1. 1974-6 (KT & TD)
One-tenth of a mole of an ideal monatomic gas undergoes a process described by the straight-line path AB shown in the p-V diagram below.

a. Show that the temperature of the gas is the same at points A and 1-3.

b. How much heat must be added to the gas during the process described by A → B?

c. What is the highest temperature of the gas during the process described by A → B?

2. 1975-3 (TD)
One mole of a monatomic ideal gas enclosed in a cylinder with a movable piston undergoes the process ABCDA shown on the pV diagram above.

a. In terms of \( p_0 \) and \( V_0 \) calculate the work done by the gas in the process.

b. In terms of \( p_0 \) and \( V_0 \) calculate the net heat absorbed by the gas in the process.

c. At what two lettered points in the process are the temperatures equal? Explain your reasoning.

3. 1976-5 (HT)

a. Explain why the temperature of the water at the base of a waterfall should be slightly higher than at the top of the fall.

b. Calculate the minimum height of the waterfall that could cause a rise in water temperature of 1 Celsius degree. Explain clearly any assumptions you make. (Hint: Consider a given mass \( m \) of the water.)

4. 1979-5 (TD)
Four samples of ideal gas are each initially at a pressure \( P_o \) and volume \( V_o \), and a temperature \( T_o \) as shown on the diagram above. The samples are taken in separate experiment from this initial state to the final states I, II, III, and IV along the processes shown on the diagram.

a. One of the processes is isothermal. Identify this one. Explain.

b. One of the processes is adiabatic. Identify this one. Explain.

c. In which process or processes does the gas do work? Explain.

d. In which process or processes is heat removed from the gas? Explain.

e. In which process or processes does the root-mean-square speed of the gas molecules increase? Explain.

5. 1981-6 (HT)
The Sun is \( 1.5 \times 10^{11} \) meters from Earth. Energy from the Sun is received at the Earth's surface at the rate of 1.4 kilowatts per square meter. This energy flux from the Sun falls on a pond of water 100 square meters in area and 0.100 meter in depth. Assume all of this energy heats the water. Find the average temperature rise of the pond after \( 10^3 \) seconds.

6. 1984-3 (HT)
A 100 watt heating coil is placed in a thermally insulated tank of negligible heat capacity. The tank contains 0.1 kilograms of water and 0.01 kilogram of ice, both initially at a temperature of 0° C. Calculate each of the following:

a. The heat transferred to the water and ice by the heating coil in time \( t \).

b. The time \( t_1 \) necessary to melt all the ice.

c. The additional time \( t_2 \) necessary to bring the water to a boil.
7. 1983-4 (KT & TD)
The $pV$ diagram above represents the states of an ideal gas during one cycle of operation of a reversible heat engine. The cycle consists of the following four processes.

<table>
<thead>
<tr>
<th>Process</th>
<th>Nature of Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>Constant temperature ($T_h = 500 \text{ K}$)</td>
</tr>
<tr>
<td>BC</td>
<td>Adiabatic</td>
</tr>
<tr>
<td>CD</td>
<td>Constant temperature ($T_c = 200 \text{ K}$)</td>
</tr>
<tr>
<td>DA</td>
<td>Adiabatic</td>
</tr>
</tbody>
</table>

During process A B, the volume of the gas increases from $V_o$ to $2V_o$ and the gas absorbs 1,000 joules of heat.

a. The pressure at A is $p_o$. Determine the pressure at B.
b. Using the first law of thermodynamics, determine the work performed by or on the gas during the process AB.
c. During the process AB, does the entropy of the gas increase, decrease, or remain unchanged? Justify your answer.
d. Calculate the heat $Q_c$ given off by the gas in the process CD.
e. During the full cycle ABCDA is the total work the gas performs on its surroundings positive, negative, or zero? Justify your answer.

