AP Chemistry - Unit 4
Wkst: Thermochemistry and energy diagram

Potential Energy Diagrams

The energy changes that occur during a chemical reaction can be shown in a diagram called a potential energy diagram, or sometimes called a reaction progress curve. A **potential energy diagram** shows the change in potential energy of a system as reactants are converted into products. The figure below shows basic potential energy diagrams for an endothermic (A) and an exothermic (B) reaction. Recall that the enthalpy change (ΔH) is positive for an endothermic reaction and negative for an exothermic reaction. This can be seen in the potential energy diagrams. The total potential energy of the system increases for the endothermic reaction as the system absorbs energy from the surroundings. The total potential energy of the system decreases for the exothermic reaction as the system releases energy to the surroundings.

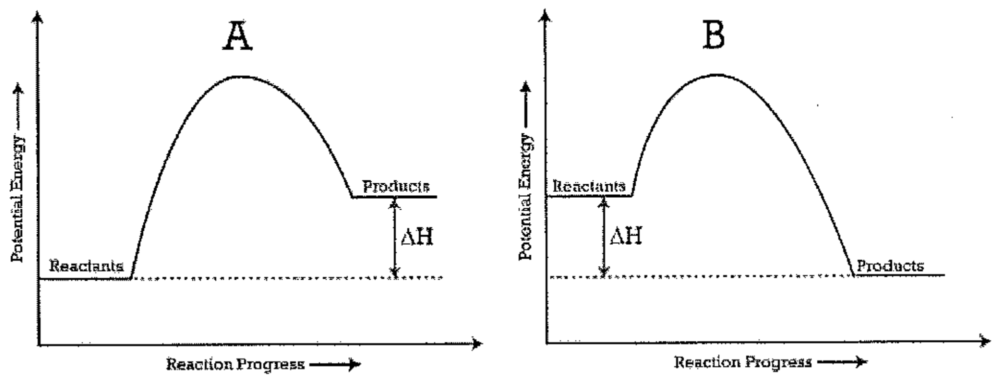

Figure 1: A potential energy diagram shows the total potential energy of a reacting system as the reaction proceeds. (A) In an endothermic reaction, the energy of the products is greater than the energy of the reactants and ΔH is positive. (B) In an exothermic reaction, the energy of the products is lower than the energy of the reactants and ΔH is negative.

The activation energy for a reaction is illustrated in the potential energy diagram by the height of the hill between the reactants and the products. For this reason, the activation energy of a reaction is sometimes referred to as the activation energy barrier. Reacting particles must have enough energy so that when they collide they can overcome that barrier (see figure below).

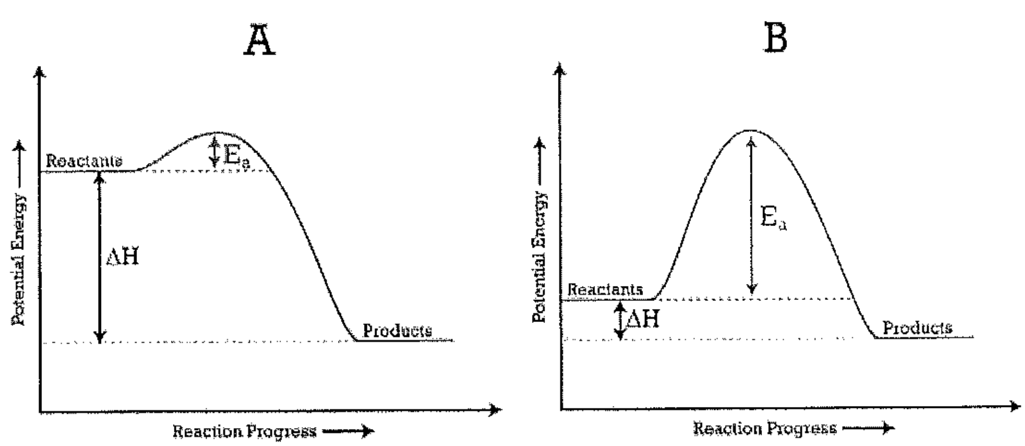

Figure 2: The activation energy (E_a) of a reaction is the barrier that must be overcome for the reactants to be able to become products. (A) The activation energy is low, meaning that the reaction is likely to be fast. (B) The activation energy is high, meaning that the reaction is likely to be slow.

