Thermodynamics

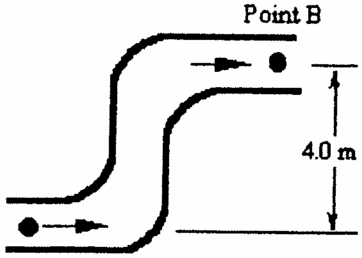
Advanced Placement Physics B
Mr. DiBucci

Name ______________________________ per. ___ Date _____
Advanced Placement Physics B **DiBucci**

Temperature and the Ideal Gas Law

Directions: Place your work on a separate sheet of paper and hand in at the end of the period

1. Oil ($\rho = 925$ kg/m^3) is flowing through a pipeline at a constant speed when it encounters a vertical bend in the pipe raising it 4.0 m. The cross sectional area of the pipe does not change. What is the difference in pressure ($P_B - P_A$) in the portions of the pipe before and after the rise?



2. Absolute zero on the Celsius temperature scale is –273.15 °C. What is absolute zero on the Fahrenheit temperature scale?

3. The coefficient of linear expansion of steel is 12×10^{-6}/C°. A railroad track is made of single rails of steel 1.0 km in length. By what length would these single rails change between a cold day when the temperature is –10 °C and a hot day at 30 °C?

4. A steel gas tank of volume 0.070 m^3 is filled to the top with gasoline at 20 °C. The tank is placed inside a chamber with an interior temperature of 50 °C. The coefficient of volume expansion for gasoline is 9.50×10^{-4}/C°; and the coefficient of linear expansion

of steel is 12×10^{-6}/C°. After the tank and its contents reach thermal equilibrium with the interior of the chamber, how much gasoline has spilled?

5. How many molecules are in 0.064 kg of sulfur dioxide, SO_2? (atomic masses: S = 32 u; O = 16 u)

6. What is the mass of 1.5 moles of hydrogen molecules, H_2? (atomic mass of H = 1 u)

7. How many moles are in a 0.23-kg sample of carbon dioxide, CO_2? (C = 12 u; O = 16 u)

8. A sample of a monatomic ideal gas is originally at 20 °C. What is the final temperature of the gas if both the pressure and volume are doubled?

9. Argon gas at 305 K is confined within a constant volume at a pressure P_1. If the gas has a pressure P_2 when it is cooled to 195 K, what is the ratio of P_2 to P_1?

10. An ideal gas with a fixed number of molecules is maintained at a constant pressure. At 30.0 °C, the volume of the gas is 1.50 m^3. What is the volume of the gas when the temperature is increased to 75.0 °C?

1. -3.6×10^4 Pa
2. −459.67 °F
3. 48 cm
4. 1.92×10^{-3} m^3
5. 6.02×10^{23}
6. 0.0030 kg
7. 5.2
8. 900 °C
9. 0.639
10. 1.72 m^3

AP Physics B
Kinetic Theory of Gasses

DiBucci

1. An ideal gas with a fixed number of molecules is maintained at a constant pressure. At 30.0 °C, the volume of the gas is 1.50 m^3. What is the volume of the gas when the temperature is increased to 75.0 °C?

2. A sealed container has a volume of 0.020 m^3 and contains 15.0 g of molecular nitrogen (N_2) which has a molecular mass of 28.0 u. The gas is at a temperature of 525 K. What is the absolute pressure of the nitrogen gas?

3. Calculate the rms speed of the oxygen molecules in the air if the temperature is 5.00 °C. **Note:** The mass of the oxygen molecule is 31.9988 u.

4. What is the internal energy of 1.75 kg of helium (atomic mass = 4.00260 u) with a temperature of 100 °C?

1. 1.72 m^3
2. 1.2×10^5 Pa
3. 465 m/s
4. 2.03×10^6 J

Table 12.1 Coefficients of Thermal Expansion for Solids and Liquids[a]

Substance	Coefficient of Thermal Expansion, $(C^\circ)^{-1}$	
	Linear (α)	Volumetric (β)
Solids		
Aluminum	23×10^{-6}	69×10^{-6}
Brass	19×10^{-6}	57×10^{-6}
Concrete	12×10^{-6}	36×10^{-6}
Copper	17×10^{-6}	51×10^{-6}
Glass (common)	8.5×10^{-6}	26×10^{-6}
Glass (Pyrex)	3.3×10^{-6}	9.9×10^{-6}
Gold	14×10^{-6}	42×10^{-6}
Iron or steel	12×10^{-6}	36×10^{-6}
Lead	29×10^{-6}	87×10^{-6}
Nickel	13×10^{-6}	39×10^{-6}
Quartz (fused)	0.50×10^{-6}	1.5×10^{-6}
Silver	19×10^{-6}	57×10^{-6}
Liquids[b]		
Benzene	—	1240×10^{-6}
Carbon tetrachloride	—	1240×10^{-6}
Ethyl alcohol	—	1120×10^{-6}
Gasoline	—	950×10^{-6}
Mercury	—	182×10^{-6}
Methyl alcohol	—	1200×10^{-6}
Water	—	207×10^{-6}

[a] The values for α and β pertain to a temperature near 20 °C.
[b] Since liquids do not have fixed shapes, the coefficient of linear expansion is not defined for them.

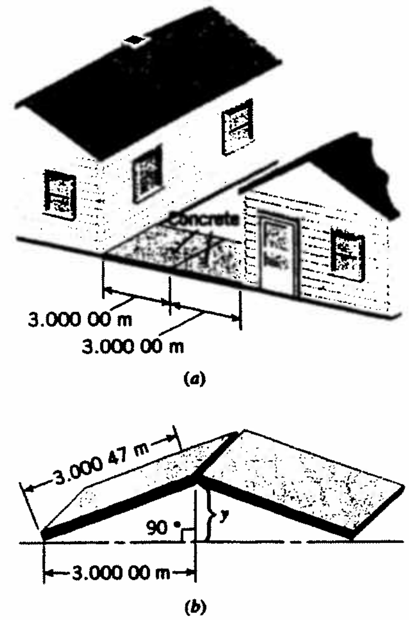
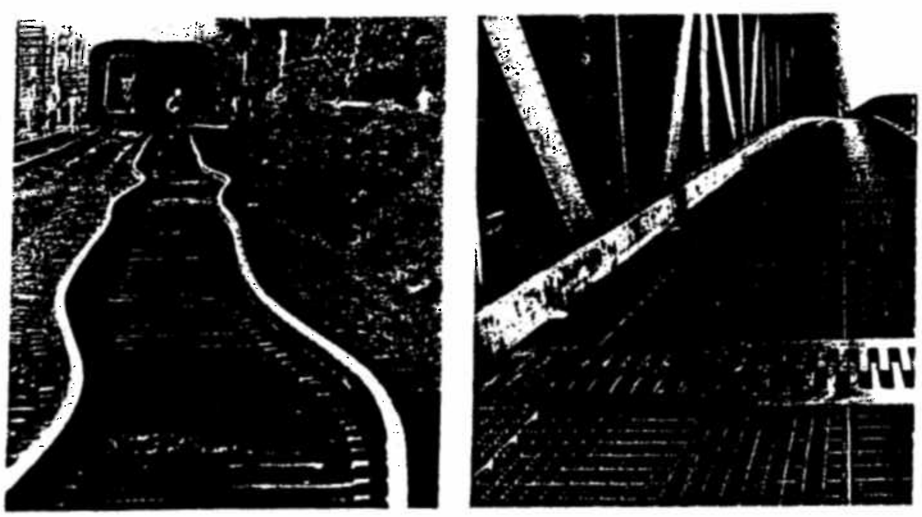


Figure 12.11 (*a*) Two concrete slabs completely fill the space between the buildings. (*b*) When the temperature increases, each slab expands, causing the sidewalk to buckle.

The buckling of a sidewalk is one consequence of not providing sufficient room for thermal expansion, and Figure 12.12*a* shows another. It is common for engineers to incorporate expansion joints or spaces at intervals along railroad tracks and bridge roadbeds to alleviate such problems. Part *b* of the figure shows such an expansion joint in a bridge.



(*a*) (*b*)

Figure 12.12 (*a*) The rails buckled because inadequate allowance was made for thermal expansion. (*b*) An expansion joint in a bridge.

THE ANOMALOUS BEHAVIOR OF WATER NEAR 4 °C

While most substances expand when heated, a few do not. For instance, if water at 0 °C is heated, its volume *decreases* until the temperature reaches 4 °C. Above 4 °C water behaves normally, and its volume increases as the temperature increases. Because a given mass of water has a minimum volume at 4 °C, the density (mass per unit volume) of water is greatest at 4 °C, as Figure 12.20 shows.

The fact that water has its greatest density at 4 °C, rather than at 0 °C, has important consequences for the way in which a lake freezes. When the air temperature drops, the surface layer of water is chilled. As the temperature of the surface layer drops toward 4 °C, this layer becomes more dense than the warmer water below. The denser water sinks and pushes up the deeper and warmer water, which in turn is chilled at the surface. This process continues until the temperature of the entire lake reaches 4 °C. Further cooling of the surface water below 4 °C makes it *less dense* than the deeper layers; consequently, the surface layer does not sink, but stays on top. Continued cooling of the top layer to 0 °C leads to the formation of ice that floats on the water, because ice has a smaller density than water at any temperature. Below the ice, however, the water temperature remains above 0 °C. The sheet of ice acts as an insulator that reduces the loss of heat from the lake, especially if the ice is covered with a blanket of snow, which is also an insulator. Furthermore, heat transferred from the ground beneath the lake helps to keep the water under the ice sheet from freezing. As a result, lakes usually do not freeze solid, even during prolonged cold spells, so fish and other aquatic life can survive during the winter.

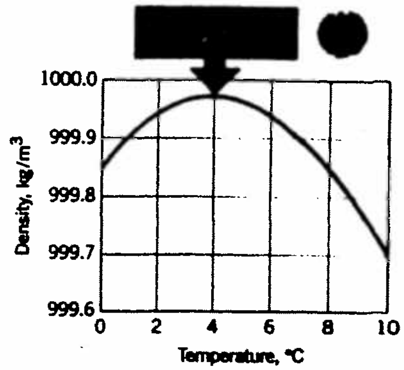


Figure 12.20 The density of water in the temperature range from 0 to 10 °C. Water has a maximum density of 999.973 kg/m³ at 4 °C. (This value for the density is equivalent to the often-quoted density of 1.000 00 grams per milliliter.)

EXAMPLE 8 An Automobile Radiator

A small plastic container, called the coolant reservoir, catches the radiator fluid that overflows when an automobile engine becomes hot (see Figure 12.19). The radiator is made of copper, and the coolant has a coefficient of volume expansion of $\beta = 410 \times 10^{-6}\,(\text{C}°)^{-1}$. If the radiator is filled to its 15-quart capacity when the engine is "cold" (6.0 °C), how much overflow from the radiator will spill into the reservoir when the coolant reaches its operating temperature of 92 °C?

Reasoning When the temperature increases, both the coolant and radiator expand. If they were to expand by the same amount, there would be no overflow. However, the liquid coolant expands more than the radiator, and the amount of overflow is the amount of coolant expansion *minus* the expansion of the radiator cavity.

Solution When the temperature increases by 86 C°, the coolant expands by an amount

$$\Delta V = \beta V_0 \Delta T = [410 \times 10^{-6}\,(\text{C}°)^{-1}](15 \text{ quarts})(86\ \text{C}°) = 0.53 \text{ quarts} \quad (12.3)$$

The volume of the radiator cavity expands as if it were filled with copper [$\beta = 51 \times 10^{-6}\,(\text{C}°)^{-1}$, see Table 12.1]. The expansion of the radiator cavity is

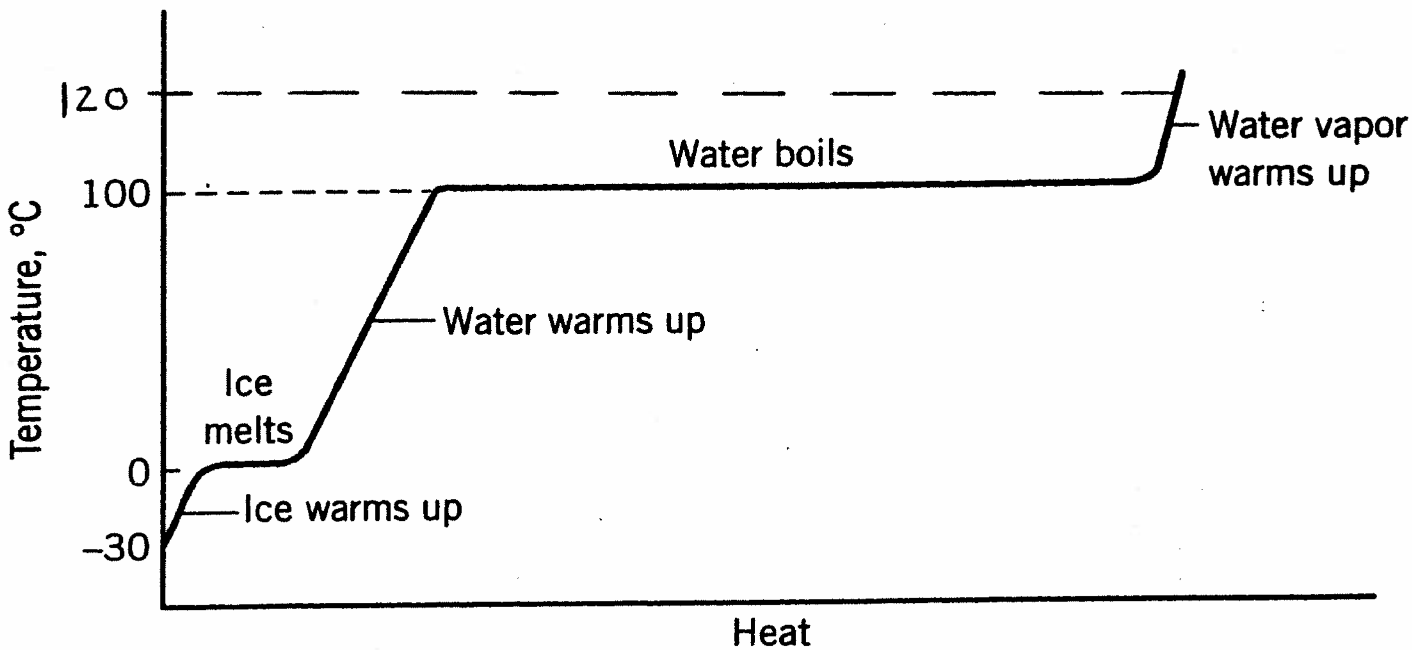
$$\Delta V = \beta V_0 \Delta T = [51 \times 10^{-6}\,(\text{C}°)^{-1}](15 \text{ quarts})(86\ \text{C}°) = 0.066 \text{ quarts}$$

The amount of coolant overflow is 0.53 quarts − 0.066 quarts = **0.46 quarts**.

