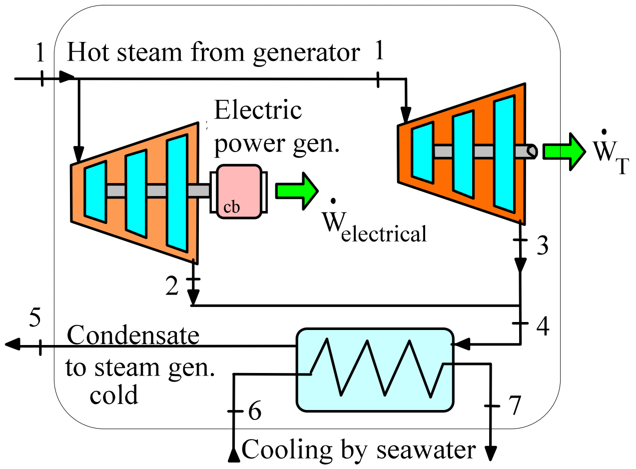
**2.3**

Make a control volume that includes the steam flow around in the main turbine loop in the nuclear propulsion system in Fig.1.3. Identify mass flows (hot or cold) and energy transfers that enter or leave the C.V.

Solution:




The electrical power also leaves the C.V. to be used for lights, instruments and to charge the batteries.

**2.4**

Separate the list P, F, V, v, ρ, T, a, m, L, t, and **V** into intensive, extensive, and non-properties.

Solution:

**Intensive properties** are independent upon mass: P, v, ρ, T
**Extensive properties** scales with mass: V, m
**Non-properties**: F, a, L, t, **V**

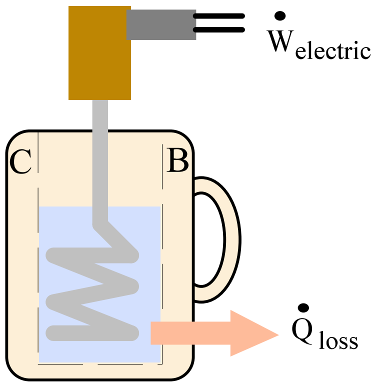
Comment: You could claim that acceleration a and velocity **V** are physical properties for the dynamic motion of the mass, but not thermal properties.

**2.5**

An electric dip heater is put into a cup of water and heats it from 20°C to 80°C. Show the energy flow(s) and storage and explain what changes.

Solution:

Electric power is converted in the heater element (an electric resistor) so it becomes hot and gives energy by heat transfer to the water. The water heats up and thus stores energy and as it is warmer than the cup material it heats the cup which also stores some energy. The cup being warmer than the air gives a smaller amount of energy (a rate) to the air as a heat loss.



**2.8**

Density of fibers, rock wool insulation, foams and cotton is fairly low. Why is that?

Solution:

All these materials consist of some solid substance and mainly air or other gas. The volume of fibers (clothes) and rockwool that is solid substance is low relative to the total volume that includes air. The overall density is

$$\rho = \frac{m}{V} = \frac{m_{solid} + m_{air}}{V_{solid} + V_{air}}$$

where most of the mass is the solid and most of the volume is air. If you talk about the density of the solid only, it is high.

**2.9**

How much mass is there approximately in 1 L of engine oil? Atmospheric air?

Solution:

A volume of 1 L equals 0.001 $m^3$, see Table A.1. From Table A.4 the density is 885 $kg/m^3$ so we get

$$m = \rho V = 885\ kg/m^3 \times 0.001\ m^3 = \mathbf{0.885\ kg}$$

For the air we see in Figure 2.7 that density is about 1 $kg/m^3$ so we get

$$m = \rho V = 1\ kg/m^3 \times 0.001\ m^3 = \mathbf{0.001\ kg}$$

A more accurate value from Table A.5 is $\rho = 1.17\ kg/m^3$ at 100 kPa, 25°C.

**2.14**

A manometer with water shows a $\Delta P$ of $P_o/10$; what is the column height difference?

Solution:

$$\Delta P = P_o/10 = \rho H g$$

$$H = P_o/(10\ \rho\ g) = \frac{101.3 \times 1000\ \text{Pa}}{10 \times 997\ \text{kg/m}^3 \times 9.80665\ \text{m/s}^2}$$

= **1.036 m**

**2.17**

Convert the formula for water density in In-text Concept Question “e” to be for T in degrees Kelvin.

