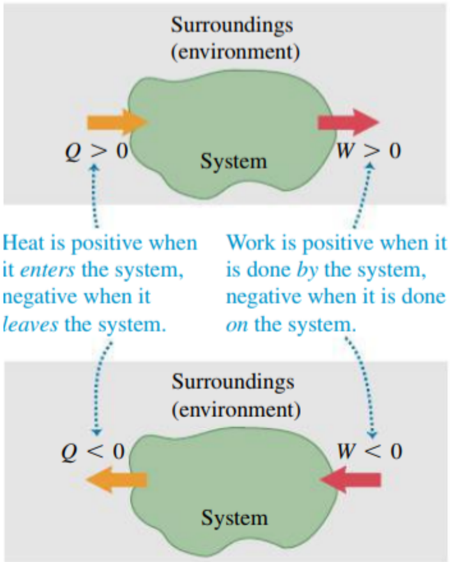
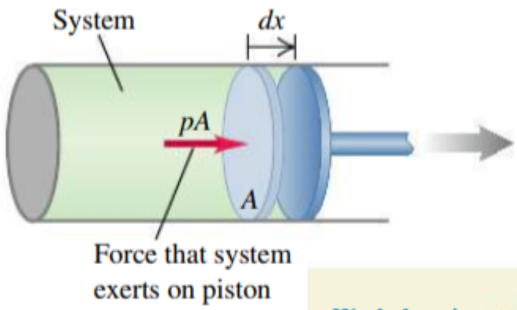

Surroundings
(environment)
Q > 0
System
W > 0
Heat is positive when it *enters* the system, negative when it *leaves* the system.
Work is positive when it is done *by* the system, negative when it is done *on* the system.
Surroundings
(environment)
Q < 0
W < 0
System

WORK DONE DURING VOLUME CHANGES

by the system



Work done in a volume change

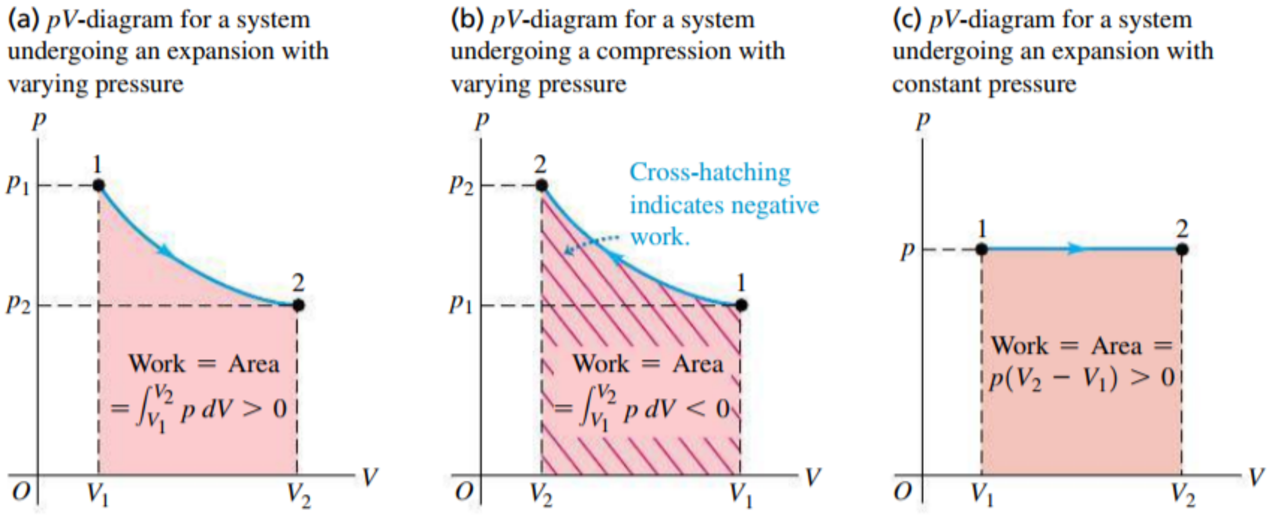
$$W = \int_{V_1}^{V_2} p\, dV$$

Upper limit = final volume

Integral of the pressure with respect to volume

Lower limit = initial volume

19.6 The work done equals the area under the curve on a pV-diagram.



$$W = P\Delta V$$

As an ideal gas undergoes an *isothermal* (constant-temperature) expansion at temperature T, its volume changes from V_1 to V_2. How much work does the gas do?