Name________________________________ per. ___ date ______
AP Physics DiBucci

Heat and Phase Change

Calculate the total amount of thermal energy needed to heat a **1.0 gram of ice initially at -30.0 deg Celsius to a temperature of 120 deg Celsius**. Label the points where there is a change of phase on diagram of the heating curve. You will also need the table of specific and latent heats to do the calculations.



A Steamy  Problem

AP Physics B
Mr. DiBucci

Calculate the mass of steam (initially at 130 deg. C) needed to warm 200.0 grams of liquid water (initially at 20.0 deg. C) to 50.0 deg. C. The water is in a glass container that is at the same initial temperature as the water.

(10.9 g)

Introduction to Thermal Energy Transfer
AP Physics B

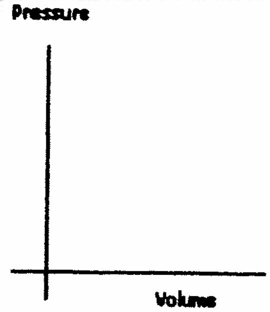
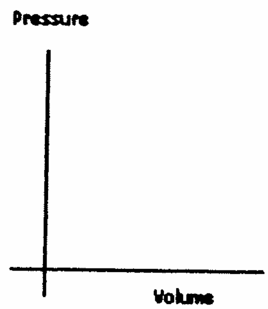
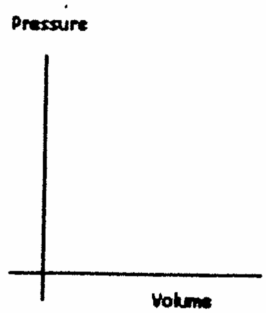
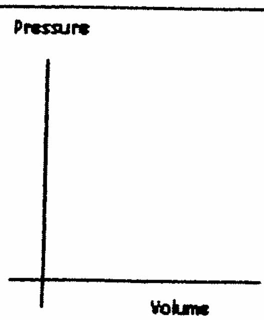
DiBucci

1. A rod, with sides insulated to prevent heat loss, has one end immersed in boiling water (T = 100°C) and the other end in a water–ice mixture. The rod has uniform cross-sectional area 4.44 cm^2 and length 17 cm. The heat conducted by the rod melts the ice at a rate of 1 gram every 26 seconds. What is the thermal conductivity of the rod? (Recall that the heat of fusion of water is 3.34 x 10^5 J/kg.)

2. How many grams of ice at –19°C must be added to 566 grams of water that is initially at a temperature of 61°C to produce water at a final temperature of 6°C? Assume that no heat is lost to the surroundings and that the container has negligible mass. The specific heat of liquid water is 4190 J/kg • °C and of ice is 2000 J/kg • °C. For water the normal melting point is 0°C and the heat of fusion is 334 x 10^3 J/kg. The normal boiling point is 100° C and the heat of vaporization is 2.256 x 10^6 J/kg.

3. A piece of iron of mass 0.12 kg is taken from an oven where its temperature is 336°C and quickly placed in an insulated copper can that contains 0.20 kg of water. The copper can has mass 0.50 kg, and it and the water in it are originally at a temperature of 20°C. Calculate the final temperature of the system, assuming no heat is lost to the surroundings. Use the following specific heats: water, c = 4190 J/kg • °C; iron, c = 470 J/kg • °C; and copper, c = 390 J/kg • °C.

Thermodynamic Processes
AP Physics B

Pressure -Volume Diagram	Description
	ISOBARIC
	ISOCHORIC
	ISOTHERMAL
	ADIABATIC

1. An Ideal Gas is slowly compressed at a constant pressure of 2.0 atmospheres (atm), from 10.0 L to 2.0 L. Heat is the added, holding the volume constant, and the temperature and pressure are allowed to rise until the temperature reaches its reaches it original value.

a. Draw a P-V diagram that represents this process
b. Calculate the total work. (+1.6 E +3 Joules)
c. Calculate the total heat that has flowed into or out of the gas.(-1.6 E +3 Joules)

2. The cylinder of an engine contains 0.25 moles of an ideal gas that expands rapidly and adiabatically against the piston. In the process the temperature drops from 1150K to 400K.

a. Draw a P-V Diagram that represents this process. Include the two isotherms for the two different temperatures.
b. Calculate the amount of work done by the gas.(-2300 Joules)

3. Two moles of a monatomic ideal gas expands isothermally at 298 K, from an initial volume of 0.025 cubic meters to a final volume of 0.050 cubic meters.

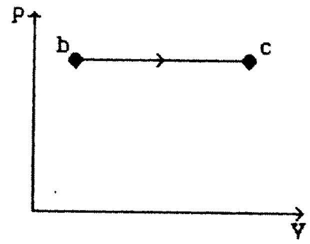
a. Draw a P-V diagram that represents this process.
b. Calculate the work done by the gas.(-3400 Joules)
c. Calculate the change in internal energy. (0.0 Joules)
d. Calculate the amount of heat supplied to the gas.(+3400 Joules)

AP Physics B
Introduction to Thermodynamic Processes Utilizing an Ideal Gas

DiBucci

Figure 19.3

1.



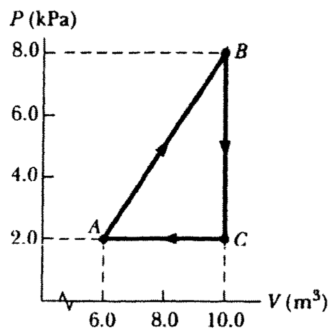
In Figure 19.3, in a certain process 1510 J of heat flows into a system, and at the same time the system expands against a constant external pressure of 7.00×10^4 Pa. If the volume of the system increases from 0.020 m^3 to 0.060 m^3, calculate the change in internal energy of the system. If the internal energy change is nonzero, be sure to indicate whether the internal energy change is positive or negative. (− 1290 J)

2. A cylinder contains 3.7 moles of ideal gas, initially at a temperature of 108°C. The cylinder is provided with a frictionless piston, which maintains a constant pressure of 6.4×10^5 Pa on the gas. The gas is cooled until its temperature has decreased to 27°C. For the gas C_V = 11.16 J/mol • K. The gas constant R = 8.314 J/mol • K.
Calculate:
(a) the work W done ~~by~~ on the gas (+ 2496 J)
(b) the net change in the internal energy, ΔU, of the gas, and (− 3737 J)
(c) the heat transfer Q. (− 6233 J)

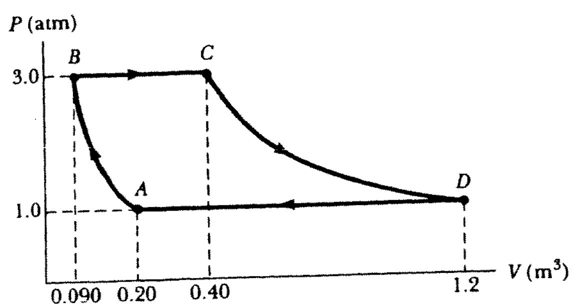
Name____ per. ___ Date _______

The First Law of Thermodynamics DiBucci

1. A gas is taken through a cyclic process as described in the figure below.
   a. Find the net thermal energy transferred to the system during one cycle. (−12KJ)
   b. If the cycle is reversed, what is the net thermal energy transferred in one cycle? (+12 KJ)



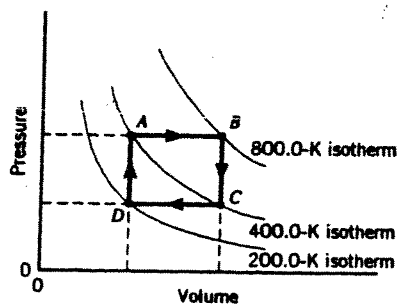
2. A gas system goes through the process shown in the diagram below. From A to B the process is adiabatic, and from B to C the process it is isobaric with 100 kJ of heat flowing into the system. From C to D the process is isothermal, and from D to A the process is isobaric with 150 kJ of heat flowing out of the system. Determine the difference in internal energy $U_B - U_A$. (43 KJ)



A. P. Physics B

Thermodynamic Analysis of Heat Engines

The drawing refers to one mole of a monatomic ideal gas and shows a process that has four steps, two isobaric (*A* to *B*, *C* to *D*) and two isochoric (*B* to *C*, *D* to *A*). Complete the following table by calculating ΔU, W, and Q (including the algebraic signs) for each of the four steps.



Step	Comment	V	P	T	Q	W	ΔU
				Totals			

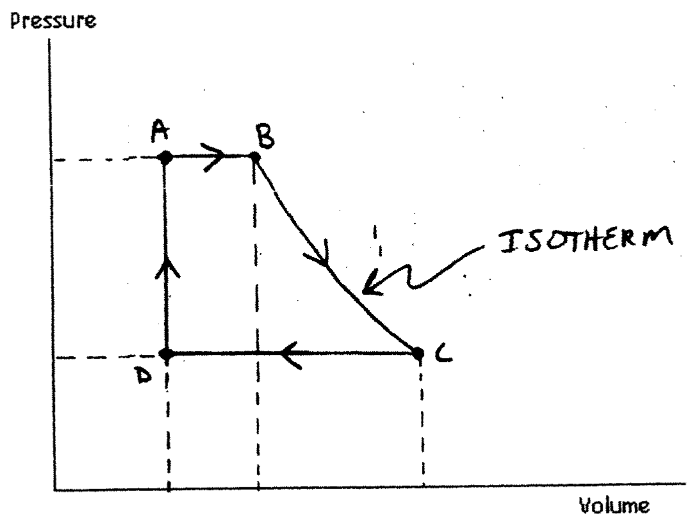
Final comments:

WERS:

STEP	ΔU	W	Q
A → B	4990	-3320	8310
B → C	-4990	0	-4990
C → D	-2490	1600	-4150
D → A	2490	0 J	2490

Advanced Placement Physics B

Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

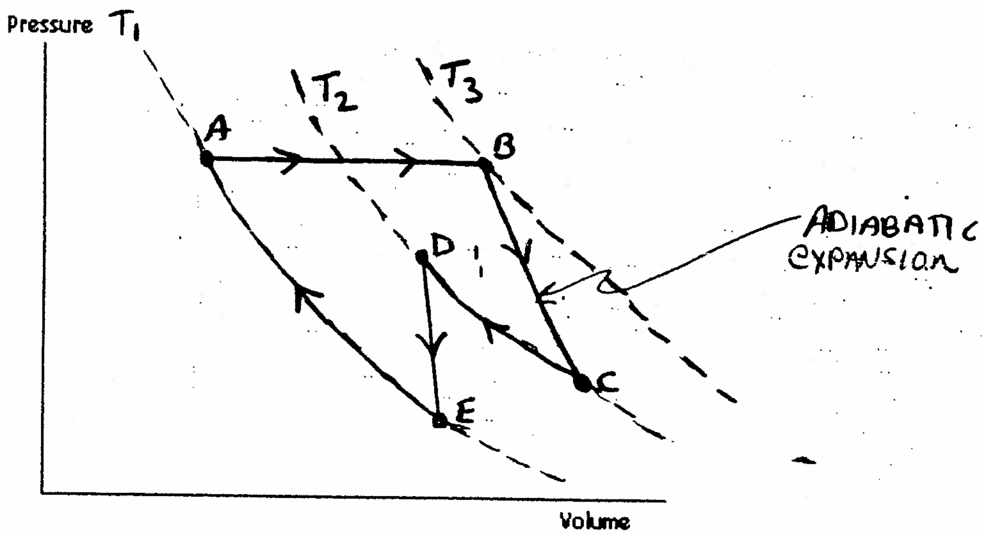
Comments:

Engine Type: __________

Cycle Used: ___________

Advanced Placement Physics B

Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

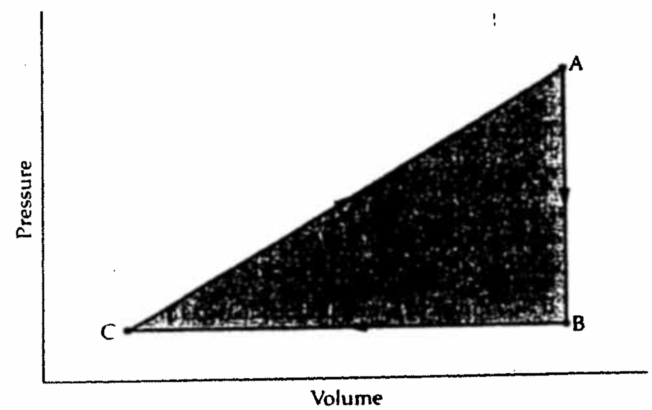
Cycle Used: __________

Thermodynamics Review
AP Physics B

Mr. DiBucci

An ideal gas is taken through the three processes shown in **Figure 18–23**. Fill in the missing entries in the following table:

	Q	W	ΔU
A → B	−53 J	(a)	(b)
B → C	−280 J	−130 J	(c)
C → A	(e)	150 J	(d)

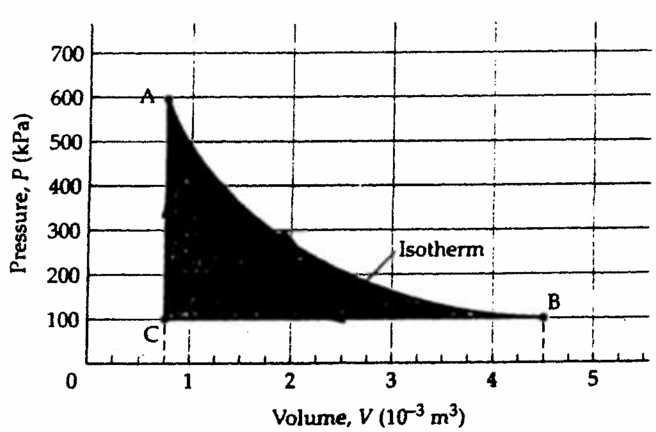


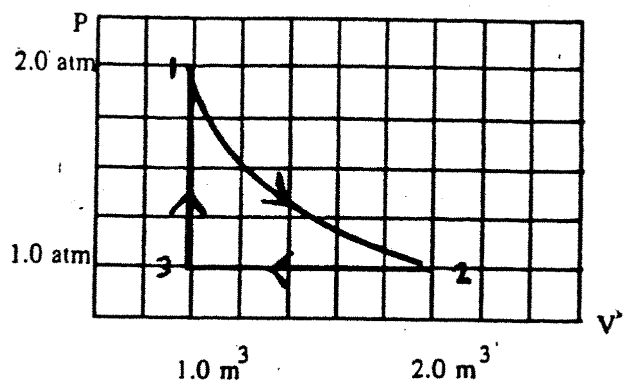
▲ **FIGURE 18–23**

One mole of an ideal monatomic gas follows the three-part cycle shown in **Figure 18–30**. **(a)** Fill in the following table:

	Q	W	ΔU
A → B			
B → C			
C → A			

(b) What is the efficiency of this cycle?





