

Hukum Termodinamika (2)



Work and Heat in Thermodynamic Processes

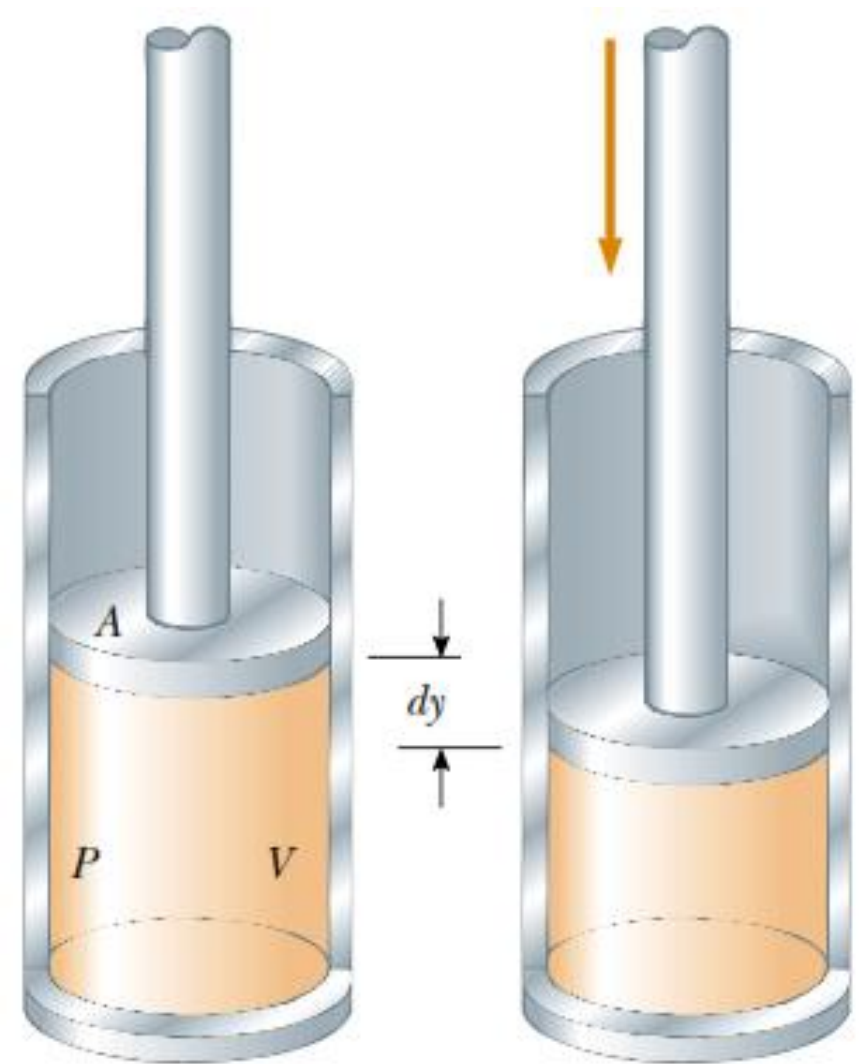
state variables

- the state of a system using such variables as pressure, volume, temperature, and internal energy
- It is important to note that a macroscopic state of an isolated system can be specified only if the system is in thermal equilibrium internally.

transfer variables

- These variables are zero unless a process occurs in which energy is transferred across the boundary of the system.
- Transfer variables are characteristic of a process in which energy is transferred between a system and its environment.

At equilibrium, the gas occupies a volume V and exerts a uniform pressure P on the cylinder's walls and on the piston. If the piston has a cross-sectional area A , the force exerted by the gas on the piston is $F = PA$. Now let us assume that we push the piston inward and compress the gas quasi-statically, that is, slowly enough to allow the system to remain essentially in thermal equilibrium at all times.

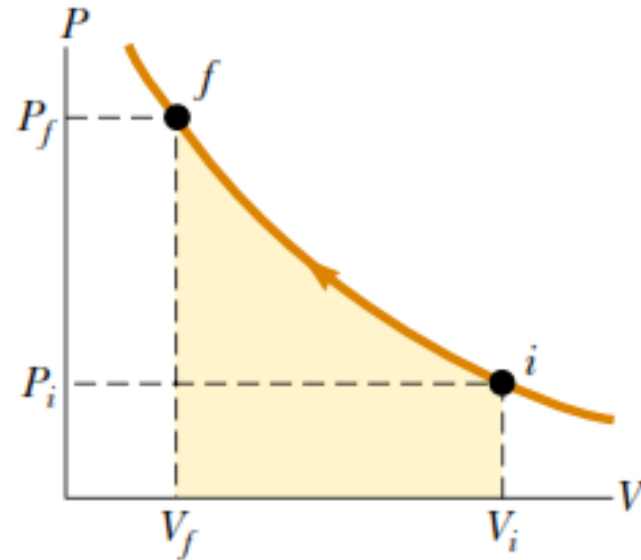


the work done on the gas is

$$dW = F dr = F dy = P A dy$$

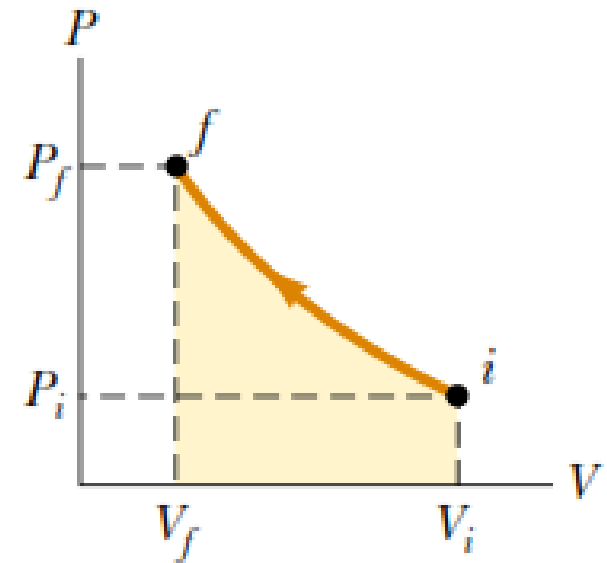
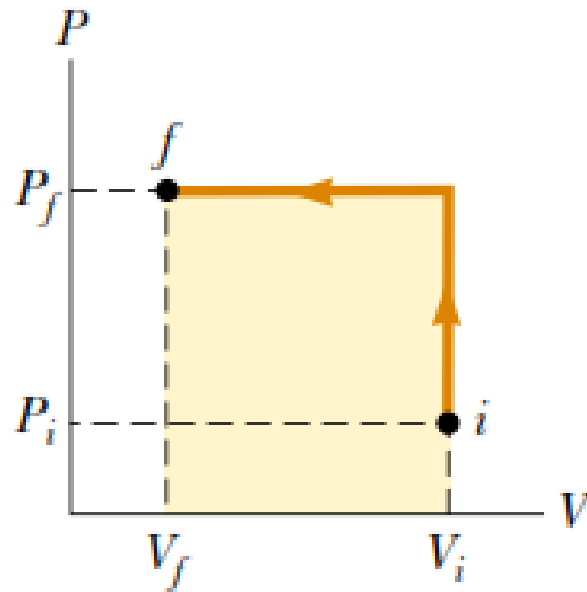
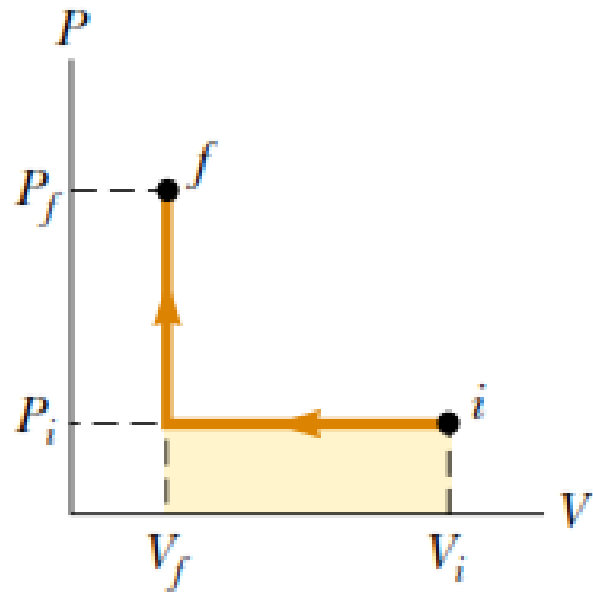
$$dW = PdV$$

