Chapter 15

First Law of Thermodynamics

15.1 Internal energy and work in gas processes

15.1.1 Derive

PIVOTAL ***Class:*** *Equipment per group:* whiteboard and markers.

You have a container filled with a gas at known conditions (its molar mass, the number of moles, and the temperature).

a. In Chapter 12, you learned how the average kinetic energy of a particle of ideal gas is related to the temperature of the gas. Work with your group members and use this knowledge to derive an expression for the internal energy of the gas, assuming the gas is ideal.

b. Discuss how the internal energy of the same amount of gas will change if you place it in a container with a larger volume while keeping the gas temperature the same. Explain.

c. Imagine that you separate the gas into two equal containers half the size of the original container. Compare the internal energy of the gas in each container with the energy before the gas was split. Compare the temperatures of the gas. What is the difference between the internal energy of the ideal gas and its temperature?

d. Now imagine that the gas for which you know the internal energy is in a container that has two chambers separated by a removable divider. The left chamber has volume V and the gas is in that chamber. The chamber on the right has the same volume, but is completely empty – there is no gas there. Now you remove the divider and the gas that previously occupied volume V is now occupying volume $2V$. What happens to the energy of the gas?

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15.1.2 Observe and explain

***PIVOTAL* Class or lab:** *Equipment:* as in the video, if available.

In the video you see a syringe and a piston that snugly fits into it. At the end of the piston is a small hook to which a small piece of cotton ball is tied. The experimenter is holding the syringe vertically and suddenly presses down hard on the piston. The high-speed video (recorded at 1200 frames per second) shows what happens: [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-1-2]. Work with your group members to discuss and answer the questions below:

a. What happens to the temperature of the air in the syringe during the experiment? How do you know?

b. What happens to the pressure of the air in the syringe during the experiment? How do you know?

c. Draw an energy bar chart for the experiment. Choose the air in the syringe as a system. The initial state is before the piston is pushed in, the final is just before the cotton ball starts to burn.

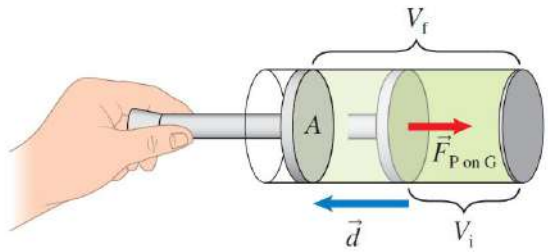
d. Describe how the outcome of the experiment will change if the experimenter moves the piston by the same distance as in the original experiment, but very slowly. Draw an energy bar chart for this experiment.

15.1.3 Derive

***PIVOTAL* Class:** *Equipment per group:* whiteboard and markers.

In the previous activity you learned that if you do work on a gas, you can increase its internal energy tremendously. But how do we calculate this work quantitatively?

Imagine that you have a gas (the system) at high pressure in a cylinder with a movable piston as in the figure below.



You hold the piston and allow it to move slowly outward to the left (if you were not holding it, the gas would push it out instantly). The gas pushes to the left on the piston and the piston in turn pushes toward the right on the gas, exerting a force on the gas $\vec{F}_{\text{P on G}}$. The gas expands slowly. What is the work done by the force that the piston exerts on the gas? Assume that the piston moves outward a distance d, allowing the gas to expand from its initial volume V_i to its final larger volume V_f, with the final volume being just slightly larger than the initial.

To derive the expression for the work, discuss with your group members and answer the following questions:

a. Recall the definition of work and when this equation is applicable.

b. Does the force the piston exert on the gas do work on the gas? Is the work positive or negative?

c. How can you express this work mathematically?

d. Revise the expression you wrote in part **c**. to use pressure and volumes instead of force and distance.

e. Represent this work on a graph of pressure against volume.

15.1.4 Reading exercise

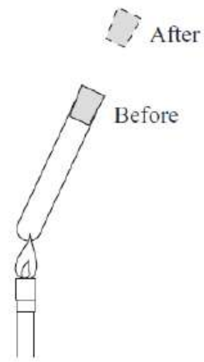
Read Section 15.1 in the textbook and compare the expression you derived for pressure with the expression in the book. Then answer Review Question 15.1.

15.2 Two ways to change the energy of a system

15.2.1 Observe and explain

PIVOTAL Class:

Observe your instructor perform the following experiment. They close a test tube with a rubber stopper. Then they place the bottom of the tube in an open flame. After about 20 seconds, the stopper shoots out. Discuss and answer the following questions with your group members:



a. Construct a microscopic explanation for how the hot gas pushes out the stopper. Remember what you know about molecules of gas, their motion, and the pressure that they exert.

b. Choose the gas inside the test tube, the stopper, and Earth (not the flame) as the system, and use the concepts of work and energy to explain the experiment. If you need a new quantity or new quantities for your explanation, define them qualitatively.

