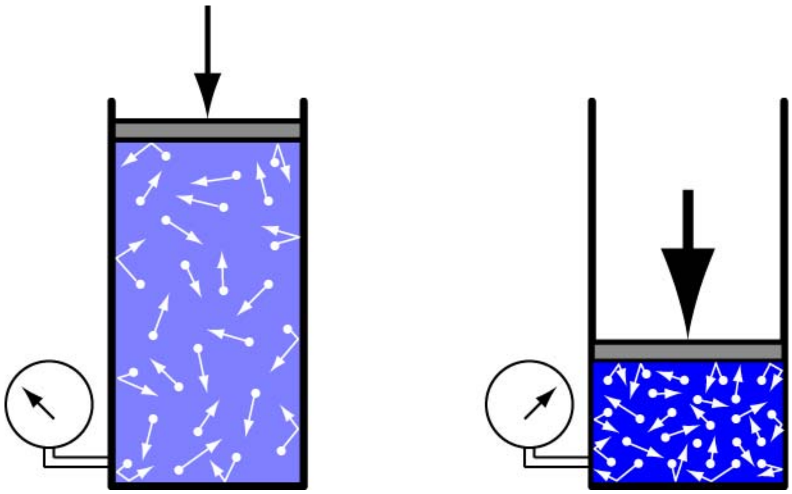


Figure 1: Pushing a Fluid into a Confined Space Increases Its Pressure

  - Force and pressure are different. Force can be described by intuitive concepts such as a push or pull that can cause an object with mass to change its velocity, i.e., to accelerate, or which can cause a flexible object to deform.

    Pressure is the amount of force acting on a unit area. It is usually more convenient to use pressure rather than force to describe the influences upon fluid behavior. Mathematically, force and pressure are related by the equation:

$$F = P \times A$$

Where: F = Force in pounds or Newtons
P = Pressure in pounds per square inch (psi) or Pascals (Pa or N/m^2)
A = Area in in^2 or m^2

Example: When a pressure of 20 psi is applied over a surface, the pressure creates a force of 20 pounds on each square inch. If the area of the surface is 100 in^2, then there are 100 – 20 pound forces acting on the surface. Refer to Figure 2. Although the 20 pound force on each square inch is shown as a single force, it is actually distributed uniformly over the one square inch surface.

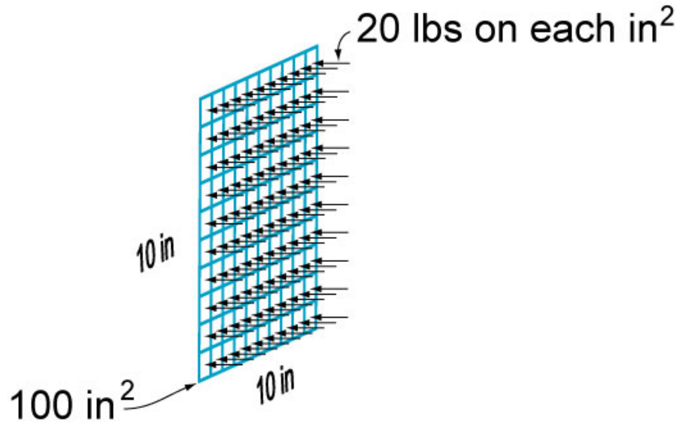


Figure 2: A Pressure of 20 psi Acting upon a 100 in^2 Surface

To keep the surface at rest, the 20 psi pressure must be equalized with a force in the opposite direction.

$$F = P \times A$$
$$F = 20\ lbs/in^2 \times 100\ in^2$$
$$F = 2000\ lbs$$

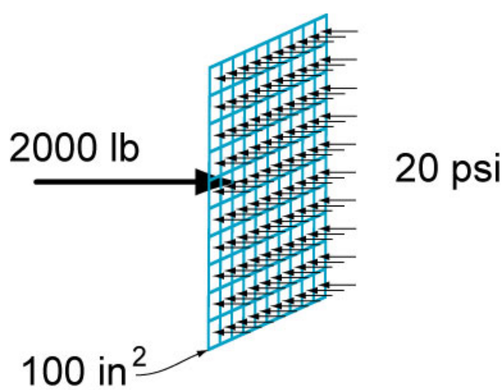


Figure 3: The Force Needed to Equalize the 20 psi Pressure over 100 in^2

- One way fluid pressure is created is by the weight of the fluid pressing down on itself. See the demonstration using water as the fluid : http://www.youtube.com/watch?v=sh2NOoDZUzM