The process shown represents three processes undergone by 1.0E+2 moles of an ideal gas.
(1 Atm = 1.013E+5 Pa)

a. Prove that path 1→2 is an Isothermal process.

b. Calculate the work done by the gas in 1→2. How much heat is absorbed or emitted?

c. How would you classify 2→3? How much work is done in step 2→3?

d. Classify the process 3→1. How much work done in this step? What is the change in internal energy for this step, and is heat emitted or absorbed? Calculate the molar heat capacity, at constant volume, for this step.

e. Calculate the total work done for the complete cycle

f. Calculate the total heat that is absorbed/emitted for the complete cycle.

g. What is the change in internal energy for the complete cycle?

h. Fill in the following chart :(use symbols only)

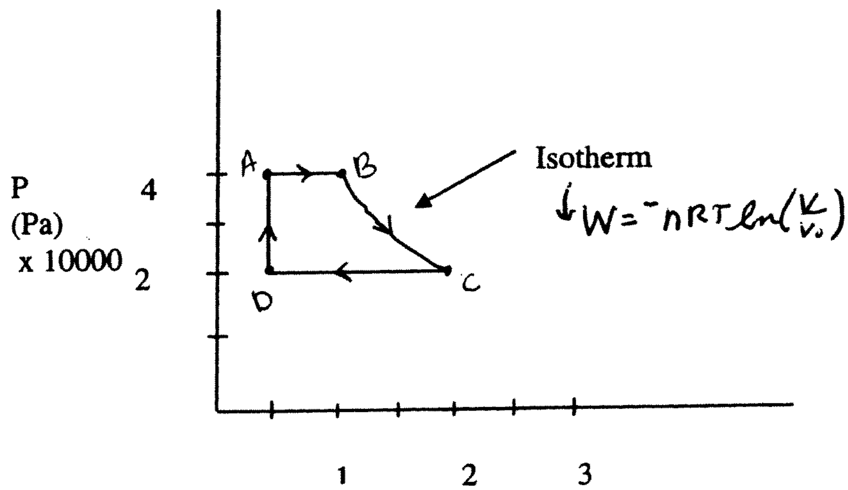
Step	description	P	V	T	Q	W	ΔU
1→2							
2→3							
3→1							
Total	XXXXXX	XXXXX	XXXXX	XXXXX			

Name ____ per. ___ date ___
DiBucci

Thermodynamic Cycles Utilizing Molar Heat Capacities

Directions: From the diagram below, complete the chart. You must use numerical values in the chart as well as positive and negative signs. Place all of your work on a separate sheet of paper.

This graph represents 1.0 moles of a monatomic gas taken Through the following cycle.



Important Equations:

$C_p = 20.775$ J/mol·K

$C_v = 12.454$ J/mol·K

$\Delta U = \frac{3}{2} nR\Delta T$

$Q = nC_p\Delta T$

$Q = nC_v\Delta T$

$PV = nRT$

$\Delta U = Q + W$

$W = -P\Delta V$ (ISOBARIC)

Step	ΔV (m^3)	ΔP (Pa)	ΔT (K)	Q (J)	W (J)	ΔU (J)
TOTAL	———	———	———			

Summary of assignments for Thermal Physics and Thermodynamics
Homework Packet
AP Physics B

DiBucci

Section from homework packet	Assigned problems from packet	Corresponding chapter in text
12.1 Common Temperature Scales	1-5	13
12.4 Linear Thermal Expansion	10-15	13
12.5 Volume Thermal Expansion	27,28,30,31,33	13
14.1 Molecular Mass, the Mole and Avogadro's Number	1-4	
14.2 The Ideal Gas Law	10,12,13,14,18	13
14.3 Kinetic Theory of Gasses	30,31,33,37	13
12.6 Heat and internal energy **12.7 Specific Heat capacity**	42,43,46,48,50,	14
12.8 Heat and Phase Change ,latent Heat	55,57,60,62,67	14
13.2 Conduction	1-4,14	14
15.3 The First Law of Thermodynamics	1-4,5	15
15.4 Thermal Processes	7-11,14 (use graphic organizer)	15
15.5 Thermal Processes that utilize an ideal gas	20-21,24,27,28 done in class,30	15
15.6 Molar Heat Capacities	33,34,35,36,38,39	15
15.8 Heat Engines	43-48	15
15.9 Carnot's principle	50-54	15
15.10 Refrigerators and heat pumps	62-64	15
15.11 Entropy and the Second Law	74-77	15

Section 12.1 Common Temperature Scales, Section 12.2 The Kelvin Temperature Scale, Section 12.3 Thermometers

1. **ssm** What's your normal body temperature? It's probably not 98.6 °F, the oft-quoted average that was determined in the nineteenth century. A recent study has reported an average temperature of 98.2 °F. What is the *difference* between these averages, expressed in Celsius degrees?

2. A personal computer is designed to operate over the temperature range from 50.0 to 104 °F. To what do these temperatures correspond (a) on the Celsius scale and (b) on the Kelvin scale?

3. A comfortable temperature for most people is around 24 °C. What is this temperature (a) on the Fahrenheit scale and (b) on the Kelvin scale?

4. Dermatologists often remove small precancerous skin lesions by freezing them quickly with liquid nitrogen, which has a temperature of 77 K. What is this temperature on the (a) Celsius and (b) Fahrenheit scales?

5. **ssm** A temperature of absolute zero occurs at −273.15 °C. What is this temperature on the Fahrenheit scale?

6. The greatest naturally occurring range in temperature of −90.0 °F to +98.0 °F was recorded in Verkhoyansk, Russia. What is the *difference* between the higher and lower temperature in (a) Celsius degrees and (b) kelvins?

*7. On the Rankine temperature scale, which is sometimes used in engineering applications, the ice point is at 491.67 °R and the steam point is at 671.67 °R. Determine a relationship (analogous to Equation 12.1) between the Rankine and Fahrenheit temperature scales.

*8. Space invaders land on earth. On the invaders' temperature scale, the ice point is at 25 °I (I = invader), and the steam point is at 156 °I. The invaders' thermometer shows the temperature on earth to be 58 °I. Using logic similar to that in Example 1 in the text, what would this temperature be on the Celsius scale?

9. **ssm A constant-volume gas thermometer (see Figures 12.3 and 12.4) has a pressure of 5.00×10^3 Pa when the gas temperature is 0.00 °C. What is the temperature (in °C) when the pressure is 2.00×10^3 Pa?

1) 0.2 C°

2) 10.0°C
40.0°C
283.15 K
313.15 K

3) 75°F

4) −196°C, −321°F

5) −459.67°F

6) 104 C°, 104 K

7) $T_R = T_F + 459.67$

8) 25°C

9) −164°C

Section 12.4 Linear Thermal Expansion

10. A baking dish is taken from a refrigerator at 8 °C and put into an oven that is set for 155 °C. Each side of the cold dish has a length of 0.15 m. By how much does a side of the dish expand as it heats up, if the dish is made from (a) common glass and (b) Pyrex?

11. A steel aircraft carrier is 370 m long when moving through the icy North Atlantic at a temperature of 2.0 °C. By how much does the carrier lengthen when it is traveling in the warm Mediterranean Sea at a temperature of 21 °C?

12. Conceptual Example 5 provides background for this problem. A hole is drilled through a copper plate whose temperature is 11 °C. (a) When the temperature of the plate is increased, will the radius of the hole be larger or smaller than the radius at 11 °C? Why? (b) When the plate is heated to 110 °C, by what fraction $\Delta r/r_0$ will the radius of the hole change?

13. ssm www Find the approximate length of the Golden Gate bridge if it is known that the steel in the roadbed expands by 0.53 m when the temperature changes from +2 to +32 °C.

14. An aluminum baseball bat has a length of 0.86 m at a temperature of 25.0 °C. When the temperature of the bat is raised, the bat expands by 0.000 16 m. Determine the final temperature of the bat.

15. A steel beam is used in the construction of a skyscraper. By what fraction $\Delta L/L_0$ does the length of the beam increase when the temperature changes from that on a cold winter day (−15 °F) to that on a summer day (+105 °F)?

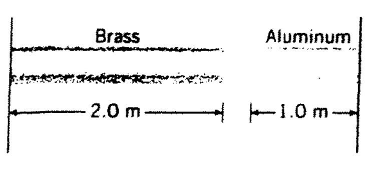
16. When a fused quartz rod and a lead rod experience the same temperature change, they change lengths by the same amount. If the initial length of the lead rod is 0.10 m, what is the initial length of the quartz rod?

17. ssm A rod made from a particular alloy is heated from 25.0 °C to the boiling point of water. Its length increases by 8.47×10^{-4} m. The rod is then cooled from 25.0 °C to the freezing point of water. By how much does the rod shrink?

18. When a copper rod is stretched, it will rupture when a tensile stress of 2.3×10^7 N/m^2 is applied at each end. A copper rod is fastened securely at both ends to an immovable support. The rod is then cooled. What is the change in temperature of the rod when it ruptures?

***19.** A lead sphere has a diameter that is 0.050% larger than the inner diameter of a steel ring when each has a temperature of 70.0 °C. Thus, the ring will not slip over the sphere. At what common temperature will the ring just slip over the sphere?

***20.** The brass bar and the aluminum bar in the drawing are each attached to an immovable wall. At 28 °C the air gap between the rods is 1.3×10^{-3} m. At what temperature will the gap be closed?



***21. ssm www** A simple pendulum consists of a ball connected to one end of a thin brass wire. The period of the pendulum is 2.0000 s. The temperature rises by 140 C°, and the length of the wire increases. Determine the period of the heated pendulum.

***22.** A cylindrical drinking glass is placed inside another cylindrical glass. The two just fit, because the outer radius (0.035 m) of the inside glass is equal to the inner radius of the outside glass. The glasses are made from common glass. The inside glass is then filled with cold water at 5 °C, while the outside glass is heated to 45 °C by running hot water over it. Find the separation distance between the two glasses.

***23.** A steel ruler is accurate when the temperature is 25 °C. When the temperature drops to −15 °C, the ruler no longer reads correctly, but it can be made to read correctly if a stress is applied to each end of the ruler. (a) Should the stress be a compression or a tension? Why? (b) What is the magnitude of the necessary stress?

****24.** A steel ruler is calibrated to read true at 20.0 °C. A draftsman uses the ruler at 40.0 °C to draw a line on a 40.0 °C copper plate. As indicated on the warm ruler, the length of the line is 0.50 m. To what temperature should the plate be cooled, such that the length of the line truly becomes 0.50 m?

****25. ssm** A wire is made by attaching two segments together, end to end. One segment is made of aluminum and the other is steel. The effective coefficient of linear expansion of the two-segment wire is 19×10^{-6} (C°)$^{-1}$. What fraction of the length is aluminum?

****26.** A steel bicycle wheel (without the rubber tire) is rotating freely with an angular speed of 18.00 rad/s. The temperature of the wheel changes from −100.0 to +300.0 °C. No net external torque acts on the wheel, and the mass of the spokes is negligible. (a) Does the angular speed increase or decrease as the wheel heats up? Why? (b) What is the angular speed at the higher temperature?

14) 33.1°C
15) 8.0×10⁻⁴
16) 5.8m
17) −2.82×10⁻⁴m
18) 12°C
19) −29°C
41°C
20) 49°C
21) 2.0027s
22) 1.2×10⁻⁵m
23) 9.6×10⁷ N/m²
24) 26°C
25) 0.6
26) 17.83 rad/s

10) 1.9×10⁻⁴m
7.3×10⁻⁵m
11) 0.084m
12) Larger 0.0017
13) 1500m

Section 12.5 Volume Thermal Expansion

27. A swimming pool contains 110 m^3 of water. The sun heats the water from 17 to 27 °C. What is the change in the volume of the water?

28. A copper kettle contains water at 24 °C. When the water is heated to its boiling point, the volume of the kettle expands by 1.2×10^{-5} m^3. Determine the volume of the kettle at 24 °C.

29. **ssm** When heated at constant pressure, a given volume of gas expands much more than an equal volume of liquid. The coefficient of volume expansion for air is about 3.7×10^{-3} $(C°)^{-1}$ at room temperature and one atmosphere of pressure. Find the ratio of the change in volume of air to the change in volume of water, assuming the same initial volumes and temperature changes.

30. A 1.5000-L (L = liter) flask is filled with a liquid at 97.0 °C. When the liquid is cooled to 15.0 °C, the flask is full only to the 1.3832-L mark. Neglect the contraction of the flask and use Table 12.1 to identify the liquid.

31. Many hot-water heating systems have a reservoir tank connected directly to the pipeline, so as to allow for expansion when the water becomes hot. The heating system of a house has 76 m of copper pipe whose inside radius is 9.5×10^{-3} m. When the water and pipe are heated from 24 to 78 °C, what must be the minimum volume of the reservoir tank to hold the overflow of water?

32. During an all-night cram session, a student heats up a one-half liter (0.50×10^{-3} m^3) glass (Pyrex) beaker of cold coffee. Initially, the temperature is 18 °C, and the beaker is filled to the brim. A short time later when the student returns, the temperature has risen to 92 °C. The coefficient of volume expansion of coffee is the same as that of water. How much coffee (in cubic meters) has spilled out of the beaker?

33. **ssm** Suppose you were selling apple cider for two dollars a gallon when the temperature is 4.0 °C. The coefficient of volume expansion of the cider is 280×10^{-6} $(C°)^{-1}$. If the expansion of the container is ignored, how much more money (in pennies) would you make per gallon by refilling the container on a day when the temperature is 26 °C?

34. An aluminum can is filled to the brim with 3.5×10^{-4} m^3 of soda at 5 °C. When the can and soda are heated to 78 °C, 3.6×10^{-6} m^3 of soda spills over. What is the coefficient of volume expansion of the soda?

35. A thin spherical shell of silver has an inner radius of 1.5×10^{-2} m when the temperature is 25 °C. The shell is heated to 135 °C. Find the change in the interior volume of the shell.

36. The density of mercury is 13 600 kg/m^3 at 0 °C. What would be its density at 166 °C?

37. **ssm** The bulk modulus of water is $B = 2.2 \times 10^9$ N/m^2. What change in pressure ΔP (in atmospheres) is required to keep water from expanding when it is heated from 15 to 25 °C?

38. A solid aluminum sphere has a radius of 0.50 m and a temperature of 75 °C. The sphere is then completely immersed in a pool of water whose temperature is 25 °C. The sphere cools, while the water temperature remains nearly at 25 °C, because the pool is very large. The sphere is weighed in the water immediately after being submerged (before it begins to cool) and then again after cooling to 25 °C. (a) Which weight is larger? Why? (b) Use Archimedes' principle to find the magnitude of the *difference* between the weights.

27) 0.23 m3
28) 3.1x10^-3 m3
29) 18
30) gasoline
31) 1.8x10^-4 m3
32) 7.3x10^-6 m3
33) one penny
34) 210x10^-6 C°-1
35) 8.9x10^-8 m3
36) 13,200kg/m3
37) 45 ATM
38) 18N

Section 12.6 Heat and Internal Energy, Section 12.7 Heat and Temperature Change: Specific Heat Capacity

42. An ice chest at a beach party contains 12 cans of soda at 5.0 °C. Each can of soda has a mass of 0.35 kg and a specific heat capacity of 3800 J/(kg · C°). Someone adds a 6.5-kg watermelon at 27 °C to the chest. The specific heat capacity of watermelon is nearly the same as that of water. Ignore the specific heat capacity of the chest and determine the final temperature *T* of the soda and watermelon.