15.2.2 Observe and explain

PIVOTAL Class:

Watch the video of a cup of cold water in an aluminum container being placed in a container with warm water [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-2-2]. The video is taken with a thermal camera and allows you to see the change of the temperature of water.

a. Describe what you observe (choose the initial state to be when the cup is outside the container and the final state when cup is inside and the temperature reaches some intermediate value).

b. Consider the water in the cup as the system and explain this observed process using your knowledge of molecules and their motion. Then use the generalized work–energy principle developed in Chapter 7 to explain what happened to the cold water. If you cannot explain this process with this principle, try to modify the principle (for example, introduce a new physical quantity) to account for your observations.

c. Repeat part **b.**, only this time consider the water in the container as the system.

d. Use your knowledge of molecules and their motion to explain why when two liquids of different temperatures mix together, the mixture will eventually reach some intermediate temperature (called the *equilibrium temperature*).

15.2.3 Observe and explain

PIVOTAL Class or lab: *Equipment per student:* two pieces of paper.

Vigorously rub two pieces of paper together, pressing the fingers of each hand firmly on the paper as you rub it. Consider one piece of paper as the system. Why did the thermal energy of that piece of paper increase?

15.2.4 Reading exercise

Read Section 15.2 in the textbook and answer Review Question 15.2.

15.3 First law of thermodynamics

15.3.1 Observe and explain

PIVOTAL Class or lab:

Watch the video of a cup of glycerin being stirred by a mixer used to whip cream [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-3-1]. The video is taken with a thermal camera and allows you to follow the temperature of the glycerin at the spot marked by cross hairs.

a. Describe what you observe.

b. Draw a bar chart to represent the process. Indicate any assumptions that you made.

15.3.2 Explain

PIVOTAL Class: *Equipment per group:* whiteboard and markers.

Try to use the generalized work–energy principle (without heating), written in the form $\left(U_{\text{gi}}+K_{\text{i}}\right)+W=\left(U_{\text{gf}}+K_{\text{f}}+\Delta U_{\text{int}}\right)$, to explain the following phenomena. If the principle accounts for the phenomenon, describe in symbols or words the work or energy changes. If it does not account for the phenomenon, describe the difficulty and see whether including heating $\left(U_{\text{gi}}+K_{\text{i}}\right)+W+Q=\left(U_{\text{gf}}+K_{\text{f}}+\Delta U_{\text{int}}\right)$ in the principle helps to account for your observations, where Q stands for heating. Be sure to indicate the system used in your analysis of each experiment and any assumptions that you made about the process or the system.

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Process described	**Write a W/E word explanation (if possible).**	**Or write a $W/Q/E$ word explanation (if the left cell is not possible).**
Drop a golf ball from a window. The process begins the instant the ball leaves your hand and ends just before it hits the grass below. The system is the golf ball and Earth.		
Drop a golf ball from a window. The process begins at the instant the ball leaves your hand and ends just after the ball stops in the grass below. The system is the golf ball, Earth, and the grass.		
Place a warm golf ball on top of a cube of ice. The process begins at the instant you place the ball on the ice cube and ends when the ice has melted and the ball has cooled. Choose the ice cube as the system.		
While walking on a golf course in the winter, you find a golf ball and slowly lift it from the frozen grass and place it in your pocket. The process starts with the ball at rest in the cold grass and ends 10 minutes later after it has warmed in your pocket. Choose the ball and Earth as the system (you are not in the system).		

15.3.3 Explain

PIVOTAL Class: *Equipment per group:* whiteboard and markers.

Use the generalized work–energy principle with heating, called the first law of thermodynamics $W + Q = \Delta E$, to explain in words the processes described below. Decide whether the gravitational and kinetic energies of the system change.

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Process	**Write an explanation in words using the terms of energy, heating, and work.**	**Indicate the signs of the $W/Q/U_{\text{int}}$ terms in the equation.**	**Represent the process with a bar chart.**
Gas originally at 20.0 °C resides in a cylinder with a movable piston. Push on the piston, thus compressing and warming the gas. The cylinder is insulated so that there is no thermal energy transfer into or out of the gas. Choose the gas in the cylinder as the system.		W: Q: ΔU_{int} :	
Gas originally at 0.0 °C resides in a cylinder with a movable piston, the cylinder is inside a bath filled with ice water. Push slowly on the piston, thus compressing the gas, but this time the gas does not warm up. The cylinder has thin metal walls and slightly warms the water surrounding it. Choose the gas in the cylinder as the system.		W: Q: ΔU_{int} :	
A burning match warms a paper cup that holds ice water. After 2 minutes of warming, the water is still at 0°C but now has less ice and more liquid water. Choose the ice water as the system.		W: Q: ΔU_{int} :	

15.3.4 Explain

Class:

a. Compare and contrast the physical quantities of temperature, internal thermal energy, and heating. What is similar about them? What is different?

b. Why do we use the term “heating” instead the term “heat”? If you have difficulty answering this question, refer to Section 15.3 in the textbook for help.