- Atmospheric Pressure - Pressure caused by the weight of the atmosphere. At sea level it has a mean value of one atmosphere (1 atm) but reduces with increasing altitude. See Figure 4.

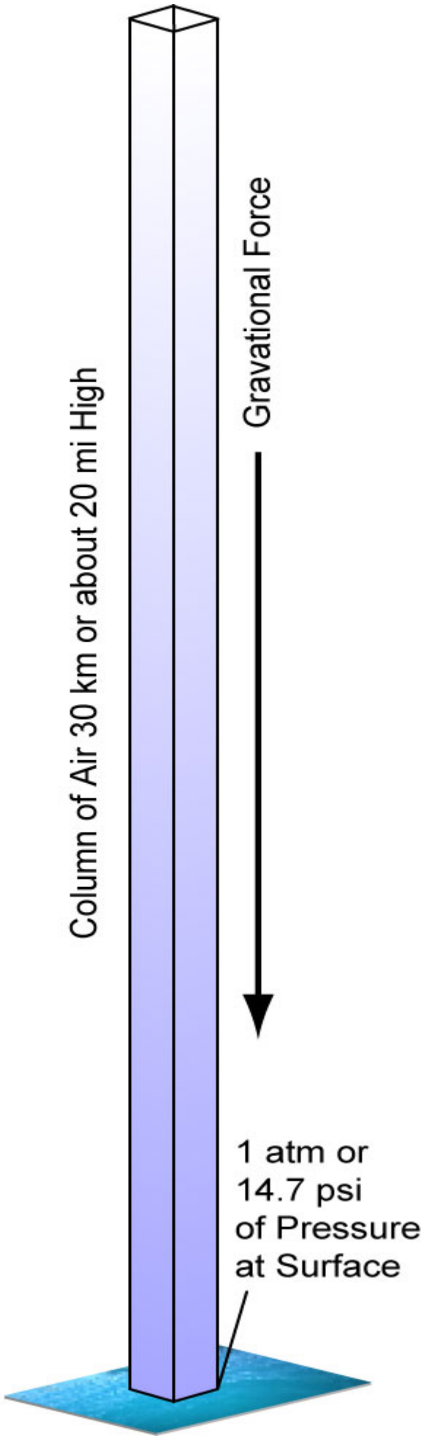


Figure 4: Atmospheric Pressure

- Pressure Differentials:
  - Pressure differential – the difference in pressure between two points.

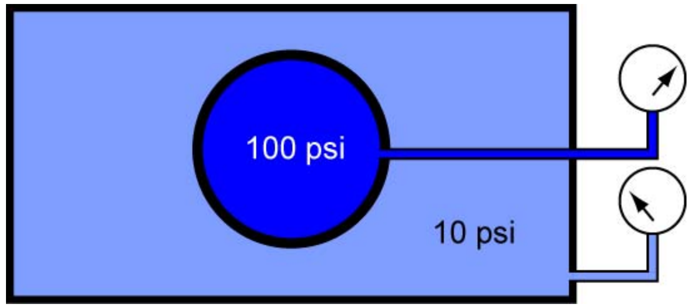
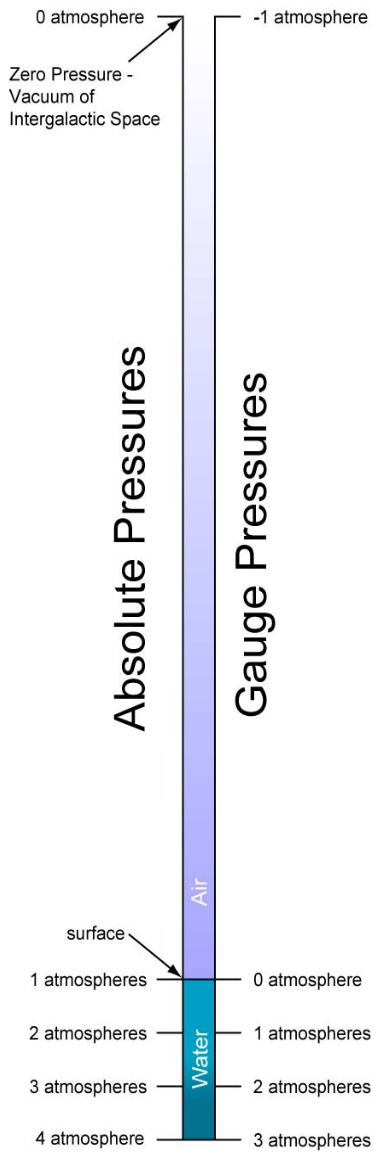


