Fisica do Calor (4300159)

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B06

Exercícios

Example 19.4 Comparing thermodynamic processes

A series of thermodynamic processes is shown in the pV-diagram of Fig. 19.13. In process ab, 150 J of heat is added to the system, and 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).

SOLUTION

IDENTIFY: In each process we use $\Delta U = Q - W$ to determine the desired quantity.

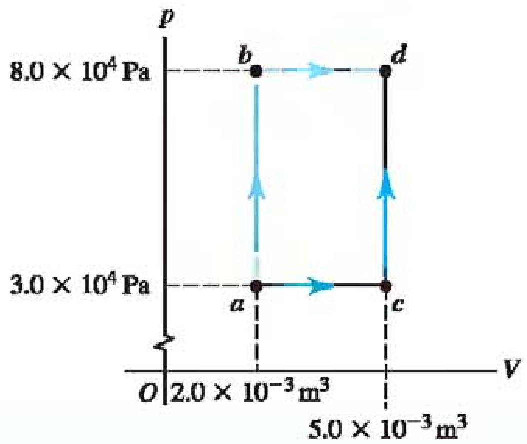
SET UP: We are given $Q_{ab} = +150\ \text{J}$ and $Q_{bd} = +600\ \text{J}$ (both values are positive because heat is *added* to the system). Our target variables are (a) ΔU_{ab}, (b) ΔU_{abd}, and (c) Q_{acd}.

EXECUTE: (a) No volume change occurs during process ab, so $W_{ab} = 0$ and $\Delta U_{ab} = Q_{ab} = 150\ \text{J}$.

(b) Process bd occurs at constant pressure, so the work done by the system during this expansion is

$$\begin{aligned} W_{bd} &= p(V_2 - V_1) \\ &= (8.0 \times 10^4\ \text{Pa})(5.0 \times 10^{-3}\ \text{m}^3 - 2.0 \times 10^{-3}\ \text{m}^3) \\ &= 240\ \text{J} \end{aligned}$$

19.13 A pV-diagram showing the various thermodynamic processes.



The total work for process abd is

$$W_{abd} = W_{ab} + W_{bd} = 0 + 240\ \text{J} = 240\ \text{J}$$

and the total heat is

$$Q_{abd} = Q_{ab} + Q_{bd} = 150\ \text{J} + 600\ \text{J} = 750\ \text{J}$$

Applying Eq. (19.4) to abd, we find

$$\Delta U_{abd} = Q_{abd} - W_{abd} = 750\ \text{J} - 240\ \text{J} = 510\ \text{J}$$

(c) Because ΔU is independent of path, the internal energy change is the same for path acd as for path abd; that is,

$$\Delta U_{acd} = \Delta U_{abd} = 510\ \text{J}$$

The total work for the path acd is

$$\begin{aligned} W_{acd} &= W_{ac} + W_{cd} = p(V_2 - V_1) + 0 \\ &= (3.0 \times 10^4\ \text{Pa})(5.0 \times 10^{-3}\ \text{m}^3 - 2.0 \times 10^{-3}\ \text{m}^3) \\ &= 90\ \text{J} \end{aligned}$$

Now we apply Eq. (19.5) to process acd:

$$Q_{acd} = \Delta U_{acd} + W_{acd} = 510\ \text{J} + 90\ \text{J} = 600\ \text{J}$$

Here is a tabulation of the various quantities:

Step	Q	W	$\Delta U = Q - W$	Step	Q	W	$\Delta U = Q - W$
ab	150 J	0 J	150 J	ac	?	90 J	?
bd	600 J	240 J	360 J	cd	?	0 J	?
abd	750 J	240 J	510 J	acd	600 J	90 J	510 J

EVALUATE: We see that although ΔU is the same (510 J) for abd and acd, W (240 J versus 90 J) and Q (750 J versus 600 J) are quite different for the two processes.

Notice that we don't have enough information to find Q or ΔU for the processes ac and cd. We were nonetheless able to analyze the composite process acd by comparing it to the process abd, which has the same initial and final states and for which we have more complete information.

Example 19.5 Thermodynamics of boiling water

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

SOLUTION

IDENTIFY: The new feature of this problem is that the heat added causes the system (water) to change phase from liquid to vapor. We can nonetheless apply the first law of thermodynamics, which is true for thermodynamic processes of all kinds.

SET UP: The water is boiled at a constant pressure, so we can calculate the work W done by the water using Eq. (19.3). We can calculate the heat Q added to the water from the mass and the heat of vaporization, and we can then find the internal energy change using $\Delta U = Q - W$.