Solution:

$$\rho = 1008 - T_C/2 \quad [kg/m^3]$$

We need to express degrees Celsius in degrees Kelvin

$$T_C = T_K - 273.15$$

and substitute into formula

$$\rho = 1008 - T_C/2 = 1008 - (T_K - 273.15)/2 = 1144.6 - T_K/2$$

**2.20**

A steel cylinder of mass 2 kg contains 4 L of liquid water at 25°C at 200 kPa. Find the total mass and volume of the system. List two extensive and three intensive properties of the water

Solution:

Density of steel in Table A.3: $\rho = 7820 \text{ kg/m}^3$

Volume of steel: $V = m/\rho = \frac{2 \text{ kg}}{7820 \text{ kg/m}^3} = 0.000\,256 \text{ m}^3$

Density of water in Table A.4: $\rho = 997 \text{ kg/m}^3$

Mass of water: $m = \rho V = 997 \text{ kg/m}^3 \times 0.004 \text{ m}^3 = 3.988 \text{ kg}$

Total mass: $m = m_{steel} + m_{water} = 2 + 3.988 = \mathbf{5.988 \ kg}$

Total volume: $V = V_{steel} + V_{water} = 0.000\,256 + 0.004$

$= \mathbf{0.004\,256 \ m^3 = 4.26 \ L}$

Extensive properties: m, V
Intensive properties: $\rho$ (or $v = 1/\rho$), T, P

**2.21**

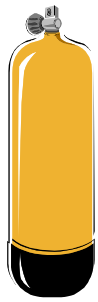
A storage tank of stainless steel contains 7 kg of oxygen gas and 5 kg of nitrogen gas. How many kmoles are in the tank?

Table A.2: $M_{O2} = 31.999$ ; $M_{N2} = 28.013$

$$n_{O2} = m_{O2} / M_{O2} = \frac{7}{31.999} = 0.21876 \text{ kmol}$$

$$n_{O2} = m_{N2} / M_{N2} = \frac{5}{28.013} = 0.17848 \text{ kmol}$$

$$n_{tot} = n_{O2} + n_{N2} = 0.21876 + 0.17848 = \mathbf{0.3972\ kmol}$$



**2.37**

A 1 $m^3$ container is filled with 400 kg of granite stone, 200 kg dry sand and 0.2 $m^3$ of liquid 25°C water. Use properties from tables A.3 and A.4. Find the average specific volume and density of the masses when you exclude air mass and volume.

Solution:

Specific volume and density are ratios of total mass and total volume.

$$m_{liq} = V_{liq}/v_{liq} = V_{liq}\,\rho_{liq} = 0.2\text{ m}^3 \times 997\text{ kg/m}^3 = 199.4\text{ kg}$$

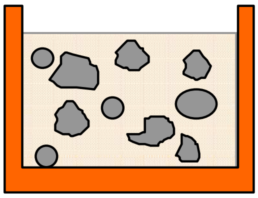
$$m_{TOT} = m_{stone} + m_{sand} + m_{liq} = 400 + 200 + 199.4 = 799.4\text{ kg}$$

$$V_{stone} = mv = m/\rho = 400\text{ kg}/\ 2750\text{ kg/m}^3 = 0.1455\text{ m}^3$$

$$V_{sand} = mv = m/\rho = 200/\ 1500 = 0.1333\text{ m}^3$$

$$V_{TOT} = V_{stone} + V_{sand} + V_{liq}$$

$$= 0.1455 + 0.1333 + 0.2 = 0.4788\text{ m}^3$$



$$v = V_{TOT} / m_{TOT} = 0.4788/799.4 = \mathbf{0.000599\ m^3/kg}$$

$$\rho = 1/v = m_{TOT}/V_{TOT} = 799.4/0.4788 = \mathbf{1669.6\ kg/m^3}$$

**2.38**

One kilogram of diatomic oxygen ($O_2$ molecular weight 32) is contained in a 500-L tank. Find the specific volume on both a mass and mole basis ($v$ and $\bar{v}$).

Solution:

From the definition of the specific volume

$$v = \frac{V}{m} = \frac{0.5}{1} = \mathbf{0.5\ m^3/kg}$$

$$\bar{v} = \frac{V}{n} = \frac{V}{m/M} = M\,v = 32 \times 0.5 = \mathbf{16\ m^3/kmol}$$

**2.39**

A tank has two rooms separated by a membrane. Room A has 1 kg air and volume 0.5 $m^3$, room B has 0.75 $m^3$ air with density 0.8 kg/$m^3$. The membrane is broken and the air comes to a uniform state. Find the final density of the air.

