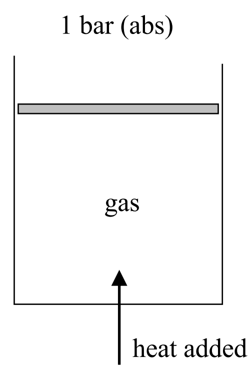
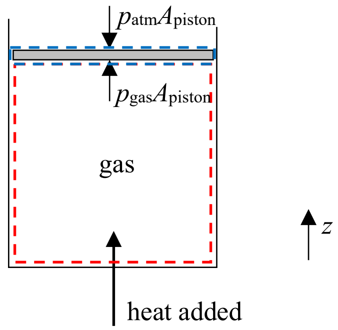
As shown in the figure, a gas contained within a piston-cylinder assembly, initially at a volume of 0.1 m^3, undergoes a constant-pressure expansion at 2 bar (abs) to a final volume of 0.12 m^3, while being slowly heated through the base. The change in internal energy of the gas is 0.25 kJ. The piston and cylinder walls are fabricated from heat-resistant material, and the piston moves smoothly in the cylinder. The local atmospheric pressure is 1 bar (abs).

a. Evaluate the work done by the gas and the heat added to the gas.
b. What is the work done on the piston due to the surrounding pressures?
c. Evaluate the change in potential energy of the piston.



SOLUTION:
Apply the First Law to a system consisting of the gas (indicated by the red dashed line in the figure).



The work done by the gas on the surroundings is,

$$W_{by\ sys} = \int_{V_1}^{V_2} p dV = p \int_{V_1}^{V_2} dV = p(V_2 - V_1) = \left(2\ bar \cdot \frac{100*10^3 Pa}{1\ bar}\right)(0.12\ m^3 - 0.1\ m^3) = 4000\ J \quad (1)$$

$\boxed{W_{by\ sys} = 4\text{ kJ}}$

Use the 1st Law of Thermodynamics to determine the heat added to the system,

$$\Delta E_{sys} = Q_{into\ sys} - W_{by\ sys} \quad (2)$$

where

$$\Delta E_{sys} = \Delta U_{sys} = 0.25\ kJ \quad \text{(changes to } KE \text{ and } PE \text{ are negligible)} \quad (3)$$

Thus, using the previous result for the work,

$\boxed{Q_{into\ sys} = 4.25\text{ kJ}}$

Now make the piston the system (indicated by the blue dashed line in the figure). The work done on the piston due to the surrounding pressures is,

$$W_{on\ sys} = \int_1^2 \boldsymbol{F} \cdot d\boldsymbol{s} = \int_1^2 \left(p_{gas,abs}A - p_{atm,abs}A\right)\hat{\boldsymbol{k}} \cdot dz\hat{\boldsymbol{k}} = \left(p_{gas,abs} - p_{atm,abs}\right)A \int_0^{\Delta h} dz, \quad (4)$$

$$W_{on\ sys} = \left(p_{gas,abs} - p_{atm,abs}\right)A\Delta h, \quad (5)$$

$$\boxed{W_{on\ sys} = \left(p_{gas,abs} - p_{atm,abs}\right)\Delta V.} \quad (6)$$

Using,

$p_{gas,abs}$ = 2 bar = $200*10^3$ Pa,
$p_{atm,abs}$ = 1 bar = $100*10^3$ Pa,
$\Delta V = V_2 - V_1 = 0.12\text{ m}^3 - 0.1\text{ m}^3 = 0.02\text{ m}^3$,

Thus,

$\boxed{W_{on\ sys} = 2\text{ kJ}}$.

Applying the 1st Law to the system, i.e, the piston,

$$\Delta E_{sys} = Q_{into\ sys} - W_{by\ sys} \quad (7)$$

where

$$\Delta E_{sys} = \Delta PE_{sys} \quad \text{(changes to } KE \text{ and } IE \text{ are negligible)} \quad (8)$$

$$Q_{into\ sys} = 0 \quad \text{(the piston is heat resistant so it doesn't absorb much heat)} \quad (9)$$

Thus, using the previous result for the work,

$$\Delta PE_{sys} = -W_{by\ sys} = W_{on\ sys}, \quad (10)$$

so that,

$\boxed{\Delta PE_{sys} = 2\text{ kJ}}$.