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15.3.4 Evaluate

Class:

Eugenia and Gorazd were traveling in New Zealand and bought some raspberry jam. Evaluate the text in red on the jam lid (see the photo at right below).

15.3.5 Reading exercise

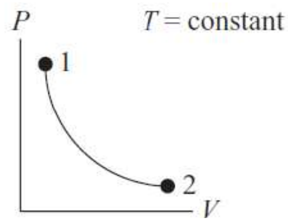
Read Section 15.3 in the textbook and answer Review Question 15.3.

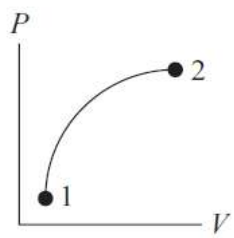
15.4 Applying the first law of thermodynamics to gas processes

15.4.1 Represent and reason

PIVOTAL ***Class:*** *Equipment per group:* whiteboard and markers.

A graphical description of three processes for a gas in a container is provided in the table below (+ means a positive value and – a negative value). The gravitational and kinetic energies of the system do not change. Complete the table that follows. Note that the process in part **c**. is cyclic—the system returns to its starting state. For part **c**. you are to decide the changes in the three quantities for each part of the cycle (1 to 2 and 2 to 1) and for the complete cycle.

a.		
Describe the process in words.	Graphical description 	Was ΔU_{int} $+, -, 0$?
Was W $+, -, 0$? (Also indicate this on the graph in the graphical description.)	Was Q $+, -, 0$?	Explain each process by using your knowledge of the motion of molecules in an ideal gas.

b.		
Describe the process in words.	Graphical description 	Was ΔU_{int} $+, -, 0$?
Was W $+, -, 0$? (Also indicate this on the graph in the graphical description.)	Was Q $+, -, 0$?	Explain each process by using your knowledge of the motion of molecules in an ideal gas.

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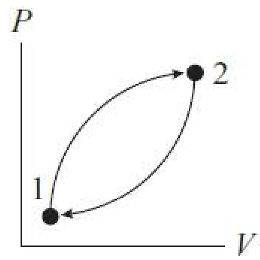
c.		
Describe the process in words.	Graphical description 	Was ΔU_{int} +,−,0? For $1 \rightarrow 2$: For $2 \rightarrow 1$: For $1 \rightarrow 2 \rightarrow 1$:
Was W +,−,0? (Also indicate this on the graph in the graphical description.) For $1 \rightarrow 2$: For $2 \rightarrow 1$: For $1 \rightarrow 2 \rightarrow 1$:	Was Q +,−,0? For $1 \rightarrow 2$: For $2 \rightarrow 1$: For $1 \rightarrow 2 \rightarrow 1$:	Explain each process by using your knowledge of the motion of molecules in an ideal gas. For $1 \rightarrow 2$: For $2 \rightarrow 1$: For $1 \rightarrow 2 \rightarrow 1$:

15.4.2 Represent and reason

Class: *Equipment per group:* whiteboard and markers.

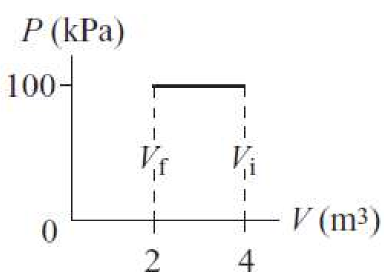
Work with your group member to answer the following questions about two gas processes represented with *P*-versus-*V* graphs:

a. Determine the work done on the system during the process.

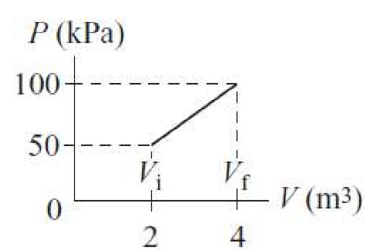
b. Describe in words a possible process.

c. Explain the process using your knowledge of gas particles.

1.



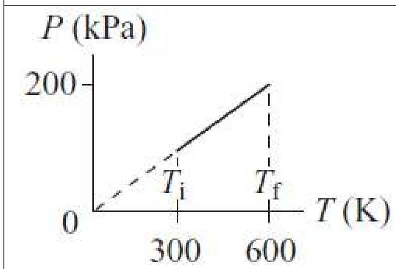
2.



15.4.3 Represent and reason

***PIVOTAL* Class:** *Equipment per group:* whiteboard and markers.

The first row of the table below graphically represents an isochoric (constant volume) process, an isothermal (constant temperature) process, and an isobaric (constant pressure) process. Each process involves 1.0 mol of an ideal gas. Complete the table for each process.

