Chemistry – Unit 3 Reading Assignment
Energy and Kinetic Molecular Theory

The story behind the difficulty we have with energy is fascinating to those of us who struggle with trying to teach energy in a coherent way, but it is long and difficult - much of it would be lost on students whose goal is to get a grip on how to use energy to describe change in the world. Nonetheless, a brief bit of background might help you understand how we are going to approach the study of energy. In the 18th and 19th centuries scientists wrestled with identifying and describing the nature of the “stuff” that produced change. One concept that became popular for a while was that of “caloric” (what we now call heat).

“Caloric was originally conceived of as a quantity that would flow from a hotter object to a cooler one that would warm up as a result. It answered the need for a way for the cause of warming to get from here to there. Not only did caloric serve as a cause for warming, it was also considered to be the cause for changes of phase. Caloric enabled particles of a substance to move farther apart until the attraction of the particles for each other became too weak to hold them together. Although Lavoisier did not think that caloric necessarily was an actual substance, in its storage and transfer it was like a substance.”

When scientists recognized that the “stuff” involved when forces were applied to objects to lift them or change their speed was the same “stuff” that was involved when the temperature of objects changed, they worked to develop a single energy concept. “So when the energy concept was developed it was important to distinguish it from caloric. In snuffing out the caloric concept, the clear picture of energy storage and transfer that it fostered was unnecessarily lost, too.”

Even though we recognize that energy is not a physical substance, we choose to use the substance metaphor to describe it. We’ll use three principles to guide us in the development of the energy concept.

1. Energy can be viewed as a substance-like quantity that can be stored in a physical system.

2. Energy can “flow” or be “transferred” from one system to another and so cause changes.

3. Energy maintains its identity after being transferred.
If you are unsure what we mean by the use of a substance metaphor, consider how we describe information. We say that it can be stored in books, on computer hard drives or floppy disks or CD-ROMs. Information can be transferred from place to place via cables or by wireless transmission techniques - in fact you just did this when you accessed this lesson via the Internet, transferred it to your computer and then (perhaps) printed it. But there is nothing substantial about the information itself; you can’t touch it or measure its mass on a balance. The third point is important to consider because many texts talk about energy transformations as if somehow it is the energy that is changing rather than the physical system that gains or loses it. Consider the information metaphor again: even though we move information from place to place or store it in different ways, nothing about the information itself has changed.

**Energy Storage and Transfer**

At this point, let us consider another metaphor to describe energy storage and transfer – that of money. We store money in accounts at the bank or credit union. We can have checking accounts, various savings accounts, certificates of deposit, etc. These accounts store money. There is nothing different about the money in checking and savings accounts. This money can be transferred back and forth in the bank without changing the nature of the money or the total quantity of money that resides in the collection of accounts that is attached to your name; let’s call this the system for convenience.

The same is true of energy. It is stored in objects and in the arrangement of objects in a physical system. We use different “accounts” to help us keep track of energy as its transfer causes change in the objects or in their arrangement. As with money, nothing about the energy itself has changed. Let’s consider the accounts we will use in this course.

1. **Thermal energy, \( E_{th} \) – energy of motion.** The quantity of thermal (kinetic) energy stored by an object is related to both its mass and velocity. You instinctively recognize this as you would rather catch barehanded a baseball thrown by your instructor than one thrown by a major league pitcher. Similarly, you wouldn’t mind if a softball landed on your toe, but would suddenly move if a shot put were heading that way.

2. **Phase energy, \( E_{ph} \) – energy stored in the system due to the arrangement of molecules that exert attractions on one another.** Attractions can result in a decrease in the energy of a system. As the particles become more tightly bound, their \( E_{ph} \) is lowered. Solids possess the lowest \( E_{ph} \); liquids possess more \( E_{ph} \) since the molecules in a liquid are freer to move than those in a solid; and a gas possesses
the greatest amount of $E_{ph}$ since the molecules in a gas have completely broken free from one another. $E_{ph}$ is the energy account involved when phase changes occur.