43. Blood can carry excess energy from the interior to the surface of the body, where the energy is dispersed in a number of ways. While a person is exercising, 0.6 kg of blood flows to the surface of the body and releases 2000 J of energy. The blood arriving at the surface has the temperature of the body interior, 37.0 °C. Assuming that blood has the same specific heat capacity as water, determine the temperature of the blood that leaves the surface and returns to the interior.

44. Two bars of identical mass are at 25 °C. One bar is made from glass and the other from another substance in Table 12.2. Identical amounts of heat are supplied to each. The glass bar reaches a temperature of 88 °C, while the other reaches 250.0 °C. What is the other substance?

45. ssm At a fabrication plant, a hot metal forging has a mass of 75 kg and a specific heat capacity of 430 J/(kg · C°). To harden it, the forging is quenched by immersion in 710 kg of oil that has a temperature of 32 °C and a specific heat capacity of 2700 J/(kg · C°). The final temperature of the oil and forging at thermal equilibrium is 47 °C. Assuming that heat flows only between the forging and the oil, determine the initial temperature of the forging.

46. Heat is supplied to an 0.850-kg copper pot at the rate of 203 joules per second. How much time does it take to raise the temperature of the pot from 21.0 °C to 95.0 °C if the pot (a) is empty and (b) contains 0.200 kg of water?

47. When resting, a person has a metabolic rate of about 4.2×10^5 joules per hour. The person is submerged neck-deep into a tub containing 1.0×10^3 kg of water at 27.00 °C. If the heat from the person goes only into the water, find the water temperature after half an hour.

48. When you take a bath, how many kilograms of hot water (49.0 °C) must you mix with cold water (13.0 °C) so that the temperature of the bath is 36.0 °C? The total mass of water (hot plus cold) is 191 kg. Ignore any heat flow between the water and its external surroundings.

49. ssm If the price of electrical energy is $0.10 per kilowatt · hour, what is the cost of using electrical energy to heat the water in a swimming pool (12.0 m × 9.00 m × 1.5 m) from 15 to 27 °C?

***50.** Heat is added to a silver bar of mass 0.039 kg and length 0.15 m. The bar expands by an amount of 4.3×10^{-4} m. How much heat was added?

***51.** The box of a well-known breakfast cereal states that one ounce of the cereal contains 110 Calories (1 food Calorie = 4186 J). If 2.0% of this energy could be converted by a weight lifter's body into work done in lifting a barbell, what is the heaviest barbell that could be lifted a distance of 2.1 m?

***52.** Water is moving with a speed of 5.00 m/s just before it passes over the top of a waterfall. At the bottom, 5.00 m below, the water flows away with a speed of 3.00 m/s. What is the largest amount by which the temperature of the water at the bottom could exceed the temperature of the water at the top?

***53. ssm** An electric hot water heater takes in cold water at 13.0 °C and delivers hot water. The hot water has a constant temperature of 45.0 °C, when the "hot" faucet is left open all the time and the volume flow rate is 5.0×10^{-6} m³/s. What is the minimum power rating of the hot water heater?

****54.** A steel rod (ρ = 7860 kg/m³) has a length of 2.0 m. It is bolted at both ends between immobile supports. Initially there is no tension in the rod, because the rod just fits between the supports. Find the tension that develops when the rod loses 3300 J of heat.

42) 19 °C
43) 36.2 °C
44) 235 J/kg C°
silver
45) 940 °C
46) 120 sec
425 sec
47) 27.05 °C
48) 121 kg
49) $230
50) 1.4×10^3 J
51) 4.4×10^3 N
52) 1.36×10^{-2} C°
53) 6.7×10^2 W
54) 1.1×10^3 N
55)

Section 12.8 Heat and Phase Change: Latent Heat

55. An ice cube tray holds 0.39 kg of water at 0 °C. How much heat must a freezer remove to make ice cubes at 0 °C?

56. Heat (5.64×10^5 J) is added to 1.70 kg of a substance in Table 12.4. The substance completely melts without any change in temperature. What is the substance?

57. **ssm** How much heat must be added to 0.45 kg of aluminum to change it from a solid at 130 °C to a liquid at 660 °C (its melting point)? The latent heat of fusion for aluminum is 4.0×10^5 J/kg.

58. A 10.0-kg block of ice has a temperature of −10.0 °C. The pressure is one atmosphere. The block absorbs 4.11×10^6 J of heat. What is the final temperature of the liquid water?

59. Suppose the amount of heat removed when 3.0 kg of water freezes at 0 °C were removed from ethyl alcohol at its freezing/melting point of −114 °C. How many kilograms of ethyl alcohol would freeze?

60. A woman finds the front windshield of her car covered with ice at −12.0 °C. The ice has a thickness of 4.50×10^{-4} m, and the windshield has an area of 1.25 m^2. The density of ice is 917 kg/m^3. How much heat is required to melt the ice?

61. **ssm** Liquid nitrogen boils at a chilly −195.8 °C when the pressure is one atmosphere. A silver coin of mass 1.5×10^{-2} kg and temperature 25 °C is dropped into the liquid. What mass of nitrogen boils off as the coin cools to −195.8 °C?

62. The latent heat of vaporization of H_2O at body temperature (37.0 °C) is 2.42×10^6 J/kg. To cool the body of a 75-kg jogger [average specific heat capacity = 3500 J/(kg · C°)] by 1.5 C°, how many kilograms of water in the form of sweat have to be evaporated?

63. When it rains, water vapor in the air condenses into liquid water, and energy is released. (a) How much energy is released when 0.0254 m (one inch) of rain falls over an area of 2.59×10^6 m^2 (one square mile)? (b) If the average energy needed to heat one home for a year is 1.50×10^{11} J, how many homes can be heated with the energy determined in part (a)?

64. Water at 23 °C is sprayed on 0.180 kg of molten gold at 1063 °C (its melting point). The water boils away, leaving solid gold at 1063 °C. What minimum mass of water must be used?

***65.** **ssm** Ice at −10.0 °C and steam at 130 °C are brought together at atmospheric pressure in a perfectly insulated container. After thermal equilibrium is reached, the liquid phase at 50.0 °C is present. Ignoring the container and the equilibrium vapor pressure of the liquid at 50.0 °C, find the ratio of the mass of steam to the mass of ice.

***66.** To help keep his barn warm on cold days, a farmer stores 840 kg of solar-heated water in barrels. For how many hours would a 2.0-kW electric space heater have to operate to provide the same amount of heat as the water does, when it cools from 10.0 to 0.0 °C and completely freezes?

***67.** A 35-kg block of ice at 0 °C is sliding on a horizontal surface. The initial speed of the ice is 6.5 m/s and the final speed is 4.8 m/s. Assume that the part of the block that melts has a very small mass and that all the heat generated by kinetic friction goes into the block of ice, and determine the mass of ice that melts into water at 0 °C.

***68.** In the British engineering system, the latent heat of fusion of H_2O is 144 Btu/lb. Suppose an air conditioner can remove heat at a rate of 12 000 Btu/h. Determine the number of tons (1 ton = 2000 lb) of water at 0 °C that such an air conditioner could freeze into ice at 0 °C in 24 h. This is the number of "tons of air-conditioning" that the unit can provide, a phrase that is sometimes used to rate the cooling capacity of air conditioners.

***69.** **ssm www** An unknown material has a normal melting/freezing point of −25.0 °C, and the liquid phase has a specific heat capacity of 160 J/(kg · C°). One-tenth of a kilogram of the solid at −25.0 °C is put into a 0.150-kg aluminum calorimeter cup that contains 0.100 kg of glycerin. The temperature of the and the glycerin is initially 27.0 °C. All the unknown r melts, and the final temperature at equilibrium is 20. calorimeter loses no energy to the external environment. the latent heat of fusion of the unknown material?

55) 1.3×10^5 J
56) 3.32×10^5 J/kg
Ammonia
57) 3.9×10^5 J
58) 13°C
59) 9.3 kg
60) 1.85×10^5 J
61) 3.9×10^{-3} kg
62) 0.16 kg
63) 1.49×10^{14} J
993 Homes
64) 4.4×10^{-3} kg
65) 0.223
66) 44 hrs
67) 1×10^{-3} kg
68) 1 ton
69) 1.9×10^4 J/kg

Section 13.2 Conduction

1. **ssm** One end of an iron poker is placed in a fire where the temperature is 502 °C, and the other end is kept at a temperature of 26 °C. The poker is 1.2 m long and has a radius of 5.0×10^{-3} m. Ignoring the heat lost along the length of the poker, find the amount of heat conducted from one end of the poker to the other in 5.0 s.

2. A refrigerator has a surface area of 5.3 m^2. It is lined with 0.075-m-thick insulation whose thermal conductivity is 0.030 J/(s · m · C°). The interior temperature is kept at 5 °C, while the temperature at the outside surface is 25 °C. How much heat per second is being removed from the unit?

3. A closed box is filled with dry ice at a temperature of −78.5 °C, while the outside temperature is 21.0 °C. The box is cubical, measuring 0.350 m on a side, and the thickness of the walls is 3.00×10^{-2} m. In one day, 3.10×10^6 J of heat is conducted through the six walls. Find the thermal conductivity of the box.

4. The temperature in an electric oven is 160 °C. The temperature at the outer surface in the kitchen is 50 °C. The oven (surface area = 1.6 m^2) is insulated with material that has a thickness of 0.020 m and a thermal conductivity of 0.045 J/(s · m · C°). (a) How much energy is used to operate the oven for six hours? (b) At a price of $0.10 per kilowatt · hour for electrical energy, what is the cost of operating the oven?

5. **ssm** Due to a temperature difference ΔT, heat is conducted through an aluminum plate that is 0.035 m thick. The plate is then replaced by a stainless steel plate that has the same temperature difference and cross-sectional area. How thick should the steel plate be, so that the same amount of heat per second is conducted through it?

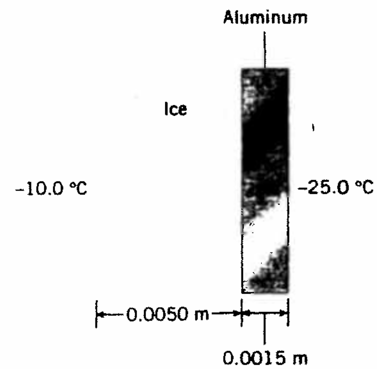
6. A hollow, cylindrical glass tube is filled with hydrogen (H_2) gas. The tube has a length of 0.25 m and an inner and outer radii of 0.020 and 0.023 m. One end of the tube is maintained at a temperature of 85 °C, while the other end is kept at 15 °C. There is no heat loss through the curved surface of the glass. Determine the heat that flows through the glass and hydrogen in a time of 55 s.

7. A skier wears a jacket filled with goose down that is 15 mm thick. Another skier wears a wool sweater that is 5.0 mm thick. Both have the same surface area. Assuming the temperature difference between the inner and outer surfaces of each garment is the same, calculate the ratio (wool/goose down) of the heat lost due to conduction during the same time interval.

8. Heat is conducted by two bars, one made from silver and the other from brass. The bars have the same cross-sectional area and the same length. The temperature difference between the ends of each bar is the same. Ignore any heat lost through the sides of the bars. What percentage of the total power, or energy per second, is conducted by the silver bar?

9. **ssm www** In the conduction equation $Q = (kA\,\Delta T)t/L$, the combination of factors kA/L is called the *conductance*. The human body has the ability to vary the conductance of the tissue beneath the skin by means of vasoconstriction and vasodilation, in which the flow of blood to the veins and capillaries underlying the skin is decreased and increased, respectively. The conductance can be adjusted over a range such that the tissue beneath the skin is equivalent to a thickness of 0.080 mm of Styrofoam or 3.5 mm of air. By what factor can the body adjust the conductance?

***10.** Review Conceptual Example 4 before attempting this problem. To illustrate the effect of ice on the aluminum cooling plate, consider the drawing below and the data contained therein. Ignore any limitations due to significant figures. (a) Calculate the heat per second per square meter that is conducted through the ice–aluminum sandwich. (b) Calculate the heat per second per square meter that would be conducted through the aluminum if the ice were not present. Notice how much larger the answer is in (b) as compared to (a).



***11.** One end of a brass bar is maintained at 295 °C, while the other end is kept at a constant but lower temperature. The cross-sectional area of the bar is 4.0×10^{-4} m^2. Because of insulation, there is negligible heat loss through the sides of the bar. Heat flows through the bar, however, at the rate of 2.7 J/s. What is the temperature of the bar at a point 0.20 m from the hot end?

***12.** Two identical bars are attached end to end, as part *a* of the drawing illustrates. In a time of 44 minutes, a certain amount of heat is conducted from the left end to the right end. Suppose, instead, that the two bars were placed on top of one another, as in part *b* of the drawing, where the difference in temperature between the ends of the bars is the same as in part *a*. How long (in

over →

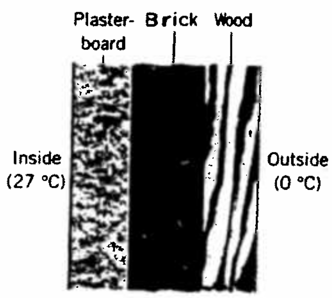
1) 12 J
2) 42 J/s
3) 1.47×10^{-2} J/(s·m·C°)
4) 8.6×10^6 J
5) 2×10^{-3} m
6) 8.5 J
7) 4.8
8) 79%
9) 17
10) 6.58×10^{3} J/(s·m²)
2.40×10^{6} J/(s·m²)
11) 203 °C
12) 11 min
13) 130 °C, 850 J, 273 °C
14) 21 °C, 18 °C
15) 100.78 °C, 107.2 °C
16) 0.11 mm
17) 2.0, 0.61

minutes) would it take for the same amount of heat to be conducted from left to right along this combination?

(a) (b)

• **13.** **ssm** Two rods, one of aluminum and the other of copper, are joined end to end. The cross-sectional area of each is 4.0×10^{-4} m², and the length of each is 0.040 m. The free end of the aluminum rod is kept at 302 °C, while the free end of the copper rod is kept at 25 °C. The loss of heat through the sides of the rods may be ignored. (a) What is the temperature at the aluminum–copper interface? (b) How much heat is conducted through the unit in 2.0 s? (c) What is the temperature in the aluminum rod at a distance of 0.015 m from the hot end?

• **14.** Three building materials, plasterboard [$k = 0.30$ J/(s · m · C°)], brick [$k = 0.60$ J/(s · m · C°)], and wood [$k = 0.10$ J/(s · m · C°)], are sandwiched together as the drawing illustrates. The temperatures at the inside and outside surfaces are 27 °C and 0 °C, respectively. Each material has the same thickness and cross-sectional area. Find the temperature (a) at the plasterboard–brick interface and (b) at the brick–wood interface.