<table>
<tr><th>Isochoric process</th><th>Isothermal process</th><th>Isobaric process</th></tr>
<tr>
<td>
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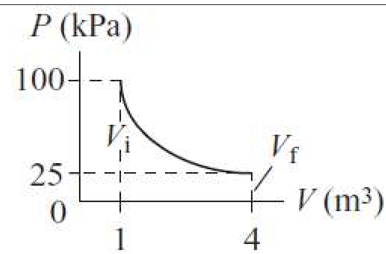
<td>
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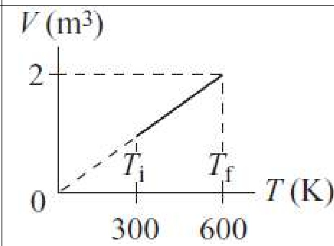
<td>
</td>
</tr>
<tr><td>Use the ideal gas law to calculate the volume of the gas. Then determine the work done by the environment on the gas during the process.</td><td>Use the ideal gas law to calculate the temperature of the 1.0 mol of gas. Then use the temperature to determine the change of the internal energy of the gas.</td><td>Use the ideal gas law to determine the gas pressure. Then determine the work done by the environment on the gas during the process.</td></tr>
<tr><td>Use the initial and final temperatures to determine the change in internal energy of the 1.0 mol of gas during the process.</td><td>Use the ideal gas to write the pressure of the gas in terms of its volume (and other constant quantities).</td><td>Use the initial and final temperatures to determine the change in internal energy of the 1.0 mol of gas during the process.</td></tr>
<tr><td>Use these results to construct a qualitative work–heating–internal energy change bar chart for the process.</td><td>Use these results to construct a qualitative work–heating–internal energy change bar chart for the process.</td><td>Use these results to construct a qualitative work–heating–internal energy change bar chart for the process.</td></tr>
</table>

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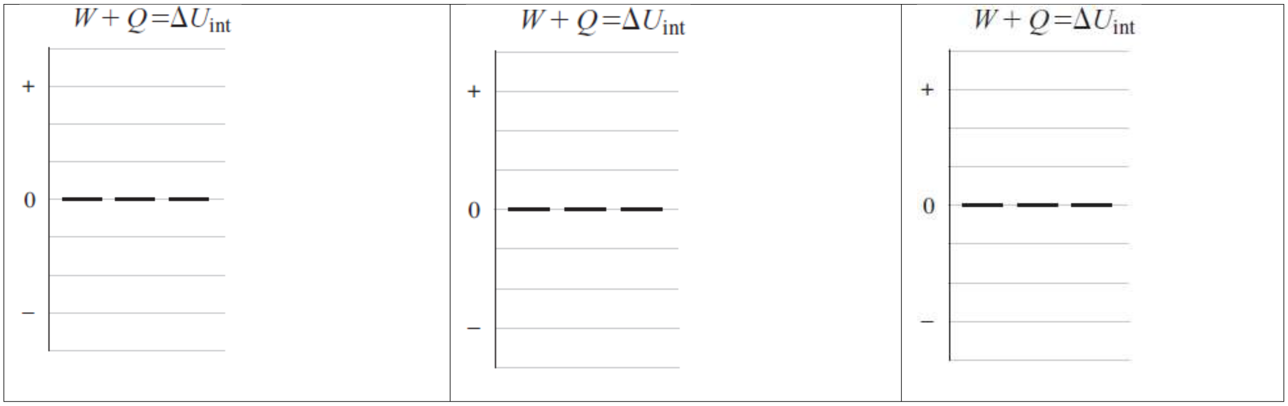

15.4.4 Reason

PIVOTAL Class:

Work with your group members to answer the questions concerning the processes described in Activity 15.4.3.

a. Isochoric process**:** Explain why the line in the P-versus-T graph passes through the origin; explain the process using the knowledge of the molecules and their motion.

b. Isothermal process**:** Explain why the P-versus-T graph is not a straight line; explain the process using the knowledge of the molecules and their motion.

c. Isobaric process**:** Explain why the line in the V-versus-T graph passes through the origin; explain the process using the knowledge of the molecules and their motion.

15.4.5 Regular problem

PIVOTAL Class: *Equipment per group:* whiteboard and markers.

Solve this problem following the steps of the problem-solving strategy outlined below and then compare your solution to the solution in Example 15.1 in the textbook.

A burner heats $1.0\ \text{m}^3$ of air inside a small hot air balloon. Initially, the air is at $37\ ^\circ\text{C}$ and atmospheric pressure. Estimate the amount of energy that needs to be transferred to the air through heating (in joules) to make it expand from $1.0\ \text{m}^3$ to $1.2\ \text{m}^3$. Indicate any assumptions that you made.

15.4.6 Explain

Class:

Is it possible for gas to cool while you are transferring energy to it through heating? Discuss with your group, come to a consensus, explain your answer and give an example.

15.4.7 Reading exercise

Read Section 15.4 in the textbook and answer Review Question 15.4.

15.5 Specific heat

15.5.1 Observe and find a pattern

PIVOTAL Class or Lab: *Equipment per group:* whiteboard and markers.