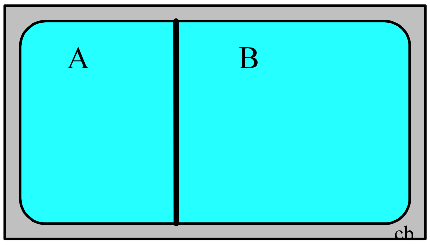
Solution:

Density is mass per unit volume

$$m = m_A + m_B = m_A + \rho_B V_B = 1 + 0.8 \times 0.75 = 1.6 \text{ kg}$$

$$V = V_A + V_B = 0.5 + 0.75 = 1.25 \text{ m}^3$$

$$\rho = \frac{m}{V} = \frac{1.6}{1.25} = \mathbf{1.28\ kg/m^3}$$



**2.40**

A 5 $m^3$ container is filled with 900 kg of granite (density 2400 $kg/m^3$ ) and the rest of the volume is air with density 1.15 $kg/m^3$. Find the mass of air and the overall (average) specific volume.

Solution:

$$m_{air} = \rho\ V = \rho_{air}\ (\ V_{tot} - \frac{m_{granite}}{\rho}\ )$$

$$= 1.15\ [\ 5 - \frac{900}{2400}\ ] = 1.15\ \times 4.625 = \mathbf{5.32\ kg}$$

$$v = \frac{V}{m} = \frac{5}{900 + 5.32} = \mathbf{0.005\ 52\ m^3/kg}$$

Comment: Because the air and the granite are not mixed or evenly distributed in the container the overall specific volume or density does not have much meaning.

**2.43**

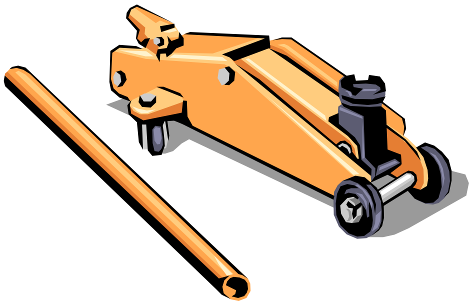
A hydraulic lift has a maximum fluid pressure of 500 kPa. What should the piston-cylinder diameter be so it can lift a mass of 850 kg?

Solution:

With the piston at rest the static force balance is

$$F\uparrow = P\,A = F\downarrow = mg$$
$$A = \pi\,r^2 = \pi\,D^2/4$$
$$PA = P\,\pi\,D^2/4 = mg \quad \Rightarrow \quad D^2 = \frac{4mg}{P\,\pi}$$

$$D = 2\sqrt{\frac{mg}{P\pi}} = 2\sqrt{\frac{850\text{ kg} \times 9.807\text{ m/s}^2}{500\text{ kPa} \times \pi \times 1000\text{ (Pa/kPa)}}} = \mathbf{0.146\ m}$$



**2.45**

A vertical hydraulic cylinder has a 125-mm diameter piston with hydraulic fluid inside the cylinder and an ambient pressure of 1 bar. Assuming standard gravity, find the piston mass that will create a pressure inside of 1500 kPa.

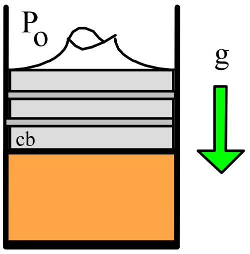
Solution:

Force balance:

$$F\uparrow = PA = F\downarrow = P_0A + m_p g;$$

$$P_0 = 1 \text{ bar} = 100 \text{ kPa}$$

$$A = (\pi/4)\ D^2 = (\pi/4)\ \times 0.125^2 = 0.01227 \text{ m}^2$$

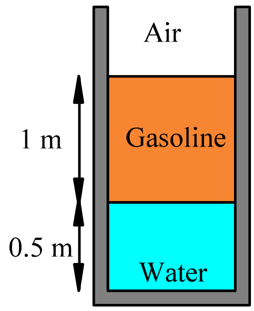



$$m_p = (P - P_0)\,\frac{A}{g} = (\ 1500 - 100\ ) \times 1000 \times \frac{0.01227}{9.80665} = \mathbf{1752\ kg}$$

**2.51**

A 2.5 m tall steel cylinder has a cross sectional area of 1.5 $m^2$. At the bottom with a height of 0.5 m is liquid water on top of which is a 1 m high layer of gasoline. This is shown in Fig. P2.51. The gasoline surface is exposed to atmospheric air at 101 kPa. What is the highest pressure in the water?