3. Chemical potential energy, $E_{ch}$ - energy due to attractions of atoms within molecules. These attractions are described as chemical bonds because they are directed between specific atoms in the molecule.

There are three energy transfer modes and these are described as gerunds to emphasize that they are processes rather than real things apart from energy. They are working (W), heating (Q) and radiating (R). These transfer modes operate to move energy between the system and the surroundings. It is very important to recognize that such energy transfers affect both the system and the surroundings. Energy doesn’t mysteriously appear or get lost.

1. **Working** (referred to as work by the physicists as if it is something different from energy) is the way in which energy is transferred between macroscopic (large enough to be seen) objects that exerts forces on one another. It is OK to calculate how much “work” one object does on another so long as you do not think that work is something an object stores.

2. **Heating** (referred to as heat by the chemists) is the way in which energy is transferred by the collisions of countless microscopic objects. Energy is always transferred from the “hotter” object (one in which the molecules have greater $E_k$) to a colder one (one in which the molecules have lower $E_k$). If all the molecules have the same mass, then the “hotter” ones are moving faster than the “colder” ones. It’s OK to say that you heat an object – just not that the object stores heat.

3. **Radiating** is the process in which energy is transferred by the absorption or emission of photons (particles of light). A light bulb filament can be heated to the point that it glows; this is the emission of photons that carry energy away from the filament. You can be warmed by light from the sun as the photons transfer energy to you.
The relationship between energy storage and transfer is given by the 1st Law of Thermodynamics, $\Delta E = W + Q + R$. This is shown by the system schema below:

\[ W \rightarrow \Delta E \rightarrow Q \rightarrow R \]

It shows that energy transferring into and out of the system affects the nature of the energy storage in the system. The 1st Law of Thermodynamics and the Law of Conservation of Energy state that the algebraic sum of these energy changes and transfers must add up to zero, accounting for all changes relative to the system.

**Kinetic Molecular Theory (KMT)**

This is one of the really important theories in chemistry. It accounts for the behavior of substances during all sorts of physical change. There are three key points:

1. Matter is made of tiny particles that are in constant random motion.

2. These particles exert long-range attractions and short-range repulsions on one another. Attractions bring about a reduction in the energy state ($E_{\text{ph}}$) of the system; repulsions bring about an increase in the energy.

3. A hotter sample is one whose molecules are moving (on average) faster than the molecules in a colder sample.
**Unit 3, Worksheet 1 — Energy Reading Questions**

**Historical view:**

1. Describe what early chemists meant by *caloric*.

2. What is our more modern word for *caloric*? __________

3. Our understanding of what causes changes to happen took two different paths that we eventually realized were the same. In paragraph 3 these are identified. Describe the two kinds of change scientists had studied.

   A.

   B.

4. What two ideas about energy were lost when the caloric idea was abandoned?

   The ________________ and ________________ of energy

5. Summarize the three principles guiding our modern view of energy

   A.

   B.

   C.

6. Information is used as a metaphor to describe what energy is like. Describe the ways information is like energy, according to your reading.
7. Money accounts is another metaphor that can help us understand energy storage and transfer. Describe the ways money accounts are like energy.

8. We will be discussing three storage “accounts” to understand the changes we see in chemistry. State their names and describe how energy is stored in these three storage modes (how would you recognize that energy is present in these accounts in a system of matter?).

   A.

   B.

   C.

9. We can transfer energy by three mechanisms. Identify the three and state how you would recognize each one in a system of matter.

   A.

   B.

   C.
Unit 3 – Notes on Energy Accounts

From X-ray diffraction patterns, we can learn about the structure of matter at the particle level:

1. In solids, sharp diffraction patterns suggest the existence of long range order – the particles are ordered in a repeating pattern (sometimes even observable by the naked eye).
2. In liquids, fuzzy diffraction patterns suggest the existence of short range order – at about the same bulk density as solids, some particles are squeezed closer together, leaving random gaps which break the repeating pattern. These gaps allow the particles to switch places and move around (this is why you can pour liquids).
3. In gases, no diffraction pattern is obtained – all the particles are very far apart, resulting in no pattern whatsoever.