Figure 5: Pressure Differential of 90 psi

  - In 2008, a team of researchers exploring the Japan Trench with a ROV filmed footage of the deepest-known species of fish. The fish was living at the extreme depth of 25,272 ft (7703 m). The fish are not crushed because their internal pressure is the same as the pressure surrounding them.
  - Pressure differentials, not pressures alone, generate the complexity in an underwater vehicle design. Large differentials will require a more robust hull than smaller pressure differentials.

- Gauge Pressure vs. Absolute Pressure
  - There are two kinds of references to measure pressure – gauge pressure and absolute pressure.
  - The absolute pressure (psia) is measured relative to the absolute zero pressure. Absolute pressure is pressure that would occur at absolute vacuum, or zero pounds per square inch. Absolute pressure is used for scientific experimentations and calculations. All calculations involving the gas laws require pressure, and temperature to be in absolute units.
  - Gauge pressure (psig) uses local atmospheric pressure as its zero point. Gauge pressure is the most commonly used reference of pressure. Machines like air compressors, well pumps, and tire gauges will all use gauge pressure.
  - It should be noted that atmospheric pressure may vary, depending on many factors, such as locality. Altitude and temperature are essential factors. Due to varying atmospheric pressure, gauge pressure measurement is not precise.



Generally,

$$psia = psig + 1\ atm$$

Where:

psia = Absolute pressure
psig = Gauge pressure
atm = 1 atmosphere

Figure 6: Absolute Pressure vs. Gauge Pressure

- Pressure Units:
  - All pressure units refer to force per area.
  - **Pounds per Square Inch** (psi) – 1 pound of force per 1 square inch
  - **Atmosphere** (atm) – the normal atmospheric pressure at sea level, about 14.7 pounds per square inch (101.3 kilopascals), with the air temperature of 20 degrees C (68 degrees F) (NIST).
  - **Pascal** (Pa) – the SI (International System of Units) derived unit of pressure, defined as one newton per square meter.
  - **Bar** (bar) – a unit of pressure equal to 100 kilopascals (100,000 Pa)
  - **Inches or mm of mercury (" Hg)** – a unit of measurement for pressure that is still widely used for barometric pressure in weather reports and aviation in the United States, but is seldom used elsewhere. See Figure 7 and the section regarding barometers later in this lesson.