$$PV = nRT$$

$$P = \frac{nRT}{V}$$

n, R, T are constants

$$W = \int_{V_1}^{V_2} P\, dV$$

$$= \int_{V_1}^{V_2} \frac{nRT}{V}\, dV$$

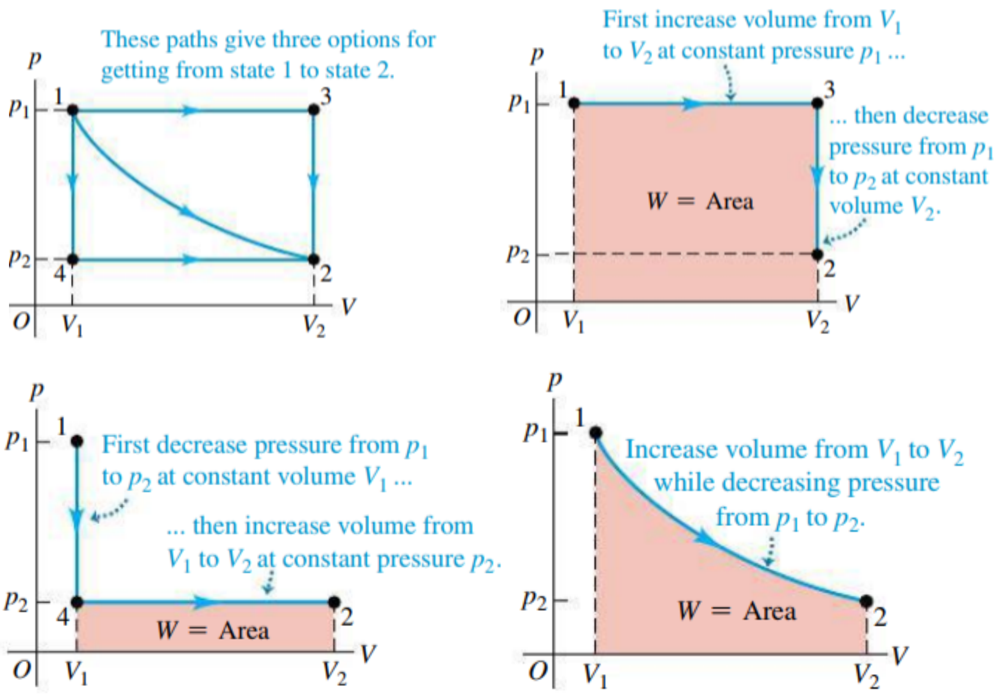
$$= nRT \int_{V_1}^{V_2} \frac{1}{V}\, dV$$

$$W = nRT \ln(V) \Big|_{V_1}^{V_2}$$

$$W = nRT \left[\ln(V_2) - \ln(V_1) \right]$$

$$W = nRT \ln\left[\frac{V_2}{V_1}\right]$$

Work is path dependant



Internal Energy of a System - The sum of the Kinetic Energies of all the particles that make up the system plus the sum of all the Potential Energies of these particles.

$$\Delta U = U_2 - U_1$$

The change in internal energy is independent of path.

Zeroth law of thermodynamics ▶ If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other.

First law of thermodynamics ▶ If a system undergoes a change from an initial state to a final state, then the change in the internal energy ΔU is given by

First law of thermodynamics:

$$\underbrace{\Delta U}_{\text{Internal energy change of thermodynamic system}} = \underbrace{Q}_{\text{Heat added to system}} - \underbrace{W}_{\text{Work done by system}}$$

$$Q = \Delta U + W$$

Isobaric Process - Process in which pressure is a constant

$$Q = \Delta U + W = \Delta U + P\Delta V$$

Isovolumetric (Isochoric) Process - Process in which volume is a constant

$$W = 0 \qquad \Delta U = Q$$

Isothermal Process - Process in which temperature is a constant

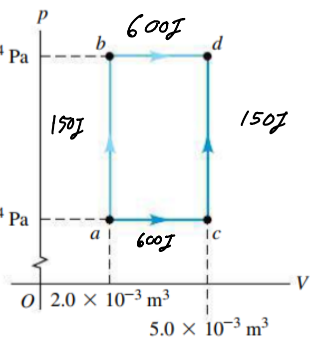
$$\Delta U = 0 \text{ because } \Delta T = 0. \qquad W = Q$$