You have a small electric heater and water in a calorimeter (an insulated container). The amount of energy provided to the system and the change in water temperature are shown below.

t (s)	ΔU (J)	ΔT (°C) $= T_f - T_i$
0	0	0.0
10	1000	2.4
20	2000	4.8
30	3000	7.2
40	4000	9.6
50	5000	12.0
60	6000	14.4

a. Graph the data in the table to decide whether there is a relation between the amount of energy provided to the system (the water) and its temperature change ΔT. Think about which quantity is the independent variable and which quantity is the dependent variable.

b. Write the mathematical relation.

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15.5.2 Observe and find a pattern

PIVOTAL Lab or class: *Equipment per group:* whiteboard and markers.

In a second set of experiments, recorded in the table below, the same amount of energy (4000 J) is provided to the insulated water containers with different masses of water.

m **(kg)**	ΔT(°C)
0.10	9.6
0.20	4.8
0.30	3.2
0.40	2.4

a. Graph the data and decide whether there is a mathematical relation between the change in temperature and the mass of water (the system) when the amount of energy provided is the same.

b. Write the mathematical relation.

15.5.3 Observe and find a pattern

PIVOTAL Lab or class: *Equipment per group:* whiteboard and markers.

The same amount of energy (4000 J) is provided to four identical-mass (1 kg) systems with different substances. What can you conclude based on the data in the table below? Can we say that the density of the liquid determined how much its temperature changes when a certain amount of energy is provided? If it is not density, then what is this property of liquids?

Substance	ΔT(°C)
Freshwater	0.95
Seawater	1.03
Alcohol	1.65
Mercury	28.47

15.5.4 Reason

PIVOTAL ***Lab or class:*** *Equipment per group:* whiteboard and markers.

You found in Activity 15.5.1 a relationship between the amount of energy provided to the system and the temperature change (for constant mass), and in Activity 15.5.2 a relationship between the mass and the temperature change. You also found that the same amount of energy provided to different types of materials caused different temperature changes. Combine these results to write a mathematical expression that shows how the change in the temperature ΔT of a system depends on the amount of energy provided, ΔU, the system's mass m, and the particular type of material of that system. You can account for the type of material using a new quantity c (called the specific heat of that particular type of material) measured in J/(kg · °C). Be sure that the units in your new equation are consistent.

15.5.5 Predict and test

Lab: *Equipment:* insulated containers, heaters, thermometers, scales, and objects made of known materials.

Describe two experiments, A and B, that you can perform to test the relationship devised in Activity 15.5.4. Show how the relationship allows you to make predictions concerning the outcomes of these experiments.

a. Perform experiment A and record the data and the value of the predicted quantity. Decide whether its deviation from the predicted value can be explained by the experimental uncertainties and assumptions.

b. Perform experiment B and record the data and the value of the predicted quantity. Decide whether its deviation from the predicted value can be explained by the experimental uncertainties and assumptions.

15.5.6 Design an experiment

Lab: *Equipment:* immersion heater. Other necessary equipment should be requested by the students.

Examine the water heater and note its stated power rating. Work with your group members to design and conduct an experiment to test whether the manufacturer provided an accurate rating.

a. Brainstorm on what experiments you can carry out and describe in words an experiment that you agree to perform to test the power rating.

b. Draw a picture of the experimental set-up. Include quantities you will measure and calculations you will make.

c. Complete the calculations to predict the outcome of the experiment.

d. List assumptions and how they affect the result. List experimental uncertainties and how they will affect the result.

e. Perform the experiment; record the outcome of the experiment, and decide whether the manufacturer's rating is reasonable.

15.5.7 Analyze

Class or lab: *Equipment per group:* whiteboard and markers.

Watch the video of a cup of glycerin being stirred by a mixer used to whip cream [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-5-7]. The video is taken with a thermal camera and allows you to follow the temperature of the glycerin at the location of the cross hairs.

a. Use the data provided in the video to estimate how much energy provided by the mixer went into warming up the glycerin.

b. Could this experiment be used to test the equivalence of work and heating as a means for energy transfer similar to the historical experiment performed by James Joule and described in the Testing Experiment Table 15.2? Explain why or why not.

15.5.8 Design an experiment

PIVOTAL Lab: *Equipment per group:* a reservoir with hot water, a reservoir with cold water, thermometers, precision scale, calorimeters, objects to determine specific heat, a hot plate, beakers, gloves.

You have an object made of an unknown material. Work with your group members to design two independent experiments to determine the specific heat of the material.

a. Describe the experimental procedures. What data will you collect and how will you analyze them?

b. Conduct the experiments, record the data, and determine specific heat. Do not forget uncertainties!

c. Compare the outcomes of the experiments and account for the differences.

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15.5.9 Reading exercise

Read Section 15.5 in the textbook and answer Review Question 15.5.