Particles in a solid undergo primarily vibrational motion. Energy added to the system that does not melt the solid can increase these vibrations, but does not change the long-range order of the system.

Particles in a liquid undergo vibrational, rotational and some gradual translational motion. Energy added to the system that does not vaporize the liquid increases these kinds of motion, yet the short-range order in the particles still exists.

Particles of a gas undergo translational, rotational and vibrational motions. There is no apparent structure in such a system of particles.

Let’s examine how energy is stored in a system of vibrating particles. When particles undergo vibration, the velocity of the particles constantly changes as the relative positions of the particles change. [Recall the 1<sup>st</sup> Eureka video: Molecules in Solids.] As the kinetic energy of the particles decreases, the “elastic” energy (due to interactions between the particles) increases; as the $E_k$ increases, the $E_{el}$ decreases.
On average, the $E_k$ and the $E_{el}$ of the particles are equal, therefore an addition of energy to the system via heating will be equally split between the two accounts. Therefore, it would take twice as much energy to produce the same effect on $E_k$ in a metal as it would for the $E_k$ in a monatomic gas. Evidence for this is the fact that the heat capacity of metals is roughly double that of monatomic gases (at constant volume).

We will define an account (thermal energy, $E_{th}$) which includes both the $E_k$ (for all types of motion) and $E_{el}$ energy (associated with vibrations). You can change the amount of energy in the $E_{th}$ account without changing the overall structure of the particles in the system.

When energy supplied to the system results in structural change, overcoming the attractions that keep the particles in a specific structure, we say that this energy is stored by the system as interaction energy ($E_i$). When a system of particles becomes more closely bound, we say that there is a decrease in the energy stored in the $E_i$ account. You cannot change the amount of energy in the $E_i$ account without changing the structure. So, for a given structure, you cannot exchange energy between the $E_{th}$ and $E_i$ accounts.

When the constituent atoms of our basic particles undergo rearrangement (a more drastic structural change), we say that chemical energy ($E_{ch}$) is involved.
Unit 3, Lab 1

Title

Purpose

Question

Hypothesis

Hypothesis Graph
(and explanation)

Procedures
Data

1. In the space below, sketch your graph. Make sure you have a title, axis labels, etc.
2. Below the x-axis, also write "Energy Supplied." Why? ______________________________________
   ______________________________________________________________
   ___________________________________
3. Record what phase(s) are present in each region of your graph. Draw dotted vertical lines separating sections of the graph.
4. In each section, draw 2 particle diagrams (one at the beginning of the section and one at the end of the section) showing the behavior of the water particles.
5. Be sure to take additional notes on our board meeting discussion.
For each of the situations described below, use an energy bar chart to represent the ways that energy is stored in the system and flows into or out of the system. To the right each diagram, describe how the arrangement and motion of the molecules change from the initial to the final state.

1. A cup of hot coffee cools as it sits on the table.

   **Motion before:**
   - Motion after:
   - Arrangement before:
   - Arrangement after:

2. A can of cold soda warms as it is left on the counter.

   **Motion before:**
   - Motion after:
   - Arrangement before:
   - Arrangement after:

3. A tray of water (20 °C) is placed in the freezer and turns into ice cubes (- 8 °C)

   **Motion before:**
   - Motion after:
   - Arrangement before:
   - Arrangement after:
4. Where does the energy that leaves the system in #3 go? How does this energy transfer affect the room temperature in the kitchen? Do you have any experience that supports your answer?

5. One of the ice cubes described in #3 is placed in a glass of room temperature (25 °C) soft drink. Do separate bar charts for the ice cube and the soft drink.