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



PV diagram

The work done on a gas as it is taken from an initial state to a final state depends on the path between these states.



- energy transfer by heat, like work done, depends on the initial, final, and intermediate states of the system.

The First Law of Thermodynamics

- The first law of thermodynamics is a special case of the law of conservation of energy that encompasses changes in internal energy and energy transfer by heat and work.

Energy transfer by heat Q to the system occurs, and work W is done on the system.

Although Q and W both depend on the path, the quantity $Q + W$ is independent of the path.

$$\Delta E_{\text{int}} = Q + W$$

When a system undergoes an infinitesimal change in state in which a small amount of energy dQ is transferred by heat and a small amount of work dW is done, the internal energy changes by a small amount dE . Thus, for infinitesimal processes we can express the first law as

$$dE_{\text{int}} = dQ + dW$$

Consider the case of a system (one not isolated from its surroundings) that is taken through a cyclic process—that is, a process that starts and ends at the same state. In this case, the change in the internal energy must again be zero, because E is a state variable, and therefore the energy Q added to the system must equal the negative of the work W done on the system during the cycle. That is, in a cyclic process

$$\Delta E_{\text{int}} = 0 \quad \text{and} \quad Q = -W \quad (\text{cyclic process})$$

An adiabatic process is one during which no energy enters or leaves the system by heat—that is, $Q = 0$.

$$\Delta E_{\text{int}} = W \quad (\text{adiabatic process})$$

A process that occurs at constant pressure is called an isobaric process.

In such a process, the values of the heat and the work are both usually nonzero.

$$W = -P(V_f - V_i) \quad (\text{isobaric process})$$

where P is the constant pressure.

A process that takes place at constant volume is called an isovolumetric process.

$$\Delta E_{\text{int}} = Q \quad (\text{isovolumetric process})$$

In such a process, the value of the work done is zero because the volume does not change. Hence, from the first law we see that in an isovolumetric process, because $W = 0$,

A process that occurs at constant temperature is called an isothermal process.

Isothermal Expansion of an Ideal Gas

$$PV = nRT$$

$$W = - \int_{V_i}^{V_f} P dV = - \int_{V_i}^{V_f} \frac{nRT}{V} dV$$

$$W = - nRT \int_{V_i}^{V_f} \frac{dV}{V} = - nRT \ln V \Big|_{V_i}^{V_f}$$

$$W = nRT \ln \left(\frac{V_i}{V_f} \right)$$

A 1.0-mol sample of an ideal gas is kept at 0.0°C during an expansion from 3.0 L to 10.0 L.

- (A) How much work is done on the gas during the expansion?
- (B) How much energy transfer by heat occurs with the surroundings in this process?
- (C) If the gas is returned to the original volume by means of an isobaric process, how much work is done on the gas?

$$W = nRT \ln \left(\frac{V_i}{V_f} \right)$$

$$= (1.0 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(273 \text{ K}) \ln \left(\frac{3.0 \text{ L}}{10.0 \text{ L}} \right)$$

$$= -2.7 \times 10^3 \text{ J}$$

$$\Delta E_{\text{int}} = Q + W$$

$$0 = Q + W$$

$$Q = -W = 2.7 \times 10^3 \text{ J}$$

$$W = -P(V_f - V_i) = -\frac{nRT_i}{V_i} (V_f - V_i)$$

$$= -\frac{(1.0 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(273 \text{ K})}{10.0 \times 10^{-3} \text{ m}^3}$$

$$\times (3.0 \times 10^{-3} \text{ m}^3 - 10.0 \times 10^{-3} \text{ m}^3)$$

$$= 1.6 \times 10^3 \text{ J}$$

Suppose 1.00 g of water vaporizes isobarically at atmospheric pressure (1.013×10^5 Pa). Its volume in the liquid state is $V_i = V_{\text{liquid}} = 1.00 \text{ cm}^3$, and its volume in the vapor state is $V_f = V_{\text{vapor}} = 1\,671 \text{ cm}^3$. Find the work done in the expansion and the change in internal energy of the system. Ignore any mixing of the steam and the surrounding air—imagine that the steam simply pushes the surrounding air out of the way.

$$\begin{aligned}W &= -P(V_f - V_i) \\&= -(1.013 \times 10^5 \text{ Pa})(1.671 \times 10^{-6} \text{ m}^3 - 1.00 \times 10^{-6} \text{ m}^3) \\&= -169 \text{ J}\end{aligned}$$

$$Q = mL_v = (1.00 \times 10^{-3} \text{ kg})(2.26 \times 10^6 \text{ J/kg}) = 2260 \text{ J}$$

$$\Delta E_{\text{int}} = Q + W = 2260 \text{ J} + (-169 \text{ J}) = 2.09 \text{ kJ}$$

No 1

The temperature of a silver bar rises by 10.0°C when it absorbs 1.23 kJ of energy by heat. The mass of the bar is 525 g . Determine the specific heat of silver.

$$\Delta Q = mc_{\text{silver}}\Delta T$$

$$1.23 \text{ kJ} = (0.525 \text{ kg})c_{\text{silver}}(10.0^\circ\text{C})$$

$$c_{\text{silver}} = \boxed{0.234 \text{ kJ/kg}\cdot^\circ\text{C}}$$

No 2

A 50.0-g sample of copper is at 25.0°C. If 1 200 J of energy is added to it by heat, what is the final temperature of the copper?