Adiabatic Process - Process in whcih no energy enters or leaves the system

$$Q = 0 \qquad \Delta U = -W$$

The pV-diagram of **Fig. 19.13** shows a series of thermodynamic processes. In process ab, 150 J of heat is added to the system; in process bd, 600 J of heat is added. Find (a) the internal energy change in process ab; (b) the internal energy change in process abd (shown in light blue); and (c) the total heat added in process acd (shown in dark blue).

19.13 A pV-diagram showing the various thermodynamic processes.



a) $\Delta U_{ab} = Q - W$

$Q_{ab} = 150J$

$W = P\Delta V$

$= P(\emptyset)$

$= \emptyset$

$\Delta U = Q_{ab} - \emptyset$

$\Delta U = 150J$

b) $\Delta U_{abd} = \Delta U_{ab} + \Delta U_{bd}$

$= 150J + (Q_{bd} - W_{bd})$

$= 150J + (600J - 240J)$

$\Delta U_{abd} = 510J$

$Q_{bd} = 600J$

$W_{bd} = P\Delta V$

$= 8.0\times10^4 Pa(5\times10^{-3} m^3 - 2\times10^{-3} m^3)$

$= 8\times10^4 Pa(3\times10^{-3} m^3)$

$W_{bd} = 240J$

c) $Q_{acd} = \Delta U_{acd} + W_{ac} + W_{cd}$

$= \Delta U_{abd} + 90 + \emptyset$

$= 510J + 90$

$Q_{acd} = 600J$

One gram of water (1 cm^3) becomes 1671 cm^3 of steam when boiled at a constant pressure of 1 atm (1.013×10^5 Pa). The heat of vaporization at this pressure is $L_V = 2.256 \times 10^6$ J/kg. Compute (a) the work done by the water when it vaporizes and (b) its increase in internal energy.

$J = Pa \cdot m^3$

a) $W = P\Delta V$

$= 1.013 \times 10^5\, Pa\,(1671 \times 10^{-6}\, m^3 - 1 \times 10^{-6}\, m^3)$

$= 1.013 \times 10^5\, Pa\,(1670 \times 10^{-6}\, m^3)$

$W = 169.17\, J$

b) $\Delta U = Q - W$ $\qquad W = 169\, J$

$Q = m L_V$

$Q = 0.001\, kg\,(2.256 \times 10^6\, J/kg)$

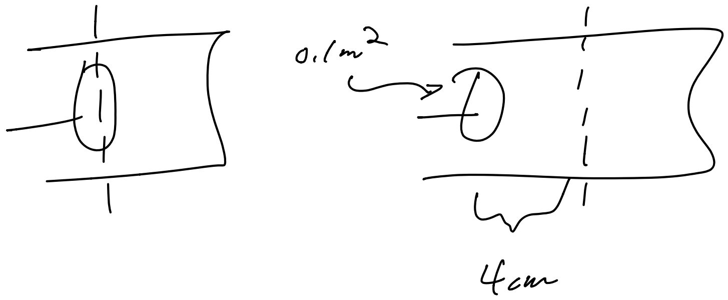
$Q = 2{,}256\, J$

$\Delta U = 2{,}256\, J - 169\, J$

$\Delta U = 2{,}087\, J$

HW

PROBLEM In a system similar to that shown in Figure 12.1, the gas in the cylinder is at a pressure equal to 1.01×10^5 Pa and the piston has an area of 0.100 m^2. As energy is slowly added to the gas by heat, the piston is pushed up a distance of 4.00 cm. Calculate the work done by the expanding gas on the surroundings, W_{env}, assuming the pressure remains constant.