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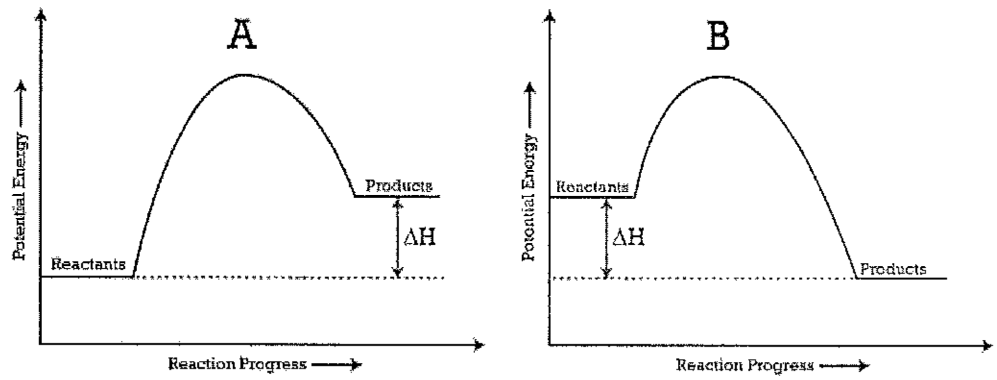

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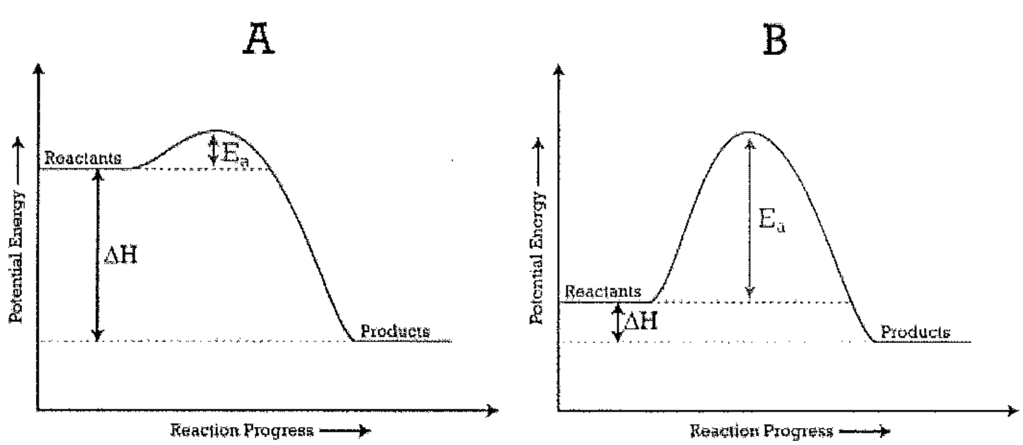