From $Q = mc\Delta T$

we find $\Delta T = \frac{Q}{mc} = \frac{1\,200\text{ J}}{0.050\,0\text{ kg}(387\text{ J/kg}\cdot^\circ\text{C})} = 62.0^\circ\text{C}$

Thus, the final temperature is $\boxed{87.0^\circ\text{C}}$.

No 3

A water heater is operated by solar power. If the solar collector has an area of 6.00 m^2 and the intensity delivered by sunlight is 550 W/m^2 , how long does it take to increase the temperature of 1.00 m^3 of water from 20.0°C to 60.0°C ?

$$c = 4186 \text{ J/kg } ^\circ\text{C}$$

The rate of collection of energy is $\mathcal{P} = 550 \text{ W/m}^2 (6.00 \text{ m}^2) = 3\,300 \text{ W}$. The amount of energy required to raise the temperature of 1 000 kg of water by 40.0°C is:

$$Q = mc\Delta T = 1\,000 \text{ kg}(4\,186 \text{ J/kg}\cdot^\circ\text{C})(40.0^\circ\text{C}) = 1.67 \times 10^8 \text{ J}$$

Thus, $\mathcal{P}\Delta t = 1.67 \times 10^8 \text{ J}$

or $\Delta t = \frac{1.67 \times 10^8 \text{ J}}{3\,300 \text{ W}} = \boxed{50.7 \text{ ks}} = 14.1 \text{ h}.$

No 4

A combination of 0.250 kg of water at 20.0°C, 0.400 kg of aluminum at 26.0°C, and 0.100 kg of copper at 100°C is mixed in an insulated container and allowed to come to thermal equilibrium. Ignore any energy transfer to or from the container and determine the final temperature of the mixture.

$$C_p \text{ air} = 4186 \text{ J/kg}^\circ\text{C}$$

$$C_p \text{ aluminium} = 900 \text{ J/kg}^\circ\text{C}$$

$$C_p \text{ tembaga} = 387 \text{ J/kg}^\circ\text{C}$$

We do not know whether the aluminum will rise or drop in temperature. The energy the water can absorb in rising to 26°C is $mc\Delta T = 0.25 \text{ kg } 4186 \frac{\text{J}}{\text{kg } ^\circ\text{C}} 6^\circ\text{C} = 6279 \text{ J}$. The energy the copper can put out in dropping to 26°C is $mc\Delta T = 0.1 \text{ kg } 387 \frac{\text{J}}{\text{kg } ^\circ\text{C}} 74^\circ\text{C} = 2864 \text{ J}$. Since $6279 \text{ J} > 2864 \text{ J}$, the final temperature is less than 26°C . We can write $Q_h = -Q_c$ as

$$Q_{\text{water}} + Q_{\text{Al}} + Q_{\text{Cu}} = 0$$

$$0.25 \text{ kg } 4186 \frac{\text{J}}{\text{kg } ^\circ\text{C}} (T_f - 20^\circ\text{C}) + 0.4 \text{ kg } 900 \frac{\text{J}}{\text{kg } ^\circ\text{C}} (T_f - 26^\circ\text{C})$$

$$+ 0.1 \text{ kg } 387 \frac{\text{J}}{\text{kg } ^\circ\text{C}} (T_f - 100^\circ\text{C}) = 0$$

$$1046.5T_f - 20930^\circ\text{C} + 360T_f - 9360^\circ\text{C} + 38.7T_f - 3870^\circ\text{C} = 0$$

$$1445.2T_f = 34160^\circ\text{C}$$

$$T_f = \boxed{23.6^\circ\text{C}}$$

No 5

A 50.0-g copper calorimeter contains 250 g of water at 20.0°C. How much steam must be condensed into the water if the final temperature of the system is to reach 50.0°C?

$C_p \text{ air} = 4186 \text{ J/kg}^\circ\text{C}$

$C_p \text{ tembaga} = 387 \text{ J/kg}^\circ\text{C}$

$\text{Panas laten air - steam} = 2,26 \times 10^6 \text{ J/kg}$

$$Q_{\text{cold}} = -Q_{\text{hot}}$$

$$(m_w c_w + m_c c_c)(T_f - T_i) = -m_s [-L_v + c_w (T_f - 100)]$$

$$\begin{aligned} & [0.250 \text{ kg}(4186 \text{ J/kg}\cdot^\circ\text{C}) + 0.0500 \text{ kg}(387 \text{ J/kg}\cdot^\circ\text{C})](50.0^\circ\text{C} - 20.0^\circ\text{C}) \\ & = -m_s [-2.26 \times 10^6 \text{ J/kg} + (4186 \text{ J/kg}\cdot^\circ\text{C})(50.0^\circ\text{C} - 100^\circ\text{C})] \end{aligned}$$

$$m_s = \frac{3.20 \times 10^4 \text{ J}}{2.47 \times 10^6 \text{ J/kg}} = 0.0129 \text{ kg} = \boxed{12.9 \text{ g steam}}$$

No 6


A 1.00-kg block of copper at 20.0°C is dropped into a large vessel of liquid nitrogen at 77.3 K . How many kilograms of nitrogen boil away by the time the copper reaches 77.3 K ? (The specific heat of copper is $0.0920\text{ cal/g}\cdot^{\circ}\text{C}$. The latent heat of vaporization of nitrogen is 48.0 cal/g .)

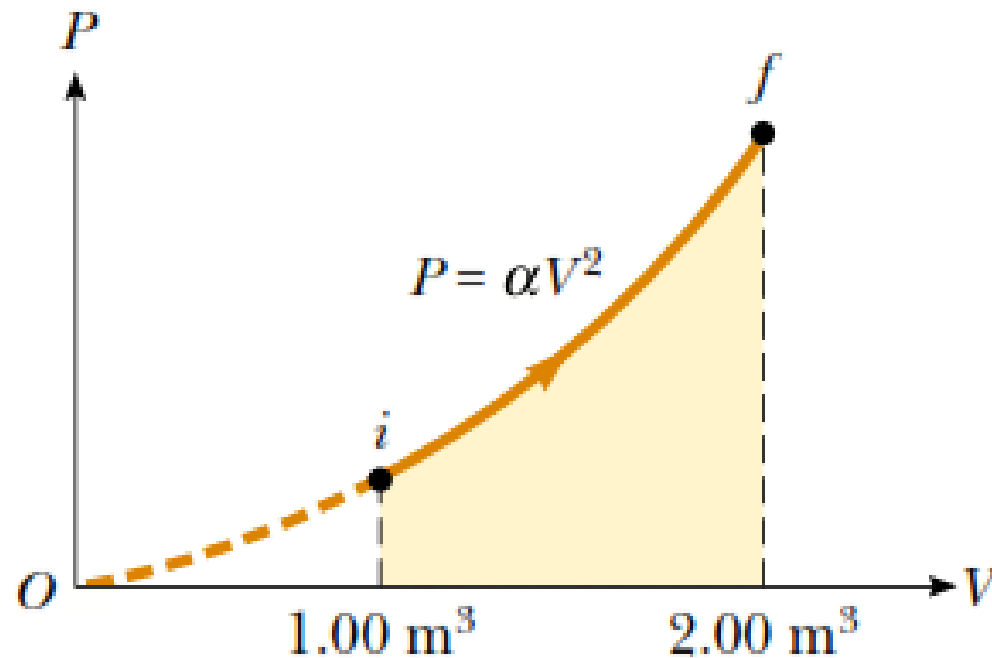
$$Q = m_{\text{Cu}} c_{\text{Cu}} \Delta T = m_{\text{N}_2} (L_{\text{vap}})_{\text{N}_2}$$