$\Delta V = A \cdot l$

$= 0.1 m^2 \cdot 0.04 m$

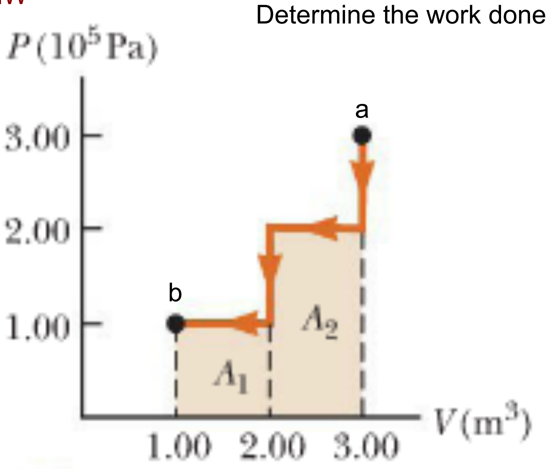
$\Delta V = 0.004 m^3$

$W = P \Delta V = (1.01 \times 10^5 Pa)(0.004 m^3)$

$W = 404 J$

HW

Determine the work done by this ideal gas as it goes from a to b.



$A_1 = l \times w$

$= (1\,m^3)(1 \times 10^5\,Pa)$

$A_1 = 1 \times 10^5\,J$

$A_2 = l \times w$

$= (1\,m^3)(2 \times 10^5\,Pa)$

$A_2 = 2 \times 10^5\,J$

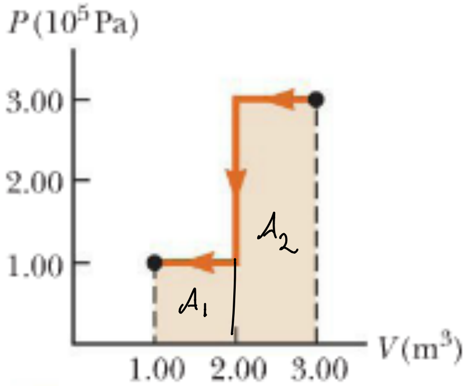
$W = A_1 + A_2 = 3 \times 10^5\,J$

losing energy + down arrow

$\therefore$ W is negative

$\therefore W = -3 \times 10^9\,J$

HW Determine the work done by this ideal gas as it goes from a to b.



$A_1 = 1 \times 10^5 J$

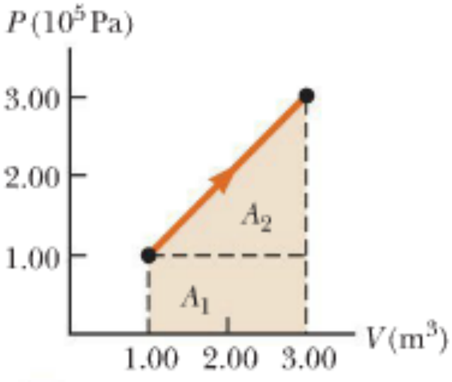
$A_2 = 1m^3 (3 \times 10^5 Pa)$

$A_2 = 3 \times 10^5 Pa$

$W = A_1 + A_2 = 4 \times 10^5 Pa$

$W = -4 \times 10^5 Pa$

HW Determine the work done by this ideal gas as it goes from a to b.



$A_1 = 2\,m^3(1\times10^5\,Pa)$

$A_1 = 2\times10^5\,J$

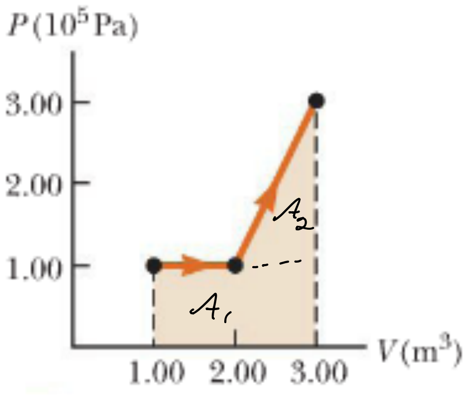
$A_2 = \frac{1}{2}(2m^3)(2\times10^5\,Pa)$

$= \frac{1}{2}(4\times10^5)J$

$A_2 = 2\times10^5\,J$

$W = A_1 + A_2 = 4\times10^5\,J$

HW Determine the work done by this ideal gas as it goes from a to b.



