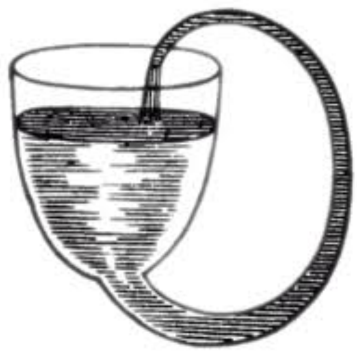
INDIAN INSTITUTE OF TECHNOLOGY, BOMBAY
Department of Metallurgical Engineering and Materials Science
MM 209: THERMODYNAMICS : 2017-18: FALL

Tutorial 1 **Date:1/08/2017**

1. Does the following capillary bowl work? Why?



In reality, this is not possible because surface tension will hold it in a droplet at the end of the tube rather than letting it fall.

2. Recent communication with the inhabitants of Neptune has revealed that they have a Celsius-type temperature scale, but based on the melting point (0°N) and boiling point (100°N) of their most common substance, hydrogen. Further communications have revealed that the Neptunians know about perfect gas behaviour and they find that, in the limit of zero pressure, the value of pV is 28 dm^3 atm at 0°N and 40 dm^3 atm at 100°N. What is the value of the absolute zero of temperature on their temperature scale?

Since the Neptunians know about perfect gas behavior, we may assume that they will write $pV = nRT$ at both temperatures. We may also assume that they will establish the size of their absolute unit to be the same as the °N, just as we write 1 K = 1°C. Thus

$$pV(T_1) = 28.0\,\text{dm}^3\,\text{atm} = nRT_1 = nR \times (T_1 + 0°\text{N}),$$

$$pV(T_2) = 40.0\,\text{dm}^3\,\text{atm} = nRT_2 = nR \times (T_1 + 100°\text{N}),$$

or $T_1 = \dfrac{28.0\,\text{dm}^3\,\text{atm}}{nR}$, $\quad T_1 + 100°\text{N} = \dfrac{40.0\,\text{dm}^3\,\text{atm}}{nR}$.

Dividing, $\dfrac{T_1 + 100°\text{N}}{T_1} = \dfrac{40.0\,\text{dm}^3\,\text{atm}}{28.0\,\text{dm}^3\,\text{atm}} = 1.42\overline{9}$ or $T_1 + 100°\text{N} = 1.42\overline{9}T_1$, $T_1 = 233$ absolute units.
As in the relationship between our Kelvin scale and Celsius scale $T = \theta -$ absolute zero(°N) so absolute zero (°N) = $\boxed{-233°\text{N}}$.

3. Air is contained in a vertical piston–cylinder assembly fitted with an electrical resistor. The atmosphere exert a pressure of 14.7 lbf/in.^{2} on the top of the piston, which has a mass of 100 lb and a face area of 1 ft^2. Electric current passes through the resistor, and the volume of the air slowly increases by 1.6 ft^3 while its pressure remain constant. The mass of the air is 0.6 lb, and its specific internal energy increases by 18 Btu/lb. The air and piston are at rest initially and finally. The piston–cylinder material is a ceramic composite and thus a good insulator Friction between the piston and cylinder wall can be ignored, and the local acceleration of gravity is g 5 32.0 ft/s^2 Determine the heat transfer from the resistor to the air, in Btu, for a system consisting of **(a)** the air alone **(b)** the air and the piston.

Known: Data are provided for air contained in a vertical piston–cylinder fitted with an electrical resistor.

Find: Considering each of two alternative systems, determine the heat transfer from the resistor to the air

$$\Delta \text{KE} + \Delta \text{PE} + \Delta U = Q - W \quad \text{(2.35b)}$$

$$W = \int_{V_1}^{V_2} p\, dV \quad \text{(2.17)}$$

Analysis: (a) Taking the air as the system, the energy balance, Eq. 2.35, reduces with assumption 3 to

$$(\cancel{\Delta \text{KE}}^0 + \cancel{\Delta \text{PE}}^0 + \Delta U)_{\text{air}} = Q - W$$

Or, solving for Q,

$$Q = W + \Delta U_{\text{air}}$$

For this system, work is done by the force of the pressure p acting on the *bottom* of the piston as the air expands. With Eq. 2.17 and the assumption of constant pressure

$$W = \int_{V_1}^{V_2} p\, dV = p(V_2 - V_1)$$

To determine the pressure p, we use a force balance on the slowly moving, frictionless piston. The upward force exerted by the air on the *bottom* of the piston equals the weight of the piston plus the downward force of the atmosphere acting on the *top* of the piston. In symbols

$$p\text{A}_{\text{piston}} = m_{\text{piston}}\, g + p_{\text{atm}}\text{A}_{\text{piston}}$$

Solving for p and inserting values

$$\begin{aligned} p &= \frac{m_{\text{piston}}\, g}{\text{A}_{\text{piston}}} + p_{\text{atm}} \\ &= \frac{(100 \text{ lb})(32.0 \text{ ft/s}^2)}{1 \text{ ft}^2} \left| \frac{1 \text{ lbf}}{32.2 \text{ lb} \cdot \text{ft/s}^2} \right| \left| \frac{1 \text{ ft}^2}{144 \text{ in.}^2} \right| + 14.7 \frac{\text{lbf}}{\text{in.}^2} = 15.4 \frac{\text{lbf}}{\text{in.}^2} \end{aligned}$$