15.6 Changing state

15.6.1 Explain

PIVOTAL Class:

Water in a pan is at its boiling temperature (about 100 °C). A gas flame continues to contact the pan holding the water, and after some time, all of the water has boiled away. The water vapor is at about the same temperature as the water at its boiling point (about 100 °C).

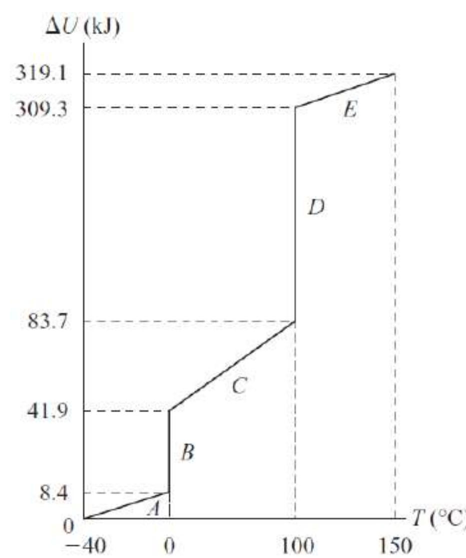
a. Consider the water as the system and explain this process using your knowledge of work and energy. If you need any new quantity for your explanation, define it qualitatively.

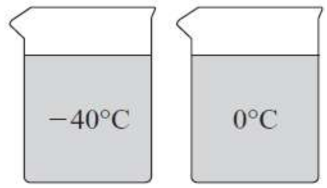
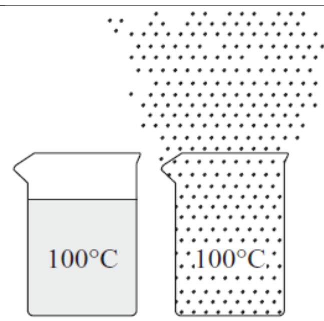
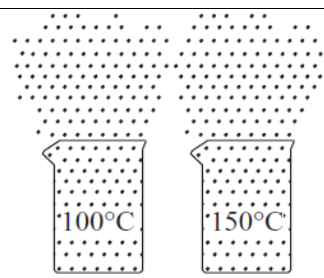
b. After contact with the flame for some time interval, the pan, liquid water, and water vapor were at about the same temperature. On a molecular level, what happened to the energy transferred from the hot flame to the water?

15.6.2 Represent and reason

PIVOTAL Class:

A process with five parts is shown in the graph at right. Carefully examine the following table, which represents the parts of the process in multiple ways—words, sketches, a graph, and an equation. The process starts with 0.10 kg of ice at $-40\ °\text{C}$ and ends with 0.10 kg of steam at $+150\ °\text{C}$. *Note: c* stands for specific heat and ΔU for the change in internal energy.



Words	**Sketch the initial and final parts of the process.**	**Equation**
A. Ice starts at –40 °C and warms to its melting temperature at 0 °C.		$\Delta U_A = mc_{\text{solid}}\left[T_{\text{melt}} - \left(-40°\text{C}\right)\right]$
B. Energy provided to the ice causes the solid ice to convert slowly to liquid at 0 °C.		$\Delta U_B = +mL_{\text{f}}$
C. After the ice has completely melted, more energy causes the liquid water to warm from 0 °C to 100 °C, its boiling temperature.		$\Delta U_C = mc_{\text{liquid}}\left(T_{\text{boil}} - T_{\text{melt}}\right)$
D. Now, energy provided causes the water to convert slowly from the liquid to the gaseous state while still at 100 °C.		$\Delta U_D = +mL_{\text{v}}$
E. Additional energy causes the gas to warm from 100 °C to 150 °C.		$\Delta U_E = mc_{\text{gas}}\left(150°\text{C} - T_{\text{boil}}\right)$

a. Are the equations for parts B and D consistent with the corresponding parts of the graph? Explain.

b. Consider the so-called state changes that occur when ice is melting from a solid to a liquid in part B and evaporating from a liquid to a gas in part D. What happens to the temperature of the matter during these state-change processes? Explain.

c. Explain microscopically what is needed in terms of energy for parts B and D—that is, to convert the solid water to liquid water and then to convert the liquid water to gaseous water.

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15.6.3 Reason

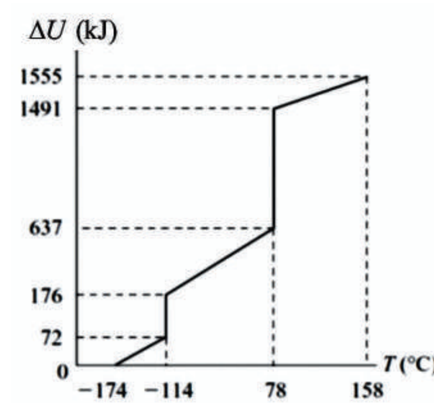
Class:

Use the information in the graph in Activity 15.6.2 to determine the heat capacity for the solid, the liquid, and the gaseous phases of water and its latent heats of fusion and vaporization.