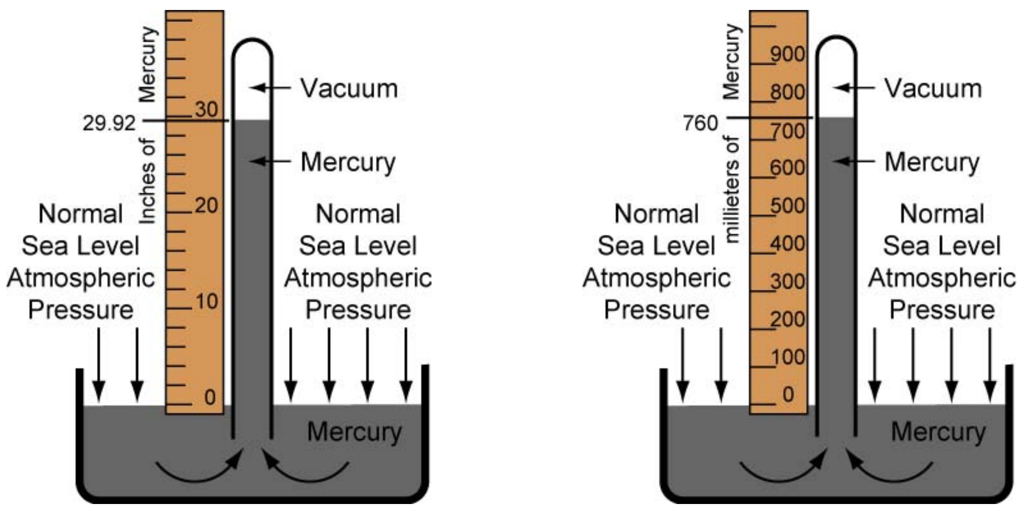


Figure 7: Mercury Barometer Standard Atmospheric Pressure at Sea Level is 29.92 Inches or 760 mm of Mercury

  - 1 atm = 14.6959 psi = 101,325 Pa = 1.01325 bars = 29.9213 "Hg
  - On-line pressure calculator: http://www.cleavebooks.co.uk/scol/ccpress.htm

- Devices for Measuring Pressure (and Depth):
  - **Manometer:** an instrument for measuring the pressure of fluids, consisting of a tube filled with a colored liquid, the level of the colored liquid being determined by the pressure of the fluids.
  - As a sensitive instrument, a manometer is used to measure small not large pressure differences

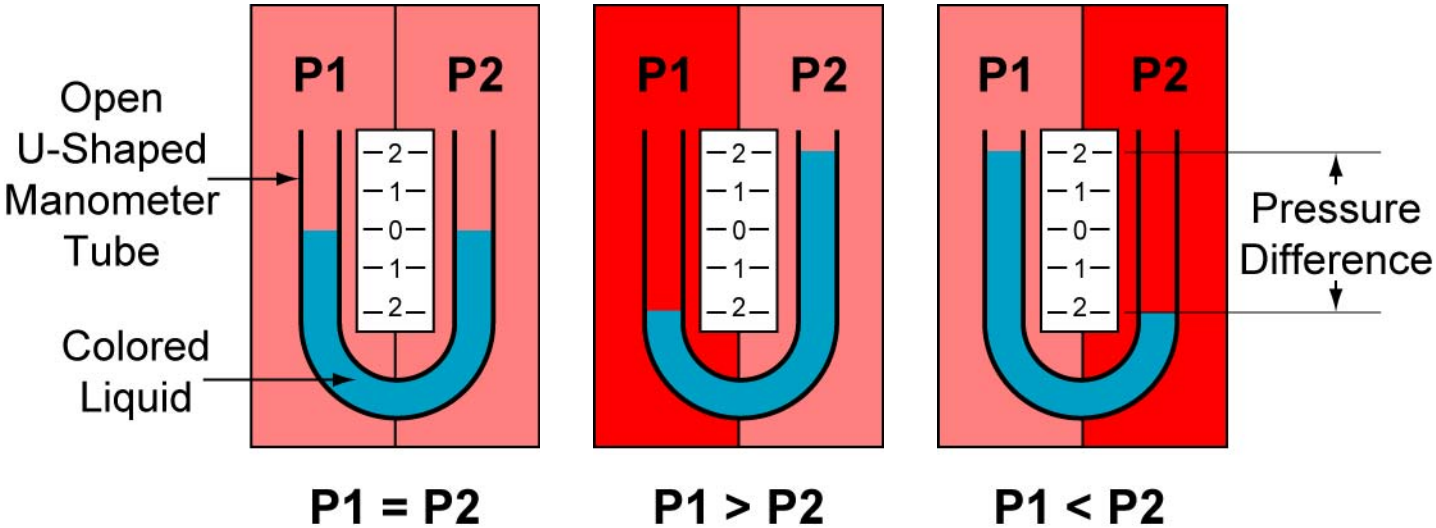


Figure 8: Manometer Responds to Fluid Pressure 1 (P1) and Fluid Pressure 2 (P2)