Solution:




The pressure in the fluid goes up with the depth as

$$P = P_{top} + \Delta P = P_{top} + \rho g h$$

and since we have two fluid layers we get

$$P = P_{top} + [(\rho h)_{gasoline} + (\rho h)_{water}]\ g$$

The densities from Table A.4 are:

$$\rho_{gasoline} = 750\ kg/m^3; \quad \rho_{water} = 997\ kg/m^3$$

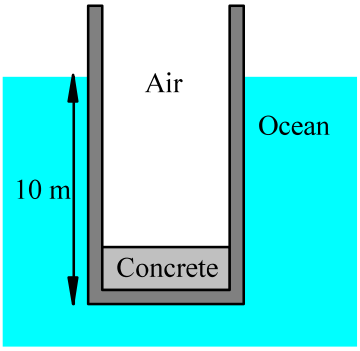
$$P = 101 + [750 \times 1 + 997 \times 0.5] \frac{9.807}{1000} = \mathbf{113.2\ kPa}$$

**2.54**

A steel tank of cross sectional area 3 $m^2$ and 16 m tall weighs 10 000 kg and it is open at the top. We want to float it in the ocean so it sticks 10 m straight down by pouring concrete into the bottom of it. How much concrete should I put in?

Solution:

The force up on the tank is from the water pressure at the bottom times its area. The force down is the gravitation times mass and the atmospheric pressure.




$$F\uparrow = PA = (\rho_{ocean}gh + P_0)A$$

$$F\downarrow = (m_{tank} + m_{concrete})g + P_0A$$

The force balance becomes

$$F\uparrow = F\downarrow = (\rho_{ocean}gh + P_0)A = (m_{tank} + m_{concrete})g + P_0A$$

Solve for the mass of concrete

$$m_{concrete} = (\rho_{ocean}hA - m_{tank}) = 997 \times 10 \times 3 - 10\ 000 = \mathbf{19\ 910\ kg}$$

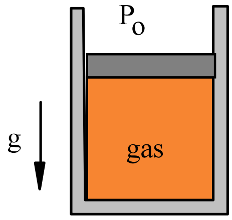
Notice: The first term is the mass of the displaced ocean water. The net force up is the weight (mg) of this mass called bouyancy, $P_0$ cancel.

**2.55**

A piston, $m_p$= 5 kg, is fitted in a cylinder, $A$ = 15 cm$^2$, that contains a gas. The setup is in a centrifuge that creates an acceleration of 25 m/s$^2$ in the direction of piston motion towards the gas. Assuming standard atmospheric pressure outside the cylinder, find the gas pressure.

Solution:

Force balance: $F\uparrow = F\downarrow = P_0A + m_pg = PA$




$$P = P_0 + \frac{m_pg}{A}$$

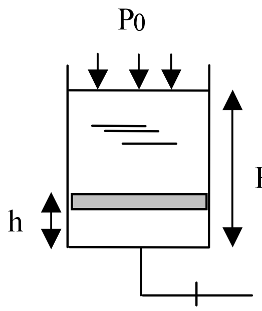
$$= 101.325 + \frac{5 \times 25}{1000 \times 0.0015} \; \frac{\text{kPa kg m/s}^2}{\text{Pa m}^2}$$

$$= \mathbf{184.7\ kPa}$$

**2.56**

Liquid water with density ρ is filled on top of a thin piston in a cylinder with cross-sectional area *A* and total height *H,* as shown in Fig. P2.56. Air is let in under the piston so it pushes up, spilling the water over the edge. Derive the formula for the air pressure as a function of piston elevation from the bottom, *h.*

Solution:



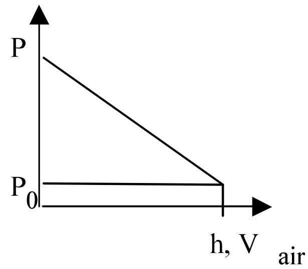

Force balance

Piston: F↑ = F↓

$$PA = P_0A + m_{H_2O}g$$

$$P = P_0 + m_{H_2O}g/A$$

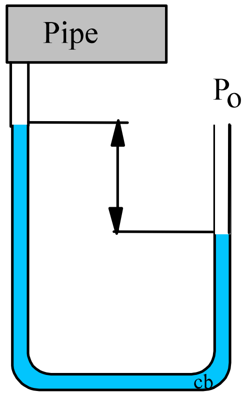
$$\mathbf{P = P_0 + (H - h)\rho g}$$



**2.62**

Blue manometer fluid of density 925 kg/m$^3$ shows a column height difference of 3 cm vacuum with one end attached to a pipe and the other open to $P_0$ = 101 kPa. What is the absolute pressure in the pipe?

