Thermochemistry is the area of chemistry that focuses on the amount of heat ________________ or ________________ during chemical and physical changes.

All chemical reactions involve energy ________________, changing from one form (chemical potential energy found in the bonds of the reactants or the kinetic energy of moving molecules) to another form such as __________, __________ and __________. In some reactions, these energy changes can be observed by either an increase or a decrease in the overall energy of the system.

**Heat Energy**

Heat or thermal energy is ________________energy which is related to the random movement of atoms and molecules. Temperature is a ________________ measure of “hot” or “cold.” When the atoms and molecules in an object are moving or vibrating quickly, they have a higher ________________ ________________ (KE), and the object is “_____.” When the atoms and molecules are moving slowly, they have ________________; the object is “_____”. Increasing the amount of thermal energy of a substance will cause its temperature to increase and the substance will __________. Likewise, decreasing the amount of thermal energy in a substance will cause its temperature to decrease and the substance will __________.
What causes the energy changes in chemical reactions?
When substances participate in a chemical reaction they either release or absorb _____ During a reaction, the bonds in the reactants are _______ and new bonds are ________, creating the product(s). Energy is required to break bonds, which is then _______ when new bonds are formed. The amount of energy needed or released for a reaction depends on the _______ _______ _______ between that which is required to break the bonds and that which is released when the new bonds are formed.

Example: Forming Water
Hydrogen reacts with oxygen to form water, as is seen by the following equation:
\[ 2H_2 + O_2 \rightarrow 2H_2O \]

In this reaction, the _____ between the two hydrogen atoms in the H\textsubscript{2} molecule breaks, as will the bond between the oxygen atoms in the O\textsubscript{2} molecule. New bonds will form between two of the hydrogen atoms and a single oxygen atom in the water molecule (the _______). When bonds break, energy is _________ from the surroundings, making this an ____________ process. Energy is _________ when new bonds form, this is an ______________ process.

Making and Breaking Bonds
There are several factors which affect the ability of a bond to be broken.

Bond Order:
This is the _______ of electron pairs shared between two bonded _____.
- Bond order one – where two electrons are shared in a _________ bond between two atoms.
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- Bond order two – two electron pairs (i.e. four electrons in total) in a ______ bond.
- Bond order three – three electrons pairs (6 electrons in total) between two atoms in a ______ bond.

Bond Length:
This is the ______ between the nuclei of the atoms in a bond at the minimum point of energy.
Bond lengths depend on the _____ of the atoms involved and the bond ________. Where there is a bond order of two or three, the levels of attraction between the nuclei are much ______ and the atoms are _______ _______ (i.e. there is a smaller bond length). Therefore, as the bond order __________, the bond length __________. The table below shows the bond length for some common carbon bonds.

<table>
<thead>
<tr>
<th>Bond</th>
<th>Bond length (picometers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C—O</td>
<td>143</td>
</tr>
<tr>
<td>C = O</td>
<td>122</td>
</tr>
<tr>
<td>C—C</td>
<td>154</td>
</tr>
<tr>
<td>C = C</td>
<td>134</td>
</tr>
<tr>
<td>C ≡ O</td>
<td>120</td>
</tr>
</tbody>
</table>

Bond Energy:
The energy required to break a bond is called the _______ _______ or bond dissociation energy. Bond energies are measured in the units of kilojoules per mole (kJ.mol⁻¹).

Practice Questions:
1. What is thermochemistry?
2. Name the types of observable energy released in a chemical reaction.
3. Define temperature
4. Why is energy required for a chemical reaction?

5. List the three factors which affect the strength of a chemical bond.

Calculating Bond Energies
Since energy is always needed to break a bond (i.e. the process is ___________), bond energy is always represented as a __________ number. The ________of energy needed to break a bond is then released when that particular bond ____. The table below shows some of the common bonds seen in this course and their respective bond energies. The examples that follow show how this information can be used to calculate the change in energy (called _______ _________) during the course of a reaction.

<table>
<thead>
<tr>
<th>Bond</th>
<th>Bond Energy (kJ mol⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C−H</td>
<td>414</td>
</tr>
<tr>
<td>C−O</td>
<td>358</td>
</tr>
<tr>
<td>C=O</td>
<td>804</td>
</tr>
<tr>
<td>H−O</td>
<td>463</td>
</tr>
<tr>
<td>N−H</td>
<td>391</td>
</tr>
<tr>
<td>H−H</td>
<td>436</td>
</tr>
<tr>
<td>C−C</td>
<td>346</td>
</tr>
<tr>
<td>C=C</td>
<td>614</td>
</tr>
</tbody>
</table>

Example Question
The combustion of methane forms carbon dioxide and water, as shown in the equation below:

\[ CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \]
Calculate the enthalpy change for this reaction.

Drawing the diagrams as Lewis diagrams enables the bonds to be viewed:

<table>
<thead>
<tr>
<th>Step 1: Identify and total the bonds which are broken for each reactant:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reactant</strong></td>
</tr>
<tr>
<td>CH₄</td>
</tr>
<tr>
<td>O₂</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step 2: Total the energy for the bonds broken:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1656 + 996 = ____________________</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step 3: Identify and total the bonds which are made for each product:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product</strong></td>
</tr>
<tr>
<td>CO₂</td>
</tr>
<tr>
<td>H₂O</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step 4: Total the energy for the bonds made:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1608 + 1852 = __________</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step 5: Use the equation change in energy = energy required to break bonds – energy required to form bonds</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta H = 2652 – 3460 = __________ )</td>
</tr>
</tbody>
</table>

**Practice Question:**

Use the bond enthalpies in the table below to calculate the enthalpy change for formation of HCl.