• **15.** In an aluminum pot, 0.20 kg of water at 100 °C boils away in five minutes. The bottom of the pot is 2.5×10^{-3} m thick and has a surface area of 0.020 m². To prevent the water from boiling too rapidly, a stainless steel plate has been placed between the pot and the heating element. The plate is 1.2×10^{-3} m thick, and its area matches that of the pot. Assuming that heat is conducted into the water only through the bottom of the pot, find the temperature at (a) the aluminum–steel interface and (b) the steel surface in contact with the heating element.

•• **16.** A 0.30-m-thick sheet of ice covers a lake. The air temperature at the ice surface is −15 °C. In five minutes, the ice thickens by a small amount. Assume that no heat flows from the ground below into the water and that the added ice is very thin compared to 0.30 m. Find the number of millimeters by which the ice thickens.

• **17.** **ssm www** Two cylindrical rods have the same mass. One is made of silver (density = 10 500 kg/m³), and one is made of iron (density = 7860 kg/m³). Both rods conduct the same amount of heat per second when the same temperature difference is maintained across their ends. What is the ratio (silver-to-iron) of (a) the lengths and (b) the radii of these rods?

Section 14.1 Molecular Mass, the Mole, and Avogadro's Number

1. **ssm** Hemoglobin has a molecular mass of 64 500 u. Find the mass (in kg) of one molecule of hemoglobin.

2. The artificial sweetener NutraSweet is a chemical called aspartame ($C_{14}H_{18}N_2O_5$). What is (a) its molecular mass (in atomic mass units) and (b) the mass (in kg) of an aspartame molecule?

3. The chlorophyll-*a* molecule, $C_{55}H_{72}MgN_4O_5$, is important in photosynthesis. (a) Determine its molecular mass (in atomic mass units). (b) What is the mass (in grams) of 3.00 moles of chlorophyll-*a* molecules?

4. A glass of water has a volume of 6.0×10^{-4} m^3. How many moles of water molecules are there in the glass?

5. **ssm** A mass of 135 g of an element is known to contain 30.1×10^{23} atoms. What is the element?

6. Manufacturers of headache remedies routinely claim that their own brands are more potent pain relievers than the competing brands. The best way of making the comparison is to compare the number of molecules in the standard dosage. Tylenol uses 325 mg of acetaminophen ($C_8H_9NO_2$) as the standard dose, while Advil uses 2.00×10^2 mg of ibuprofen ($C_{13}H_{18}O_2$). Find the number of molecules of pain reliever in the standard doses of (a) Tylenol and (b) Advil.

*7. What mass of chlorine gas (Cl_2) must be added to four grams of hydrogen gas (H_2), if all the molecules are used to produce hydrochloric acid (HCl)?

*8. Ethyl alcohol (C_2H_5OH) has a density of 806 kg/m^3 and a volume of 2.00×10^{-3} m^3. (a) Determine the mass (in kg) of a molecule of ethyl alcohol, and (b) find the number of molecules in the liquid.

9. **ssm www At the normal boiling point of a material, the liquid phase has a density of 958 kg/m^3, and the vapor phase has a density of 0.598 kg/m^3. Determine the ratio of the distance between neighboring molecules in the gas phase to that in the liquid phase. *(Hint: Assume that the volume of each phase is filled with many cubes, with one molecule at the center of each cube.)*

1) 1.07×10^{-22} kg
2) 294.307 u
4.88×10^{-25} kg
3) 893.51 u
2680 g
4) 33 mol
5) 27.0 g/mol
Aluminum
6) 1.29×10^{21}
5.84×10^{20}
7) 141 g
8) 7.65×10^{-26} kg, 2.11×10^{25}
9) 11.7

Section 14.2 The Ideal Gas Law

10. An ultrahigh vacuum pump can reduce the absolute pressure to 1.2×10^{-7} Pa. In a volume of $2.0\ m^3$ and at a temperature of 3.0×10^2 K, how many molecules of gas are present at this pressure?

11. At the start of a trip, a driver adjusts the absolute pressure in her tires to be 2.81×10^5 Pa when the outdoor temperature is 284 K. At the end of the trip she measures the pressure to be 3.01×10^5 Pa. Ignoring the expansion of the tires, find the air temperature inside the tires at the end of the trip.

12. Find the volume occupied by one mole of an ideal gas at STP conditions. Express your answer in liters (1 liter = $1000\ cm^3 = 10^{-3}\ m^3$).

13. **ssm** In a diesel engine, the piston compresses air at 305 K to a volume that is one-sixteenth of the original volume and a pressure that is 48.5 times the original pressure. What is the temperature of the air after the compression?

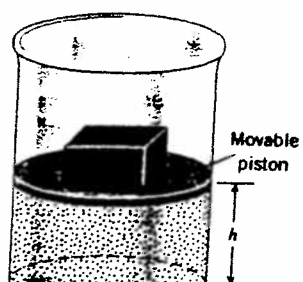
14. A $0.030\text{-}m^3$ container is initially evacuated, and then 4.0 g of water is placed in it. After a time, all the water evaporates, and the temperature is 388 K. Find the pressure.

15. Oxygen for hospital patients is kept in special tanks, where the oxygen has a pressure of 65.0 atmospheres and a temperature of 288 K. The tanks are stored in a separate room, and the oxygen is pumped to the patient's room, where it is administered at a pressure of 1.00 atmosphere and a temperature of 297 K. What volume does $1.00\ m^3$ of oxygen in the tanks occupy at the conditions in the patient's room?

16. In a portable oxygen system, the oxygen (O_2) is contained in a cylinder whose volume is $0.0028\ m^3$. A full cylinder has an absolute pressure of 1.5×10^7 Pa when the temperature is 296 K. Find the mass (in kg) of oxygen in the cylinder.

17. **ssm** A young male adult takes in about $5.0 \times 10^{-4}\ m^3$ of fresh air during a normal breath. Fresh air contains approximately 21% oxygen. Assuming that the pressure in the lungs is 1.0×10^5 Pa and air is an ideal gas at a temperature of 310 K, find the number of oxygen molecules in a normal breath.

18. A frictionless gas-filled cylinder is fitted with a movable piston, as the drawing shows. The block resting on the top of the piston determines the constant pressure that the gas has. The height h is 0.120 m when the temperature is 273 K and increases as the temperature increases. What is the value of h when the temperature reaches 318 K?



See Reverse side for Answers

19. On the sunlit surface of Venus, the atmospheric pressure is 9.0×10^6 Pa, and the temperature is 740 K. On the earth's surface the atmospheric pressure is 1.0×10^5 Pa, while the surface temperature can reach 320 K. These data imply that Venus has a "thicker" atmosphere at its surface than does the earth, which means that the number of molecules per unit volume (N/V) is greater on the surface of Venus than on the earth. Find the ratio $(N/V)_{Venus}/(N/V)_{Earth}$.

20. Two ideal gases have the same mass density and the same absolute pressure. One of the gases is helium (He), and its temperature is 175 K. The other gas is neon (Ne). What is the temperature of the neon?

*21. **ssm** The relative humidity is 55% on a day when the temperature is 30.0 °C. Using the graph that accompanies problem 76 in Chapter 12, determine the number of moles of water vapor per cubic meter of air.

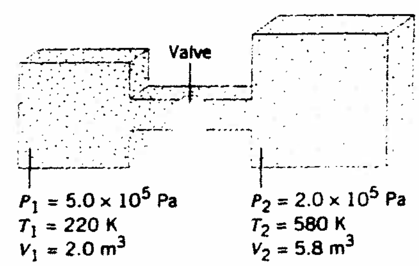
*22. Review Conceptual Example 3 before starting this problem. A bubble, located 0.200 m beneath the surface of the beer, rises to the top. The air pressure at the top is 1.01×10^5 Pa. Assume that the density of beer is the same as that of fresh water. If the temperature and number of moles of CO_2 remain constant as the bubble rises, find the ratio of its volume at the top to that at the bottom.

*23. One assumption of the ideal gas law is that the atoms or molecules themselves occupy a negligible volume. Verify that this assumption is reasonable by considering gaseous argon (Ar). Argon has an atomic radius of 0.70×10^{-10} m. For STP conditions, calculate the percentage of the total volume occupied by the atoms.

24. Assume that the pressure in a room remains constant at 1.01×10^5 Pa and the air is composed only of nitrogen (N_2). The volume of the room is $60.0\ m^3$. When the temperature increases from 289 to 302 K, what mass of air (in kg) escapes from the room?

*25. **ssm www** A primitive diving bell consists of a cylindrical tank with one end open and one end closed. The tank is lowered into a freshwater lake, open end downward. Water rises into the tank, compressing the trapped air, whose temperature remains constant during the descent. The tank is brought to a halt when the distance between the surface of the water in the tank and the surface of the lake is 40.0 m. Atmospheric pressure at the surface of the lake is 1.01×10^5 Pa. Find the fraction of the tank's volume that is filled with air.

*26. The drawing shows two thermally insulated tanks. They are connected by a valve that is initially closed. Each tank contains neon gas at the pressure, temperature, and volume indicated in the drawing. When the valve is opened, the contents of the two tanks mix, and the pressure becomes constant throughout. (a) What is the final temperature? Ignore any change in temperature of the tanks themselves. (*Hint: The heat gained by the gas in one tank is equal to that lost by the other.*) (b) What is the final pressure?



10) 5.8×10^{13}

11) 304K

12) 22.4 L

13) 925K

14) 2.4×10^{4} Pa

15) 67.0 m^3

16) 0.550 kg

17) 2.5×10^{21} molecules

18) 0.140 m

19) 39

20) 882K

21) 0.93 $\frac{mol}{m^3}$

22) 1.02

23) 3.9×10^{-3} %

24) 3.0 kg

25) 0.205

26) 3.3×10^{2} K, 2.8×10^{5} Pa

Section 14.3 Kinetic Theory of Gases

30. The surface of the sun has a temperature of about 6.0×10^3 K. This hot gas contains hydrogen atoms ($m = 1.67 \times 10^{-27}$ kg). Find the rms speed of these atoms.

31. Two moles of nitrogen (N_2) gas are placed in a container whose volume is 8.5×10^{-3} m^3. The pressure of the gas is 4.5×10^5 Pa. What is the average translational kinetic energy of a nitrogen molecule?

32. See Conceptual Example 7 as an aid in solving this problem. At what temperature is the translational rms speed of hydrogen molecules (H_2) equal to the escape speed?

33. **ssm** The average value of the squared speed $\overline{v^2}$ does not equal the square of the average speed $(\bar{v})^2$. To verify this fact, consider three particles with the following speeds: $v_1 = 3.0$ m/s, $v_2 = 7.0$ m/s, and $v_3 = 9.0$ m/s. Calculate (a) $\overline{v^2} = \frac{1}{3}(v_1{}^2 + v_2{}^2 + v_3{}^2)$ and (b) $(\bar{v})^2 = [\frac{1}{3}(v_1 + v_2 + v_3)]^2$.

34. The temperature in the ionosphere (the uppermost part of the earth's atmosphere) is about 1.0×10^3 K. What is the ratio of the translational rms speed of an oxygen molecule at this temperature to that of an oxygen molecule near the earth where the temperature is 290 K?

35. Initially, the translational rms speed of a molecule of an ideal gas is 463 m/s. The pressure and volume of this gas are kept constant, while the number of molecules is doubled. What is the final translational rms speed of the molecules?

36. At what temperature would the translational rms speed of hydrogen molecules (H_2) be equal to that of oxygen molecules (O_2) at 3.0×10^2 K?

37. **ssm** Suppose that a tank contains 680 m^3 of neon at an absolute pressure of 1.01×10^5 Pa. The temperature is changed from 293.2 to 294.3 K. What is the increase in the internal energy of the neon?

*38. Helium (He), a monatomic gas, fills a 0.010-m^3 container. The pressure of the gas is 6.2×10^5 Pa. How long would a 0.25-hp engine have to run (1 hp = 746 W) to produce an amount of energy equal to the internal energy of this gas?

*39. The temperature near the surface of the earth is 295 K. An argon atom (atomic mass = 39.948 u) has a kinetic energy equal to the average translational kinetic energy and is moving straight up. If the atom does not collide with any other atoms or molecules, how high up would it go before coming to rest? Assume that the acceleration due to gravity is constant throughout the ascent.

*40. The pressure of sulfur dioxide (SO_2) is 2.12×10^4 Pa. There are 421 moles in a volume of 50.0 m^3. Find the translational rms speed of the sulfur dioxide molecules.

30) 1.2×10^4 m/s
31) 4.8×10^{21} J
32) 1.01×10^4 K
33) 46.3 m^2/s^2
40.1 m^2/s^2
34) 1.9
35) 327 m/s
36) 19 K
37) 3.9×10^5 J
38) 5.0×10^1 s
39) 9400 m
40) 343 m/s

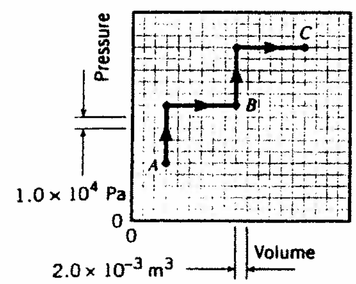
Section 15.4 Thermal Processes

7. A gas is compressed under isobaric conditions, and its volume changes from 7.0×10^{-3} to 2.0×10^{-3} m^3. The pressure of the gas is 1.5×10^5 Pa. (a) Determine the work done (including the algebraic sign). (b) How much work is done (including the algebraic sign) if the gas then expands from 2.0×10^{-3} to 8.0×10^{-3} m^3 under isobaric conditions?

8. The internal energy of a system increases by 210 J during an adiabatic process. Determine (a) whether work is done on or by the system, and (b) find the magnitude of the work.

9. **ssm** A system gains 1500 J of heat, while the internal energy of the system increases by 4500 J and the volume decreases by 0.010 m^3. Assume the pressure is constant and find its value.

10. (a) Using the data presented in the accompanying pressure-versus-volume graph, estimate the magnitude of the work done when the system changes from A to B to C along the path shown. (b) Determine whether the work is done by the system or on the system and, hence, whether the work is positive or negative.



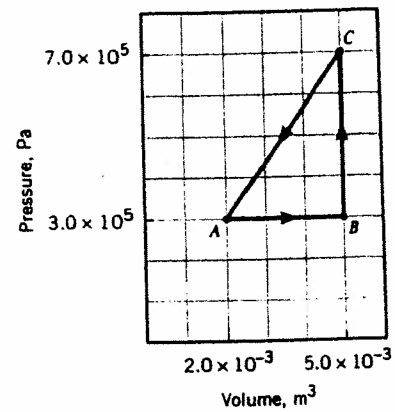
11. The internal energy of a system increases by 1350 J when the system gains 1150 J of heat at a constant pressure of 1.01×10^5 Pa. (a) What is the change in the volume of the gas? (b) Does the volume increase or decrease?

12. A gas is contained in a chamber such as that in Figure 15.5.

Suppose the region outside the chamber is evacuated and the total mass of the block and the movable piston is 135 kg. When 2050 J of heat flows into the gas, the internal energy of the gas increases by 1730 J. What is the distance s through which the piston rises?