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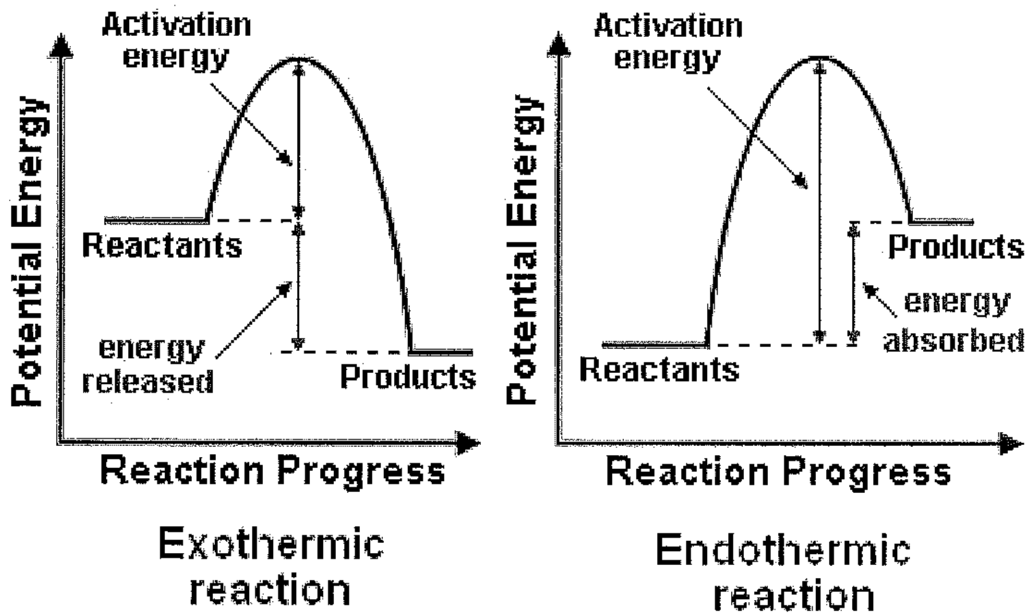
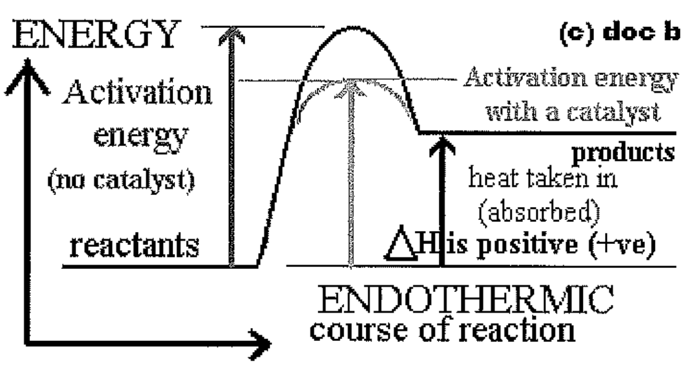
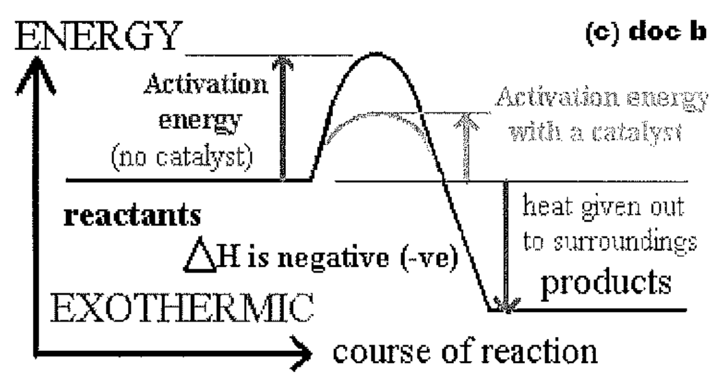


Source: Milton Beychok

Energy level diagrams of exothermic and endothermic reactions.[4][5][6]





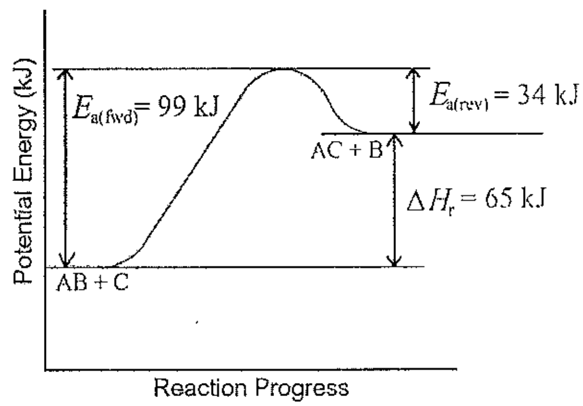
Consider the following reaction:

$AB + C \rightarrow AC + B \ \Delta H_r = +65\text{ kJ}, E_{a(rev)} = +34\text{ kJ}$

Draw and label a potential energy diagram for this reaction. Calculate and label $E_{a(fwd)}$.

What Is Required?
You need to draw a potential energy diagram labelling the x-axis and y-axis, the transition state, and $E_{a(fwd)}$.

What Is Given?
You know the balanced chemical equation for the reaction.
You know the activation energy of the reverse reaction: $E_{a(rev)} = +34$ kJ
You know the enthalpy change of the forward reaction $\Delta H_r = +65$ kJ

Plan Your Strategy	Act on Your Strategy
Use the formula $\Delta H_r = E_{a(fwd)} - E_{a(rev)}$ to calculate $E_{a(fwd)}$.	$\Delta H_r = E_{a(fwd)} - E_{a(rev)}$ $+65\text{ kJ} = E_{a(fwd)} - (+34\text{ kJ})$ $E_{a(fwd)} = +99\text{ kJ}$
Draw and label the potential energy diagram.	

Check Your Solution
Since the sign of ΔH_r is positive, the reaction is endothermic and the potential energy diagram shows the reactants at a lower energy than the products.

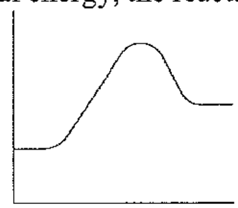
Note:
→ Fwd
← rev
$E_{a(rev)}$ = Activation Energy Reverse direction
$E_{a(fwd)}$ = A.E Forward Direction

Representing a Reaction with a Potential Energy Diagram

Complete the following potential energy diagram by adding the following labels: an appropriate label for the x-axis and y-axis, $E_{a(fwd)}$, $E_{a(rev)}$, ΔH_r.

a. Is the forward reaction endothermic or exothermic?

b. Which has the higher potential energy, the reactants or the products?