$$1.00 \text{ kg}(0.0920 \text{ cal/g}\cdot^{\circ}\text{C})(293 - 77.3)^{\circ}\text{C} = m(48.0 \text{ cal/g})$$

$$m = \boxed{0.414 \text{ kg}}$$

No 7

 A sample of ideal gas is expanded to twice its original volume of 1.00 m^3 in a quasi-static process for which $P = \alpha V^2$, with $\alpha = 5.00 \text{ atm/m}^6$, as shown in Figure P20.23. How much work is done on the expanding gas?



$$1 \text{ atm} = 1,013 \times 10^5 \text{ Pa}$$

$$W_{if} = -\int_i^f P dV$$

The work done on the gas is the negative of the area under the curve $P = \alpha V^2$ between V_i and V_f .

$$W_{if} = -\int_i^f \alpha V^2 dV = -\frac{1}{3} \alpha (V_f^3 - V_i^3)$$

$$V_f = 2V_i = 2(1.00 \text{ m}^3) = 2.00 \text{ m}^3$$

$$W_{if} = -\frac{1}{3} \left[(5.00 \text{ atm/m}^6) (1.013 \times 10^5 \text{ Pa/atm}) \right] \left[(2.00 \text{ m}^3)^3 + (1.00 \text{ m}^3)^3 \right] = \boxed{-1.18 \text{ MJ}}$$

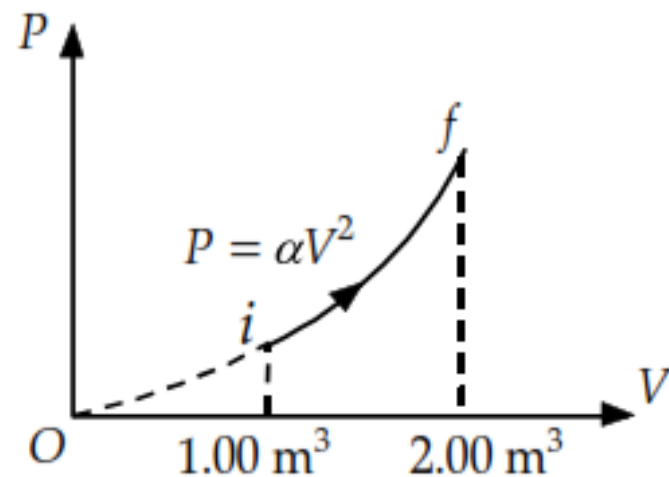


FIG. P20.23

No 8

(a) Determine the work done on a fluid that expands from i to f as indicated in Figure P20.24. (b) **What If?** How much work is performed on the fluid if it is compressed from f to i along the same path?