  - **Barometer:** an instrument that measures absolute atmospheric pressure used especially in forecasting the weather and determining altitude.
    - May be considered an adaptation of the manometer

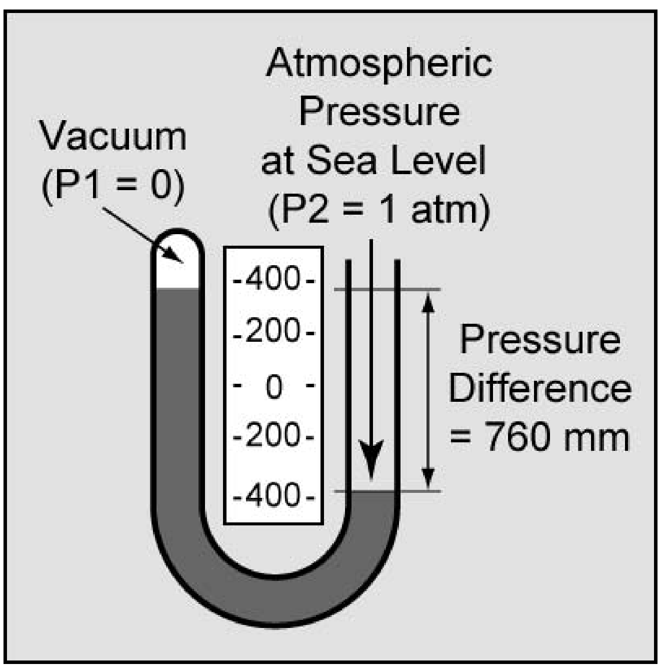


Figure 9: Barometer as an Adaptation of a Manometer

- Mercury barometer as a closed tube filled with mercury inverted in a mercury reservoir:

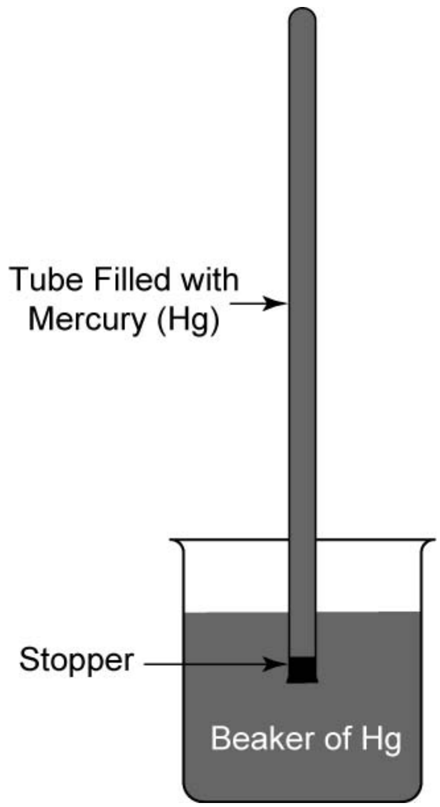


Figure 10a: A tube filled with mercury (Hg) is stopped with a cork and inverted into a beaker of mercury.

