Unit 11: Thermochemistry

Ms. Johnson
Honors Chemistry

Unit Learning Objectives: By the end of the unit students will be able to…
(1) Define temperature and heat and give the appropriate unit for each.
(2) Describe and graph the temperature changes for a heating or cooling curve, and label each part of the curve with the appropriate phase(s). Determine the melting/freezing point and boiling/condensing point from a heating or cooling curve. Describe what is happening to particles at each region of a heating/cooling curve including where particles begin to move faster/slower and where bonds between particles are broken/formed.
(3) Define heat of vaporization and heat of fusion and give the appropriate unit for each.
(4) Perform calculations involving heat of vaporization and heat of fusion for phase changes of substances.
(5) Define specific heat capacity and give the appropriate units.
(6) Perform calculations involving specific heat capacity for heating and cooling of substances.
(7) Define heat of reaction/enthalpy and give the appropriate units.
(8) Use data from a calorimetry experiment to determine the heat of a reaction in kJ/mol.
(9) Define exothermic and endothermic reactions and give examples of each.
(10) Determine if a reaction is exothermic or endothermic from the chemical equation or ΔH value. Given the ΔH value, add the heat term to the appropriate side of a chemical reaction.
(11) Draw Lewis structures for molecules to determine the number and type of bonds being broken and formed in a chemical reaction. Calculate the heat of a reaction from tabulated bond energies.
(12) Calculate the heat of a reaction from tabulated heats of formation.
(13) Calculate the heat of a reaction using Hess' Law.
(14) Interpret a potential energy diagram to determine heat of reaction and activation energy for forward and reverse reactions as well as for catalyzed and uncatalyzed reactions.

Monday	Tuesday	Wednesday	Thursday	Friday
April 4 **Demo**: Heat v. Temp. Temperature, Heat, Phase Changes	**5** Heating and Cooling Curves	**6** Heating and Cooling Curves	**7** Water Calculations/ Calorimetry	**8** **Spring Rally** **Partner Quiz:** Heating and Cooling
11 Calorimetry	**12** **Lab:** Calorimetry	**13** Heat of Reaction	**14** Heat of formation	**15** Heat of formation **Partner Quiz:** Water Calcs and Calorimetry
18 *CST/CMA Life Science Testing (Periods Am, 1,3,5)*	**19** *CST/CMA Life Science Testing (Periods Am, 2,4,6)*	**20** Hess' Law & Potential Energy Diagrams	**21** *Problem of the Unit & Review (Periods Am, 1, 3, 5)*	**22** *Problem of the Unit & Review (Periods Am, 2,4,6)*
25 **Unit 11 Test** **HW packet Due**	*** Note: Testing will occur from Monday, April 18th- Friday April 29** *** Block Schedule from Monday, April 18th- Friday April 29** ** ODD periods meet on Mon & Thurs* ** EVEN periods meet on Tues & Fri* ** ALL classes meet Wed* ** AM meets @ regular time*			

Thermochemistry: ____

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Temperature: ____

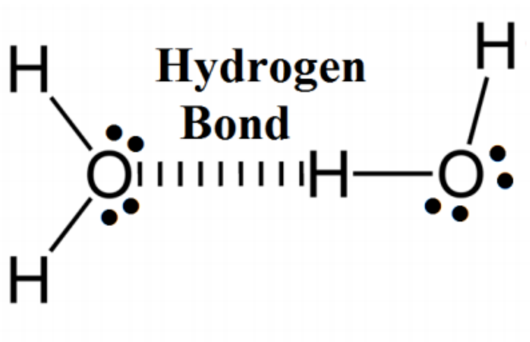
Heat, ΔH: ____

Heating and Cooling of Water:

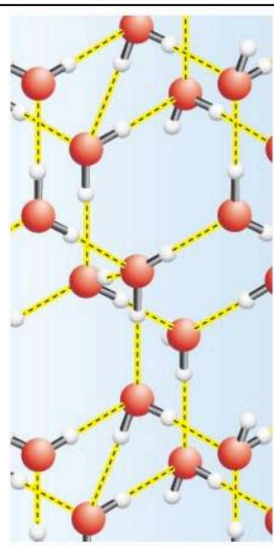
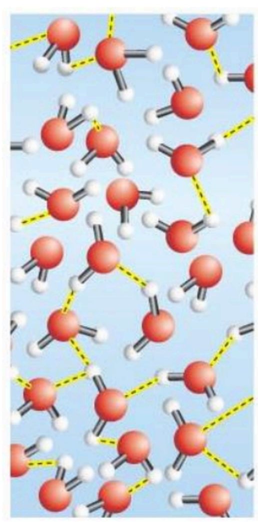
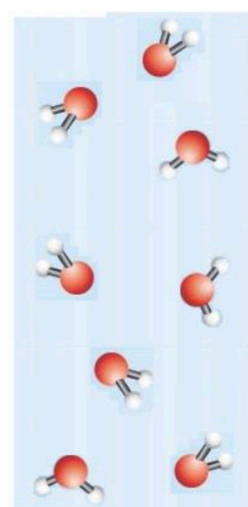
The Nature of Water:

Water is a unique molecule because it has a "bent" structure which causes the molecule to be polar. Due to this polarity, the water molecules become attracted to one another and form a type of bond called *"hydrogen bonds"* ***<u>between</u>*** molecules.

Hydrogen Bonds can be represented as shown below.

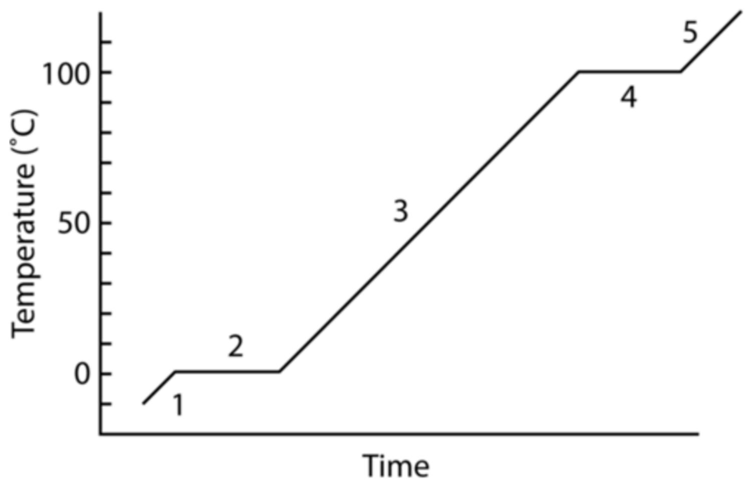


Predict: What do you think happens to the hydrogen bonds when water boils? What do you think happens when water freezes?

Phase	Solid/Ice	Liquid	Gas/Steam
Diagram			
Percent of water molecules involved in hydrogen bonds			

Consider the changes that take place over a temperature range for water.

Heating Curve for water



What happens during each stage that water is heated?

1.

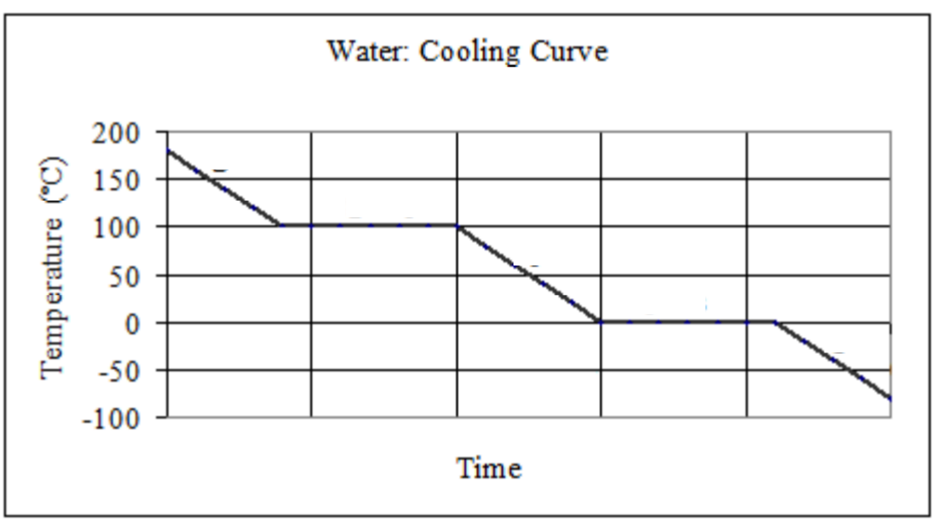
2.

3.

4.

5.