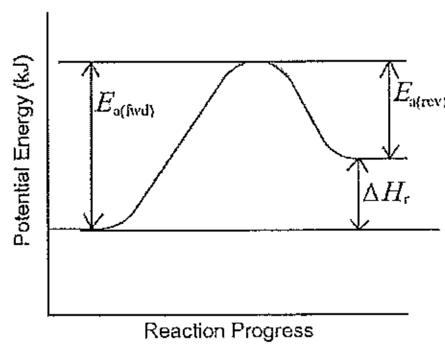


What Is Required?

You need to label the given potential energy diagram, determine if the reaction is exothermic or endothermic and indicate which has the higher potential energy, reactants or products.

What Is Given?

You have an unlabelled potential energy diagram.

Plan Your Strategy	Act on Your Strategy
The y-axis is an energy scale, and the x- axis follows the reaction progress. The reactants will be shown as the first level portion, and the products will be the second level portion of the diagram. The activation energy in the forward direction, $E_{a(fwd)}$, is the difference between the reactant energy and the transition state at the peak of the diagram. The activation energy for the reverse reaction, $E_{a(rev)}$, is the difference between the product energy and transition state at the peak of the diagram. ΔH_r is the difference between the potential energy of the reactant and the potential energy of the product.	**a.** The reaction is endothermic. **b.** The products have a higher potential energy than the reactants. 

Check Your Solution

The potential energy of the reactant is lower than the potential energy of the product. This corresponds to an endothermic reaction.

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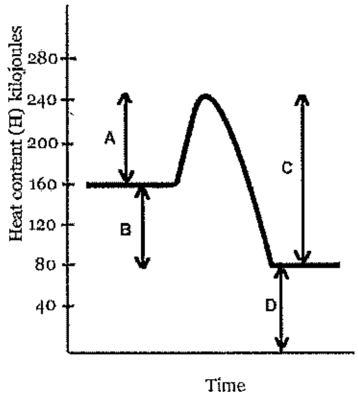

Diagram 1

1. If you were holding in your hand a test tube in which the reaction, Diagram 1, is taking place, it would
    a. feel cold, because energy is being absorbed
    b. feel hot, because energy is being released
    c. feel hot, because energy is being absorbed
    d. feel cold, because energy is being released

2. The reaction whose energy diagram 1 is shown here is
    a. exothermic
    b. endothermic
    c. isothermic

3. In the reaction depicted in the diagram 1
    a. the energy content of the reactants is greater than the energy content of the products
    b. the energy content of the reactants is the same energy content of the products
    c. the energy content of the products is greater than the energy content of the reactants

4. In the reaction in diagram 2
    a. the energy content of the products is greater than the energy content of the reactants
    b. the energy content of the reactants is the same as the energy content of the products
    c. the energy content of the reactants is greater than the energy content of the products

5. The activation energy (E_a), diagram 2, of this reaction is
    a. 240 KJ
    b. 160 KJ
    c. -80 KJ
    d. 40 KJ
    e. 80 KJ

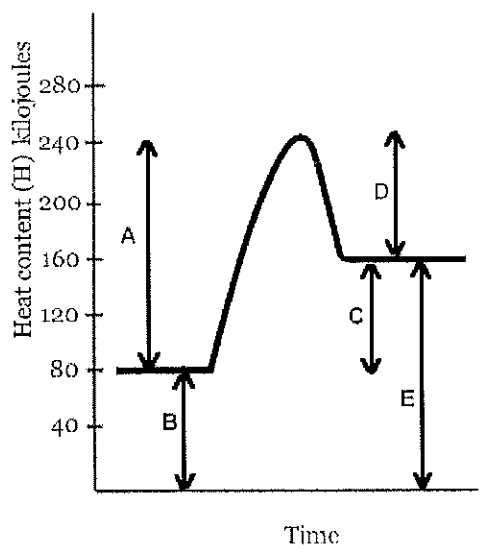

Diagram 2

6. The heat of reaction (ΔH, or Δ E), diagram 2, of this reaction is
   a. 160 KJ
   b. -80 KJ
   c. -160 KJ
   d. 240 KJ
   e. 80 KJ