8. 1985-4 (HT)
A 0.020-kilogram sample of a material is initially a solid at a temperature of 20° C. Heat is added to the sample at a constant rate of 100 joules per second until the temperature increases to 60° C. The graph above represents the temperature of the sample as a function of time.

a. Calculate the specific heat of the solid sample in units of J/kg°C.
b. Calculate the latent heat of fusion of the sample at its melting point in units of joules per kilogram.
c. Referring to the three intervals AB, BC, and CD shown on the graph, select the interval or interval on the graph during which:
   i. the average kinetic energy of the molecules of the sample is increasing
   ii. the entropy of the sample is increasing

9. 1987-3 (HT)
A freezer contains 20 kilograms of food with a specific heat of $2 \times 10^3 \text{ joules per kilogram} \cdot \text{°C}$. The temperature inside the freezer is initially -5° C. The freezer then operates for 10 minutes, reducing the temperature to -8 °C. The freezer motor operates at 400 watts.

a. How much heat is removed from the food during this time?
b. How much energy is delivered to the freezer motor during the 10-minute period?
c. During this time how much total heat is ejected into the room in which the freezer is located? Determine the temperature change in the room if the specific heat of air is 700 J/kg·°C. Assume there are 80 kilograms of air in the room, the volume of the air is constant, and there is no heat loss from the room.
10. 1986-5 (TD)
A proposed ocean power plant will utilize the temperature difference between surface seawater and seawater at a depth of 100 m. Assume the surface temperature is 25 °C and the temperature at the 100-meter depth is 3 °C.
a. What is the ideal (Carnot) efficiency of the plant?
b. If the plant generates useful energy at the rate of 100 megawatts while operating with the efficiency found in part (a), at what rate is heat given off to the surroundings?
c. A nuclear power plant operates with an overall efficiency of 40 percent. At what rate must mass be converted into energy to give the same 100-megawatt output as the ocean power plant above? Express your answer in kilograms per second.
d. In the chart to the right, for each part of the cycle indicate with +, -, or 0 whether the heat transferred Q and temperature change ΔT are positive, negative, or zero, respectively.

11. 1988-2 (HT)
A ball thrown vertically downward strikes a horizontal surface with a speed of 15 meters per second. It then bounces, and reaches a maximum height of 5 meters. Neglect air resistance on the ball.
a. What is the speed of the ball immediately after it rebounds from the surface?
b. What fraction of the ball’s initial kinetic energy is apparently lost during the bounce?
c. If the specific heat of the ball is 1,800 J/kg °C, and if all of the lost energy is absorbed by the molecules of the ball, by how much does the temperature of the ball increase?

12. 1989-4 (TD)
An ideal gas initially has pressure $p_o$, volume $V_o$, and absolute temperature $T_o$. It then undergoes the following series of processes:
I. It is heated, at constant volume, until it reaches a pressure $2p_o$.
II. It is heated, at constant pressure, until it reaches a volume $3V_o$.
III. It is cooled, at constant volume, until it reaches a pressure $p_o$.
IV. It is cooled, at constant pressure, until it reaches a volume $V_o$.
a. On the axes to the right
   i. draw the pV diagram representing the series of processes;
   ii. label each end point with the appropriate value of absolute temperature in terms of $T_o$.
b. For this series of processes, determine the following in terms of $p_o$ and $V_o$.
   i. The net work done by the gas
   ii. The net change in internal energy
   iii. The net heat absorbed
c. Given that $C_p = (5/2)R$ and $C_v = (3/2)R$, determine the heat transferred during process 2 in terms of $p_o$ and $V_o$. 

