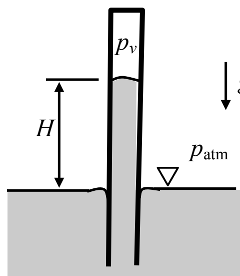
Pressure Measurements Using Barometers and Manometers
As noted previously, differences in elevation can be used to measure differences in pressure. This is the principle by which barometers and manometers operate. Let's first consider a barometer, which is most often used to measure atmospheric pressure. A sketch of a **barometer** is shown below. A barometer consists of a tube that is open on one end. The tube is filled with a "working liquid", often mercury or water, which is then immersed in a large bath of the liquid and turned upside down and lifted out of the bath to the configuration shown in the figure. Using this method, the weight of the liquid in the tube is balanced by the pressure difference between the external pressure (normally atmospheric pressure, p_{atm}) and the pressure at the top of the column of liquid column, which is the vapor pressure of the liquid (p_v).



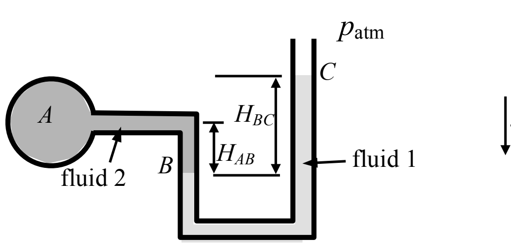
Using Eq. (2.10),

$$p_v = p_{\text{atm}} - \rho g H \Rightarrow p_{\text{atm}} = p_v + \rho g H \ . \tag{2.21}$$

Thus, atmospheric pressure can be measured by measuring the height of the column of liquid in the barometer and knowing the liquid density and vapor pressure.

Notes:
1. Vapor pressure varies with temperature. Thus, it's important to also measure the temperature when using a barometer for obtaining accurate results. Since the vapor pressure is often much smaller than atmospheric pressure, it is sometimes neglected in Eq. (2.21), but doing so does introduce some inaccuracy into the atmospheric pressure calculation.
2. At a standard atmospheric pressure and temperature of 101.3 kPa (abs) and 15 °C, respectively, the height of a column of mercury (ρ = 13600 kg/m^3, p_v = 1.11*10^{-4} kPa (abs)) is 760 mm, which is a reasonable height to have in a laboratory setting. Using water, (ρ = 1000 kg/m^3, p_v = 1.71 kPa (abs)), the height is 10.2 m, which is much more challenging to accommodate. Hence, most barometers still use mercury as a working liquid.

A manometer is similar to a barometer in that the height difference in a working fluid, typically a liquid, is used to measure pressure differences. However, a manometer does not have one end of the working liquid at vapor pressure. An example of a **U-tube manometer** is shown in the following figure.



In this previous figure, there are two incompressible fluids, fluid 1 and fluid 2 with corresponding densities ρ_1 and ρ_2. Let's determine the pressure at *A* starting with the pressure at *C* using Eq. (2.10), which depends only on elevation differences in a given fluid,

$$p_C = p_{\text{atm}} , \tag{2.22}$$

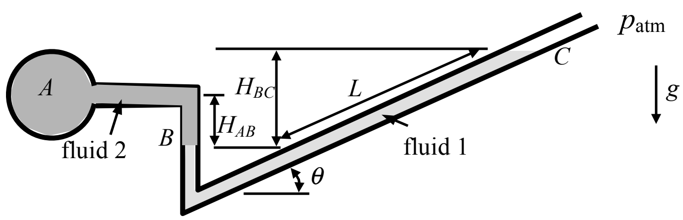
$$p_B = p_C + \rho_1 g H_{BC} \quad \text{(moving through fluid 1)}, \tag{2.23}$$

$$p_A = p_B - \rho_2 g H_{AB} \quad \text{(moving through fluid 2)}, \tag{2.24}$$

$$\Rightarrow \quad p_A = p_{\text{atm}} + \rho_1 g H_{BC} - \rho_2 g H_{AB} \quad \text{or} \quad p_A - p_{\text{atm}} = \rho_1 g H_{BC} - \rho_2 g H_{AB} \tag{2.25}$$

Thus, by measuring differences in height, it's possible to measure differences in pressure.

Another common type of manometer is known as an **inclined tube manometer** and is shown in the following sketch. This type of manometer is used most often when small differences in pressure are to be measured since small elevation differences correspond to large differences in length in the inclined arm, especially for small angles θ.



As before, determine the pressure at *A* starting with the pressure at *C*,

$$p_C = p_{\text{atm}} , \tag{2.26}$$

$$p_B = p_C + \rho_1 g H_{BC} \quad \text{(moving through fluid 1)}, \tag{2.27}$$

$$p_A = p_B - \rho_2 g H_{AB} \quad \text{(moving through fluid 2)}, \tag{2.28}$$

$$\Rightarrow \quad p_A - p_{\text{atm}} = \rho_1 g H_{BC} - \rho_2 g H_{AB} \quad \text{or} \quad p_A - p_{\text{atm}} = \rho_1 g L \sin\theta - \rho_2 g H_{AB} , \tag{2.29}$$

where,

$$H_{AB} = L \sin\theta . \tag{2.30}$$

Thus, for small θ, small variations in H_{BC}, will be magnified into large variations in *L*.

Notes:

1. If a gas is used as one of the fluids in the manometer, then the pressure in that gas can be reasonably assumed to remain constant with elevation.
2. One of the reasons we use gage pressures instead of absolute pressures is because if one of the ends of the manometer is open to the atmosphere, then the pressure at the other end can be treated as a gage pressure, such as in Eqs. (2.25) and (2.29).
3. A good approach to working through manometer pressures is to start at one end of the manometer and calculate the pressure at each fluid interface until reaching the other end of the manometer, as done in the previous two examples. Moving down in the fluid adds pressure (to support the weight of the fluid above it) while moving up in the manometer subtracts pressure (less weight to support). Note that moving horizontally *in the same fluid* does not change the pressure.
4. There are other styles of manometers, but they all operate on the same principle: pressure differences are measured using differences in elevations of fluids.
5. Nowadays, the use of electronic pressure transducers is common for measuring pressures. Pressure transducers have much faster response times than manometers and can more accurately measure small pressure differences. Nevertheless, manometers are still useful since (a) they are simple and cheap and (b) need not be calibrated.