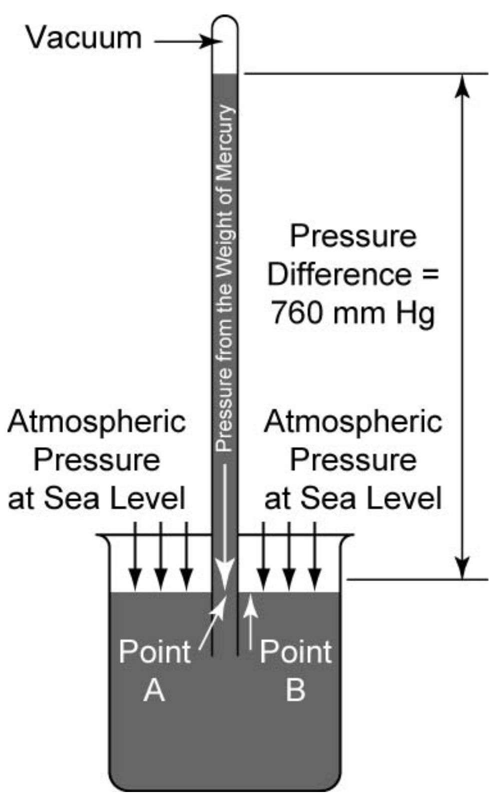


Figure 10b: When the cork is removed, mercury flows out of the tube until pressure due to the column of mercury at Point A just balances atmospheric pressure at Point B. The region above the mercury in the tube is an almost perfect vacuum with zero pressure. Therefore, the pressure of the mercury column at sea level equals the atmospheric pressure of 1 atm (760 mm Hg).

- **Dial Pressure Gauges:** A gauge that indicates pressure by needle movements usually on a round dial. Dial gauges measure pressure relative to ambient atmospheric pressure as its zero point.

Figure 11: Several Dial Pressure Gauges

- **Integrated (Electronic) Pressure Sensors:** Pressure sensors made of integrated circuits that generate digital output signals that vary with pressure. These sensors are interfaced with other electronic device for display and recording.

Figure 12: An Assortment of Integrated Pressure Sensors

- **Depth Gauges:** A pressure gauge with a display in feet or meters.

Figure 13: Examples of Analog and Digital Depth Gauges

- o Two sources of pressure under water, hydrostatic and hydrodynamic:

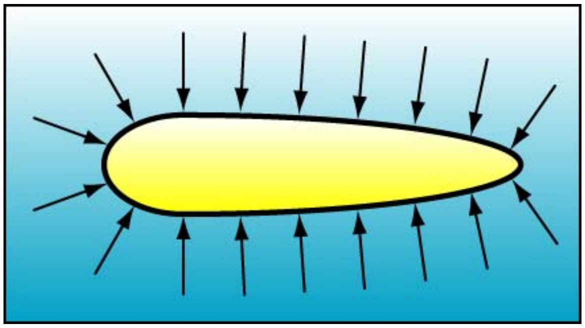


Figure 14a: Hydrostatic pressure is the pressure that exists in static conditions – when the object is at rest in water that is not moving. The source of hydrostatic pressure is the weight of the water above the object.

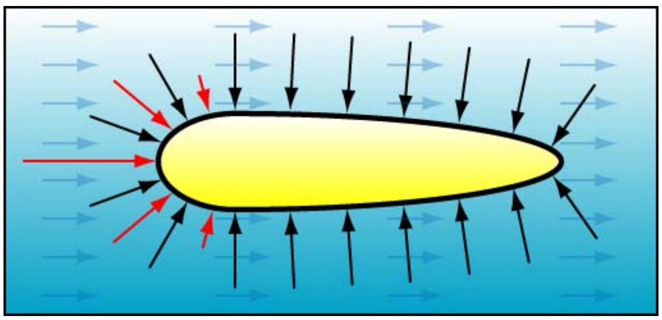


Figure 14b: Hydrodynamic pressure is the pressure related to motion in water. The relative motion between the object and the water may be due to the movement of the object, the water, or a combination of both. Pressure is increased on the upstream end of the object. Figure 14b illustrates hydrostatic pressure with black arrows and the hydrodynamic pressure with red arrows.