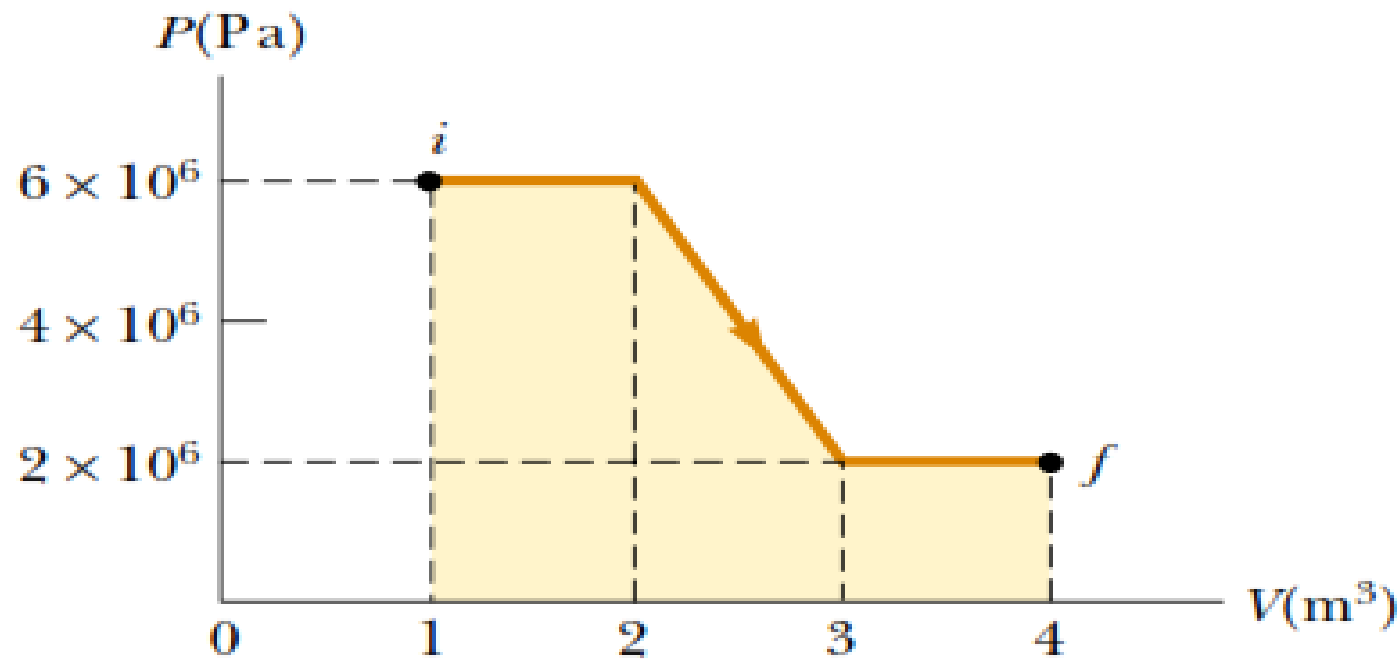


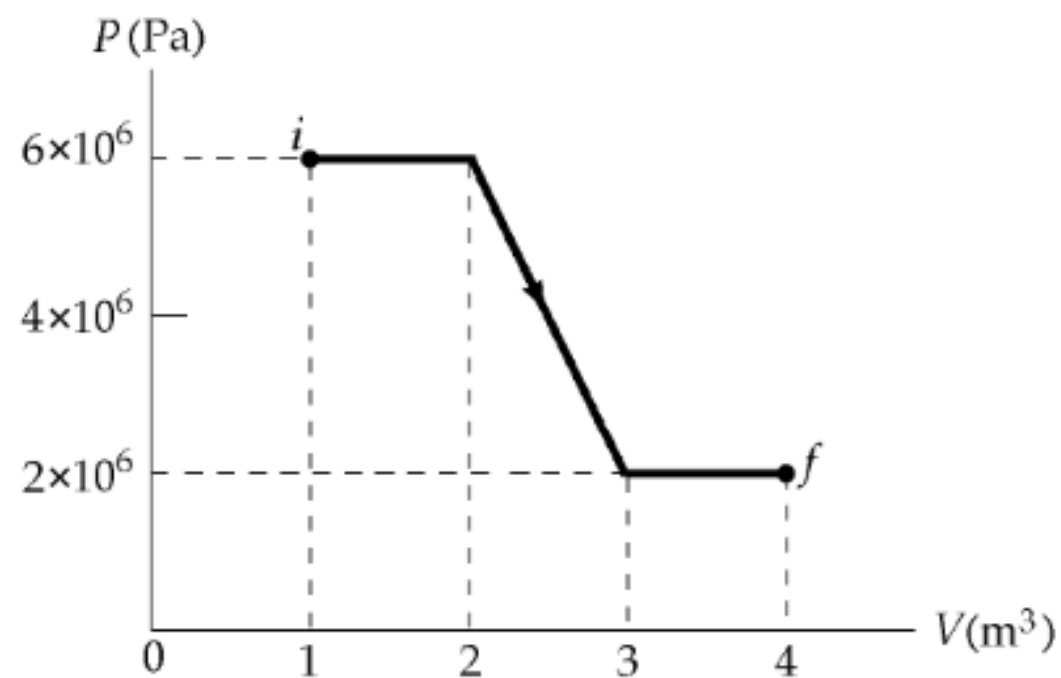
Figure P20.24

(a) $W = -\int P dV$

$$W = -(6.00 \times 10^6 \text{ Pa})(2.00 - 1.00) \text{ m}^3 +$$
$$-(4.00 \times 10^6 \text{ Pa})(3.00 - 2.00) \text{ m}^3 +$$
$$-(2.00 \times 10^6 \text{ Pa})(4.00 - 3.00) \text{ m}^3$$

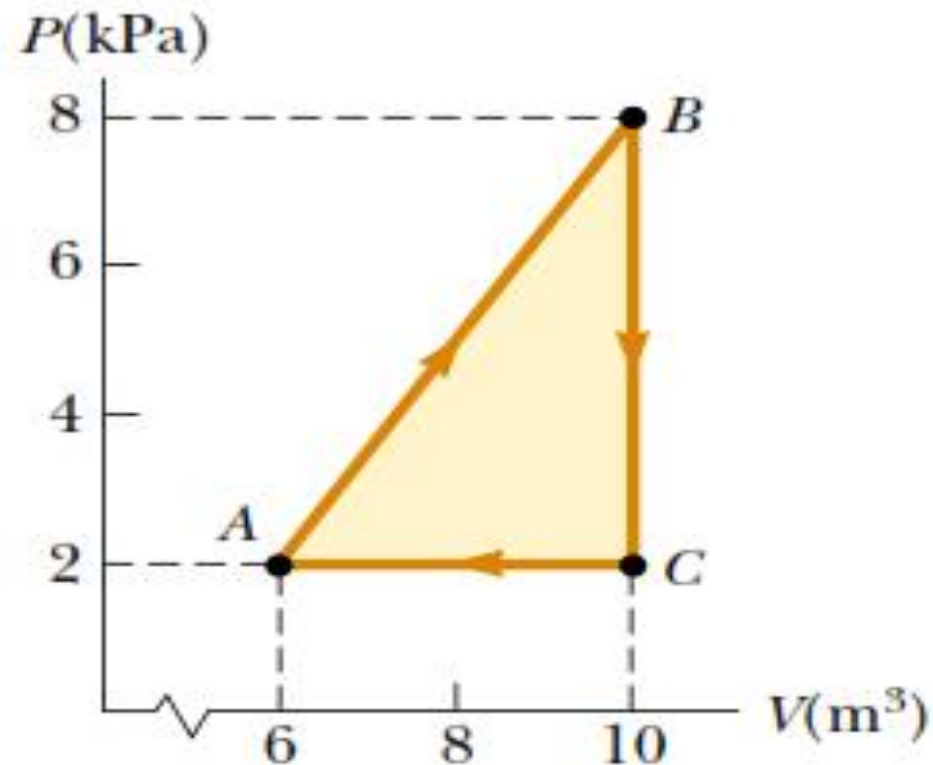
$$W_{i \rightarrow f} = \boxed{-12.0 \text{ MJ}}$$

(b) $W_{f \rightarrow i} = \boxed{+12.0 \text{ MJ}}$



No 9

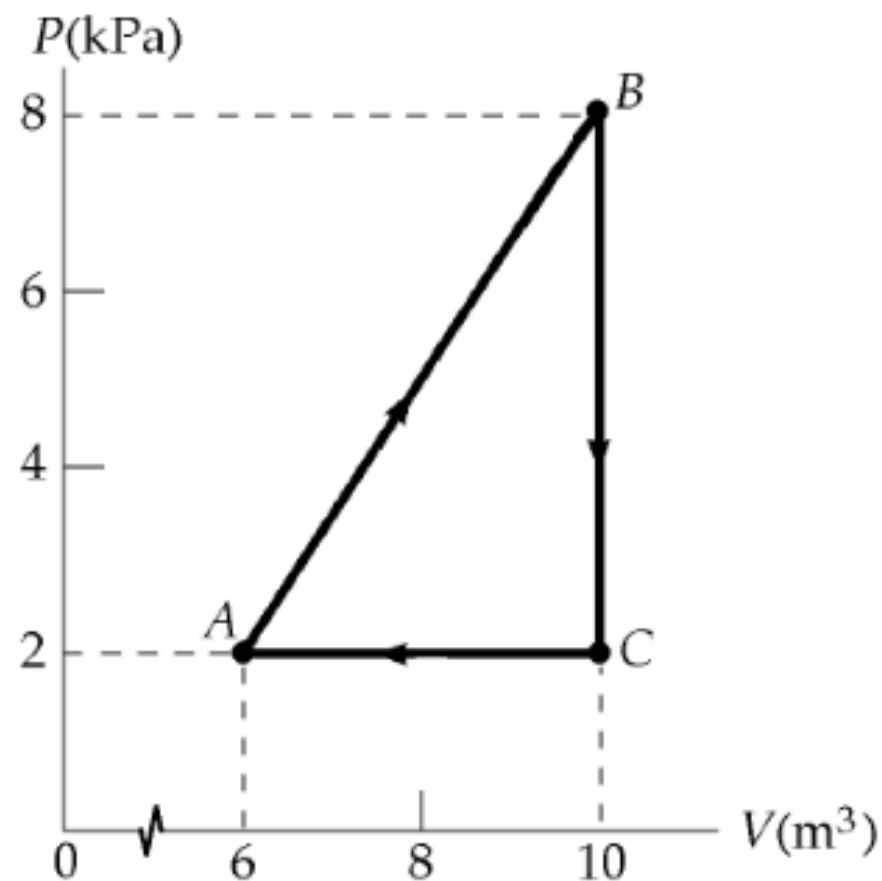
A gas is taken through the cyclic process described in Figure P20.30. (a) Find the net energy transferred to the system by heat during one complete cycle. (b) **What If?** If the cycle is reversed—that is, the process follows the path *ACBA*—what is the net energy input per cycle by heat?