Ex. Cooling Curve for Water



Label the following on the curve:

1. The phases of water
2. The phase changes of water
3. Where hydrogen bonds are formed/broken
4. The boiling point, and the melting point.

Calculating Heat, ΔH: The formation or breaking of bonds

1. Phase Changes

At a phase change, the temperature of a substance will remain constant. When a substance is melted or boiled, the heat energy added is used to break bonds ***between*** particles. When a substance is frozen or condensed, heat energy is released as bonds are formed ***between*** particles.

The heat associated with a phase change can be calculated using the following equations.

Melting and Freezing

$$\Delta H = H_{fus} m$$

where: ΔH = Heat (J)
H_{fus} = Heat of Fusion (J/g)
m = mass (g)

The heat of fusion is the energy required to melt one gram of a substance.

Boiling and Condensing

$$\Delta H = H_{vap} m$$

where: ΔH = Heat (J)
H_{vap} = Heat of Vapourization (J/g)
m = mass (g)

The heat of vapourization is the energy required to boil one gram of a substance.

ex. Calculate the heat required to melt 0.500 g of ice.

Ex. Calculate the mass of water that can be boiled with 564 J of heat energy.

2. Heating and Cooling

When a substance is heated, the energy added is used to increase the speed of the particles, so temperature is increased. When a substance is cooled, heat energy is released as the speed of the particles decreases.

The amount of heat associated with changing the temperature of a substance can be calculated according to the following equation:

$$\Delta H = m c \Delta T$$

where: ΔH = Heat (J)
m = mass (g)
c = specific heat capacity (J/g˚C)
ΔT = Temperature Change (Final Temperature – Initial Temperature) (˚C)

The specific heat capacity of a substance is the energy required to increase the temperature of one gram of the substance by 1ºC.

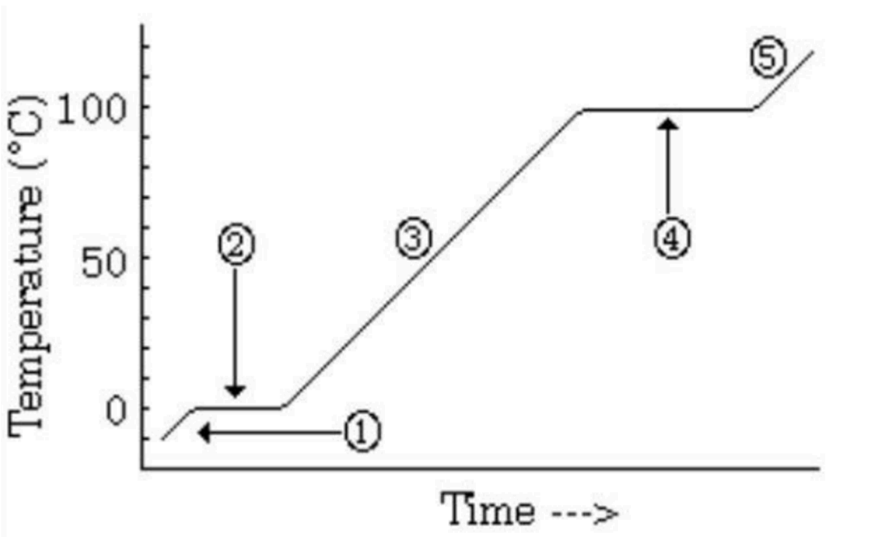
ex. Calculate the amount of energy required to heat 100 g of water from 30.0 °C to 40.0 °C. How many kilojoules (kJ) is this?

Ex. Calculate the mass of gold that requires 208 J to heat from 30 °C to 80 °C. How many moles is this?

Ex. Calculate the change in temperature if 2100 J of energy are used to heat 250 g of glass at 150 °C. What is the final temperature of the glass?

To amount of energy that is needed to break/form hydrogen bonds in a heating/cooling curve for water can be calculated using the above operations.