11. 1988-2 (HT)
A ball thrown vertically downward strikes a horizontal surface with a speed of 15 meters per second. It then bounces, and reaches a maximum height of 5 meters. Neglect air resistance on the ball.
a. What is the speed of the ball immediately after it rebounds from the surface?
b. What fraction of the ball’s initial kinetic energy is apparently lost during the bounce?
c. If the specific heat of the ball is 1,800 J/kg °C, and if all of the lost energy is absorbed by the molecules of the ball, by how much does the temperature of the ball increase?
13. 1990-4 (KT & TD)
One mole of an ideal monatomic gas, initially at point A at a pressure of $1.0 \times 10^5$ N/m$^2$ and a volume of $25 \times 10^{-3}$ m$^3$, is taken through a 3-process cycle, as shown in the $pV$ diagram above. Each process is done slowly and reversibly. For a monatomic gas, the heat capacities for constant volume and constant pressure are, respectively, $C_v = (3/2)R$ and $C_p = (5/2)R$, where $R$ is the universal gas constant, 8.32 J/mole K. 
Determine each of the following:
   a. the temperature of the gas at each of the vertices, A, B, and C, of the triangular cycle
   b. the net work done by the gas for one cycle
   c. the net heat absorbed by the gas for one full cycle
   d. the heat given off by the gas for the third process from C to A
   e. the efficiency of the cycle

14. 1992-3 (Modified) (HT)
A 90.0 watt heating coil is embedded in 0.20 kilogram of a solid substance in a calorimeter.
   a. Assuming that all of the heat generated by the heating coil is absorbed by the solid substance, and that it takes 4 minutes to raise the temperature of the substance from 20°C to 80°C, calculate the specific heat of the substance.
   b. At 80°C the substance begins to melt. The heat of fusion of the substance is $1.35 \times 10^5$ joules per kilogram. How long after the temperature reaches 80°C will it take to melt all of the substance? (300 s)
   c. Draw a graph of the heating curve for the substance on axes like those above, showing the temperature as a function of time until all of the solid has melted. Be sure to put numbers and units on the time scale.

15. 1995-5 (TD)
A heat engine operating between temperatures of 500 K and 300 K is used to lift a 10-kilogram mass vertically at a constant speed of 4 meters per second.
   a. Determine the power that the engine must supply to lift the mass.
   b. Determine the maximum possible efficiency at which the engine can operate.
   c. If the engine were to operate at the maximum possible efficiency, determine the following.
      i. The rate at which the hot reservoir supplies heat to the engine
      ii. The rate at which heat is exhausted to the cold reservoir

16. 2000-6 (HT)
You are to design a procedure to determine experimentally the specific heat of an unknown liquid. You may not damage or destroy any equipment you use, and your method must be feasible and practical.
   a. List the equipment you would need. Include a labeled diagram.
   b. Describe the measurements you would make. Assign each measurement a symbol (such as time = $t$).
   c. Show explicitly using equations how the measured quantities would be used to determine the specific heat of the unknown liquid.
   d. Indicate one possible source of experimental error and discuss how it would affect your value for the specific heat. Justify your answer.
17. **1998-3 (HT)**

Students are designing an experiment to demonstrate the conversion of mechanical energy into thermal energy. They have designed the apparatus shown in the figure above. Small lead beads of total mass $M$ and specific heat $c$ fill the lower hollow sphere. The valves between the spheres and the hollow tube can be opened or closed to control the flow of the lead beads. Initially both valves are open.

a. The lower valve is closed and a student turns the apparatus 180° about a horizontal axis, so that the filled sphere is now on top. This elevates the center of mass of the lead beads by a vertical distance $h$. What minimum amount of work must the student do to accomplish this?

b. The valve is now opened and the lead beads tumble down the hollow tube into the other hollow sphere. If all of the gravitational potential energy is converted into thermal energy in the lead beads, what is the temperature increase of the lead?

c. The values of $M$, $h$, and $c$ for the students’ apparatus are $M = 3.0$ kg, $h = 2.00$ m, and $c = 128$ J/(kg · K). The students measure the initial temperature of the lead beads and then conduct 100 repetitions of the "elevate-and-drain" process. Again, assume that all of the gravitational potential energy is converted into thermal energy in the lead beads. Calculate the theoretical cumulative temperature increase after the 100 repetitions.

d. Suppose that the experiment were conducted using smaller reservoirs, so that $M$ was one-tenth as large (but $h$ was unchanged). Would your answers to parts (b) and (c) be changed? If so, in what way, and why? If not, why not?

e. When the experiment is actually done, the temperature increase is less than calculated in part (c). Identify a physical effect that might account for this discrepancy and explain why it lowers the temperature.