7. The reaction whose energy diagram 2 is
   a. exothermic
   b. endothermic
   c. isothermic

8. If you where holding in your hand a test tube in which the reaction in diagram 2 is taking place, it would feel
   a. feel hot, because energy is being released
   b. feel hot, because energy is being absorbed
   c. feel cold, because energy is being absorbed
   d. feel cold , because energy is being released

9. The line that represents the heat of reaction (ΔH, or Δ E), diagram 2, of this reaction is
   a. Line E
   b. Line A
   c. Line B
   d. Line D
   e. Line C

10. The heat of reaction (ΔH, or Δ E) of this reaction in diagram 3 is
    a. 80 KJ
    b. 240 KJ
    c. -160 KJ
    d. 160 KJ
    e. -80 KJ

11. The line that represents the heat of reaction (ΔH, or Δ E), in diagram 3, of this reaction is
    a. Line B
    b. Line C
    c. Line D
    d. Line A

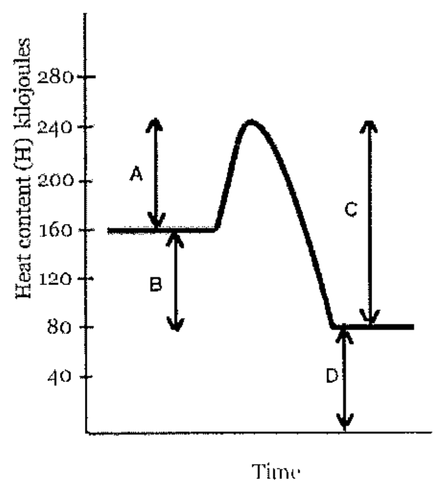

Diagram 3

12. The activation energy (E_a) of diagram 3 is
    a. 160 KJ
    b. 240 KJ
    c. 80 KJ
    d. -80 KJ
    e. 40 KJ

13. Consider the reaction below:

$$C + D \rightarrow CD \quad E_{a(fwd)} = +61 \text{ kJ}, \qquad E_{a(rev)} = +150 \text{ kJ}$$

Draw and label a potential energy diagram for this reaction. Calculate and label ΔH_r.

What Is Required?
You need to draw and label a potential energy diagram for this reaction and calculate and label ΔH_r.

What Is Given?
You know the activation energy of the forward reaction: $E_{a(fwd)} = +61$ kJ
You know the activation energy of the reverse reaction: $E_{a(rev)} = +150$ kJ

Plan Your Strategy	Act on Your Strategy
Use the formula $\Delta H_r = E_{a(fwd)} - E_{a(rev)}$ to calculate ΔH_r.	$\Delta H_r = E_{a(fwd)} - E_{a(rev)}$
Draw and label the potential energy diagram.	

14. In the upper atmosphere, oxygen exists as $O_2(g)$, as ozone, $O_3(g)$, and as individual oxygen atoms, O(g). Ozone and atomic oxygen react to form two molecules of oxygen gas. The enthalpy change is –392 kJ and the activation energy is +19.0 kJ. Draw and label a potential energy diagram. Include a value for $E_{a(rev)}$.

What Is Required?
You need to determine the value of $E_{a(rev)}$ for a reaction and draw and label a potential energy diagram.

What Is Given?
You know the activation energy of the forward reaction: $E_{a(fwd)}$ = ?
You know the enthalpy change of the forward reaction: ΔH_r = ?

Plan Your Strategy	Act on Your Strategy
Use the formula $\Delta H_r = E_{a(fwd)} - E_{a(rev)}$ to determine $E_{a(rev)}$.	$\Delta H_r = E_{a(fwd)} - E_{a(rev)}$
Draw and label a potential energy diagram.	

15 For a reaction, on an arbitrary scale, the potential energies are as follows: activated complex, +112 kJ; reactants, +36 kJ; products, +78 kJ.

a. Determine the activation energy and the enthalpy change for the reaction.

b. Draw a labelled potential energy diagram for the reaction, indicating the relative energies of the reactants, products, and activated complex.

What Is Required?

You need to determine the activation energy, E_a, and the enthalpy change, ΔH_r, for the reaction.

You need to draw a potential energy diagram for the reaction.

What Is Given?

You know the potential energies: activated complex, +112 kJ; reactants, +36 kJ; products, +78 kJ.

Plan Your Strategy	Act on Your Strategy
a. The activation energy is the difference between the potential energy of the activated complex and the potential energy of the reactants. The enthalpy change is the difference in potential energy between the products and reactants. Estimate the energy scale (y-axis) that will include the calculated differences in energy.	
b. Draw and label the potential energy diagram.	