(a) $Q = -W = \text{Area of triangle}$

$$Q = \frac{1}{2}(4.00 \text{ m}^3)(6.00 \text{ kPa}) = \boxed{12.0 \text{ kJ}}$$

(b) $Q = -W = \boxed{-12.0 \text{ kJ}}$



No 10

. A gas is compressed at a constant pressure of 0.800 atm from 9.00 L to 2.00 L. In the process, 400 J of energy leaves the gas by heat. (a) What is the work done on the gas? (b) What is the change in its internal energy?

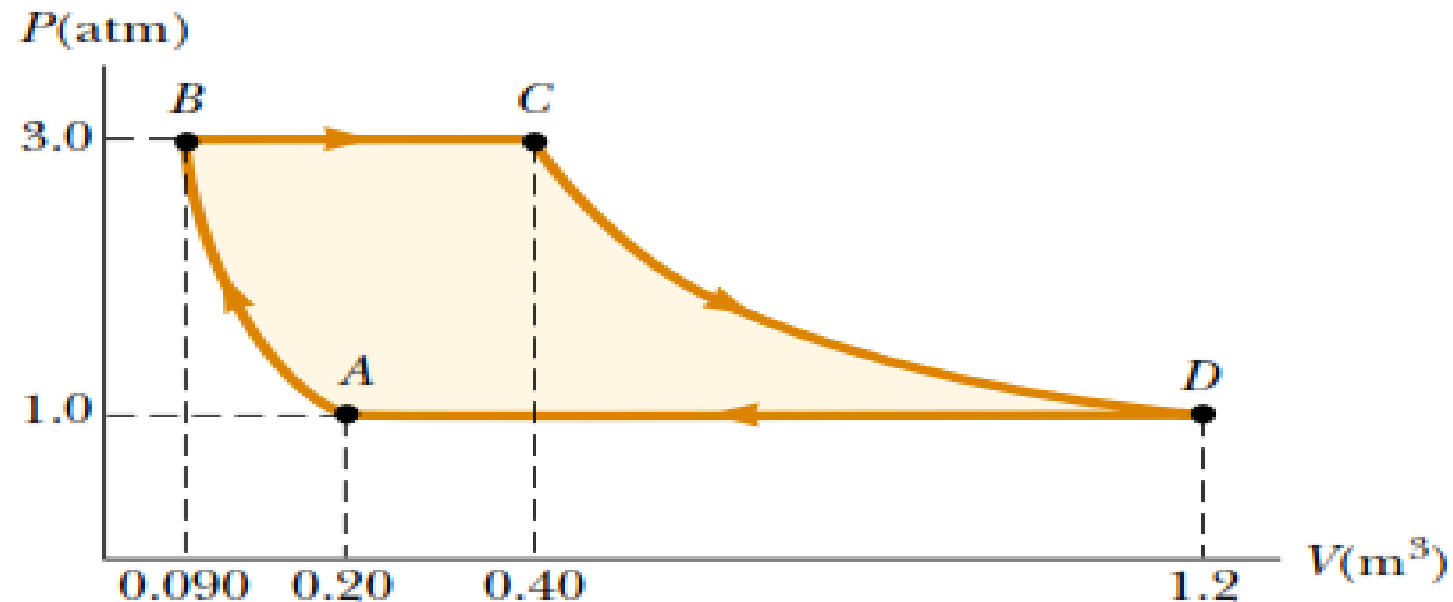
• 1 atm = 1.013×10^5 Pa

$$(a) \quad W = -P\Delta V = -(0.800 \text{ atm})(-7.00 \text{ L})(1.013 \times 10^5 \text{ Pa/atm})(10^{-3} \text{ m}^3/\text{L}) = \boxed{+567 \text{ J}}$$

$$(b) \quad \Delta E_{\text{int}} = Q + W = -400 \text{ J} + 567 \text{ J} = \boxed{167 \text{ J}}$$

No 11

A sample of an ideal gas goes through the process shown in Figure P20.32. From A to B , the process is adiabatic; from B to C , it is isobaric with 100 kJ of energy entering the system by heat. From C to D , the process is isothermal; from D to A , it is isobaric with 150 kJ of energy leaving the system by heat. Determine the difference in internal energy $E_{\text{int}, B} - E_{\text{int}, A}$.



$$W_{BC} = -P_B(V_C - V_B) = -3.00 \text{ atm}(0.400 - 0.0900) \text{ m}^3$$

$$= -94.2 \text{ kJ}$$

$$\Delta E_{\text{int}} = Q + W$$

$$E_{\text{int}, C} - E_{\text{int}, B} = (100 - 94.2) \text{ kJ}$$

$$E_{\text{int}, C} - E_{\text{int}, B} = 5.79 \text{ kJ}$$

Since T is constant,

$$E_{\text{int}, D} - E_{\text{int}, C} = 0$$

$$W_{DA} = -P_D(V_A - V_D) = -1.00 \text{ atm}(0.200 - 1.20) \text{ m}^3$$

$$= +101 \text{ kJ}$$

$$E_{\text{int}, A} - E_{\text{int}, D} = -150 \text{ kJ} + (+101 \text{ kJ}) = -48.7 \text{ kJ}$$

$$\text{Now, } E_{\text{int}, B} - E_{\text{int}, A} = -\left[(E_{\text{int}, C} - E_{\text{int}, B}) + (E_{\text{int}, D} - E_{\text{int}, C}) + (E_{\text{int}, A} - E_{\text{int}, D})\right]$$

$$E_{\text{int}, B} - E_{\text{int}, A} = -[5.79 \text{ kJ} + 0 - 48.7 \text{ kJ}] = \boxed{42.9 \text{ kJ}}$$

