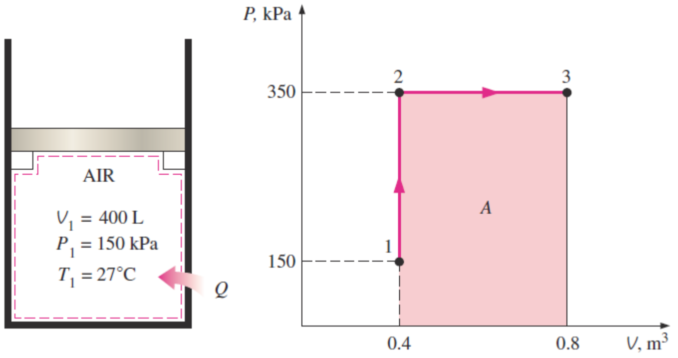
PROBLEMS

1.

A piston–cylinder device initially contains air at 150 kPa and 27°C. At this state, the piston is resting on a pair of stops, as shown in Fig. 4–32, and the enclosed volume is 400 L. The mass of the piston is such that a 350-kPa pressure is required to move it. The air is now heated until its volume has doubled. Determine (*a*) the final temperature, (*b*) the work done by the air, and (*c*) the total heat transferred to the air.



(*a*) The final temperature can be determined easily by using the ideal-gas relation between states 1 and 3 in the following form:

$$\frac{P_1V_1}{T_1} = \frac{P_3V_3}{T_3} \longrightarrow \frac{(150\text{ kPa})(V_1)}{300\text{ K}} = \frac{(350\text{ kPa})(2V_1)}{T_3}$$

$$T_3 = \mathbf{1400\ K}$$

(*b*) The work done could be determined by integration, but for this case it is much easier to find it from the area under the process curve on a *P-V* diagram,

$$A = (V_2 - V_1)P_2 = (0.4\text{ m}^3)(350\text{ kPa}) = 140\text{ m}^3\cdot\text{kPa}$$

Therefore,

$$W_{13} = \mathbf{140\ kJ}$$

The work is done by the system (to raise the piston and to push the atmospheric air out of the way), and thus it is work output.

(*c*) Under the stated assumptions and observations, the energy balance on the system between the initial and final states (process 1–3) can be expressed as

$$Q_{\text{in}} - W_{b,\text{out}} = \Delta U = m(u_3 - u_1)$$

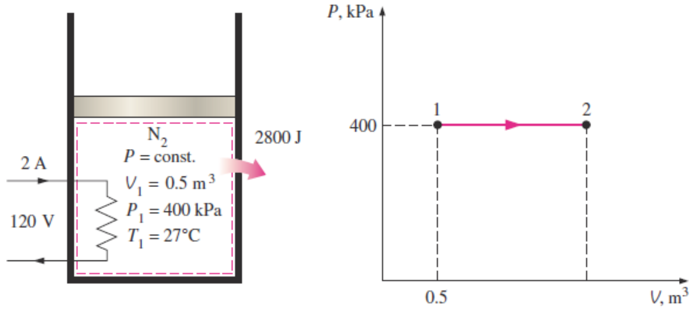
The mass of the system can be determined from the ideal-gas relation:

$$m = \frac{P_1V_1}{RT_1} = \frac{(150\text{ kPa})(0.4\text{ m}^3)}{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(300\text{ K})} = 0.697\text{ kg}$$

Q - W = m*(u3-u1) = m*cv*(T3-T1)
Q - 140 kj = 0.697kg*0.71 kJ/kg.K *(1400 - 300)K
Q = 684 kJ

2.

A piston–cylinder device initially contains 0.5 m^3 of nitrogen gas at 400 kPa and 27°C. An electric heater within the device is turned on and is allowed to pass a current of 2 A for 5 min from a 120-V source. Nitrogen expands at constant pressure, and a heat loss of 2800 J occurs during the process. Determine the final temperature of nitrogen.



$$W_e = VI\,\Delta t = (120\text{ V})(2\text{ A})(5 \times 60\text{ s})\left(\frac{1\text{ kJ/s}}{1000\text{ VA}}\right) = 72\text{ kJ}$$

The mass of nitrogen is determined from the ideal-gas relation:

$$m = \frac{P_1V_1}{RT_1} = \frac{(400\text{ kPa})(0.5\text{ m}^3)}{(0.297\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(300\text{ K})} = 2.245\text{ kg}$$

Q - W = u2 - u1   Q - (Wb + We) = u2 - u1   Q - (P*(V2-V1) + We) = u2 -u1

Q - (We) = (u2 + PV2) - (u1 +PV1)   Q - (We) = h2 - h1

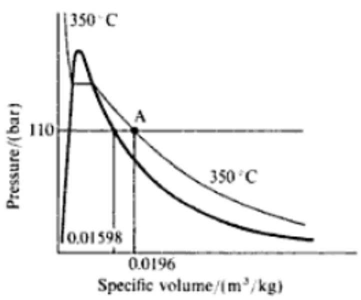
Q - (We) = m*cp*(T2 -T1)   -2.8 kJ - (-72 kJ) = 2.245 kg*1.04 kJ/kg.K*(T2-27)

T2 = 57 C

3.

Steam at 110 bar has a specific volume of 0.0196 m^3/kg, calculate the temperature, the specific enthalpy, and the specific internal energy.

First it is necessary to decide whether the steam is wet, dry saturated, or superheated. At 110 bar, v_g = 0.01598 m^3/kg, which is less than the actual specific volume of 0.0196 m^3/kg, and hence the steam is superheated. The state of the steam is shown as point A of Fig. 2.6.



From the superheat tables at 110 bar, the specific volume is 0.0196 m^3/kg at a temperature of 350 °C. Hence this is the isothermal which passes through point A as shown. The degree of superheat in this case is 350 − 318 = 32 K. From tables the enthalpy, h, is 2889 kJ/kg. Then using equation (1.9), we have

$$u = h - pv = 2889 - \frac{110 \times 10^5 \times 0.0196}{10^3}$$

i.e. $$u = 2889 - 215.6 = 2673.4\text{ kJ/kg}$$

4.

A mass of 0.05 kg of a fluid is heated at a constant pressure of 2 bar until the volume occupied is 0.0658 m^3. Calculate the heat supplied and the work done:

(i) when the fluid is steam, initially dry saturated;
(ii) when the fluid is air, initially at 130 °C.

(i) Initially the steam is dry saturated at 2 bar, hence,

$$h_1 = h_g \text{ at 2 bar} = 2707 \text{ kJ/kg}$$

Finally the steam is at 2 bar and the specific volume is given by

$$v_2 = \frac{0.0658}{0.05} = 1.316 \text{ m}^3/\text{kg}$$

Hence the steam is superheated finally. From superheat tables at 2 bar and 1.316 m^3/kg the temperature of the steam is 300 °C, and the enthalpy is $h_2 = 3072$ kJ/kg.

Then from equation (3.4)

$$Q = H_2 - H_1 = m(h_2 - h_1) = 0.05(3072 - 2707)$$

i.e. Heat supplied $= 0.05 \times 365 = 18.25$ kJ

The process is shown on a p–v diagram in Fig. 3.3,

$$-W = p(v_2 - v_1) = \text{shaded area}$$

Now $v_1 = v_g$ at 2 bar $= 0.8856$ m^3/kg, and $v_2 = 1.316$ m^3/kg. Therefore

$$W = -2 \times 10^5(1.316 - 0.8856) = -86080 \text{ N m/kg}$$