18. **2001-6 (KT & TD)**

A cylinder is fitted with a freely moveable piston of area $1.20 \times 10^{-2}$ m$^2$ and negligible mass. The cylinder below the piston is filled with a gas. At state 1, the gas has volume $1.50 \times 10^{-3}$ m$^3$, pressure $1.02 \times 10^5$ Pa, and the cylinder is in contact with a water bath at a temperature of 0°C. The gas is then taken through the following four-step process.

- A 2.50 kg metal block is placed on top of the piston, compressing the gas to state 2, with the gas still at 0°C.
- The cylinder is then brought in contact with a boiling water bath, raising the gas temperature to 100°C at state 3.
- The metal block is removed and the gas expands to state 4 still at 100°C.
- Finally, the cylinder is again placed in contact with the water bath at 0°C, returning the system to state 1.

a. Determine the pressure of the gas in state 2.

b. Determine the volume of the gas in state 2.

c. Indicate below whether the process from state 2 to state 3 is isothermal, isobaric, or adiabatic. 

- _____ Isothermal 
- _____ Isobaric 
- _____ Adiabatic

Explain your reasoning.

d. Is the process from state 4 to state 1 isobaric? _____ Yes _____ No

Explain your reasoning.

e. Determine the volume of the gas in state 4.
19. 2003-5 (TD)
A cylinder with a movable piston contains 0.1 mole of a monatomic ideal gas. The gas, initially at state $a$, can be taken through either of two cycles, $abca$ or $abcd$, as shown on the PV diagram above. The following information is known about this system.

- $Q_{c\rightarrow a} = 685$ J along the curved path
- $W_{c\rightarrow a} = -120$ J along the curved path
- $U_a - U_b = 450$ J
- $W_{a\rightarrow b\rightarrow c} = 75$ J

a. Determine the change in internal energy, $U_a - U_c$, between states $a$ and $c$.
b. i. Is heat added to or removed from the gas when the gas is taken along the path $abc$?
   - _____ added to the gas   _____ removed from the gas
   ii. Calculate the amount added or removed.
c. How much work is done on the gas in the process $cda$?
d. Is heat added to or removed from the gas when the gas is taken along the path $cda$?
   - _____ added to the gas   _____ removed from the gas
   Explain your reasoning.

20. 2003b-5 (KT & TD)
One mole of an ideal gas is taken around the cycle $A\rightarrow B\rightarrow C\rightarrow A$ as shown on the PV diagram above.
a. Calculate the temperature of the gas at point $A$.
b. Calculate the net work done on the gas during one complete cycle.
c. i. Is heat added to or removed from the gas during one complete cycle?
   - _____ added to the gas   _____ removed from the gas
   ii. Calculate the heat added to or removed from the gas during one complete cycle.
d. After one complete cycle, is the internal energy of the gas greater, less, or the same as before?
   - _____ greater   _____ less   _____ the same
   Justify your answer.
e. After one complete cycle, is the entropy of the gas greater, less, or the same as before?
   - _____ greater   _____ less   _____ the same
   Justify your answer.

21. 2004b-5 (KT & TD)
One mole of an ideal gas is initially at pressure $P_1$, volume $V_1$, and temperature $T_1$, represented by point $A$ on the PV diagram above. The gas is taken around cycle $ABCA$ shown. Process $AB$ is isobaric, process $BC$ is isochoric, and process $CA$ is isothermal.
a. Calculate the temperature $T_2$ at the end of process $AB$ in terms of temperature $T_1$.
b. Calculate the pressure $P_2$ at the end of process $BC$ in terms of pressure $P_1$.
c. Calculate the net work done on the gas when it is taken from $A$ to $B$ to $C$. Express your answer in terms of $P_1$ and $V_1$.
d. Indicate below all of the processes that result in heat being added to the gas.
   - _____ AB   _____ BC   _____ CA
   Justify your answer.
22. 2004-5 (TD)