$A_1 = 2\,m^3(1\times10^5\,Pa)$

$A_1 = 2\times10^5\,J$

$A_2 = \frac{1}{2}(1m^3)(2\times10^5 Pa)$

$= \frac{1}{2}(2\times10^5\,Pa)$

$A_2 = 1\times10^5\,J$

$W = A_1 + A_2 = 3\times10^5\,J$

HW

PROBLEM An ideal gas absorbs 5.00×10^3 J of energy while doing 2.00×10^3 J of work on the environment during a constant pressure process. **(a)** Compute the change in the internal energy of the gas. **(b)** If the internal energy now drops by 4.50×10^3 J and 7.50×10^3 J is expelled from the system, find the change in volume, assuming a constant pressure process at 1.01×10^5 Pa.

a) $Q = 5{,}000\,J$

$W = 2{,}000\,J$

$\Delta U = Q - W$

$\Delta U = 5{,}000 - 2000$

$\Delta U = 3{,}000\,J$

b) $\Delta U = -4500\,J$

$Q = -7{,}500$

$\Delta U = Q - W$ $\quad W = P\Delta V$

$-4500 = -7500 - (P\Delta V)$

$-4500 = -7500 - (1.01 \times 10^5)\Delta V$

$\Delta V = -0.029$

HW

6.624×10^{24} particles of an ideal gas undergoes an isothermal expansion at 20° C from 0.015 m^3 to 0.55 m^3. Calculate the work done.

$T = 293°K$

$$PV = n k_b T$$

$$P = \frac{n k_b T}{V}$$

$$W = \int P\,dV$$

$$W = \int_{V_1}^{V_2} \frac{n k_b T}{V}\,dV$$

$$W = n k_b T \int_{V_1}^{V_2} \frac{1}{V}\,dV$$

$$= n k_b T \left[\ln(V_2) - \ln(V_1)\right]$$

$$= n k_b T \left[\ln\left(\frac{V_2}{V_1}\right)\right]$$

$$W = 6.624 \times 10^{24} (1.38 \times 10^{-23})(293) \ln\left(\frac{0.55}{0.015}\right)$$

$$W = 96,470\ J$$

$$= 96.4\ kJ$$

28. (a) Determine the work done on a gas that expands **W** from i to f as indicated in Figure P20.28. (b) **What If?** How much work is done on the gas if it is compressed from f to i along the same path?

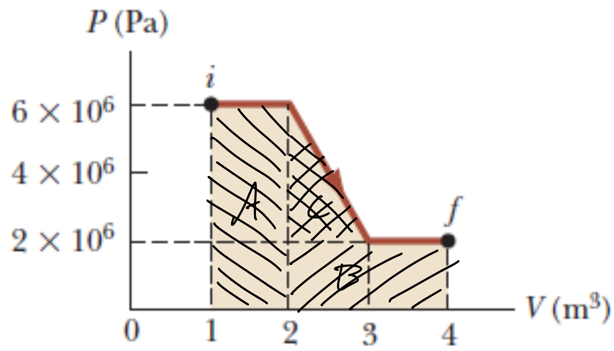


Figure P20.28

$W = P\Delta V$

$W_A = 6\times10^6\ Pa\,(1\ m^3)$

$W_A = 6\times10^6\ J$

$W_B = 2\times10^6\ Pa\,(2\ m^3)$

$W_B = 4\times10^6\ Pa$

$W_C = \frac{1}{2}\left(4\times10^6\ Pa\,(1\ m^3)\right)$

$W_C = 2\times10^6\ J$

$W = W_A + W_B + W_C$

$\boxed{W = 12\times10^6\ J}$

b) $\boxed{W = -12\times10^6\ J}$

Just invert

29. **M** An ideal gas is taken through a quasi-static process described by $P = \alpha V^2$, with $\alpha = 5.00\ \text{atm/m}^6$, as shown in Figure P20.29. The gas is expanded to twice its original volume of $1.00\ \text{m}^3$. How much work is done on the expanding gas in this process?