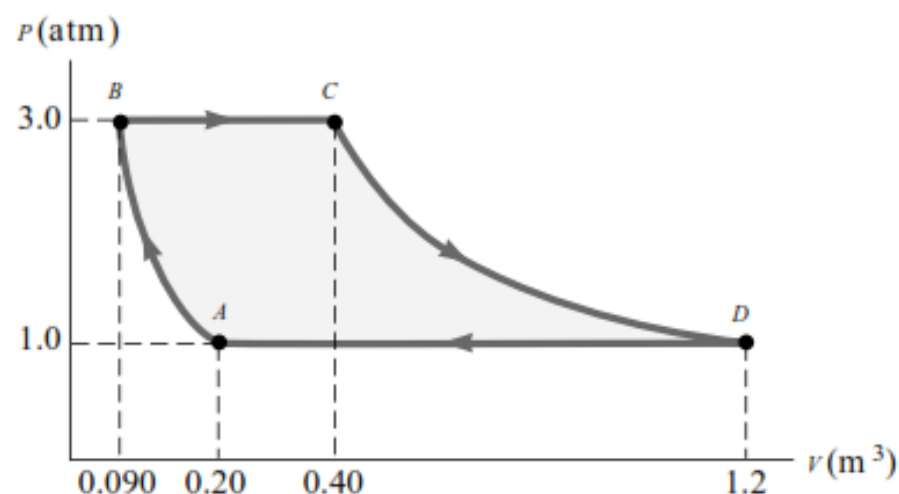


FIG. P20.32

No 12

One mole of an ideal gas does 3 000 J of work on its surroundings as it expands isothermally to a final pressure of 1.00 atm and volume of 25.0 L. Determine (a) the initial volume and (b) the temperature of the gas.

$$(a) \quad W = -nRT \ln\left(\frac{V_f}{V_i}\right) = -P_f V_f \ln\left(\frac{V_f}{V_i}\right)$$

$$\text{so } V_i = V_f \exp\left(+\frac{W}{P_f V_f}\right) = (0.0250) \exp\left[\frac{-3000}{0.0250(1.013 \times 10^5)}\right] = \boxed{0.00765 \text{ m}^3}$$

$$(b) \quad T_f = \frac{P_f V_f}{nR} = \frac{1.013 \times 10^5 \text{ Pa}(0.0250 \text{ m}^3)}{1.00 \text{ mol}(8.314 \text{ J/K} \cdot \text{mol})} = \boxed{305 \text{ K}}$$

No 13

A 1.00-kg block of aluminum is heated at atmospheric pressure so that its temperature increases from 22.0°C to 40.0°C. Find (a) the work done on the aluminum, (b) the energy added to it by heat, and (c) the change in its internal energy.

Remember

$$\Delta V = 3\alpha V\Delta T$$

$$\alpha = 24 \times 10^{-6} / ^\circ\text{C}$$

$$C_{\text{aluminum}} = 900 \text{ J/kg } ^\circ\text{C}$$

$$\begin{aligned} \text{(a)} \quad W &= -P\Delta V = -P[3\alpha V\Delta T] \\ &= -(1.013 \times 10^5 \text{ N/m}^2) \left[3(24.0 \times 10^{-6} \text{ }^\circ\text{C}^{-1}) \left(\frac{1.00 \text{ kg}}{2.70 \times 10^3 \text{ kg/m}^3} \right) (18.0^\circ\text{C}) \right] \end{aligned}$$

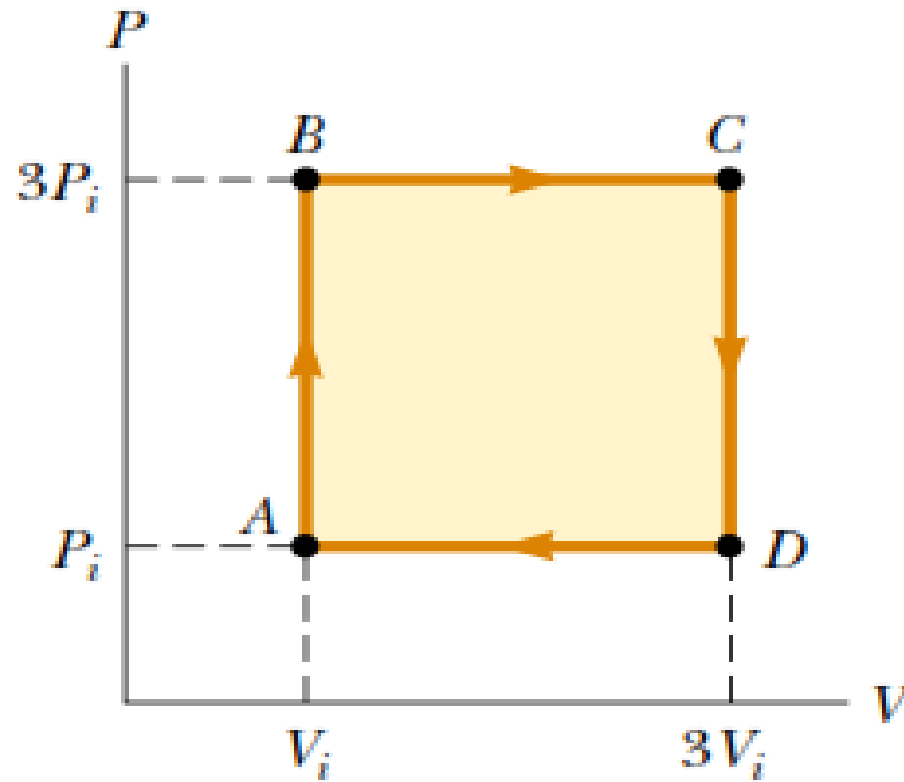
$$W = \boxed{-48.6 \text{ mJ}}$$

$$\text{(b)} \quad Q = cm\Delta T = (900 \text{ J/kg}\cdot^\circ\text{C})(1.00 \text{ kg})(18.0^\circ\text{C}) = \boxed{16.2 \text{ kJ}}$$

$$\text{(c)} \quad \Delta E_{\text{int}} = Q + W = 16.2 \text{ kJ} - 48.6 \text{ mJ} = \boxed{16.2 \text{ kJ}}$$

No 14

An ideal gas initially at P_i , V_i , and T_i is taken through a cycle as in Figure P20.38. (a) Find the net work done on the gas per cycle. (b) What is the net energy added by heat to the system per cycle? (c) Obtain a numerical value for the net work done per cycle for 1.00 mol of gas initially at 0°C .