15.6.4 Represent and reason

PIVOTAL ***Class:*** *Equipment per group:* whiteboard and markers.

Energy provided through heating causes the internal energy of 1.0 kg of some substance to change from a solid at $-174\ °C$ to a gas at $+158\ °C$, as shown in the graph at the right. Determine the following:



a. The freezing–melting temperature.

b. The boiling–condensing temperature.

c. The specific heat capacity of the solid.

d. The specific heat capacity of the liquid.

e. The specific heat capacity of the gas.

f. The latent heat of fusion.

g. The latent heat of vaporization.

h. Now write a mathematical expression that includes the total energy needed to convert the 1.0 kg of matter from −174 °C to +158 °C.

15.6.5 Represent and reason

Class: *Equipment per group:* whiteboard and markers.

Word descriptions for three processes are provided. Fill in the table that follows by describing each process with a picture description (including initial and final states and what happens to each type of matter in going from the initial state to the final state) and the application of the first law of thermodynamics. Do not solve for anything.

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Word description	**Sketch and translate; include the changes in going from the initial to the final state.**	**Write simplifying assumptions.**	**Represent mathematically in symbols (apply the temperature-change and state-change equations).**
A 50-g metal spoon at temperature $20\ ^\circ\mathrm{C}$ is placed in an insulated cup with 200 g of coffee at $100\ ^\circ\mathrm{C}$. The spoon and coffee reach a final temperature T_f.			
25 g of 10 °C milk is added to 200 g of 70 °C coffee in an insulated cup. The coffee and milk reach a final temperature T_f.			
A 200-g aluminum block at $+150\ ^\circ\mathrm{C}$ is placed in a large insulated cup with 40 g of ice at $-10\ ^\circ\mathrm{C}$. The aluminum and ice reach a final temperature T_f (the ice has completely melted).			

15.6.6 Equation Jeopardy

Class:

Each of the equations below describes a thermodynamics process. Describe each process in words

a. $Q = (0.40\ \mathrm{kg})(4186\ \mathrm{J/kg\cdot ^\circ C})(100\ ^\circ\mathrm{C} - 30\ ^\circ\mathrm{C}) + (0.10\ \mathrm{kg})(2.56\times 10^6\ \mathrm{J/kg})$

b. $(0.40\ \mathrm{kg})(2090\ \mathrm{J/kg\cdot ^\circ C})[0\ ^\circ\mathrm{C} - (-8\ ^\circ\mathrm{C})] + (0.40\ \mathrm{kg})(33.3\times 10^4\ \mathrm{J/kg})$
$+ (0.40\ \mathrm{kg})(4186\ \mathrm{J/kg\cdot ^\circ C})(T_\mathrm{f} - 0\ ^\circ\mathrm{C}) + (2.0\ \mathrm{kg})(4186\ \mathrm{J/kg\cdot ^\circ C})(T_\mathrm{f} - 50\ ^\circ\mathrm{C}) = 0$

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15.6.7 Evaluate the solution

A group in your physics lab has produced a graph that group members think describes the following process.

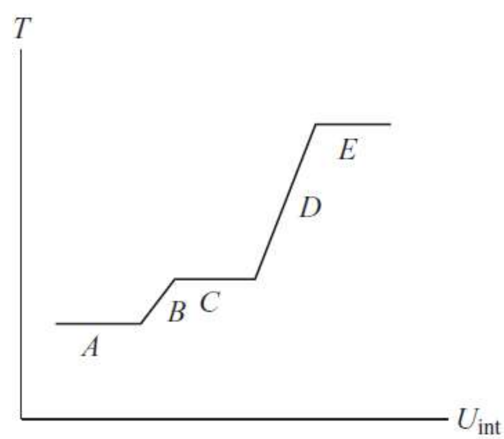
A: Heating causes a solid to warm to its melting temperature.

B: Continued heating causes the solid to melt, thus producing a liquid.

C: With more heating, the liquid warms slowly to its boiling temperature.

D: Continued heating causes the liquid to convert to a gas.

E: The heating then warms the gas.



Indicate any flaws in the group's graphical description of this process. Use words and different graphical representations to explain and correct errors.

15.6.8 Apply

Class: *Equipment per group:* whiteboard and markers.

You have 1 L of water in a pan at room temperature. You put the pan on a 200 W electric heating plate. After some time, you observe that the water in the pan reaches a temperature of almost $100\ ^\circ\text{C}$ but does not start boiling even if left on the heater for long time. Estimate the time it takes the water to cool by $10\ ^\circ\text{C}$ when removed from the heater. Indicate any assumptions that you made.

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15.6.9 Apply

Class:

Discuss with your group: which is more effective in extinguishing a fire, cold water or boiling water?