EXECUTE: (a) From Eq. (19.3), the work done by the vaporizing water is

$$\begin{aligned} W &= p(V_2 - V_1) \\ &= (1.013 \times 10^5\ \text{Pa})(1671 \times 10^{-6}\ \text{m}^3 - 1 \times 10^{-6}\ \text{m}^3) \\ &= 169\ \text{J} \end{aligned}$$

(b) From Eq. (17.20), the heat added to the water to vaporize it is

$$Q = mL_v = (10^{-3}\ \text{kg})(2.256 \times 10^6\ \text{J/kg}) = 2256\ \text{J}$$

From the first law of thermodynamics, Eq. (19.4), the change in internal energy is

$$\Delta U = Q - W = 2256\ \text{J} - 169\ \text{J} = 2087\ \text{J}$$

EVALUATE: To vaporize 1 gram of water, we have to add 2256 J of heat. Most (2087 J) of this added energy remains in the system as an increase in internal energy. The remaining 169 J leaves the system again as it does work against the surroundings while expanding from liquid to vapor. The increase in internal energy is associated mostly with the intermolecular forces that hold the molecules together in the liquid state. These forces are attractive, so the associated potential energies are greater after work has been done to pull the molecules apart, forming the vapor state. It's like increasing gravitational potential energy by pulling an elevator farther from the center of the earth.

Example 19.6 Cooling your room

A typical dorm room or bedroom contains about 2500 moles of air. Find the change in the internal energy of this much air when it is cooled from 23.9°C to 11.6°C at a constant pressure of 1.00 atm. Treat the air as an ideal gas with $\gamma = 1.400$.

SOLUTION

IDENTIFY: Our target variable is the change in the internal energy ΔU of an ideal gas in a constant-pressure process. We are given the number of moles and the temperature change.

SET UP: Your first impulse may be to find C_p and then calculate Q from $Q = nC_p\,\Delta T$; find the volume change and find the work done by the gas from $W = p\,\Delta V$; then finally use the first law to find ΔU. This would be perfectly correct, but there's a much easier way. For an ideal gas the internal energy change is $\Delta U = nC_V\,\Delta T$ for *every* process, *whether the volume is constant or not*. So all we have to do is find C_V and use this expression for ΔU.

EXECUTE: We are given the value of γ for air, so we use Eqs. (19.17) and (19.18) to determine C_V:

$$\gamma = \frac{C_p}{C_V} = \frac{C_V + R}{C_V} = 1 + \frac{R}{C_V}$$

$$C_V = \frac{R}{\gamma - 1} = \frac{8.314\ \text{J/mol}\cdot\text{K}}{1.400 - 1} = 20.79\ \text{J/mol}\cdot\text{K}$$

Then

$$\begin{aligned}\Delta U &= nC_V\,\Delta T \\ &= (2500\ \text{mol})(20.79\ \text{J/mol}\cdot\text{K})(11.6^\circ\text{C} - 23.9^\circ\text{C}) \\ &= -6.39 \times 10^5\ \text{J}\end{aligned}$$

EVALUATE: A room air conditioner must extract this much internal energy from the air in your room and transfer it to the air outside. We'll discuss how this is done in Chapter 20.

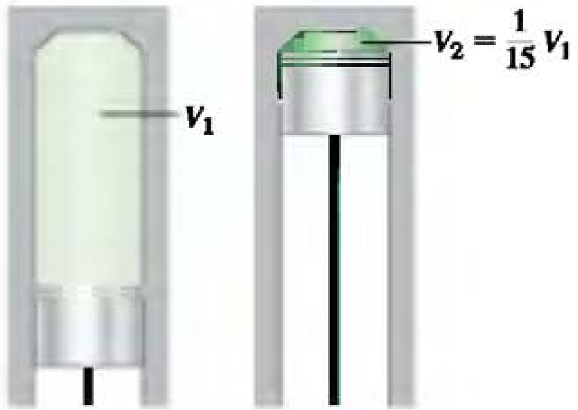
Example 19.7 Adiabatic compression in a diesel engine

The compression ratio of a diesel engine is 15 to 1; this means that air in the cylinders is compressed to $\frac{1}{15}$ of its initial volume (Fig. 19.21). If the initial pressure is 1.01×10^5 Pa and the initial temperature is 27°C (300 K), find the final pressure and the temperature after compression. Air is mostly a mixture of diatomic oxygen and nitrogen; treat it as an ideal gas with $\gamma = 1.40$.

SOLUTION

IDENTIFY: Since this problem involves the adiabatic compression of an ideal gas, we can use the ideas of this section.

19.21 Adiabatic compression of air in a cylinder of a diesel engine.



SET UP: We are given the initial pressure $p_1 = 1.01 \times 10^5$ Pa and the initial temperature $T_1 = 300$ K, and we are told that the ratio of initial and final volumes is $V_1/V_2 = 15$. We can find the final temperature T_2 using Eq. (19.22) and the final pressure p_2 using Eq. (19.24).

EXECUTE: From Eq. (19.22),

$$T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} = (300\text{ K})(15)^{0.40} = 886\text{ K} = 613°\text{C}$$

From Eq. (19.24),

$$p_2 = p_1\left(\frac{V_1}{V_2}\right)^{\gamma} = (1.01 \times 10^5\text{ Pa})(15)^{1.40}$$
$$= 44.8 \times 10^5\text{ Pa} = 44\text{ atm}$$

EVALUATE: If the compression had been isothermal, the final pressure would have been 15 atm, but because the temperature also increases during an adiabatic compression, the final pressure is much greater. When fuel is injected into the cylinders near the end of the compression stroke, the high temperature of the air attained during compression causes the fuel to ignite spontaneously without the need for spark plugs.