6. The graph shows the cooling curve for a substance as it freezes.
   a. Sketch the cooling curve for a larger sample of the same substance on the second graph.
   b. Label which phase (or phases) of the substance is present in each of the three portions of the cooling curve.
   c. Describe the arrangement and motion of the molecules during each portion of the graph.
Unit 3, Worksheet 3—
Energy Bar Charts

For each of the situations described below, use an energy bar chart to represent the ways that energy is stored in the system and flows into or out of the system. To the right each diagram, describe how the arrangement and motion of the molecules change from the initial to the final state.

1. Some of the water you spilled on your shirt evaporates.

   Motion before:
   Motion after:
   Arrangement before:
   Arrangement after:

2. Water vapor in the room condenses on a cold surface.

   Motion before:
   Motion after:
   Arrangement before:
   Arrangement after:

3. A pan of water (25°C) is heated to boiling and some of the water is boiled away. Complete an energy bar chart for heating and then for boiling.

   Motion before:
   Motion after:
   Arrangement before:
   Arrangement after:
4. During boiling, bubbles appear in the liquid water. In the boxes below, represent the arrangement of molecules inside the liquid water and inside a bubble.

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liquid water
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bubble
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What is inside the bubble? Why do you think so?

5. Suppose the burner under the pan of boiling water is turned to a higher setting. How will this affect the temperature of the water in the pan? Explain.

6. The graph below left represents the heating curve for a liquid heated from room temperature to a temperature above its boiling point.

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<table>
<thead>
<tr>
<th>time</th>
<th>temperature</th>
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<tbody>
<tr>
<td>1</td>
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<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>
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a. Sketch the heating curve for a larger sample of the same liquid.

b. Label which phase (or phases) of the substance is present in each of the three portions of the heating curve.

c. Describe the arrangement and motion of the molecules during each portion of the graph.

1.

2.

3.
Unit 3, Worksheet 4—Representing Phase Changes

I. Temperature-Time Graphs:
The temperature of a substance as it is steadily heated or cooled is shown in Graphs 1 and 2. Show changes in matter and changes in energy by adding the following to each graph:

1. At each labeled point (A, B, C...) on the graphs draw
   a. a particle diagram to show the arrangement of matter particles (above letter)
   b. a qualitative energy bar graph (below letter)

2. Between each pair of labeled points (A-B, B-C, C-D...), write or draw
   a. the state(s) of matter that are present (in orange pen/pencil)
   b. the change that is occurring (ex: temperature change, melting, condensing...) (in purple pen/pencil)
   c. an energy flow diagram (the “O” in “LOL”) showing how the energy of the system is changing (is it by working, heating, or radiating? is energy being transferred into or out of the system?)

1. Temperature - Time During a State Change
II. Explain the differences and/or similarities between the terms in each set below:


2. Thermal Energy, Phase Energy

3. Solid, Liquid, Gas

4. Melting, Freezing

5. Evaporating, Condensing
Chemistry - Unit 3 Energy and Heating/Cooling

Energy is a substance-like quantity that is always involved whenever a system undergoes change (hotter--colder, faster--slower, higher--lower).

A key to understanding energy is to recognize that energy is always and everywhere only energy. Energy is stored in a system in several different “accounts” and can be transferred between system and surroundings in different ways, but it does not come in different forms. When there is a change in the way the system stores energy or if energy is transferred between system and surroundings, something about the system changes, but the energy remains the same.

One difficulty we have in understanding energy is that our everyday use of words can sometimes muddy the waters. For example, use of the word “heat” can leave the impression that it is somehow different from energy. It would be better if we viewed “heat” as one of the ways that energy is transferred from one object to another. While it is helpful to say that we “heat” an object (as a shortcut for “transfer energy to”), it is not useful to say that an object stores “heat.” It’s fine to describe an object that stores a lot of thermal energy as “hot,” but saying that is stores a lot of “heat” confuses energy with a way that is moved from one object to another.