The diagram to the right of pressure P versus volume V shows the expansion of 2.0 moles of a monatomic ideal gas from state A to state B. As shown in the diagram, \( P_A = P_B = 600 \text{ N/m}^2 \), \( V_A = 3.0 \text{ m}^3 \), and \( V_B = 9.0 \text{ m}^3 \).

a. i. Calculate the work done by the gas as it expands.
   ii. Calculate the change in internal energy of the gas as it expands.
   iii. Calculate the heat added to or removed from the gas during this expansion.

b. The pressure is then reduced to 200 N/m2 without changing the volume as the gas is taken from state B to state C. Label state C on the diagram and draw a line or curve to represent the process from state B to state C.

c. The gas is then compressed isothermally back to state A.
   i. Draw a line or curve on the diagram to represent this process.
   ii. Is heat added to or removed from the gas during this isothermal compression?

   _______added to _______removed from

   Justify your answer.

23. 2005-6 (KT)

An experiment is performed to determine the number \( n \) of moles of an ideal gas in the cylinder shown above. The cylinder is fitted with a movable, frictionless piston of area \( A \). The piston is in equilibrium and is supported by the pressure of the gas. The gas is heated while its pressure \( P \) remains constant. Measurements are made of the temperature \( T \) of the gas and the height \( H \) of the bottom of the piston above the base of the cylinder and are recorded in the table to the right. Assume that the thermal expansion of the apparatus can be ignored.

a. Write a relationship between the quantities \( T \) and \( H \), in terms of the given quantities and fundamental constants, that will allow you to determine \( n \).

b. Plot the data on the axes to the right so that you will be able to determine \( n \) from the relationship in part (a). Label the axes with appropriate numbers to show the scale.

c. Using your graph and the values \( A = 0.027 \text{ m}^2 \) and \( P = 1.0 \text{ atmosphere} \), determine the experimental value of \( n \).

24. 2006-5 (KT and TD)

A cylinder with a movable frictionless piston contains an ideal gas that is initially in state 1 at \( 1 \times 10^5 \text{ Pa} \), 373 K, and 0.25 m³. The gas is taken through a reversible thermodynamic cycle as shown in the PV diagram to the right.

a. Calculate the temperature of the gas when it is in the following states.
   i. State 2
   ii. State 3

b. Calculate the net work done on the gas during the cycle.

c. Was heat added to or removed from the gas during the cycle?

   _______Added   _______Removed   _______Neither added nor removed

   Justify your answer.
25. 2005b (KT)
You are given a cylinder of cross-sectional area \( A \) containing \( n \) moles of an ideal gas. A piston fitting closely in the cylinder is lightweight and frictionless, and objects of different mass \( m \) can be placed on top of it, as shown in the figure above. In order to determine \( n \), you perform an experiment that consists of adding 1 kg masses one at a time on top of the piston, compressing the gas, and allowing the gas to return to room temperature \( T \) before measuring the new volume \( V \). The data collected are given in the table below.

a. Write a relationship between total pressure \( P \) and volume \( V \) in terms of the given quantities and fundamental constants that will allow you to determine \( n \). You also determine that \( A = 3.0 \times 10^{-4} \) m\(^2\) and \( T = 300 \) K.

<table>
<thead>
<tr>
<th>m (kg)</th>
<th>( V ) (m(^3))</th>
<th>( 1/V ) (m(^{-3}))</th>
<th>( P ) (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.0 \times 10^{-5}</td>
<td>1.7 \times 10^4</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.5 \times 10^{-5}</td>
<td>2.2 \times 10^4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.6 \times 10^{-5}</td>
<td>2.8 \times 10^4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.0 \times 10^{-5}</td>
<td>3.3 \times 10^4</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.6 \times 10^{-5}</td>
<td>3.8 \times 10^4</td>
<td></td>
</tr>
</tbody>
</table>

b. Calculate the value of \( P \) for each value of \( m \) and record your values in the data table above.

c. Plot the data on the graph to the right, labeling the axes with appropriate numbers to indicate the scale.

d. Using your graph in part c., calculate the experimental value of \( n \).