15.6.9 Reading exercise

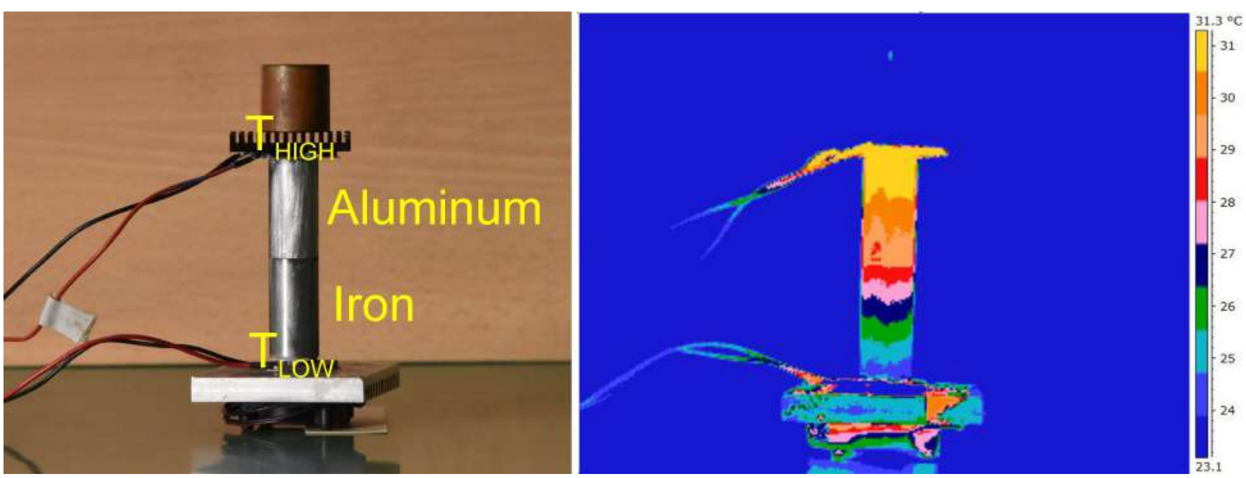
Read Section 15.6 and answer Review Question 15.6.

15.7 Heating mechanisms

15.7.1 Observe and explain

Lab or class:

Examine the photos below. The photo on the left is taken with a regular camera and it shows the set-up of the experiment. The photo on the right is taken with a thermal camera and allows you to observe the temperatures of different parts of the set up (colors indicate 1 °C -temperature intervals (see also the color coding on the right of the photo)). The T_{high} and T_{low} labels indicate the temperatures that are kept constant during the experiment. Carefully examine the photo on the right.

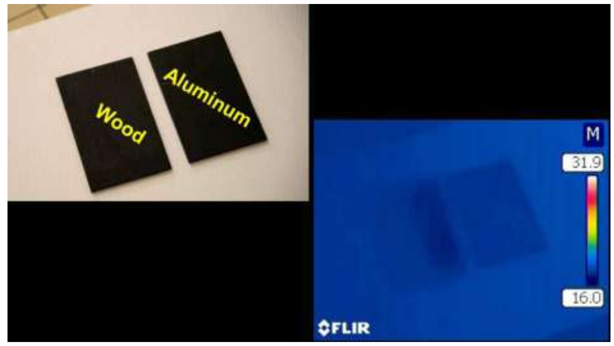


a. Describe what you observe.

b. Explain what you observe.

15.7.2 Observe and explain

Lab or class:



Observe the video of an experiment taken with a regular camera and a thermal camera [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-7-2]. In the experiment, two identical metal objects (made of brass) are taken from the same hot water bath and placed on two identical-shape (height, length, and width) plates made of wood and aluminum (colored with the same black paint to reduce the reflective properties of aluminum) that have beem sitting on the table for a long time.

a. Describe what you observe.

b. Devise one or more explanations for your observation.

15.7.3 Test your ideas

Lab or class:

You use the same plates as in Activity 15.7.2, but this time you place an ice cube on each one.

a. Use the explanations you made in Activity 15.7.2 to predict what you will observe.

b. View the video [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-7-3] and compare the outcome to your predictions. Do you need to revise your explanation?

15.7.4 Observe and explain

Lab or class:

Observe the video of an experiment taken with a thermal camera [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-7-4]. In the experiment, you have two identical pieces of paper, one wet with water (on the right) and the other (on the left) wet with acetone.

a. Describe what you observe. Make sure you watch the video to the end.

b. Explain your observation. Make sure you use the knowledge from the first section of Chapter 12.

15.7.5 Observe and explain

Lab or class:

a. Observe the video of the experiment [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-7-5] and describe what you observed.

b. Explain why the position of the ice cube affects whether it melts or not.

c. Now examine the photo in Activity 15.7.1 and explain why the experimenters placed the hot temperature part of the device on the top and the cold temperature part of the device at the bottom.

15.7.6 Reading exercise

Read Section 15.7 and answer Review Question 15.7.

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