*Heating* a system increases its thermal energy ($E_{th}$) through the collisions of more energetic particles with particles of lower energy; as a result, the particles in the system move more rapidly than before. Use of the -ing ending helps us view “heating” as a process of energy transfer through collisions of particles rather than as something different from energy. The *quantity of energy* transferred in this way is often referred to as “heat” (assigned the variable name $Q$), but it is important to remember that it is simply energy. Conversely, a system cools when its particles transfer (through collisions) thermal energy to particles in the surroundings. This process lowers the amount of thermal energy ($E_{th}$) stored by the system.

Temperature is a useful tool because it allows us to assign a numerical value that helps us describe the thermal energy of a system (or surroundings). It is important to recognize that temperature and energy are not the same. *Changes* in temperature ($\Delta T$) help us to determine the amount of thermal energy gained or lost by a system, as we shall discuss at a later time.

We’re now ready to discuss the role of energy during phase change. We’ll first examine what happens when a solid melts. As energy is transferred into the system, the thermal energy (and motion) of the particles increases. At some temperature, the particles are vibrating to and fro so rapidly that they can no longer maintain the orderly arrangement of a solid. They break free of the attractions and begin to move around more freely – they become “liquid.”
We use another account to describe the way the system stores energy when the particles exist as a liquid than as a solid; we call this phase energy, $E_{ph}$. Particles in the liquid phase store more phase energy than do particles in the solid phase.

As you recall from the experiment, during the melting of the solid, the temperature remained more or less constant, despite the fact that energy was being continually transferred to the system. To explain this, consider the fact that energy is required to overcome the attractions that bind the particles in an orderly array. Apparently, at the melting point, energy entering the system can no longer be stored in the motion of particles in the solid phase -- the particles are moving too rapidly to remain as solid. Instead, the particles trade thermal energy for phase energy as they break free from their neighbors and are able to move around more freely. This decrease in thermal energy is temporary, however, as energy is still being supplied via collisions to the particles in the system.

A closer examination of the plateau region of the heating curve would reveal tiny zigzags in the temperature, like the teeth of a hacksaw blade. Energy enters the thermal account (raising the temperature) and then is immediately transferred to the phase account (lowering the temperature) as the particles break free from their mutual attractions. This internal energy transfer keeps the temperature more or less constant during the phase change. This process of energy shuttling between accounts continues until the solid is completely melted.

It may be helpful to consider an analogy for this process. Let's substitute money for energy and substitute a checking account for the thermal energy account and a savings account for the phase energy account. Let's also say that the checking account is set up to have a maximum balance of $1000. So long as the checking balance is lower than this amount, money can be deposited into this account. Once the balance reaches $1000, however, any money entering the checking account is quickly transferred to the savings account. If $50 is deposited into the checking account, the balance becomes too high so the excess is transferred to savings. This transfer increases the amount in the savings account by $50 and the checking account balance returns to $1000.

Once all the particles in the system are in the liquid phase, energy transfers to the system are once again stored in the thermal account and the temperature increases. This process continues until the temperature reaches the boiling point. At this temperature, the particles are moving too rapidly to remain in the liquid phase. Thermal energy is again exchanged for phase energy as the particles break free from one another and enter the gas phase.
Now, let's examine a situation where energy is transferred out of a system during a phase change. An example of such a situation is the condensation of water vapor. In order for a collection of gaseous water particles to condense (become bound to one another in the liquid phase) they must transfer phase energy to the thermal account. The particles of liquid water are now hotter than they once were. When these higher temperature particles in the liquid phase come into contact with lower temperature particles in the surroundings, a transfer of thermal energy from system to surroundings via heating occurs. The system cools and the immediate surroundings get warmer.