Solution:




Since the manometer shows a vacuum we have

$P_{PIPE} = P_0 - \Delta P$

$\Delta P = \rho g h = 925 \times 9.807 \times 0.03$

$= 272.1 \text{ Pa} = 0.272 \text{ kPa}$

$P_{PIPE} = 101 - 0.272 =$ **100.73 kPa**

**2.69**

A barometer measures 760 mmHg at street level and 735 mmHg on top of a building. How tall is the building if we assume air density of 1.15 kg/m$^3$?

Solution:

$$\Delta P = \rho g H$$

$$H = \Delta P/\rho g = \frac{760 - 735}{1.15 \times 9.807} \frac{\text{mmHg}}{\text{kg/m}^2\text{s}^2} \frac{133.32 \text{ Pa}}{\text{mmHg}} = \mathbf{295 \text{ m}}$$

**2.74**

Two cylinders are filled with liquid water, $\rho = 1000 \text{ kg/m}^3$, and connected by a line with a closed valve. A has 100 kg and B has 500 kg of water, their cross-sectional areas are $A_A = 0.1 \text{ m}^2$ and $A_B = 0.25 \text{ m}^2$ and the height *h* is 1 m. Find the pressure on each side of the valve. The valve is opened and water flows to an equilibrium. Find the final pressure at the valve location.

Solution:

$$V_A = v_{H_2O} m_A = m_A/\rho = 0.1 = A_A h_A \quad => \quad h_A = 1 \text{ m}$$

$$V_B = v_{H_2O} m_B = m_B/\rho = 0.5 = A_B h_B \quad => \quad h_B = 2 \text{ m}$$

$$P_{VB} = P_0 + \rho g(h_B + H) = 101325 + 1000 \times 9.81 \times 3 = 130\ 755 \text{ Pa}$$

$$P_{VA} = P_0 + \rho g h_A = 101325 + 1000 \times 9.81 \times 1 = 111\ 135 \text{ Pa}$$

Equilibrium: same height over valve in both

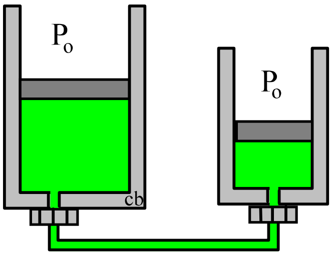
$$V_{tot} = V_A + V_B = h_2 A_A + (h_2 - H)A_B \Rightarrow h_2 = \frac{h_A A_A + (h_B + H)A_B}{A_A + A_B} = 2.43 \text{ m}$$

$$P_{V2} = P_0 + \rho g h_2 = 101.325 + (1000 \times 9.81 \times 2.43)/1000 = \mathbf{125.2 \text{ kPa}}$$

**2.75**

Two piston/cylinder arrangements, A and B, have their gas chambers connected by a pipe. Cross-sectional areas are $A_A = 75\ cm^2$ and $A_B = 25\ cm^2$ with the piston mass in A being $m_A = 25$ kg. Outside pressure is 100 kPa and standard gravitation. Find the mass $m_B$ so that none of the pistons have to rest on the bottom.

Solution:




Force balance for both pistons: $F\uparrow = F\downarrow$

A: $m_{PA}g + P_0A_A = PA_A$

B: $m_{PB}g + P_0A_B = PA_B$

Same P in A and B gives no flow between them.

$$\frac{m_{PA}g}{A_A} + P_0 = \frac{m_{PB}g}{A_B} + P_0$$

=> $m_{PB} = m_{PA}\ A_A/\ A_B\ = 25 \times 25/75 =$ **8.33 kg**

**2.76**

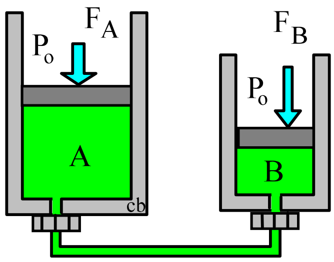
Two hydraulic piston/cylinders are of same size and setup as in Problem 2.75, but with negligible piston masses. A single point force of 250 N presses down on piston A. Find the needed extra force on piston B so that none of the pistons have to move.