The equation for this reaction is:

\[
\text{H}_2(g) + \text{Cl}_2(g) \rightarrow 2\text{HCl}(g)
\]
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<table>
<thead>
<tr>
<th>Bond</th>
<th>Bond Enthalpy (kJ mol(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>H—H</td>
<td>436</td>
</tr>
<tr>
<td>Cl—Cl</td>
<td>242</td>
</tr>
<tr>
<td>H—Cl</td>
<td>431</td>
</tr>
</tbody>
</table>

Answer:

Explanation:

Endothermic Reactions

The features of an endothermic reaction include:

- They _______ heat energy from their surroundings in order to break the bonds in the ________.
- The energy required to break these bonds is _______ _____ the total energy released when the products are formed.
- As the reaction progresses, the products have _______ energy than the reactants.
- The enthalpy change will be ______________
- This type of reaction can be represented by the following formula:

\[
\text{Reactants} + \text{Energy} \rightarrow \text{Product}
\]

Examples of Endothermic reactions

- The thermal decomposition of limestone
  The breakdown of limestone into quicklime (calcium oxide) and _______ _________ is a very important process used in a variety of industries. Quicklime is used to make steel from iron and also to neutralize soils that are too acidic. The limestone must be heated in a kiln at a temperature of over 9000°C before the thermal decomposition reaction, which breaks the bonds in the calcium carbonate will take place. The equation for the reaction is shown below:
CaCO_3(s) → CaO(s) + CO_2(g)

- Ammonium nitrate dissolving in water
  When solid ammonium nitrate (__________) dissolves in a beaker of water, the water becomes __________ since the ammonium nitrate __________ energy from the water. The equation for this reaction is shown below:

\[ \text{NH}_4\text{NO}_3(aq) \xrightarrow{H_2O} \text{NH}_4^+(aq) + \text{NO}_3^-(aq) \]

The dissolved ammonium nitrate (\(\text{NH}_4^+(aq)\) and \(\text{NO}_3^-(aq)\) ions) contain __________ energy than the solid ammonium nitrate.

Other Examples of Endothermic Reactions:
- Photosynthesis
- Liquids evaporating
- Solids melting

Exothermic Reactions
The features of an exothermic reaction include:
- They __________ energy into their surroundings in the form of __________ and __________.
- The products have _____ energy than the __________ since energy is lost from the system
- The enthalpy change will be _______________.
- We can represent an exothermic reaction using the following general formula:

\[ \text{Reactants} \rightarrow \text{Product + Energy} \]

Examples of Exothermic reactions
- Combustion Reactions
  When a fuel such as methane gas in burns oxygen it produces large amounts of __________ and __________. The burning of fuel is an example of a combustion reaction and is heavily
relied on to produce the energy used in the production of electricity. Recall that the general equation for complete combustion is:

\[ \text{Fuel} + \text{Oxygen} \rightarrow \text{Heat} + \text{Water} + \text{Carbon Dioxide} \]

The following equation describes the combustion of a hydrocarbon such as methane (CH\(_4\))

\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{Heat} + \text{H}_2\text{O} + \text{CO}_2 \]

- **Dissolving Sodium Hydroxide**
  When solid sodium hydroxide pellets, NaOH (s) are dissolved in a beaker of water, the water becomes ___________. This is an exothermic reaction since the heat energy that has been produced has been ______________ to the surrounding water. The chemical equation for this reaction is:

\[ \text{NaOH}_{(s)} \xrightarrow{H_2O} \text{Na}^+_{(aq)} + \text{OH}^-_{(aq)} \]

The dissolved sodium hydroxide (Na\(^+\)\(_{aq}\) and OH\(^-\)\(_{aq}\) ions) contains __________ energy than the solid sodium hydroxide.

**Other Examples of Exothermic Reactions:**
- Burning magnesium to form magnesium oxide
- Acid-Base (neutralization) reactions
- Explosions such as the Hindenburg disaster

**Practice Questions:**
Decide if the following reactions are endothermic or exothermic. Give a reason for your answer.

1. Magnesium metal is added to hydrochloric acid. The test tube becomes warm and the metal fizzes rapidly, releasing hydrogen gas. Water is vaporized to steam.
   
   **Answer:**
   
   **Justification:**

2. Ice melts
   
   **Answer:**
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3. Two chlorine atoms combine to form a chlorine molecule.
   Answer:
   Justification:

4. Alcohol evaporates when placed on the skin
   Answer:
   Justification:

5. Plants use photosynthesis to generate the carbohydrate glucose.
   Answer:
   Justification:

Dissolving and Energy

The process of dissolving a solid such as those described in the examples above contains both endothermic and exothermic processes. When a solid dissolves two processes occur:

1. The solid particles ________. This process must overcome the ____________
   ____________ which hold the solid particles together and therefore requires energy to be put
   into the system. This process is ________________.

2. The solvent particles are attracted to and surround the separated solid particles. This
   process is ________________ as it releases energy.
Whether the overall dissolving process is endothermic or exothermic depends on the amount of ________ ________ by the first step in the process compared to the energy ________ in the second step.

- If _____ energy is needed for the first process, than is released in the second process, then the process will be _____________. This will be observed by the test tube or beaker becoming hotter.
- If _____ energy is needed for the first step, than is released in the second step then the process is _____________ and the test tube or beaker will __________ ________.

**Practice Question:**

Explain the 2 types of processes which occur in dissolving. Discuss which process is endothermic and which is exothermic.