- o Calculating hydrostatic pressure:
  - Simple ways to remember hydrostatic pressure in water (not exact):
    - In freshwater, pressure increases 1 atm every 34 ft of depth.
    - In saltwater, pressure increases 1 atm every 33 ft of depth.
    - In saltwater, pressure increases 1 atm every 10 m of depth.
  - Verify the above relationship for freshwater:

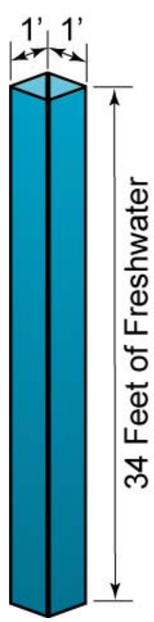


Figure 15: Pressure at the Bottom of a 34' Column of Freshwater:

Weight of 34' water column = 62.4 lbs/ft^3 x 34 ft x 1 ft x 1 ft
Weight of 34' water column = 2121.6 lbs

$$\text{Pressure} = \frac{2121.6 \text{ lbs}}{144 \text{ in}^2}$$

Pressure = 14.7 psi = 1 atm

- Calculating hydrostatic pressures at different depths:

  Example 1: Find the pressure in saltwater at 30 meters:

Set up the proportion:

Ratio with Knowns = Ratio with Unknown Pressure x

$$\frac{1\text{ atm}}{10\text{ m}} = \frac{x\text{ atm}}{30\text{ m}}$$

Solving for x,

$$x = \frac{1\text{ atm x } 30\text{ m}}{10\text{ m}}$$

$$x = 3\text{ atm}$$

Example 2: Find the pressure in freshwater at 13 feet. Give your answer in psi.

Set up the proportion:

Since 1 atm = 14.7 psi,

$$\frac{1\text{ atm}}{34\text{ ft}} = \frac{14.7\text{ psi}}{34\text{ ft}}$$

Ratio with Knowns = Ratio with Unknown Pressure x

$$\frac{14.7\text{ psi}}{34\text{ ft}} = \frac{x\text{ psi}}{13\text{ ft}}$$

Solving for x,

$$x = \frac{14.7\text{ psi x } 13\text{ ft}}{34\text{ ft}}$$

$$x = 5.6\text{ psi}$$

- **Pressure Related Forces on Submerged Objects:**
  - If a surface divides two chambers of different pressures, a force acts upon that surface pushing it toward the chamber of lower pressure.
  - For example in the sketch below, two chambers with different pressures are separated by a surface of 1 in^2.

Force = Pressure Differential x Surface Area
Force = 15 psi (lbs/in^2) x 1 in^2
Force = 15 lbs (toward the chamber of lower pressure)

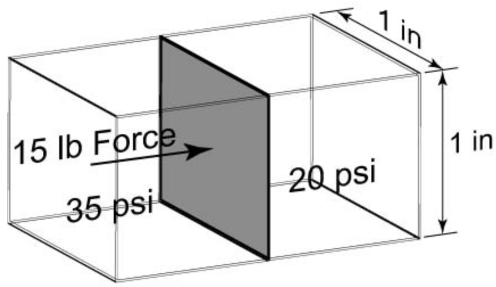


Figure 16: Calculating the Force on a 1 in^2 Surface Area

If the area between the chambers is quadrupled to 4 in^2,

Force = Pressure Differential x Surface Area
Force = 15 psi (lbs/in^2) x 4 in^2
Force = 60 lbs (toward the chamber of lower pressure)