26. 2006b-5 (KT and TD)
A sample of ideal gas is taken through steps I, II, and III in a closed cycle, as shown on the pressure \( P \) versus volume \( V \) diagram to the right, so that the gas returns to its original state. The steps in the cycle are as follows.

I. An isothermal expansion occurs from point \( A \) to point \( B \), and the volume of the gas doubles.

II. An isobaric compression occurs from point \( B \) to point \( C \), and the gas returns to its original volume.

III. A constant volume addition of heat occurs from point \( C \) to point \( A \) and the gas returns to its original pressure.

a. Determine numerical values for the following ratios, justifying your answers in the spaces next to each ratio.

i. \( \frac{P_B}{P_A} = \) 

ii. \( \frac{P_C}{P_A} = \) 

iii. \( \frac{T_B}{T_A} = \) 

iv. \( \frac{T_C}{T_A} = \) 

b. During step I, the change in internal energy is zero. Explain why.

c. During step III, the work done on the gas is zero. Explain why.
27. 2007-5 (KT and TD)
The figure above shows a 0.20 m diameter cylinder fitted with a frictionless piston, initially fixed in place. The cylinder contains 2.0 moles of nitrogen gas at an absolute pressure of $4.0 \times 10^5$ Pa. Nitrogen gas has a molar mass of 28 g mole and it behaves as an ideal gas.

a. Calculate the force that the nitrogen gas exerts on the piston.
b. Calculate the volume of the gas if the temperature of the gas is 300 K.
c. In a certain process, the piston is allowed to move, and the gas expands at constant pressure and pushes the piston out 0.15 m. Calculate how much work is done by the gas.
d. Which of the following is true of the heat energy transferred to or from the gas, if any, in the process in part c?
   - Heat is transferred to the gas.
   - Heat is transferred from the gas.
   - No heat is transferred in the process.
   Justify your answer.

28. 2007b-5 (KT and TD)
The cylinder above contains an ideal gas and has a movable, frictionless piston of diameter $D$ and mass $M$. The cylinder is in a laboratory with atmospheric pressure $P_{\text{atm}}$. Express all algebraic answers in terms of the given quantities and fundamental constants.

a. Initially, the piston is free to move but remains in equilibrium. Determine each of the following:
   i. The force that the confined gas exerts on the piston
   ii. The absolute pressure of the confined gas
b. If a net amount of heat is transferred to the confined gas when the piston is fixed, what happens to the pressure of the gas?
   - Pressure goes up.
   - Pressure goes down.
   - Pressure stays the same
   Explain your reasoning

c. In a certain process the absolute pressure of the confined gas remains constant as the piston moves up a distance $x_0$. Calculate the work done by the confined gas during the process.

29. 2008-5 (KT & TD)
A 0.03 mol sample of helium is taken through the cycle shown in the diagram the right. The temperature of state A is 400 K.

a. For each process in this cycle, indicate in the table below whether the quantities $W$, $Q$, and $\Delta U$ are positive (+), negative (-), or zero (0). $W$ is the work done on the helium sample.
b. Explain your response for the signs of the quantities for process $A \rightarrow B$.
c. Calculate $V_C$.