Solution:

$A_A = 75 \text{ cm}^2$ ;

$A_B = 25 \text{ cm}^2$

No motion in connecting pipe: $P_A = P_B$




Forces on pistons balance

$$P_A = P_0 + F_A / A_A = P_B = P_0 + F_B / A_B$$

$$F_B = F_A \times \frac{A_B}{A_A} = 250 \times \frac{25}{75} = \mathbf{83.33\ N}$$

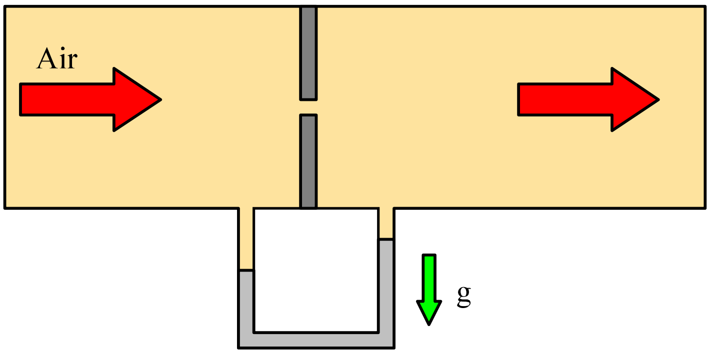
**2.77**

A piece of experimental apparatus is located where $g = 9.5\ m/s^2$ and the temperature is 5°C. An air flow inside the apparatus is determined by measuring the pressure drop across an orifice with a mercury manometer (see Problem 2.79 for density) showing a height difference of 200 mm. What is the pressure drop in kPa?

Solution:

$$\Delta P = \rho g h \; ; \qquad \rho_{Hg} = 13600\ kg/m^3$$

$$\Delta P = 13\,600\ kg/m^3 \times 9.5\ m/s^2 \times 0.2\ m = 25840\ Pa = \mathbf{25.84\ kPa}$$

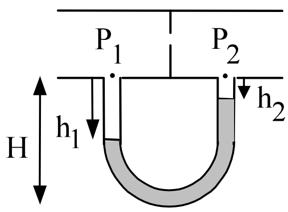


**2.84**

Repeat problem 2.77 if the flow inside the apparatus is liquid water, $\rho \cong 1000$ kg/m$^3$, instead of air. Find the pressure difference between the two holes flush with the bottom of the channel. You cannot neglect the two unequal water columns.

Solution:

Balance forces in the manometer:




$$(H - h_2) - (H - h_1) = \Delta h_{Hg} = h_1 - h_2$$

$$P_1A + \rho_{H2O}h_1gA + \rho_{Hg}(H - h_1)gA$$
$$= P_2A + \rho_{H2O}h_2gA + \rho_{Hg}(H - h_2)gA$$

$$\Rightarrow P_1 - P_2 = \rho_{H2O}(h_2 - h_1)g + \rho_{Hg}(h_1 - h_2)g$$

$$P_1 - P_2 = \rho_{Hg}\Delta h_{Hg}g - \rho_{H2O}\Delta h_{Hg}g = 13\,600 \times 0.2 \times 9.5 - 1000 \times 0.2 \times 9.5$$

$$= 25\,840 - 1900 = 23940 \text{ Pa} = \mathbf{23.94\ kPa}$$

**2.88**

Two cylinders are connected by a piston as shown in Fig. P2.88. Cylinder A is used as a hydraulic lift and pumped up to 500 kPa. The piston mass is 25 kg and there is standard gravity. What is the gas pressure in cylinder B?

Solution:

Force balance for the piston: $P_B A_B + m_p g + P_0(A_A - A_B) = P_A A_A$

$A_A = (\pi/4)0.1^2 = 0.00785\ m^2$; $A_B = (\pi/4)0.025^2 = 0.000\ 491\ m^2$

$P_B A_B = P_A A_A - m_p g - P_0(A_A - A_B) = 500\times 0.00785 - (25 \times 9.807/1000)$

$- 100\ (0.00785 - 0.000\ 491) = 2.944\ kN$

$P_B = 2.944/0.000\ 491 = 5996\ kPa =$ **6.0 MPa**