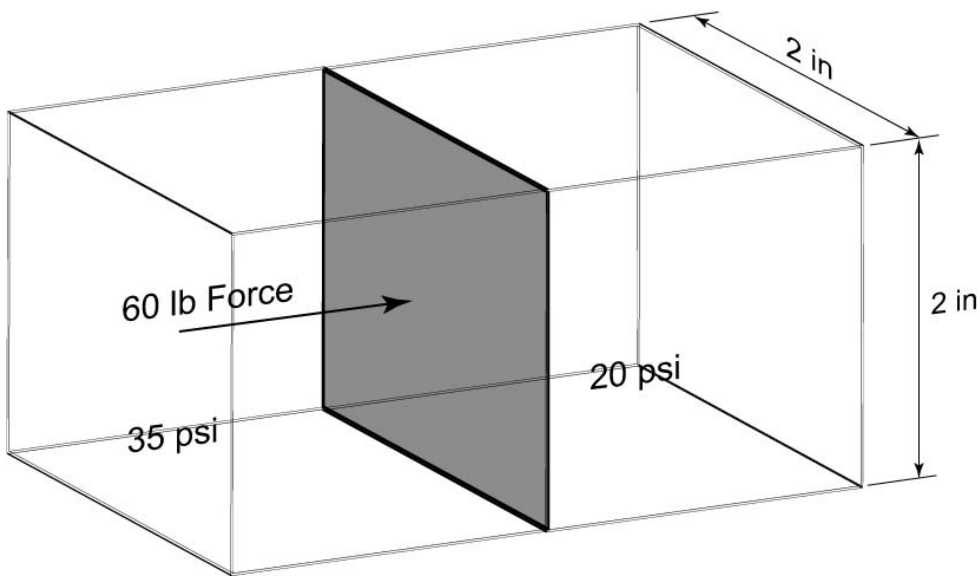


Figure 16: Calculating the Force on a 4 in^2 Surface Area

See: http://www.videojug.com/film/how-to-put-a-ruler-under-pressure-2

- **Basic Principles of Pressure Hull Design:**
  - Pressure hull design considers four criteria:
    - Minimize hull size to minimize the surface area.
    - Use pressure-resistant shapes.
    - Build the hull with materials that have a high strength-to-weight ratio to minimize the vehicle mass.
    - Use pressure to your advantage.
  - **Size:**
    - Since the force on a hull is given by:

      Force = Pressure Differential x Surface Area

      Unless the differential pressure is zero, reducing the surface area will reduce the force on the hull.
    - Smaller surface area also means less material cost for the hull.
  - **Pressure-Resistant Shapes:**
    - A sphere is the most pressure-resistant shape. Pressure is distributed uniformly over the entire surface of a sphere making it self-supporting. If a force is applied on one section of a sphere - tending to make that section collapse, another section of the sphere must bulge out because of the nature of its shape. That bulge is resisted by the uniform pressure on the sphere.
    - A cube or a rectangle has poor pressure-resistance. One section may collapse without another section bulging as in the spherical shape.
    - A cylinder is also a pressure-resistant shape because of its roundness, though not as effective as a sphere. Its advantages over a sphere are that it is easier to manufacture and its interior space is better suited for use.
  - **Materials:**
    - The ideal material for a pressure-resistant hull would be light weight, robust, corrosive-resistant, and inexpensive. Unfortunately, the first three virtues do not coincide with the last.
    - Knowing the depth of the mission lets the designer determine the maximum pressure the hull must endure. Given the size of the hull, the pressure related forces acting it can then be calculated. Now you can generate a list of materials within your budget that will withstand the forces encountered in the mission.
  - **Using Pressure to Your Advantage:**
    - Use water pressure to help seal hatches and covers on the vehicle.

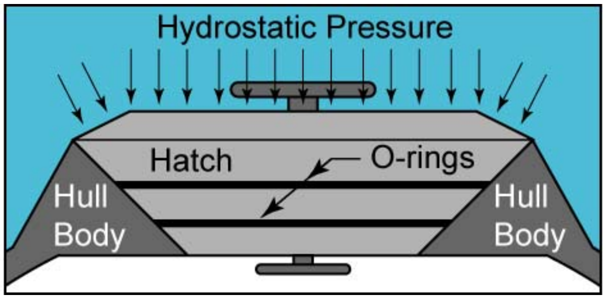


Figure 17: Water Pressure Pressing Down to Help Seal Hatch

- Choosing Canister Size and Single/Multiple Cans:
  - The pressure canister size is determined by the dimensions and weight of what has to be put into it.
  - Advantages of a single can:
    - Contains all of the electronics and batteries which minimize the number of penetrators required.
    - Simplifies construction with less complex framework
    - Often less costly
    - Can have less drag than multiple cans
  - Advantages of multiple cans:
    - More flexibility of component placement
    - More options to distribute weight on the vehicle, making it easier to trim and avoid blocking thruster propulsion
    - A leak in one canister generally saves components in other canisters from damage.
    - Canisters built exclusively for on-board batteries can be designed for easy access and change-out.