

SOLUTION

IDENTIFY and SET UP: This problem involves the properties of the Carnot cycle and those of an ideal gas. We are given the number of moles n and the pressure and temperature at point a (which is at the higher of the two reservoir temperatures); we can find the volume at a using the ideal-gas equation $pV = nRT$. We then find the pressure and volume at points b , c , and d from the known doubling of volume in step $a \rightarrow b$, from equations given in this section, and from $pV = nRT$. In each step we use Eqs. (20.10) and (20.11) to find the heat flow and work done and Eq. (19.13) to find the internal energy change.

EXECUTE: The volume at point a is

$$V_a = \frac{nRT_a}{p_a} = \frac{(0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(500 \text{ K})}{(1.00 \times 10^5 \text{ Pa})} = 8.31 \times 10^{-3} \text{ m}^3$$

The volume at point b is twice that at point a , so

$$V_b = 2V_a = 1.66 \times 10^{-2} \text{ m}^3$$

The pressure at point b is

$$p_b = \frac{nRT_b}{V_b} = \frac{(0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(500 \text{ K})}{1.66 \times 10^{-2} \text{ m}^3} = 5.00 \times 10^4 \text{ Pa}$$

The volume at point c is

$$V_c = \frac{nRT_c}{p_c} = \frac{(0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(300 \text{ K})}{(1.00 \times 10^5 \text{ Pa})} = 4.99 \times 10^{-3} \text{ m}^3$$

The pressure at point c is

$$p_c = \frac{nRT_c}{V_c} = \frac{(0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(300 \text{ K})}{4.99 \times 10^{-3} \text{ m}^3} = 1.00 \times 10^5 \text{ Pa}$$

The volume at point d is

$$V_d = \frac{nRT_d}{p_d} = \frac{(0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(500 \text{ K})}{(1.00 \times 10^5 \text{ Pa})} = 8.31 \times 10^{-3} \text{ m}^3$$

The pressure at point d is

$$p_d = \frac{nRT_d}{V_d} = \frac{(0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(300 \text{ K})}{8.31 \times 10^{-3} \text{ m}^3} = 6.00 \times 10^4 \text{ Pa}$$

For the adiabatic expansion $b \rightarrow c$, $Q_{bc} = 0$. From the first law of thermodynamics, $\Delta U_{bc} = Q_{bc} - W_{bc} = -W_{bc}$; the work W_{bc} done by the gas in this adiabatic expansion equals the negative of the change in internal energy of the gas. From Eq. (19.13) we have $\Delta U = nC_V\Delta T$, where $\Delta T = T_c - T_b$. Using $C_V = 20.8 \text{ J/mol}\cdot\text{K}$ for an ideal diatomic gas, we find

$$\begin{aligned} W_{bc} &= -\Delta U_{bc} = -nC_V(T_c - T_b) = nC_V(T_b - T_c) \\ &= (0.200 \text{ mol})(20.8 \text{ J/mol}\cdot\text{K})(500 \text{ K} - 300 \text{ K}) = 832 \text{ J} \end{aligned}$$

For the isothermal compression $c \rightarrow d$, $\Delta U_{cd} = 0$; Eq. (20.11)

$$\begin{aligned} W_{cd} &= -\int_{V_c}^{V_d} p \, dV = -\int_{V_c}^{V_d} \frac{nRT_c}{V} \, dV \\ &= -nRT_c \ln \frac{V_d}{V_c} = -(0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(300 \text{ K}) \ln \frac{8.31 \times 10^{-3} \text{ m}^3}{4.99 \times 10^{-3} \text{ m}^3} \\ &= -366 \text{ J} \end{aligned}$$

The work done by the gas in the isothermal expansion $d \rightarrow a$ is

$$W_{da} = -W_{cd} = 366 \text{ J}$$

The work done by the gas in the isothermal compression $a \rightarrow b$ is

$$W_{ab} = -nRT_a \ln \frac{V_b}{V_a} = -(0.200 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(500 \text{ K}) \ln \frac{1.66 \times 10^{-2} \text{ m}^3}{8.31 \times 10^{-3} \text{ m}^3} = -567 \text{ J}$$

The work done by the gas in the adiabatic compression $a \rightarrow d$ is

$$W_{da} = -\Delta U_{da} = -nC_V(T_d - T_a) = nC_V(T_a - T_d) = 0$$

The work done by the gas in the adiabatic expansion $b \rightarrow c$ is

$$W_{bc} = 832 \text{ J}$$

The net work done by the gas in the cycle is

$$W_{\text{net}} = W_{ab} + W_{bc} + W_{cd} + W_{da} = -567 \text{ J} + 832 \text{ J} - 366 \text{ J} + 366 \text{ J} = 265 \text{ J}$$

Now Work PROBLEM 19

MasteringPhysics™: In this chapter, we have seen that the second law of thermodynamics is a statement about the direction of natural processes. The second law of thermodynamics is a statement about the direction of natural processes. The second law of thermodynamics is a statement about the direction of natural processes.

$$W_{\text{net}} = W_{ab} + W_{bc} + W_{cd} + W_{da} = 265 \text{ J}$$

Masteringphysics Solution Chapter

Robert R. Redfield



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Table of Contents Masteringphysics Solution Chapter

1. Understanding the eBook Masteringphysics Solution Chapter
 - The Rise of Digital Reading Masteringphysics Solution Chapter
 - Advantages of eBooks Over Traditional Books
2. Identifying Masteringphysics Solution Chapter
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Masteringphysics Solution Chapter
 - User-Friendly Interface
4. Exploring eBook Recommendations from Masteringphysics Solution Chapter

-
- Personalized Recommendations
 - Masteringphysics Solution Chapter User Reviews and Ratings
 - Masteringphysics Solution Chapter and Bestseller Lists
5. Accessing Masteringphysics Solution Chapter Free and Paid eBooks
 - Masteringphysics Solution Chapter Public Domain eBooks
 - Masteringphysics Solution Chapter eBook Subscription Services
 - Masteringphysics Solution Chapter Budget-Friendly Options
 6. Navigating Masteringphysics Solution Chapter eBook Formats
 - ePub, PDF, MOBI, and More
 - Masteringphysics Solution Chapter Compatibility with Devices
 - Masteringphysics Solution Chapter Enhanced eBook Features
 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Masteringphysics Solution Chapter
 - Highlighting and Note-Taking Masteringphysics Solution Chapter
 - Interactive Elements Masteringphysics Solution Chapter
 8. Staying Engaged with Masteringphysics Solution Chapter
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Masteringphysics Solution Chapter
 9. Balancing eBooks and Physical Books Masteringphysics Solution Chapter
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Masteringphysics Solution Chapter
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Masteringphysics Solution Chapter
 - Setting Reading Goals Masteringphysics Solution Chapter
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Masteringphysics Solution Chapter

-
- Fact-Checking eBook Content of Masteringphysics Solution Chapter
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
- Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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