## Properties and units

**2.23**

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: $V = m/\rho = \dfrac{2 \text{ kg}}{7820 \text{ kg/m}^3} = 0.000\,256 \text{ m}^3$

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

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

## Specific Volume

**2.38**

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.

**2.45**

A piston/cylinder with cross sectional area of 0.01 $m^2$ has a piston mass of 100 kg resting on the stops, as shown in Fig. P2.45. With an outside atmospheric pressure of 100 kPa, what should the water pressure be to lift the piston?

Solution:

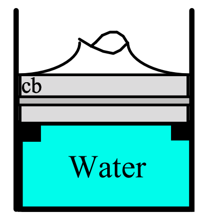
The force acting down on the piston comes from gravitation and the outside atmospheric pressure acting over the top surface.

Force balance: $F\uparrow = F\downarrow = PA = m_p g + P_0 A$

Now solve for P (divide by 1000 to convert to kPa for 2nd term)

$$P = P_0 + \frac{m_p g}{A} = 100 \text{ kPa} + \frac{100 \times 9.80665}{0.01 \times 1000}$$

$$= 100 \text{ kPa} + 98.07 \text{ kPa} = \mathbf{198\ kPa}$$



**2.47**

A valve in a cylinder has a cross sectional area of 11 cm$^2$ with a pressure of 735 kPa inside the cylinder and 99 kPa outside. How large a force is needed to open the valve?

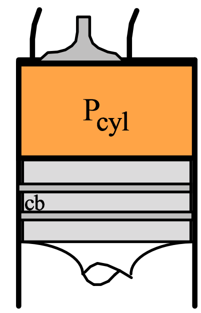
$$F_{net} = P_{in}A - P_{out}A$$

$$= (735 - 99) \text{ kPa} \times 11 \text{ cm}^2$$

$$= 6996 \text{ kPa cm}^2$$

$$= 6996 \times \frac{\text{kN}}{\text{m}^2} \times 10^{-4} \text{ m}^2$$

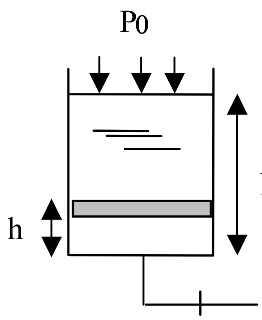
$$= \mathbf{700\ N}$$



**2.57**

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*. Air is let in under the piston so it pushes up, spilling the water over the edge. Deduce the formula for the air pressure as a function of the piston elevation from the bottom, ***h***.

Solution:



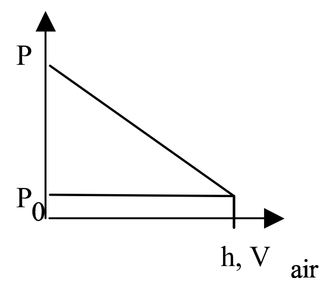

Force balance

Piston: F↑ = F↓

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

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

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



**2.68**

An exploration submarine should be able to go 4000 m down in the ocean. If the ocean density is 1020 kg/m$^3$ what is the maximum pressure on the submarine hull?

Solution:

$$\Delta P = \rho L g = (1020\ \text{kg/m}^3 \times 4000\ \text{m} \times 9.807\ \text{m/s}^2) / 1000$$
$$= 40\,012\ \text{kPa} \approx \mathbf{40\ MPa}$$

**2.82**

The main waterline into a tall building has a pressure of 600 kPa at 5 m elevation below ground level. How much extra pressure does a pump need to add to ensure a water line pressure of 200 kPa at the top floor 150 m above ground?

Solution:

The pump exit pressure must balance the top pressure plus the column $\Delta P$. The pump inlet pressure provides part of the absolute pressure.

$P_{after\ pump} = P_{top} + \Delta P$

$\Delta P = \rho gh = 997\ kg/m^3 \times 9.807\ m/s^2 \times (150 + 5)\ m$

$= 1\ 515\ 525\ Pa = 1516\ kPa$

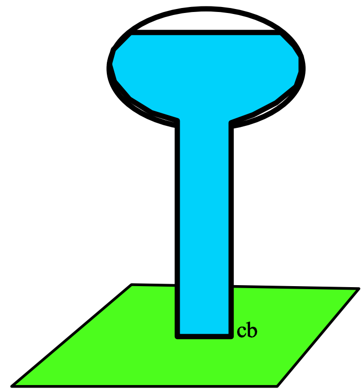
$P_{after\ pump} = 200 + 1516 = 1716\ kPa$

$\Delta P_{pump} = 1716 - 600 = \mathbf{1116\ kPa}$

**2.84**

In the city water tower, water is pumped up to a level 25 m above ground in a pressurized tank with air at 125 kPa over the water surface. This is illustrated in Fig. P2.84. Assuming the water density is 1000 kg/m$^3$ and standard gravity, find the pressure required to pump more water in at ground level.

Solution:




$\Delta P = \rho \, L \, g$

$= 1000 \text{ kg/m}^3 \times 25 \text{ m} \times 9.807 \text{ m/s}^2$

$= 245\,175 \text{ Pa} = 245.2 \text{ kPa}$

$P_{bottom} = P_{top} + \Delta P$

$= 125 + 245.2$

$=$ **370 kPa**