Thus, the work is

$$\begin{aligned} W &= p(V_2 - V_1) \\ &= \left(15.4 \frac{\text{lbf}}{\text{in.}^2}\right)(1.6 \text{ ft}^3) \left| \frac{144 \text{ in.}^2}{1 \text{ ft}^2} \right| \left| \frac{1 \text{ Btu}}{778 \text{ ft} \cdot \text{lbf}} \right| = 4.56 \text{ Btu} \end{aligned}$$

With $\Delta U_{\text{air}} = m_{\text{air}}(\Delta u_{\text{air}})$, the heat transfer is

$$\begin{aligned} Q &= W + m_{\text{air}}(\Delta u_{\text{air}}) \\ &= 4.56 \text{ Btu} + (0.6 \text{ lb})\left(18 \frac{\text{Btu}}{\text{lb}}\right) = 15.36 \text{ Btu} \end{aligned}$$

(b) Consider next a system consisting of the air and the piston. The energy change of the overall system is the sum of the energy changes of the air and the piston. Thus, the energy balance, Eq. 2.35, reads

$$\boxed{(\cancel{\Delta KE}^0 + \cancel{\Delta PE}^0 + \Delta U)_{air} + (\cancel{\Delta KE}^0 + \Delta PE + \cancel{\Delta U}^0)_{piston} = Q - W}$$

where the indicated terms drop out by assumption 3. Solving for Q

$$Q = W + (\Delta PE)_{piston} + (\Delta U)_{air}$$

For this system, work is done at the *top* of the piston as it pushes aside the surrounding atmosphere. Applying Eq. 2.17

Here we don't consider the pressure due to weight of piston as its a part of the system

$$W = \int_{V_1}^{V_2} p\, dV = p_{atm}(V_2 - V_1)$$
$$= \left(14.7\,\frac{\text{lbf}}{\text{in.}^2}\right)(1.6\ \text{ft}^3)\left|\frac{144\ \text{in.}^2}{1\ \text{ft}^2}\right|\left|\frac{1\ \text{Btu}}{778\ \text{ft}\cdot\text{lbf}}\right| = 4.35\ \text{Btu}$$

The elevation change, Δz, required to evaluate the potential energy change of the piston can be found from the volume change of the air and the area of the piston face as

$$\Delta z = \frac{V_2 - V_1}{A_{piston}} = \frac{1.6\ \text{ft}^3}{1\ \text{ft}^2} = 1.6\ \text{ft}$$

Thus, the potential energy change of the piston is

$$(\Delta PE)_{piston} = m_{piston}\, g \Delta z$$
$$= (100\ \text{lb})\left(32.0\,\frac{\text{ft}}{\text{s}^2}\right)(1.6\ \text{ft})\left|\frac{1\ \text{lbf}}{32.2\ \text{lb}\cdot\text{ft/s}^2}\right|\left|\frac{1\ \text{Btu}}{778\ \text{ft}\cdot\text{lbf}}\right| = 0.2\ \text{Btu}$$

Finally,

$$Q = W + (\Delta PE)_{piston} + m_{air}\Delta u_{air}$$
$$= 4.35\ \text{Btu} + 0.2\ \text{Btu} + (0.6\ \text{lb})\left(18\,\frac{\text{Btu}}{\text{lb}}\right) = 15.35\ \text{Btu}$$

4. A constant-volume perfect gas thermometer indicates a pressure of 6.69 kPa at the triple point temperature of water (273.16 K). (a) What change of pressure indicates a change of 1.00 K at this temperature? (b) What pressure indicates a temperature of 100.00°C? (c) What change of pressure indicates a change of 1.00 K at the latter temperature?

$\frac{p}{T} = \frac{nR}{V}$ = constant, if n and V are constant. Hence, $\frac{p}{T} = \frac{p_3}{T_3}$, where p is the measured pressure at temperature, T, and p_3 and T_3 are the triple point pressure and temperature, respectively. Rearranging, $p = \left(\frac{p_3}{T_3}\right)T$.

The ratio $\frac{p_3}{T_3}$ is a constant $= \frac{6.69\ \text{kPa}}{273.16\ \text{K}} = 0.0245\ \text{kPa K}^{-1}$. Thus the change in p, Δp, is proportional to the change in temperature, $\Delta T : \Delta p = (0.0245\ \text{kPa K}^{-1}) \times (\Delta T)$.

(a) $\Delta p = (0.0245\ \text{kPa K}^{-1}) \times (1.00\ \text{K}) = \boxed{0.0245\ \text{kPa}}$.

(b) Rearranging, $p = \left(\frac{T}{T_3}\right)p_3 = \left(\frac{373.16\ \text{K}}{273.16\ \text{K}}\right) \times (6.69\ \text{kPa}) = \boxed{9.14\ \text{kPa}}$.

(c) Since $\frac{p}{T}$ is a constant at constant n and V, it always has the value $0.0245\ \text{kPa K}^{-1}$; hence

$$\Delta p = p_{374.15\,\text{K}} - p_{373.15\,\text{K}} = (0.0245\ \text{kPa K}^{-1}) \times (1.00\ \text{K}) = \boxed{0.0245\ \text{kPa}}.$$