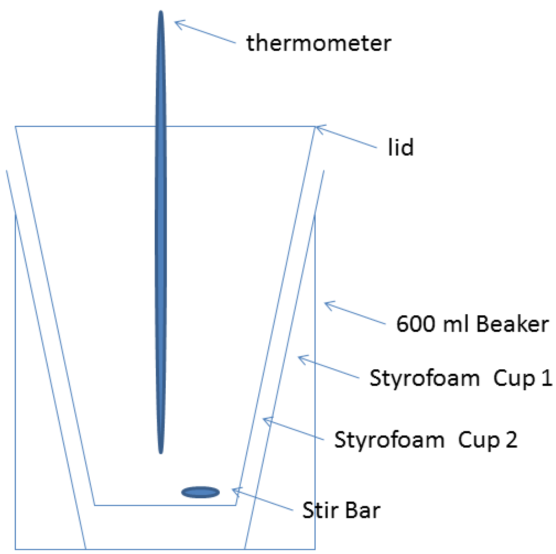
Ex. How much energy is required to turn 20 g of ice at -30 °C into steam at 140 °C?
Hint: There are five calculations needed to solve this problem.



Calorimetry

A Calorimeter is a device containing water this is used to measure the amount of heat given off in a chemical reaction. The mass and the initial temperature of the water are recorded. The reaction is then carried out such that the heat released by the reaction can be absorbed by the water. The final temperature of the water is recorded. Since the heat capacity of the water is known (4.18 J/g °C), the heat absorbed by the water can be calculated and will be equal to the amount of heat released by the chemical equation.

Ex. A Coffee Cup Calorimeter (pressure is constant)



Ex. A reaction produces enough energy to heat 500 g of water in a calorimeter from 10.0 °C to 50.0 °C. How much heat was released by the reaction?

Ex A 5.40 g sample of ethane (C_2H_6) is combusted in a calorimeter filled with 1000 g of water. The temperature of water in the calorimeter increases from 10.0 °C to 78.0 °C. Determine the heat of combustion of ethane in **kJ/mol.**

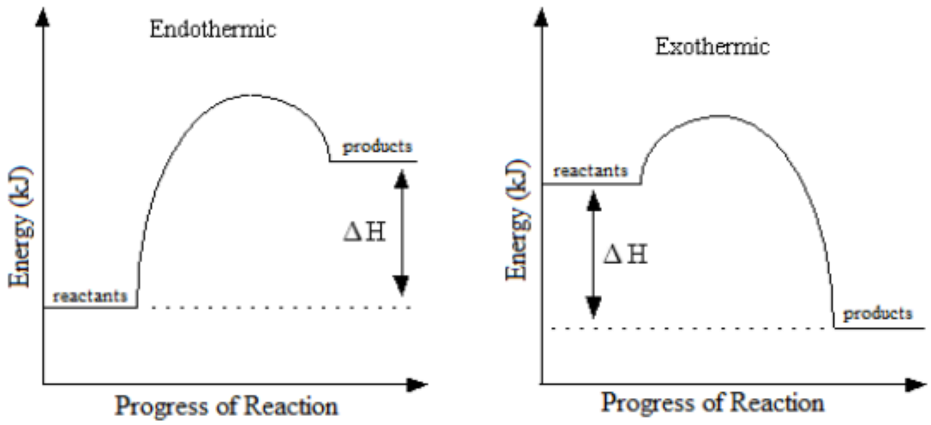
Heat of Reaction

Heat of Reaction: ____

____

ΔH = H products – H reactants
Energy is **absorbed** in an **endothermic** reaction and **released** in an **exothermic** reaction.

Below are potential energy diagrams showing the energy change for an endothermic and exothermic reaction.



In an endothermic reaction, ΔH is **POSITIVE** or written as a **reactant**

ex. ZnO (s) + H_2 (g) → Zn (s) + H_2O (g); ΔH = +106.3 kJ/mol
or
ZnO (s) + H_2 (g) + 106.3 kJ/mol → Zn (s) + H_2O (g)

In an exothermic reaction, ΔH is **NEGATIVE** or written as a **product**

ex. CH_4 (g) + $2O_2$ (g) → CO_2 (g) + $2H_2O$ (l); ΔH = –890.5 kJ/mol
or
CH_4 (g) + $2O_2$ (g) → CO_2 (g) + $2H_2O$ (l) + 890.5 kJ/mol

The units for Enthalpy, ΔH, are kJ/mol, but more specifically per mole of reaction. The amount of heat in a reaction will depend on the number of moles of reactants or products (i.e. the coefficient of the chemical in the equation).