13. **ssm** When a .22-caliber rifle is fired, the expanding gas from the burning gunpowder creates a pressure behind the bullet. This pressure causes the force that pushes the bullet through the barrel. The barrel has a length of 0.61 m and an opening whose radius is 2.8×10^{-3} m. A bullet (mass = 2.6×10^{-3} kg) has a speed of 370 m/s after passing through this barrel. Ignore friction and determine the average pressure of the expanding gas.

14. The pressure and volume of a gas are changed along the path $ABCA$. Determine the work done (including the algebraic sign) in each segment of the path: (a) A to B, (b) B to C, and (c) C to A.



***15.** A piece of aluminum has a volume of 1.4×10^{-3} m^3. The coefficient of volume expansion for aluminum is $\beta = 69 \times 10^{-6}$ $(C°)^{-1}$. The temperature of this object is raised from 20 to 320 °C. How much work is done by the expanding aluminum if the air pressure is 1.01×10^5 Pa?

***16.** When a monatomic ideal gas expands at a constant pressure of 2.6×10^5 Pa, the volume of the gas increases by 6.2×10^{-3} m^3. (a) Determine the heat that flows into or out of the gas. (b) Specify the direction of the flow.

***17.** **ssm www** A monatomic ideal gas expands isobarically. Using the first law of thermodynamics, prove that the heat Q is positive, so that it is impossible for heat to flow out of the gas.

***18.** The latent heat of sublimation for zinc (atomic mass = 65.4 u) at 6.00×10^2 K is 1.99×10^6 J/kg. Assume that the zinc vapor can be treated as a monatomic ideal gas and that the volume of one kilogram of solid is negligible compared to that of the vapor. What percentage of the latent heat serves to change the internal energy during sublimation?

****19.** Water is heated in an open pan where the air pressure is one atmosphere. The water remains a liquid, which expands by a small amount as it is heated. Determine the ratio of the work done by the water to the heat absorbed by the water.

7) $+7.5 \times 10^2$ J
-9.0×10^2 J

8) on the system
210 J

9) 3.0×10^5 Pa

10) -3.0×10^3 J
by the system

11) -2.0×10^{-3} m^3
decrease

12) 0.24 m

13) 1.2×10^7 Pa

14) -9.0×10^2 J
0
$+1.5 \times 10^3$ J

15) 2.9 J

16) 4.0×10^3 J
heat flows out

17) skip

18) 96.2 %

19) 4.44×10^{-6}

Section 15.5 Thermal Processes That Utilize an Ideal Gas

20. The temperature of three moles of an ideal gas is 373 K. How much work does the gas do in expanding isothermally to four times its initial volume?

21. **ssm** Three moles of an ideal gas are compressed from 5.5×10^{-2} to 2.5×10^{-2} m^3. During the compression, 6.1×10^3 J of work is done on the gas, and heat is removed in order to keep the temperature of the gas constant at all times. Find (a) ΔU, (b) Q, and (c) the temperature of the gas.

22. Five moles of oxygen expands isothermally from 0.100 to 0.400 m^3. To maintain the constant temperature, 2.50×10^4 J of heat is added to the system. Assuming oxygen to be an ideal gas, determine the temperature.

23. Six grams of helium (molecular mass = 4.0 u) expands isothermally at 370 K and does 9600 J of work. Assuming that helium is an ideal gas, determine the ratio of the final volume of the gas to the initial volume.

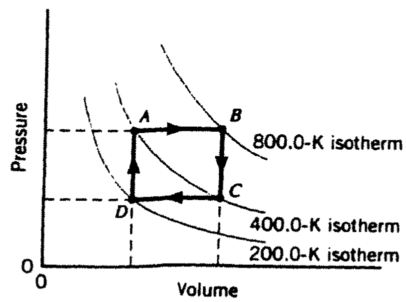
24. A monatomic ideal gas ($\gamma = \frac{5}{3}$) is compressed adiabatically, and its volume is reduced by a factor of two. Determine the factor by which its pressure increases.

25. **ssm** A monatomic ideal gas has an initial temperature of 405 K. This gas expands and does the same amount of work whether the expansion is adiabatic or isothermal. When the expansion is adiabatic, the final temperature of the gas is 245 K. What is the ratio of the final to the initial volume when the expansion is isothermal?

***26.** A bubble from the tank of a scuba diver in a lake contains 3.5×10^{-4} mol of gas. The bubble expands as it rises to the surface from a freshwater depth of 10.3 m. Assuming that the gas is an ideal gas and the temperature remains constant at 291 K, find the amount of heat that flows into the bubble.

***27.** A diesel engine does not use spark plugs to ignite the fuel and air in the cylinders. Instead, the temperature required to ignite the fuel occurs because the pistons compress the air in the cylinders. Suppose air at an initial temperature of 27 °C is compressed adiabatically to a temperature of 681 °C. Assume the air to be an ideal gas for which $\gamma = \frac{7}{5}$. Find the compression ratio, which is the ratio of the initial volume to the final volume.

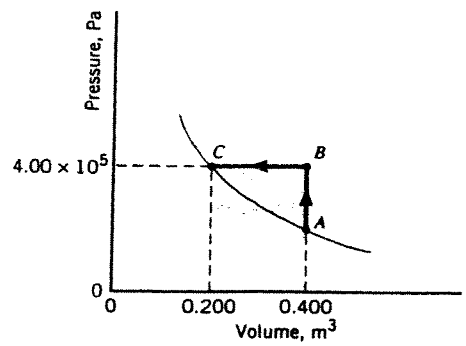
***28.** The drawing refers to one mole of a monatomic ideal gas and shows a process that has four steps, two isobaric (A to B, C to D) and two isochoric (B to C, D to A). Complete the following table by calculating ΔU, W, and Q (including the algebraic signs) for each of the four steps.



	ΔU	W	Q
A to B			
B to C			
C to D			
D to A			

***29.** Using the relationship for an adiabatic expansion or compression of an ideal gas ($P_i V_i^{\gamma} = P_f V_f^{\gamma}$) together with the ideal gas law, derive an expression similar to the one above, but involving only volume, temperature, and γ.

***30.** The pressure and volume of an ideal monatomic gas change from A to B to C, as the drawing shows. The curved line between A and C is an isotherm. (a) Determine the total heat for the process and (b) state whether the flow of heat is into or out of the gas.



****31.** **ssm** The work done by one mole of a monatomic ideal gas ($\gamma = \frac{5}{3}$) in expanding adiabatically is 825 J. The initial temperature and volume of the gas are 393 K and 0.100 m^3. Obtain (a) the final temperature and (b) final volume of the gas.

****32.** One mole of a monatomic ideal gas has an initial pressure, volume, and temperature of P_0, V_0, and 438 K, respectively. It undergoes an isothermal expansion that triples the volume of the gas. Then, the gas undergoes an isobaric compression back to its original volume. Finally, the gas undergoes an isochoric increase in pressure, so that the final pressure, volume, and temperature are P_0, V_0, and 438 K, respectively. Find the total heat for this three-step process, and state whether it is absorbed by or given off by the gas.

See other side for answers

15.6 Specific Heat Capacities and the First Law of Thermodynamics

33. **ssm** How much heat is required to change the temperature of 1.5 mol of a monatomic ideal gas by 77 K, if the pressure is held constant?

34. Suppose 750 J of heat is removed from five moles of a monatomic ideal gas. What change in temperature occurs when the energy is removed under conditions of (a) constant volume and (b) constant pressure?

35. Argon is a monatomic gas whose molecular mass is 39.9 u. The temperature of eight grams of argon is raised by 75 K under conditions of constant pressure. Assuming that argon is an ideal gas, how much heat is required?

36. Three moles of a monatomic ideal gas are heated at a constant volume of 1.50 m^3. The amount of heat added is 5.24×10^3 J. (a) What is the change in the temperature of the gas? (b) Find the change in its internal energy. (c) Determine the change in pressure.

37. **ssm** The temperature of 2.5 mol of a monatomic ideal gas is 350 K. The internal energy of this gas is doubled by the addition of heat. How much heat is needed when it is added at (a) constant volume and (b) constant pressure?

38. Heat Q is added to a monatomic ideal gas at constant pressure. As a result, the gas does work W. Find the ratio Q/W.

***39.** A ten-watt heater is used to heat a monatomic ideal gas at a constant pressure of 2.50×10^5 Pa. During the process, the 1.00×10^{-3}-m^3 volume of the gas increases by 20.0%. How long was the heater on?

***40.** Suppose that 31.4 J of heat is added to an ideal gas. The gas expands at a constant pressure of 1.40×10^4 Pa while changing its volume from 3.00×10^{-4} to 8.00×10^{-4} m^3. The gas is not monatomic, so the relation $C_P = \frac{5}{2}R$ does not apply. (a) Determine the change in the internal energy of the gas. (b) Calculate its molar specific heat capacity C_P.

***41.** **ssm** A monatomic ideal gas expands at constant pressure. (a) What percentage of the heat being supplied to the gas is used to increase the internal energy of the gas? (b) What percentage is used for doing the work of expansion?

****42.** One mole of neon, a monatomic gas, starts out at conditions of standard temperature and pressure. The gas is heated at constant volume until its pressure is tripled, then further heated at constant pressure until its volume is doubled. Assume that neon behaves as an ideal gas. For the entire process, find the heat added to the gas.

Molar heat Capacities

33) 2400 J

34) −12 K, −7.2 K

35) 310 J

36) 1.40×10^2 K
5.24×10^3 J
2.33×10^3 Pa

37) 1.1×10^4 J
1.8×10^4 J

38) 5/2

39) 12.5 seconds

40) 24.4 J
37.3 $\frac{J}{mol \cdot K}$

41) 60%

42) 2.38×10^4 Joules

15.8 Heat Engines

43. The input heat for an engine is 2.41×10^4 J, and the rejected heat is 5.86×10^3 J. Find the work done by the engine.

44. An automobile engine has an efficiency of 14% before a tune-up. After the tune-up, the efficiency increases to 20.0%. For a given amount of input energy, determine the ratio of the work done by the engine after the tune-up to that before the tune-up.

45. ssm In doing 16 600 J of work, an engine rejects 9700 J of heat. What is the efficiency of the engine?

46. An engine has an efficiency of 64% and produces 5500 J of work. Determine (a) the input heat and (b) the rejected heat.

*47. A hiker of mass 58 kg climbs up a mountain through a vertical distance of 950 m. To make the climb, her body generates an extra 4.5×10^6 J of energy. (a) How much work does she do in changing her gravitational potential energy? (b) What is her efficiency (expressed as a fraction between 0 and 1) in doing the work in part (a)?

*48. Engine A discards 72% of its input heat into a cold reservoir. Engine B has twice the efficiency as engine A. What percentage of its input heat does engine B discard?

**49. ssm www Engine A receives three times more input heat, produces five times more work, and rejects two times more heat than engine B. Find the efficiency of (a) engine A and (b) engine B.

43) 1.82×10^4 J

44) 1.4

45) 0.631

46) 8600 J, 3100 J

47) 5.4×10^5 J, 0.12

48) 44%

49) 5/9, 1/3

Section 15.10 Refrigerators, Air Conditioners, and Heat Pumps

62. What is the coefficient of performance of an air conditioner that uses 3500 J of electrical energy to remove 11 200 J of heat from a room?

63. A refrigerator does 2500 J of work in order to remove 8500 J of heat from the cold reservoir. (a) Determine the coefficient of performance of the refrigerator. (b) How much heat is deposited into the kitchen (the hot reservoir)?

64. The water in a deep underground well is used as the cold reservoir of a Carnot heat pump that maintains the temperature of a house at 301 K. To deposit 14 200 J of heat in the house, the heat pump requires 800 J of work. Determine the temperature of the well water.

65. **ssm www** The temperatures indoors and outdoors are 299 and 312 K, respectively. A Carnot air conditioner deposits 6.12×10^5 J of heat outdoors. How much heat is removed from the house?

66. The coefficient of performance of a refrigerator is 4.6. How much electrical energy is used in removing 4100 J of heat from the food inside?

67. A heat pump removes 2090 J of heat from the outdoors and delivers 3140 J of heat to the inside of a house. (a) How much work does the heat pump need? (b) What is the coefficient of performance of the heat pump?

68. A Carnot engine has an efficiency of 0.70. If this engine were run backward as a heat pump, what would be the coefficient of performance?

***69.** **ssm www** A Carnot refrigerator transfers heat from its inside (6.0 °C) to the room air outside (20.0 °C). (a) Find the coefficient of performance of the refrigerator. (b) Determine the magnitude of the minimum work needed to cool 5.00 kg of water from 20.0 to 6.0 °C when it is placed in the refrigerator.

***70.** An engine is run in reverse as a heat pump. An identical engine (with the same values of Q_H, Q_C, and W as the first engine) is run in reverse as a refrigerator. The coefficient of performance of the heat pump is three times greater than the coefficient of performance of the refrigerator. Obtain (a) the coefficient of performance of the refrigerator, (b) the coefficient of performance of the heat pump, and (c) the efficiency of the engine.

***71.** How long would a 3.00-kW space heater have to run to put into a kitchen the same amount of heat as a refrigerator (coefficient of performance = 3.00) does when it freezes 1.50 kg of water at 20.0 °C into ice at 0.0 °C?

62) 3.2
63) 3.4
64) 284 K
65) 5.86×10^5 J
66) 890 J
67) 1050 J, 2.99
68) 1.4
69) 20, 1.5×10^4 J
70) 0.05, 1.5, 0.67
71) 279 s

Section 15.11 Entropy and the Second Law of Thermodynamics

74. The inside of a house is at 20.0 °C and the outside is at −15 °C. The house loses 1.30×10^5 J of heat. Find $\Delta S_{universe}$, the change in entropy of the universe.

75. Four kilograms of carbon dioxide sublimes from solid "dry ice" to a gas at a pressure of one atmosphere and a temperature of 194.7 K. The latent heat of sublimation is 5.77×10^5 J/kg. Find the change in entropy of the carbon dioxide.

76. Heat Q flows spontaneously from a reservoir at 394 K into a reservoir that has a lower temperature T. Because of the spontaneous flow, thirty percent of Q is rendered unavailable for work when a Carnot engine operates between the reservoir at temperature T and a reservoir at 248 K. Find the temperature T.

77. **ssm** Find the change in entropy of the H_2O molecules when (a) three kilograms of ice melts into water at 273 K and (b) three kilograms of water changes into steam at 373 K. (c) On the basis of the answers to parts (a) and (b), discuss which change creates more disorder in the collection of H_2O molecules.

*78. (a) Find the equilibrium temperature that results when one kilogram of liquid water at 373 K is added to two kilograms of liquid water at 283 K in a perfectly insulated container. (b) When heat is added to or removed from a solid or liquid of mass m and specific heat capacity c, the change in entropy can be shown to be $\Delta S = mc \ln(T_f/T_i)$, where T_i and T_f are the initial and final Kelvin temperatures. Use this equation to calculate the entropy change for each amount of water. Then combine the two entropy changes algebraically to obtain the total entropy change of the universe. Note that the process is irreversible, so the total entropy change of the universe is greater than zero. (c) Assuming that the coldest reservoir at hand has a temperature of 273 K, determine the amount of energy that becomes unavailable for doing work because of the irreversible process.