The bottom line is that any time energy enters or leaves a system via heating (collisions of particles), the motion of the particles changes first. This means that energy entering or leaving a system does so via the thermal energy account. When the temperature of a single phase changes, the only account that changes is the thermal energy. During a phase change, the thermal account experiences small but temporary changes as it serves as the conduit for energy moving from the phase account to the surroundings (during freezing or condensing) or from the surroundings to the phase account (during melting or vaporization).
Quantitative Energy Problems

Problem Solving Strategy:
1. Always sketch a warming or cooling curve first. Mark your starting and ending points on the graph.
2. Divide the problem up into one, two, three, or more steps (based on the sections of the graph).
3. Select the method of calculating Q (the equation and constants to use) depending on the heating or cooling curve drawn.
4. To find total energy involved, add all of the Q values together for each step of the problem to determine the answer.

Sample Problem:
10.0 grams of ice is stored in a freezer at -15°C. The ice is removed from the freezer and is allowed to sit on the table and melt until its temperature equalizes with the temperature of the room at 24 °C. What quantity of heat must be absorbed from the surroundings for this change to occur?
Specific Heat Capacity & Quantitative Heating Problems

If you started with a sample of solid water well below the freezing point and supplied energy to it at a steady rate until it had partially boiled away, you would obtain a heating curve like the one below:

![Heating Curve](image1)

In our **energy flow diagram** we would show energy entering the system via heating during this series of changes. On the plateaus, the phase was changing and the system was storing $E_{ph}$. On the inclines, the temperature was changing and the system stored $E_{th}$.

If we had started with boiling water and allowed it to cool until it had frozen completely and cooled to below 0°C, we would have obtain a graph like the one below:

![Cooling Curve](image2)

In our energy flow diagram we would show energy leaving the system via heating. On the plateaus, the system was giving up $E_{ph}$ as the phase changed. On the declines, the temperature was changing and the system lost $E_{th}$.

We are now interested in learning just **how much** energy is transferred during these changes. From experiment, chemists have learned that it takes 4.18 joules$^1$ to raise the temperature of 1 g of liquid water by 1 °C. This amount of energy is equivalent to one **calorie**. We can write this value as a

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$^1$ A joule is the SI unit of energy.
factor \( \frac{4.18 J}{g \cdot ^\circ C} \). Suppose that we have a larger sample of liquid water, say 250g. Clearly, it would take 250x as much energy to raise the temperature by one °C. In like manner, it would take 40x as much energy to raise the temperature by 40° C. We can show this in an equation:

\[ Q = mc\Delta T \]

where \( Q \) is the quantity of heat transferred, \( m \) represents the mass (in g), \( c \) is a property of liquid water known as the **specific heat capacity**, and \( \Delta T \) is the change in temperature. Using the values above,

\[ Q = 250g \cdot \frac{4.18 J}{g \cdot ^\circ C} \cdot 40^\circ C = 41,800 J \text{ or } 41.8 kJ. \]

We usually use the kiloJoule as the unit for our answers because the joule is a pretty small unit of energy.

Experiments have shown that ice, \( \text{H}_2\text{O(s)} \), warms more rapidly than liquid water. Its heat capacity is \( \frac{2.1 J}{g \cdot ^\circ C} \). This means that only about half as much energy is required to raise the temperature of one gram of ice by one degree Celsius.

Substances like metals have much lower heat capacities. You certainly have had experience with this fact if you have ever picked up a piece of metal that was lying in the sun. The radiant energy \( R \), raises the temperature of the metal to an uncomfortably hot temperature.

We cannot use this relationship on the plateau portion of the heating (or cooling) curve because there the temperature is constant (\( \Delta T = 0 \)). So we must use a different equation: \( Q = m\Delta H_f \) when the substance is melting (or freezing) and \( Q = m\Delta H_v \) when the substance is vaporizing (or condensing). Note that the quantity of energy is related to the mass of the substance times a property of that substance. For water, \( \Delta H_f \) is 334 J/g, and \( \Delta H_v \) is 2260 J/g. These values make sense when you consider that pulling apart molecules of liquid water until they become widely separated in a gas is more difficult than simply giving the solid water enough energy to allow the molecules to move freely past one another.