For the reaction: ZnO (s) + H_2 (g) → Zn (s) + H_2O (g)

$$\Delta H = \frac{106.3 \text{ kJ}}{1 \text{ mol } ZnO} \; or \; \frac{106.3 \text{ kJ}}{1 \text{ mol } H_2} \; or \; \frac{106.3 \text{ kJ}}{1 \text{ mol } Zn} \; or \; \frac{106.3 \text{ kJ}}{1 \text{ mol } H_2O}$$

How much heat will be required for 2.000 mol H_2?

$$2.000 \, mol \, H_2 \text{ x } \frac{106.3 \text{ kJ}}{1 \text{ mol } H_2} = 212.6 \, kJ$$

For the reaction: CH_4 (g) + $2O_2$ (g) → CO_2 (g) + $2H_2O$ (l)

$$\Delta H = \frac{-890.5 \text{ kJ}}{1 \text{ mol } CH_4} \; or \; \frac{-890.5 \text{ kJ}}{2 \text{ mol } O_2} \; or \; \frac{-890.5 \text{ kJ}}{1 \text{ mol } CO_2} \; or \; \frac{-890.5 \text{ kJ}}{2 \text{ mol } H_2O}$$

How much heat will be released for 4.000 mol of H_2O?

$$4.000 \, mol \, H_2O \, x \, \frac{-890.5 \text{ kJ}}{2 \text{ mol } H_2O} = -1781 \, kJ$$

How much heat will be released for 25.60 g of O_2?

$$25.60 \, g \, O_2 \, x \, \frac{1 \, mol \, O_2}{32.00 \, g \, O_2} \, x \, \frac{-890.5 \text{ kJ}}{2 \text{ mol } O_2} = -356.2 \, kJ$$

ex. How much heat would be produced for 7.20 g of H_2O?

ex. What mass of O_2 would produce 340 kJ of heat?

Calculating the Heat of a Reaction

Bond Energy: ____

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The heat of a reaction is the total energy of the bonds broken, minus the total energy of the bonds formed.

ΔH= (total energy of bonds broken)- (total energy of the bonds formed)

Note: A Lewis Structure must first be drawn for each molecule in the reaction in order to determine the nature and the number of chemical bonds present. Bond energy values can be found on the equation sheet.

Ex. Use bond energies to calculate ΔH for the following reactions.

a. $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$

b. $2C_2H_2(g) + 5O_2(g) \rightarrow 4CO_2(g) + 2H_2O(g)$

Heat of Formation:

Heat of Formation, ΔHf: the heat released or absorbed when one mole of a compound is formed by a combination of its elements. The heat of a reaction is the total of the heats of formation of products, minus the total of the heats of formation of the reactants

ΔH= (total Hf products)- (total Hf reactants)

The heat of formation of elements in standard state is equal to zero. The standard state if an element is the form in which it exists at 25 °C and 1.00 atm. The heat of formation of a compound can be found on a table.

Ex. Use the heats of formation to calculate ΔH for each of the following reactions.

a. $ZnO\ (s) + H_2(g) \rightarrow Zn(s) +\ H_2O\ (g)$

b. $CH_4(g) + 2O_2(g) \rightarrow CO_2\,(g) + 2H_2O\,(l)$

Hess's Law:

Hess's Law: the overall enthalpy change for a reaction is equal to the sum of enthalpy changes for individual steps in the process. The steps much add to give the overall reaction.

ex. $2NO\,(g) + O_2\,(g) \rightarrow 2NO_2\,(g)$

Steps:	$2NO\,(g) \rightarrow N_2\,(g) + O_2\,(g)$	$\Delta H = -180.6$ kJ/mol
	$N_2\,(g) + 2O_2\,(g) \rightarrow 2NO_2\,(g)$	$\Delta H = 66.4$ kJ/mol
Overall:		$\Delta H =$ _________ kJ/mol

Sometimes the steps need to be manipulated so that the overall reaction can be obtained. A step can multiplied by a constant or reversed. If the step is multiplied by a number, ΔH is also multiplied by that number. If the step is reversed, the sign of ΔH is also reversed (i.e. negative becomes positive, positive becomes negative).

ex. Use the steps provided to calculate the overall heat of the reaction.
$2Mg\,(s) + SiCl_4\,(l) \rightarrow Si\,(s) + 2MgCl_2\,(s)$

Steps:	$Si\,(s) + 2Cl_2\,(g) \rightarrow SiCl_4\,(l)$	$\Delta H = -687$ kJ/mol
	$Mg\,(s) + Cl_2\,(g) \rightarrow MgCl_2\,(s)$	$\Delta H = -642$ kJ/mol
Overall:		$\Delta H =$ _________ kJ/mol

ex. Use the steps provided to calculate the overall heat of the reaction.