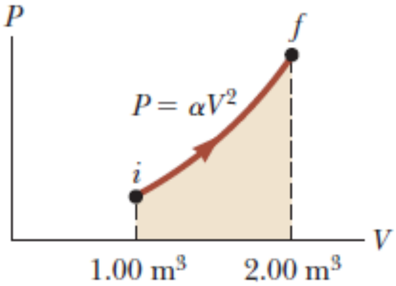


Figure P20.29

$$W = \int_{V_1}^{V_2} P\,dV$$

$$= \int_{V_1}^{V_2} a V^2\,dV$$

$$= a \int v^2\,dv$$

$$= a\left[\frac{v^3}{3}\right]\Big|_{v_1}^{v_2}$$

$$= 5\ \text{atm/m}^6 \left[\frac{2\text{m}^3}{3} - \frac{1\text{m}^3}{3}\right]$$

$$= 5\left(\frac{8}{3} - \frac{1}{3}\right)$$

$$= 5\left(\frac{7}{3}\right)$$

$$W = \frac{35}{3}\ \text{atm}\cdot\text{m}^3$$

$$\times 1.01\times10^5\ \text{Pa}$$

$$= 1.19\times10^6\ \text{Pa}\cdot\text{m}^3 \qquad W = \text{kPa/m}^3$$

$$W = 1.18\times10^6\ \text{J}$$

12. **GP** A cylinder of volume 0.300 m^3 contains 10.0 mol of neon gas at 20.0° C. Assume neon behaves as an ideal gas. (a) What is the pressure of the gas? (b) Find the internal energy of the gas. (c) Suppose the gas expands at constant pressure to a volume of 1.000 m^3. How much work is done on the gas? (d) What is the temperature of the gas at the new volume? (e) Find the internal energy of the gas when its volume is 1.000 m^3. (f) Compute the change in the internal energy during the expansion. (g) Compute $\Delta U - W$. (h) Must thermal energy be transferred to the gas during the constant pressure expansion or be taken away? (i) Compute Q, the thermal energy transfer. (j) What symbolic relationship between Q, ΔU, and W is suggested by the values obtained?

9. W One mole of an ideal gas initially at a temperature of $T_i = 0°C$ undergoes an expansion at a constant pressure of 1.00 atm to four times its original volume. (a) Calculate the new temperature T_f of the gas. (b) Calculate the work done *on* the gas during the expansion.

8. (a) Find the work done *by* an ideal gas as it expands from point A to point B along the path shown in Figure P12.8. (b) How much work is done by the gas if it compressed from B to A along the same path?

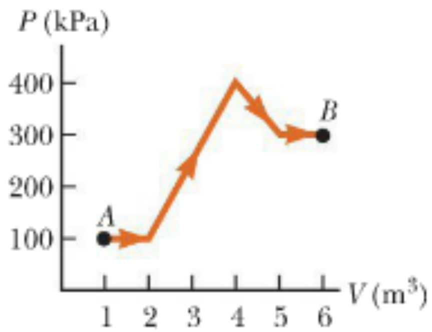


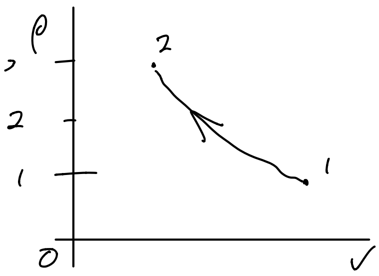
Figure P12.8

19.3 •• **CALC** Two moles of an ideal gas are compressed in a cylinder at a constant temperature of 65.0°C until the original pressure has tripled. (a) Sketch a *pV*-diagram for this process. (b) Calculate the amount of work done.

$T_i = T_f = 65°C = 338°K$

$n = 2\ mol$

$P_f = 3P_i$



$\frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f}$

$P_i V_i$

$W = \int_{V_i}^{V_f} P\, dV$

$= \int \frac{nRT}{V} dV$

$= nRT \int \frac{1}{V} dV$

$= nRT \left[\ln(V_f) - \ln(V_i)\right]$

$2\ mol\ (8.314\ J/mol \cdot K)(338\ °K)\left(\ln\left(\frac{V_f}{V_i}\right)\right)$