- (a) The work done during each step of the cycle equals the negative of the area under that segment of the PV curve.

$$W = W_{DA} + W_{AB} + W_{BC} + W_{CD}$$

$$W = -P_i(V_i - 3V_i) + 0 - 3P_i(3V_i - V_i) + 0 = \boxed{-4P_iV_i}$$

- (b) The initial and final values of T for the system are equal.

Therefore, $\Delta E_{\text{int}} = 0$ and $Q = -W = \boxed{4P_iV_i}$.

- (c) $W = -4P_iV_i = -4nRT_i = -4(1.00)(8.314)(273) = \boxed{-9.08 \text{ kJ}}$

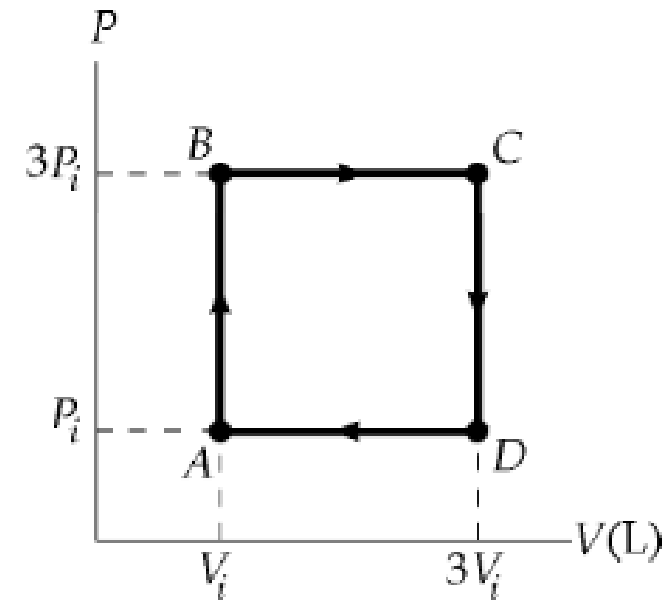
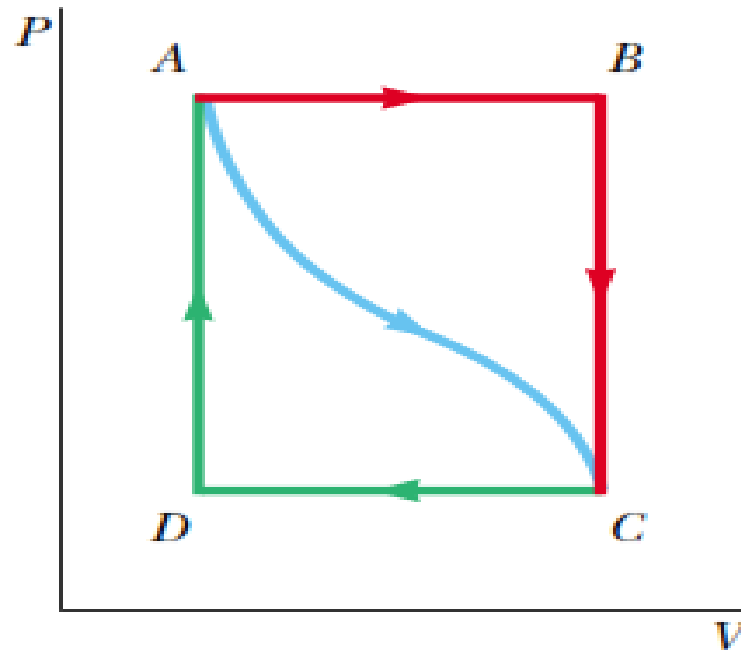


FIG. P20.38

No 15

In Figure P20.40, the change in internal energy of a gas that is taken from A to C is $+800\text{ J}$. The work done on the gas along path ABC is -500 J . (a) How much energy must be added to the system by heat as it goes from A through B to C ? (b) If the pressure at point A is five times that of point C , what is the work done on the system in going from C to D ? (c) What is the energy exchanged with the surroundings by heat as the cycle goes from C to A along the green path? (d) If the change in internal energy in going from point D to point A is $+500\text{ J}$, how much energy must be added to the system by heat as it goes from point C to point D ?



$$\Delta E_{\text{int}, ABC} = \Delta E_{\text{int}, AC} \quad (\text{conservation of energy})$$

$$(a) \quad \Delta E_{\text{int}, ABC} = Q_{ABC} + W_{ABC} \quad (\text{First Law})$$

$$Q_{ABC} = 800 \text{ J} + 500 \text{ J} = \boxed{1300 \text{ J}}$$

$$(b) \quad W_{CD} = -P_C \Delta V_{CD}, \quad \Delta V_{AB} = -\Delta V_{CD}, \quad \text{and} \quad P_A = 5P_C$$

$$\text{Then, } W_{CD} = \frac{1}{5} P_A \Delta V_{AB} = -\frac{1}{5} W_{AB} = \boxed{100 \text{ J}}$$

(+ means that work is done on the system)

$$(c) \quad W_{CDA} = W_{CD} \text{ so that } Q_{CA} = \Delta E_{\text{int}, CA} - W_{CDA} = -800 \text{ J} - 100 \text{ J} = \boxed{-900 \text{ J}}$$

(- means that energy must be removed from the system by heat)

$$(d) \quad \Delta E_{\text{int}, CD} = \Delta E_{\text{int}, CDA} - \Delta E_{\text{int}, DA} = -800 \text{ J} - 500 \text{ J} = -1300 \text{ J}$$

$$\text{and } Q_{CD} = \Delta E_{\text{int}, CD} - W_{CD} = -1300 \text{ J} - 100 \text{ J} = \boxed{-1400 \text{ J}}$$

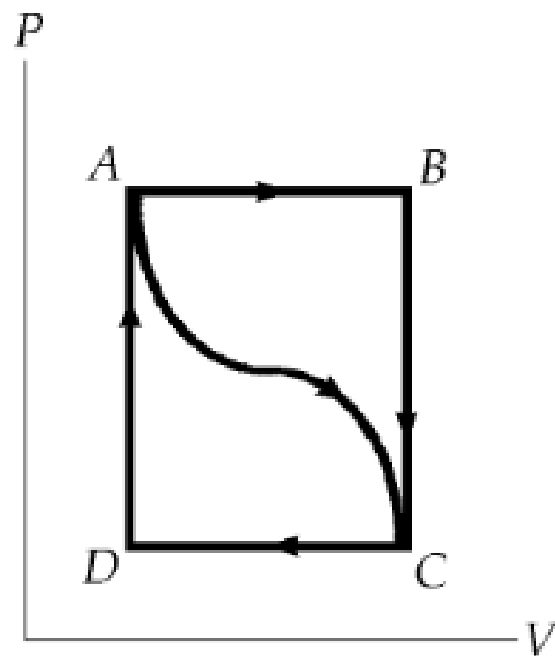


FIG. P20.40