$2C_{10}H_{22}\,(l) + 31O_2\,(g) \rightarrow 20CO_2\,(g) + 22H_2O\,(g)$

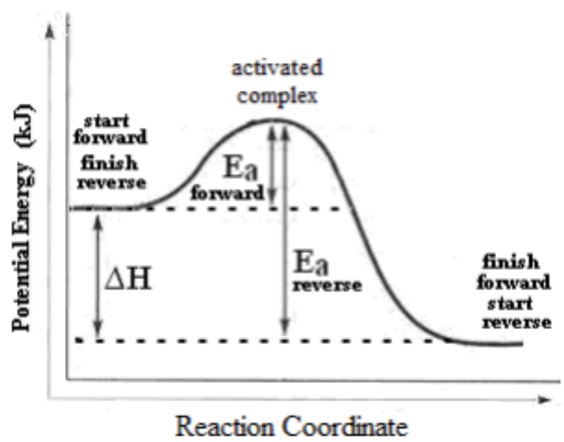
Steps:	$10C\,(s) + 11H_2\,(g) \rightarrow C_{10}H_{22}\,(l)$	$\Delta H = -249.1$ kJ/mol
	$C\,(s) + O_2\,(g) \rightarrow CO_2\,(g)$	$\Delta H = -393.5$ kJ/mol
	$2H_2\,(g) + O_2\,(g) \rightarrow 2H_2O\,(g)$	$\Delta H = -484.0$ kJ/mol

Overall:

$\Delta H =$ ___________ kJ/mol

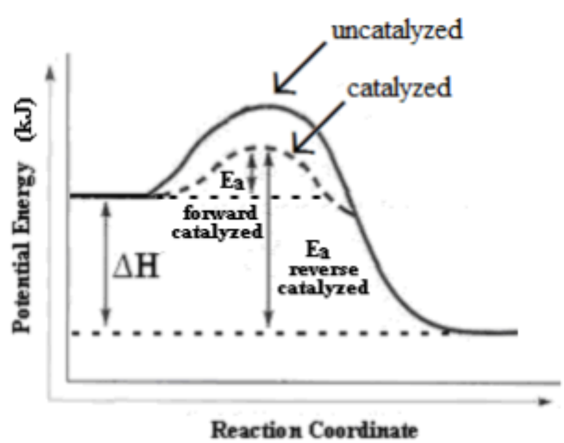
Potential Energy Diagrams
The energy changes in a reaction can be represented by a potential energy diagram.
The enthalpy change, ΔH, of a reaction is the energy difference between the products and reactants.
The activation energy, Ea, of a reaction is the energy difference from reactants to the highest energy point (called the activated complex).

Potential Energy Diagram

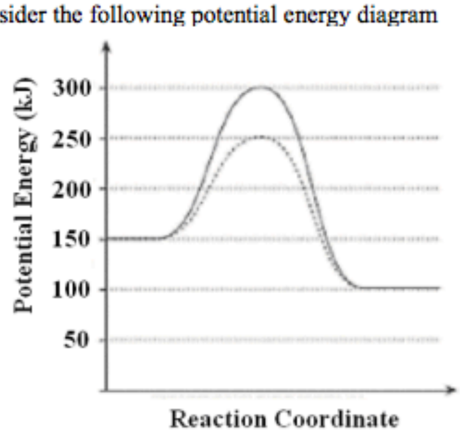


The activation energy for a chemical reaction can be lowered with the addition of a catalyst. The potential energy diagram for the catalyzed reaction is shown below. Note that the heat of the reaction does not change.

Potential Energy Diagram Catalyzed



ex: Consider the following potential energy diagram



(a) What is ΔH for the forward, uncatalyzed reaction?
(b) What is ΔH for the forward, catalyzed reaction?
(c) What is ΔH for the reverse, uncatalyzed reaction?
(d) What is ΔH for the reverse, catalyzed reaction?
(e) Is the forward reaction endothermic or exothermic?
(f) Is the reverse reaction endothermic or exothermic?
(g) What is E_a for the forward, uncatalyzed reaction?
(h) What is E_a for the forward, catalyzed reaction?
(i) What is E_a for the reverse, uncatalyzed reaction?
(j) What is E_a for the reverse, catalyzed reaction?