$\ln\left(\frac{\frac{nRT}{3P_i}}{\frac{nRT}{P_i}}\right)$

$V_i = \frac{nRT}{P_i}$

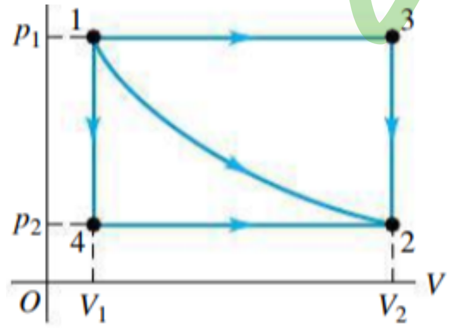
$V_f = \frac{nRT}{P_f} = \frac{nRT}{3P_i}$

$W = 2\ mol\ (8.314\ J/mol \cdot K)(338\ °K)\left(\ln\left(\frac{1}{3}\right)\right)$

$W = -6175\ J$

Homework

19.7 • **Work Done in a Cyclic Process.** (a) In Fig. 19.7a, consider the closed loop $1 \rightarrow 3 \rightarrow 2 \rightarrow 4 \rightarrow 1$. This is a *cyclic* process in which the initial and final states are the same. Find the total work done by the system in this cyclic process, and show that it is equal to the area enclosed by the loop. (b) How is the work done for the process in part (a) related to the work done if the loop is traversed in the opposite direction, $1 \rightarrow 4 \rightarrow 2 \rightarrow 3 \rightarrow 1$? Explain.



a)

$W_{13} = P\Delta V$

$= P_1(V_2 - V_1)$

$W_{32} = 0$

$W_{24} = P_2(V_1 - V_2)$

$V_{41} = 0$

$W = P_1(V_2 - V_1) - P_2(V_2 - V_1)$

$W = (P_1 - P_2)(V_2 - V_1)$

b) Same amount of work. All components will be negative of original & ∴ come out to be the same

Homeworks

19.9 • A gas in a cylinder expands from a volume of 0.110 m^3 to 0.320 m^3. Heat flows into the gas just rapidly enough to keep the pressure constant at 1.65×10^5 Pa during the expansion. The total heat added is 1.15×10^5 J. (a) Find the work done by the gas. (b) Find the change in internal energy of the gas. (c) Does it matter whether the gas is ideal? Why or why not?

$V_i = 0.110 m^3$

$V_f = 0.320 m^3$

$P_i = P_f = 1.65 \times 10^5 Pa$

$Q = 1.15 \times 10^5 J$

a) $W = P \Delta V$

$= 1.65 \times 10^5 Pa (0.32 m^3 - 0.11 m^3)$

$W = 1.65 \times 10^5 Pa (0.21 m^3)$

$W = 34,650 J$

b) $\Delta U = Q - W$

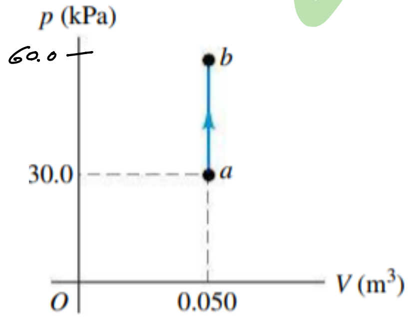
$= 1.15 \times 10^5 J - 34,650$

$\Delta U = 80,350 J$

c) No change. Ideal gas law was not used here.

Homework

19.15 • An ideal gas is taken from a to b on the pV-diagram shown in **Fig. E19.15**. During this process, 700 J of heat is added and the pressure doubles. (a) How much work is done by or on the gas? Explain. (b) How does the temperature of the gas at a compare to its temperature at b? Be specific. (c) How does the internal energy of the gas at a compare to the internal energy at b? Be specific and explain.



a) $W = P\Delta V$

$= P(\varnothing)$

$W = \varnothing J$

b) $\frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f}$

$\frac{P_i V_i}{T_i} = \frac{2P_i V_i}{T_f}$

$\frac{1}{T_i} = \frac{2}{T_f}$

$T_b = 2T_a$

c) $\Delta U = Q - w$

$U_b = U_a + 700 J$

Homework

19.16 • During an isothermal compression of an ideal gas, 410 J of heat must be removed from the gas to maintain constant temperature. How much work is done by the gas during the process?

$Q = -410 J$

$T_f = T_i$

for isothermal $\Delta U = \emptyset J$

Learn/write These Rules

$W = 410 J$