*79. (a) Five kilograms of water at 80.0 °C is mixed in a perfect thermos with 2.00 kg of ice at 0.0 °C, and the mixture is allowed to reach equilibrium. Using the expression $\Delta S = mc \ln(T_f/T_i)$ [see problem 78] and the change in entropy for melting, find the change in entropy that occurs. (b) Should the entropy of the universe increase or decrease as a result of the mixing process? Give your reasoning and state whether your answer in part (a) is consistent with your answer here.

74) 6.0×10^1 J/K

75) 1.19×10^4 J/K

76) 276

77) 3.68×10^3 J/K

1.82×10^4 J/K

vaporization process creates more Disorder

78) 313K

1.10×10^2 J/K

3.00×10^4 J

79) +541 J/K

the entropy of the universe increases

Ads for new cars often stress the increased efficiency of the new models compared with what you're driving now. In fact, the last few years have seen real improvements in engine efficiency. But how far can this continue? Let's find out by analyzing a simple model of a typical car engine.

Internal combustion engines form a special class of heat engines that generate the input heat by the combustion of fuel within the engine itself. Examples of internal combustion engines include gasoline engines, Diesel engines, and gas turbines. Here we consider the gasoline engine as a representative example of internal combustion engines.

The operating cycle of the gasoline engine used in most cars is a four-stroke cycle (Fig. B13.1). In the *intake stroke* a mixture of air and gasoline vapor is drawn through the intake valve into the cylinder by the downward motion of the piston. The valve closes and the fuel-air mixture is compressed. At the top of this *compression stroke* the gases are ignited by an electric spark from the spark plug, raising the temperature and pressure of the gases. The hot gases then expand against the piston in the *power stroke*, delivering energy to the crankshaft. The exhaust valve opens as the piston moves upward again, expelling the burned gases in the *exhaust stroke*. The exhaust valve closes, the intake valve opens, and the cycle is ready to repeat.

Analysis of an indicator diagram of a real gasoline engine is very difficult (Fig. B13.2a). For this reason, the gasoline engine is usually analyzed with a simplified model of the cycle called the Otto cycle, after its developer, Nicholas Otto (1832-1891). The Otto cycle begins at point *A* on the *PV* diagram of Fig. B13.2(b). The volume expands at constant pressure to point *B* as the piston moves down during the intake stroke. During the compression stroke the gases are compressed adiabatically to point *C*. Ignition of the gas by the spark causes an isochoric change

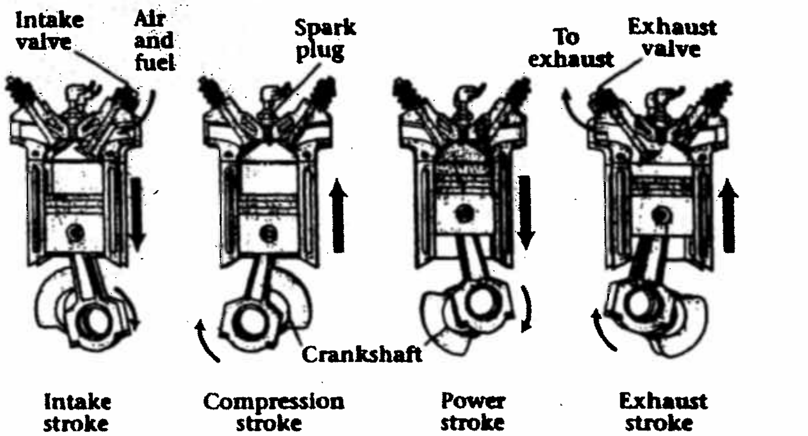


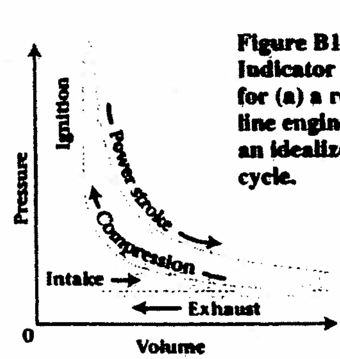
Figure B13.1 The operating cycle of a four-stroke gasoline engine. The piston goes up and down twice during each cycle.

to point *D* at higher temperature and pressure, which is followed by an adiabatic expansion to point *E* during the power stroke. Opening the exhaust valve causes the pressure to drop isochorically to point *B*, and this drop is followed by a decrease in volume at constant pressure as the piston moves through the exhaust stroke.

Physics in Practice

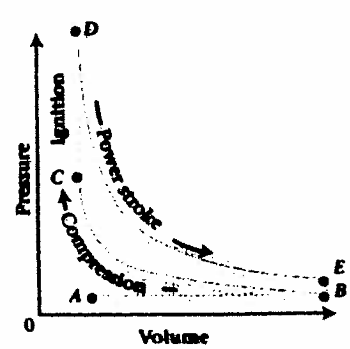
The work done by the gasoline engine is found from the area enclosed in the curve on the *PV* diagram, which for the idealized Otto cycle is the loop *B-C-D-E-B*. Comparison of the Otto cycle with a Carnot cycle operating between the same two temperatures shows that the efficiency of the Carnot cycle is more than that of the Otto cycle. The Otto cycle is, in turn, considerably more efficient than the actual gasoline engine cycle that it represents. Real gasoline engines achieve thermodynamic efficiencies of 20 to 25%, roughly half the value predicted from the simplified Otto model.

In recent years, manufacturers have been designing and building more efficient cars. Electronic sensors have been installed to monitor exhaust emissions, while computer control of air-fuel mixtures is now common. Other advances such as lean burn engines, turbocharging, multiple valves, and cast-aluminum engine blocks have been used to make cars more fuel-efficient. Future developments will undoubtedly include even more computer control of the combustion process and electronically controlled transmissions to provide the optimum gearing between the engine and the wheels for every situation.



(a)

Figure B13.2 Indicator diagrams for (a) a real gasoline engine and (b) an idealized Otto cycle.



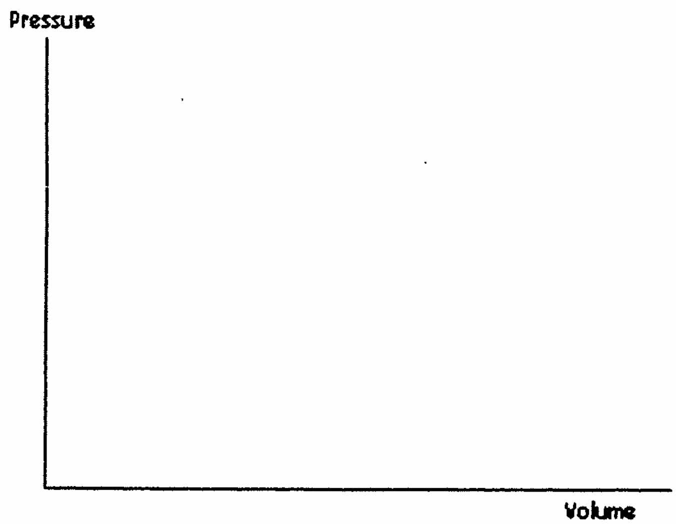
(b)

TABLE 13.1 Practical efficiencies of real engines

Type of engine	Efficiency (%)
Automobile engine (gasoline)	20–25
Diesel engine	26–38
Nuclear-powered steam turbine	35
Coal-fired steam turbine	40

Advanced Placement Physics B

Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

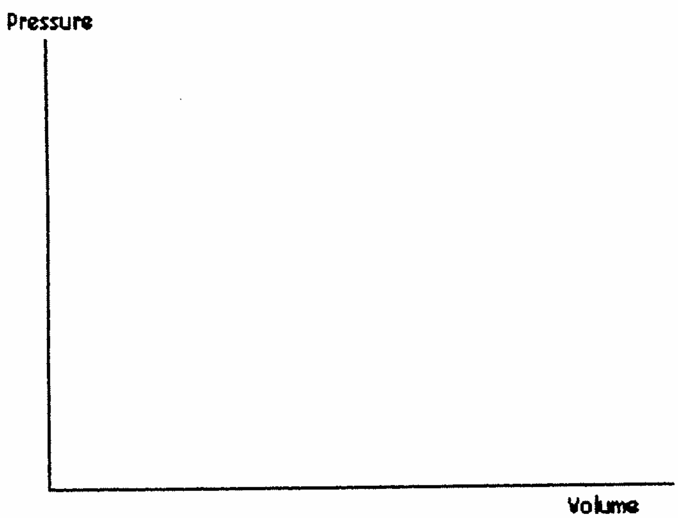
Comments:

Engine Type: __________

Cycle Used: __________

Advanced Placement Physics B

Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

Cycle Used: __________

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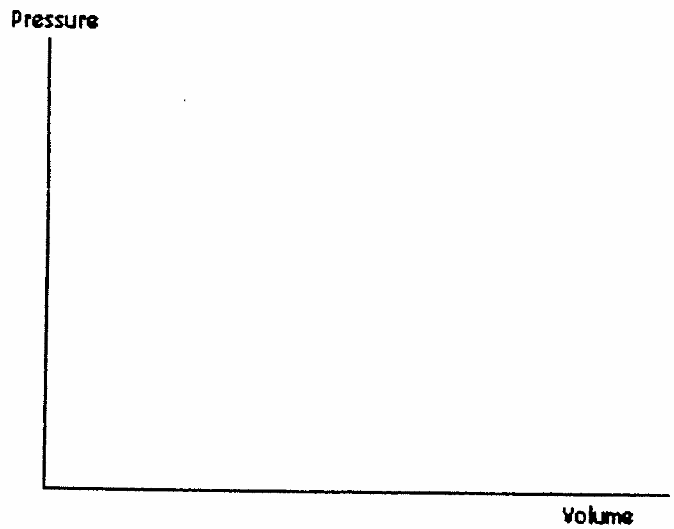
Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

Cycle Used: __________

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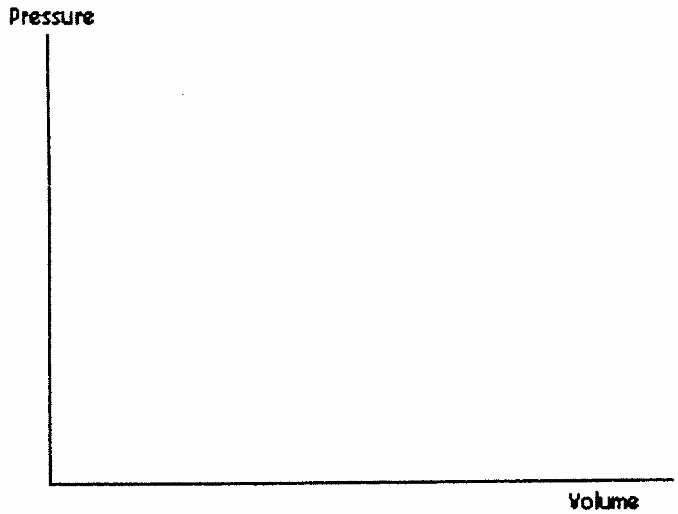
Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

Cycle Used: __________

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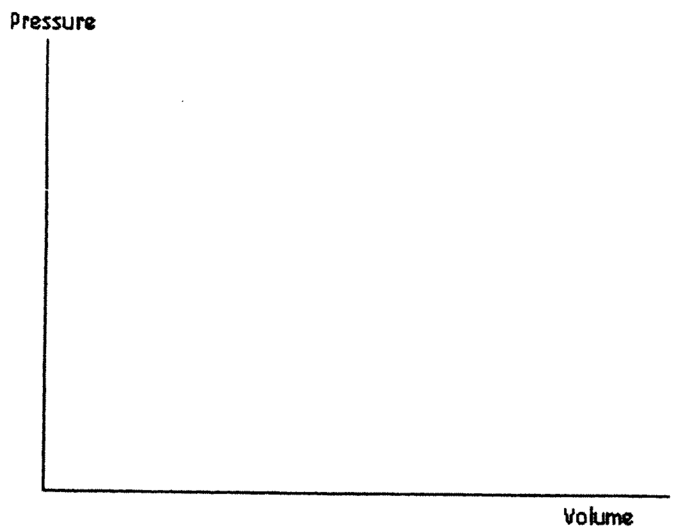
Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

Cycle Used: __________

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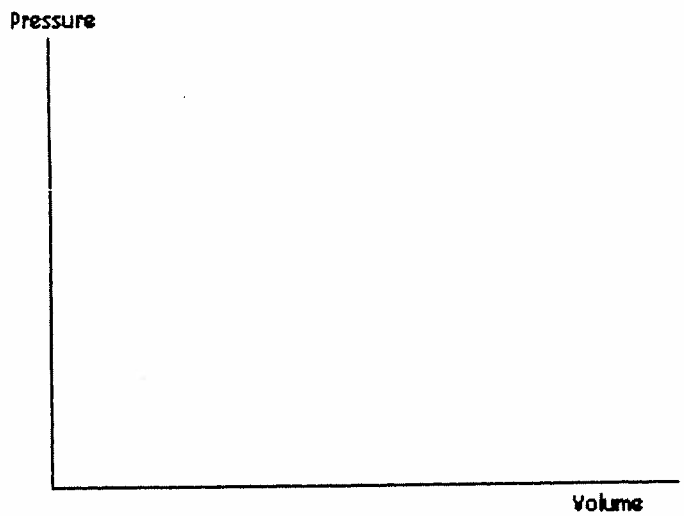
Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

Cycle Used: __________

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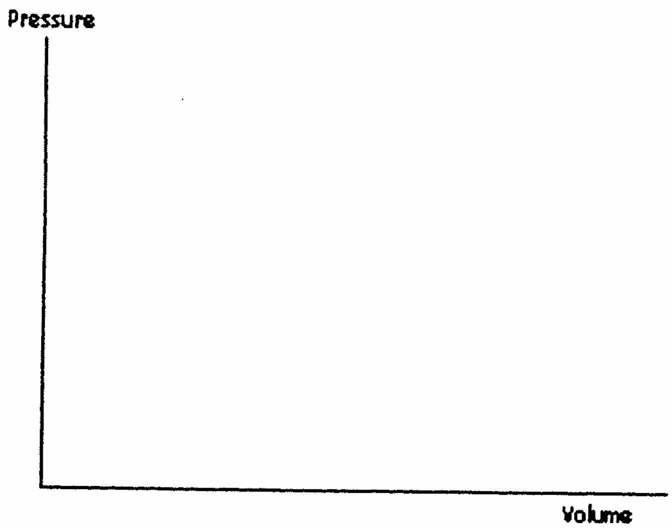
Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