Calculations of energy changes on the plateaus are easy, but you have to make sure that you use the correct value of \( \Delta H \). To melt 50 g of ice requires \( Q = 50 g \cdot \frac{334 J}{g} = 16.7 kJ \), but to vaporize that same quantity of water requires \( Q = 50 g \cdot \frac{2260 J}{g} = 113 kJ \), a much greater amount.
Unit 3, Worksheet 5—Quantitative Energy Problems

For each of the problems sketch a warming or cooling curve to help you decide which equation(s) to use to solve the problem. Keep a reasonable number of significant figures in the answers.

1. A cup of coffee (140 g) cools from 75°C down to comfortable room temperature 20.°C. How much energy does it release to the surroundings?

2. Suppose during volleyball practice, you lost 2.0 lbs of water due to sweating. If all of this water evaporated, how much energy did the water absorb from your body? Express your answer in kJ. (NOTE: 2.2 lbs = 1.0 kg)

3. Suppose that during the Icy Hot lab that 65 kJ of energy were transferred to 450 g of water at 20.°C. What would have been the final temperature of the water?
4. The specific heat capacity of solid iron is 0.447 J/g°C. If the same quantity of energy as in #3 were transferred to a 450 g chunk of iron at 20.°C, what would be the final temperature?

5. Suppose a bag full of ice (450 g) at 0.0 °C sits on the counter and begins to melt to liquid water. How much energy must be absorbed by the ice if 2/3 of it melted?

6. A serving of Cheez-Its releases 130 kcal (1 kcal = 4.18 kJ) when digested by your body. If this same amount of energy were transferred to 2.5 kg of water at 27°C, what would the final temperature be?

7. If this same quantity of energy were transferred to 2.5 kg of water at its boiling pt, what fraction of the water would be vaporized?
Unit 3, Worksheet 6—
More Quantitative Energy Problems

For each of the problems sketch a warming or cooling curve to help you decide which equation(s) to use to solve the problem. Keep a reasonable number of significant figures in the answers.

1. How much energy must be absorbed by a 150 g sample of ice at 0.0 °C that melts and then warms to room temperature at 25.0°C?

2. Suppose in the Icy Hot lab that the burner transfers 325 kJ of energy to 450 g of liquid water at 20.0°C. What mass of the water would be boiled away?

3. A 12oz can of soft drink (assume mass = 340 g) at 25°C is placed in a freezer where the temperature is –12 °C. How much energy must be removed from the soft drink for it to reach this temperature?
4. 65.0 kilojoules of energy are added to 150 g of ice at 0.0°C. What is the final temperature of the water?

5. 250 kJ of energy are removed from a 4.00 x 10^2 g sample of water at 60°C. Will the sample of water completely freeze? Explain.

6. An ice cube tray full of ice (235g) at –7.0°C is allowed to warm up to room temperature (22°C). How much energy must be absorbed by the contents of the tray in order for this to happen?

7. If this same quantity of energy were removed from 40.0 g of water vapor at 100°C, what would be the final temperature of the water?
Unit 3 — Extra Practice Problems

Energy
Think of energy as a quantity that is always involved when there is a change in the state of matter. When a substance gets hotter or colder or changes phase, energy is either transferred into or out of the system. Remember that attractions lower the energy state, so one must add energy to a system to pull particles apart.

1. What are the three energy storage “accounts” and describe how you recognize each.
   a. 
   b. 
   c. 

2. Which of these energy storage accounts have we used in this unit?

3. What are the three mechanisms used to transfer energy and describe how you recognize each.
   a. 
   b. 
   c. 

4. Which of these mechanisms have we used in this unit?

5. What are the three guiding principles we used to understand energy?
   a. 
   b. 
   c.
Energy Bar Charts (LOL charts)
For each problem, complete the bar charts and describe the motion and arrangement of the particles before and after the change.