29. 2008b-6 (KT & TD)
A 0.0040 mole sample of monatomic gas is taken through the cycle shown to the right. The temperature $T_1$ of state 1 is 300 K.

a. Calculate $T_2$ and $T_3$.
b. Calculate the amount of work done on the gas in one cycle.
c. Is the net work done on the gas in one complete cycle positive, negative, or zero?
d. Calculate the heat added to the gas during process $1 \rightarrow 2$. 
Answers to AP Physics Problems-Kinetic Theory, Heat, and Thermodynamics

1. b. 2 liter-atm  
   c. 243 K
2. a. $4p_0V_0$  
   b. $4p_0V_0$  
   c. B and D  
   d. BC
3. b. 427 m
4. a. Process II  
   b. Process III  
   c. Processes I, II, and III  
   d. Process IV  
   e. Process I
5. 3.34 K
6. a. (100 W)t  
   b. 33.4 s  
   c. 461 s
7. a. $p_0/2$  
   b. 100 J  
   c. increases  
   d. 400 J  
   e. positive
8. a. 1000 J/kg°C  
   b. $5 \times 10^4$ J/kg  
   c. i. AB, CD  
   c. ii. AB, BC, CD
9. a. $1.2 \times 10^5$ J  
   b. $2.4 \times 10^5$ J  
   c. $3.6 \times 10^5$ J  
   d. 6.4 °C
10. a. 0.074  
    b. 1250 MW  
    c. $2.77 \times 10^9$ kg/s  
   d. 
<table>
<thead>
<tr>
<th></th>
<th>Q</th>
<th>ΔT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>BC</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>CD</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>DA</td>
<td>0</td>
<td>+</td>
</tr>
</tbody>
</table>
11. a. 1800 J/kg°C  
   b. 300 s
12. a.Process II  
   b. Process III  
   c. Processes I, II, and III  
   d. Process I  
   e. Process I
13. a. $3.34$ K
14. a. $1000$ W  
   b. $5 \times 10^4$ J/kg  
   c. increases  
   d. 400 J  
   e. positive
15. a. $400$ W  
   b. $40\%$  
   c. i. 1000 W  
   c. ii. 600 W
16. Explanations
17. a. $mgh$  
   b. $gh/c$  
   c. 15.3 K  
   d. no
18. a. $1.04 \times 10^5$ Pa  
   b. $1.47 \times 10^3$ m$^3$  
   c. isobaric  
   d. yes  
   e. $2.05 \times 10^3$ m$^3$
19. a. 565 J  
   b. -640 J  
   c. -150 J  
   d. added to the gas
20. a. 481 K  
   b. 4000 J  
   c. i. removed  
   ii. -4000 J  
   d. same  
   e. same
21. a. $T_1/2$  
   b. $2P_1$  
   c. $P_1V_1/2$  
   d. BC, CA
22. a. i. 3600 J  
   b. 5400 J  
   c. ii. removed  
   d. 9000 J  
   c. ii. removed
23. a. $H = \frac{nRT}{PA}$  
   c. 1.11 moles
24. a. i. 746 K  
   ii. 546 K  
   b. +6250 J  
   c. Removed
25. a. $PV = nRT$  
   b. $1.0 \times 10^5, 1.3 \times 10^5, 1.7 \times 10^5, 2.0 \times 10^5, 2.3 \times 10^5$  
   d. 0.0025 mol
26. a. i. $\frac{1}{2}$  
   ii. $\frac{1}{2}$  
   iii. $1$  
   iv. $\frac{1}{2}$
27. a. $1.3 \times 10^4$ N  
   b. $1.2 \times 10^2$ m$^3$  
   c. $1.9 \times 10^3$ J  
   d. Heat is transferred to the gas
28. a. i. $F = \frac{P_{amb} \pi D^2}{4} + Mg$  
   ii. $P_{amb} = P_{amb} + \frac{4Mg}{\pi D^2}$  
   b. Pressure goes up  
   c. $W = \left(\frac{P_{amb} \pi D^2}{4} + Mg\right)x_0$
29. a.  
<table>
<thead>
<tr>
<th>Process</th>
<th>W</th>
<th>Q</th>
<th>ΔU</th>
</tr>
</thead>
<tbody>
<tr>
<td>A→B</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>B→C</td>
<td>-</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>C→A</td>
<td>+</td>
<td>-</td>
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<td>-</td>
</tr>
</tbody>
</table>
30. a. $T_2 = 1500$ K, $T_3 = 1800$ K  
   b. 100 J  
   c. negative  
   d. 60 J