Cycle Used: __________

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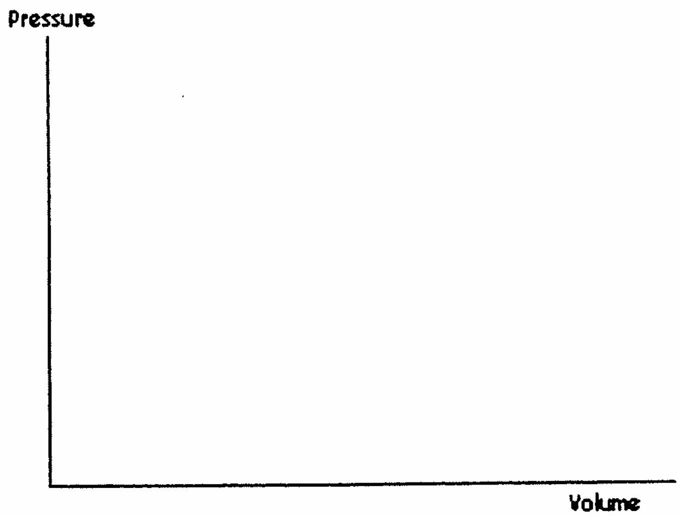
Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

Cycle Used: __________

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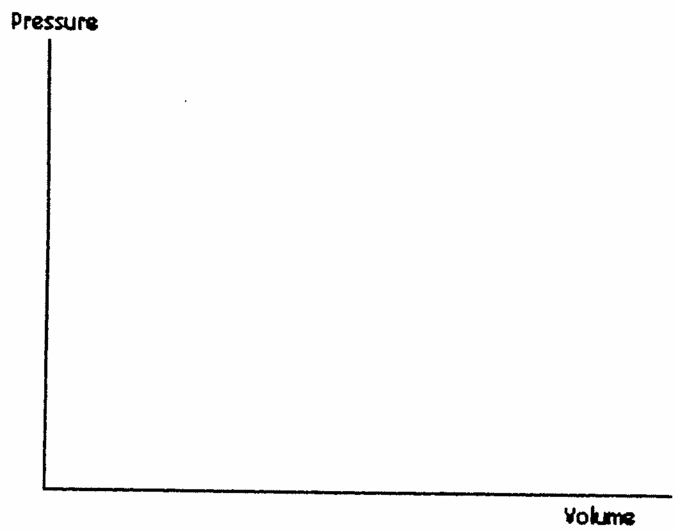
Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

Cycle Used: __________

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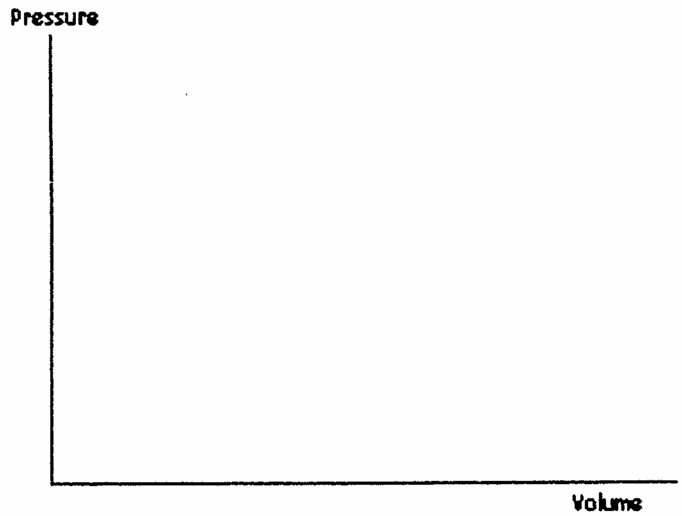
Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

Cycle Used: ___________

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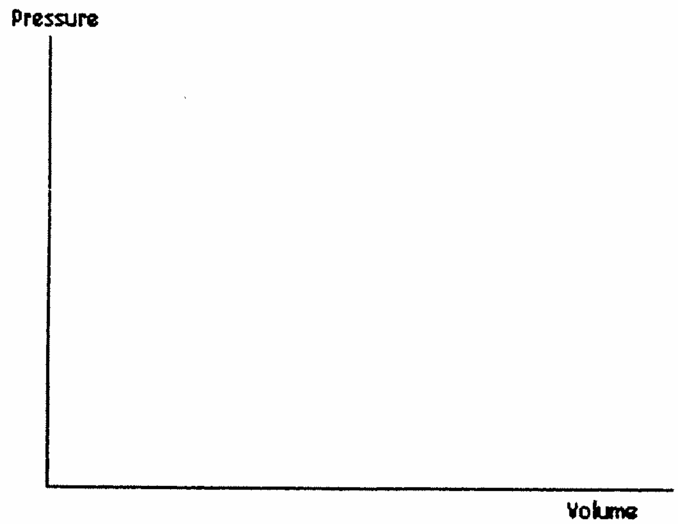
Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

Cycle Used: ___________

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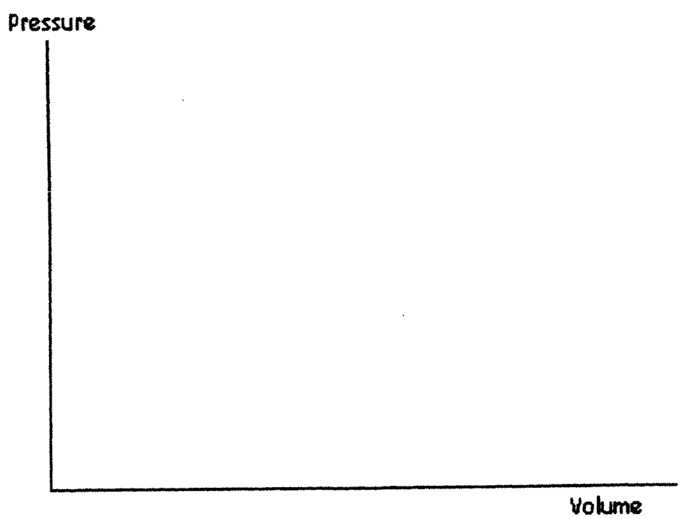
Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

Cycle Used: __________

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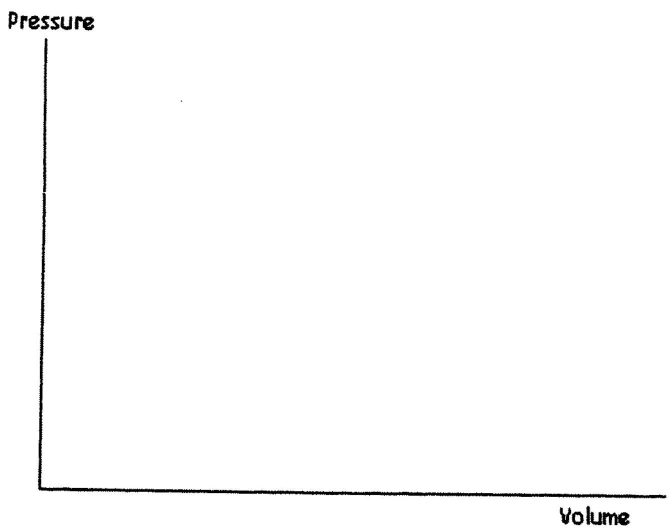
Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

Cycle Used: __________

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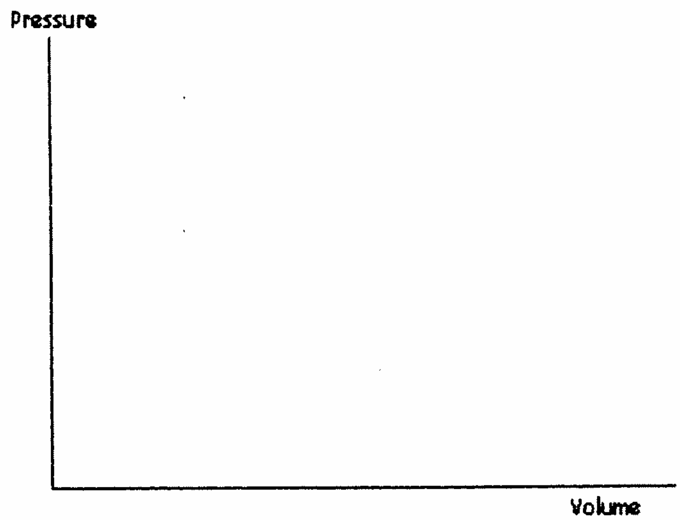
Analysis of Thermodynamic Cycles



Step	Description	P	V	T	Q	W	ΔU
Total							

Comments:

Engine Type: __________

Cycle Used: __________

Substance	Mass Density ρ (kg/m^3)
Solids	
Aluminum	2 700
Brass	8 470
Concrete	2 200
Copper	8 890
Diamond	3 520
Gold	19 300
Ice	917
Iron (steel)	7 860
Lead	11 300
Quartz	2 660
Silver	10 500
Wood (yellow pine)	550
Liquids	
Blood (whole, 37 °C)	1 060
Ethyl alcohol	806
Mercury	13 600
Oil (hydraulic)	800
Water (4 °C)	1.000×10^3
Gases	
Air	1.29
Carbon dioxide	1.98
Helium	0.179
Hydrogen	0.0899
Nitrogen	1.25
Oxygen	1.43

[a] Unless otherwise noted, densities are given at 0 °C and 1 atm pressure.

Table 12.1 Coefficients of Thermal Expansion for Solids and Liquids[a]

	Coefficient of Thermal Expansion, $(C°)^{-1}$	
Substance	Linear (α)	Volumetric (β)
Solids		
Aluminum	23×10^{-6}	69×10^{-6}
Brass	19×10^{-6}	57×10^{-6}
Concrete	12×10^{-6}	36×10^{-6}
Copper	17×10^{-6}	51×10^{-6}
Glass (common)	8.5×10^{-6}	26×10^{-6}
Glass (Pyrex)	3.3×10^{-6}	9.9×10^{-6}
Gold	14×10^{-6}	42×10^{-6}
Iron or steel	12×10^{-6}	36×10^{-6}
Lead	29×10^{-6}	87×10^{-6}
Nickel	13×10^{-6}	39×10^{-6}
Quartz (fused)	0.50×10^{-6}	1.5×10^{-6}
Silver	19×10^{-6}	57×10^{-6}
Liquids[b]		
Benzene	—	1240×10^{-6}
Carbon tetrachloride	—	1240×10^{-6}
Ethyl alcohol	—	1120×10^{-6}
Gasoline	—	950×10^{-6}
Mercury	—	182×10^{-6}
Methyl alcohol	—	1200×10^{-6}
Water	—	207×10^{-6}

[a] The values for α and β pertain to a temperature near 20 °C.
[b] Since liquids do not have fixed shapes, the coefficient of linear expansion is not defined for them.

Table 12.4 Latent Heats[a] of Fusion and Vaporization

Substance	Melting Point (°C)	Latent Heat of Fusion, L_f (J/kg)	Boiling Point (°C)	Latent Heat of Vaporization, L_v (J/kg)
Ammonia	−77.8	33.2×10^4	−33.4	13.7×10^5
Benzene	5.5	12.6×10^4	80.1	3.94×10^5
Copper	1083	20.7×10^4	2566	47.3×10^5
Ethyl alcohol	−114.4	10.8×10^4	78.3	8.55×10^5
Gold	1063	6.28×10^4	2808	17.2×10^5
Lead	327.3	2.32×10^4	1750	8.59×10^5
Mercury	−38.9	1.14×10^4	356.6	2.96×10^5
Nitrogen	−210.0	2.57×10^4	−195.8	2.00×10^5
Oxygen	−218.8	1.39×10^4	−183.0	2.13×10^5
Water	0.0	33.5×10^4	100.0	22.6×10^5

[a] The values pertain to 1 atm pressure.

Table 13.1 Thermal Conductivities[a] of Selected Materials

Substance	Thermal Conductivity, k [J/(s·m·C°)]
Metals	
Aluminum	240
Brass	110
Copper	390
Iron	79
Lead	35
Silver	420
Steel (stainless)	14
Gases	
Air	0.0256
Hydrogen (H_2)	0.180
Nitrogen (N_2)	0.0258
Oxygen (O_2)	0.0265
Other Materials	
Asbestos	0.090
Body fat	0.20
Concrete	1.1
Diamond	2450
Glass	0.80
Goose down	0.025
Ice (0 °C)	2.2
Styrofoam	0.010
Water	0.60
Wood (oak)	0.15
Wool	0.040

[a] Except as noted, the values pertain to temperatures near 20 °C.

Table 12.2 Specific Heat Capacities[a] of Some Solids and Liquids

Substance	Specific Heat Capacity, c J/(kg · C°)	kcal/(kg · C°)[b]
Solids		
Aluminum	9.00×10^2	0.215
Copper	387	0.0924
Glass	840	0.20
Human body (37 °C, average)	3500	0.83
Ice (−15 °C)	2.00×10^3	0.478
Iron or steel	452	0.108
Lead	128	0.0305
Silver	235	0.0562
Liquids		
Benzene	1740	0.415
Ethyl alcohol	2450	0.586
Glycerin	2410	0.576
Mercury	139	0.0333
Water (15 °C)	4186	1.000

[a] Except as noted, the values are for 25 °C and 1 atm of pressure.
[b] The values given are the same in units of cal/(g · C°).

Table 12.3 Specific Heat Capacities[a] of Gases

Gas	Specific Heat Capacity: Constant Pressure, c_P [J/(kg · C°)]	Constant Volume, c_V [J/(kg · C°)]
Ammonia	2190	1670
Carbon dioxide	833	638
Nitrogen	1040	739
Oxygen	912	651
Water vapor (100 °C)	2020	1520

[a] Except as noted, the values are for 15 °C and 1 atm of pressure.

TABLE 18–1 Molar heat capacities of gases at low pressure

Type of gas	Gas	C_p, J·mol^{-1}·K^{-1}	C_v, J·mol^{-1}·K^{-1}	$C_p - C_v$	$\gamma = \frac{C_p}{C_v}$
Monatomic	He	20.78	12.47	8.31	1.67
	A	20.78	12.47	8.31	1.67
Diatomic	H_2	28.74	20.42	8.32	1.41
	N_2	29.07	20.76	8.31	1.40
	O_2	29.41	21.10	8.31	1.40
	CO	29.16	20.85	8.31	1.40
Polyatomic	CO_2	36.94	28.46	8.48	1.30
	SO_2	40.37	31.39	8.98	1.29
	H_2S	34.60	25.95	8.65	1.33

TABLE 21.2 Molar Heats of Various Gases

	Molar Specific Heat (J/mol · K): C_p	C_v	$C_p - C_v$	$\gamma = C_p/C_v$
Monatomic Gases				
He	20.8	12.5	8.33	1.67
Ar	20.8	12.5	8.33	1.67
Ne	20.8	12.7	8.12	1.64
Kr	20.8	12.3	8.49	1.69
Diatomic Gases				
H_2	28.8	20.4	8.33	1.41
N_2	29.1	20.8	8.33	1.40
O_2	29.4	21.1	8.33	1.40
CO	29.3	21.0	8.33	1.40
Cl_2	34.7	25.7	8.96	1.35
Polyatomic Gases				
CO_2	37.0	28.5	8.50	1.30
SO_2	40.4	31.4	9.00	1.29
H_2O	35.4	27.0	8.37	1.30
CH_4	35.5	27.1	8.41	1.31

Note: All values obtained at 300 K.