1. Some water spilled on the chemistry lab table evaporates.

![Energy Bar Chart]

Motion before:
Motion after:
Arrangement before:
Arrangement after:

2. A warm bottle of water (30°C) is moved into the freezer. Complete two LOL charts: one for 30°C to 0°C and one for 0°C to -8°C.

![Energy Bar Chart]

Motion before:
Motion after:
Arrangement before:
Arrangement after:

![Energy Bar Chart]

Motion before:
Motion after:
Arrangement before:
Arrangement after:

3. A cold can of diet coke is placed on a desk and warms to room temperature.

![Energy Bar Chart]

Motion before:
Motion after:
Arrangement before:
Arrangement after:
**Kinetic Molecular Theory**

This theory describes all matter as being composed of tiny particles in endless random motion. In a solid, the particles vibrate, but are locked into an orderly array. In a liquid, the particles are still touching but are free to move around past one another. In a gas, the particles are moving very rapidly and are widely separated.

When energy is transferred to a sample of matter, *either* the particles speed up (temperature increases) *or* they get pulled apart (phase change), but *not* both at the same time. This helps account for the shape of the warming curve you got in the Icy Hot lab.

3. Label which phase(s) (solid, liquid, gas) are present in each portion of the curve shown below.

![Graph showing temperature changes]

Draw particle diagrams that correspond with each section of the curve above. Diagrams should depict motion and arrangement.

4. On the graph shown below, label the sections in which the thermal energy ($E_{th}$) of the sample is changing. Label the sections where the phase energy ($E_{ph}$) is changing. Indicate whether the change is an increase or a decrease.

![Graph showing energy changes]
Energy calculations
First, before you do any math, you should sketch a temperature-time curve, so that you can focus on what changes are taking place.

5. On the graph below left sketch the curve that describes the following:
   Initial state: 150 g solid water at –10 °C
   Final state: 150 g liquid water at 0°C

6. On the graph above right sketch the curve that describes the following:
   Initial state: 200 g liquid water at 40 °C
   Final state: half of the water has boiled away at 100°C

When the temperature of a solid, liquid or gas is changing, energy, in the form of heat, Q, is involved. Rather than simply plug-n-chug values into an equation, reason out the quantity of Q from the value of c. For example, you know that 4.18 J is required to increase the temperature of each gram of liquid water by one Celsius degree. If you have more than one gram of water, or if the temperature changes by more than one degree, multiply by the appropriate amounts.

When the substance is undergoing a phase change (freezing or melting, condensing or evaporating), you know that you must use either \( H_f \) or \( H_v \), both of which are factors that tell us the quantity of heat, Q involved for each gram. If more than one change is taking place, you must break the problem into steps. For these situations, temp-time graphs help you decide what is involved in each step (review ws 3).

7. Calculate the energy required to bring about the change in #5.

8. Calculate the energy required to bring about the change in #6.
9. 212 kilojoules of energy are removed from a 380.0 g sample of water at 65°C. Will the sample of water completely freeze? Write a sentence or two that explains your answer and show calculations that support your answer.

10. 0.75 kilojoules of energy are added to 120.0 g of ice at 0°C. What is the final temperature of the water?

11. The temperature of 335 g of water changed from 24.5°C to 26.4°C. How much heat did this sample absorb?
12. How much heat (in kilojoules) has to be removed from 225g of water to lower its temperature from 25.0°C to 10.0°C?

13. To bring 1.0kg of water from 25°C to 99°C takes how much heat input? (ans. 309 kJ)

14. Assuming that Coca Cola has the same specific heat as water (4.18 J/g°C), calculate the amount of heat (in kJ) transferred when one can (about 350g) is cooled from 25°C to 3°C.

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\[ Q = m \cdot C \cdot \Delta T \]

\[ Q = 225 \cdot 4.18 \cdot (25 - 10) \]

\[ Q = 10625.25 \text{ kJ} \]

\[ Q = 1062.525 \text{ kJ} \]

\[ Q = 1031.578 \text{ kJ} \]

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