Chapter 16: Chemical Equilibrium

Problems: 1-2, 5, 9-10, 13-14, 17-18

Why does a reaction occur?
– Molecules collide with one another
– As a result of some collisions, bonds are broken, and bonds are formed.
– If the bonds that form are different than the bonds broken
  → a chemical reaction has occurred!

16.1 Collision Theory

Collision Theory: *Molecules must collide to react*.

The more often molecules collide
⇒ more likely the collision will result in bonds breaking and forming (chemical reaction)

Two ways to increase collision frequency

i. **Increase the concentration**
   – more atoms/molecules
     ⇒ more collisions that could result in a chemical reaction
       ⇒ higher the reaction rate

ii. **Increase the temperature**
   – atoms/molecules are moving faster
     ⇒ more collisions that could result in a chemical reaction
       ⇒ higher the reaction rate

Two requirements for a reaction to occur:

1. **Collision Energy**
   – For a reaction to occur, molecules have to be moving quickly enough that they can break and reform bonds when they collide.
     – If they're moving too slowly, they merely bounce off each other.
     – The minimum amount of energy required for a reaction is called the **activation energy (E_a)**.

2. **Collision Geometry**
   – Molecules must be in the correct orientation for a reaction to occur
     – See the reaction between A_2 and B_2 in Fig. 16.3 on p. 432

Conditions That Affect the Rate of a Chemical Reaction

1. Reactant Concentration

– The higher the concentration
  ⇒ more molecules present
    ⇒ more collisions that result in a reaction
      ⇒ higher the reaction rate

2. Temperature

– Increasing the temperature increases reaction rate in 2 ways
  i. Collision frequency increases since reactants moving faster
  ii. Collision energy is greater, so more molecules have the necessary activation energy to react.

3. Catalyst: a substance that speeds up a chemical reaction (see Fig. 16.7 on p. 435) without being consumed in the reaction.

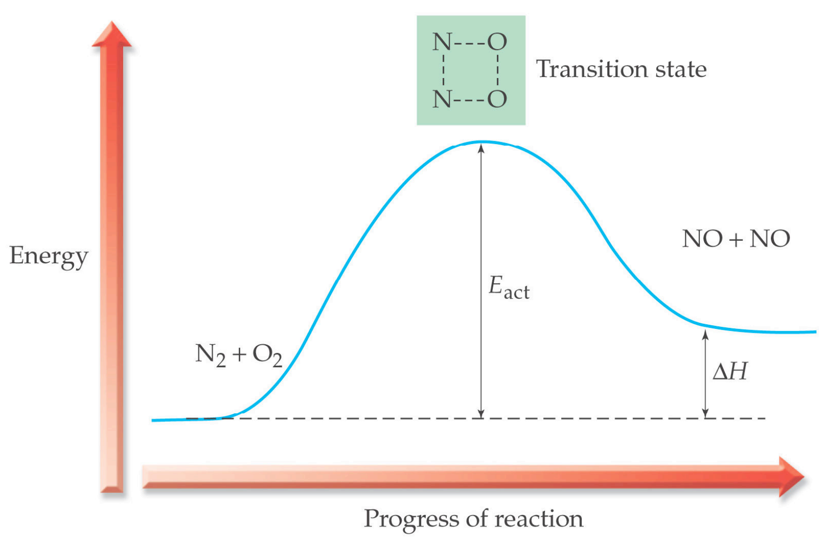
Catalysts generally increase the reaction rate by providing an alternative collision geometry requirement that lowers the activation energy barrier.

16.2 ENERGY PROFILES OF CHEMICAL REACTIONS

We can show a reaction in terms of a **Reaction Profile** (or **Energy Diagram**). Consider Fig. 16.5 on p. 434.

The **transition state** is the arrangement of atoms at the peak of the energy profile when bonds between reactants and products are half-formed and half-broken.

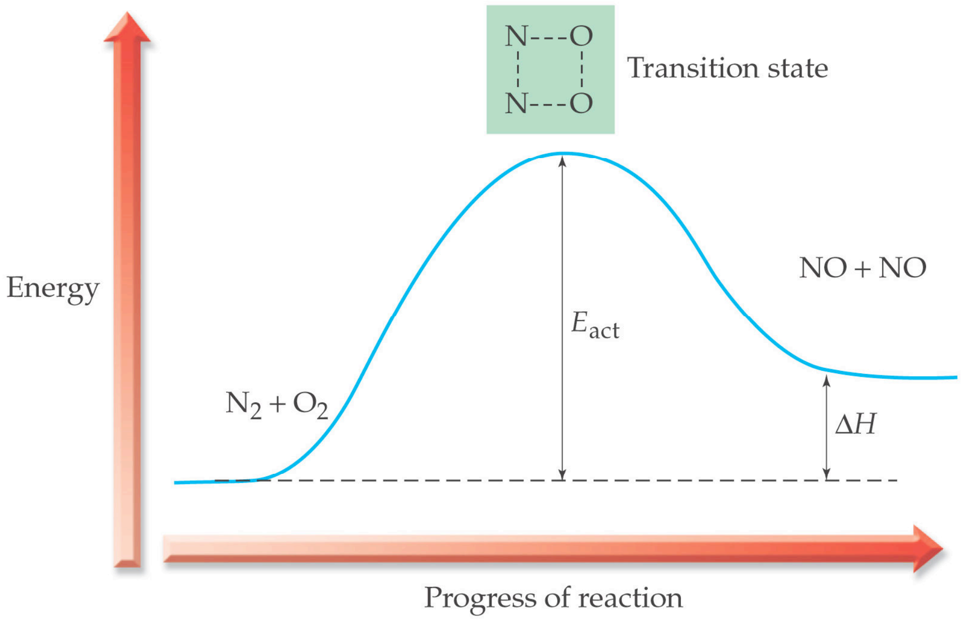
The **activation energy** (**E_a**) is the difference in energy between the reactants and the **transition state**.



The difference in energy between reactants and products is the **heat of the reaction** (usually indicated as **ΔH**).

Endothermic Reaction Profiles

Fig. 16.5 on p. 434 shows the energy profile for an **endothermic reaction**.



Example 1: Write a chemical equation to represent the reaction shown in the energy profile above, including heat as a reactant or product.

- Note that in an ***endothermic reaction***, the reactants are lower in energy than the products, so the reaction absorbs energy usually as heat
  → **Heat is like a reactant** in **endothermic** reactions.
  - Thus, ***endothermic reactions*** absorb heat from the surroundings, making the surroundings feel colder

Ex 2. In an endothermic reaction, the energy of the reactants is ________ than the energy of the products.

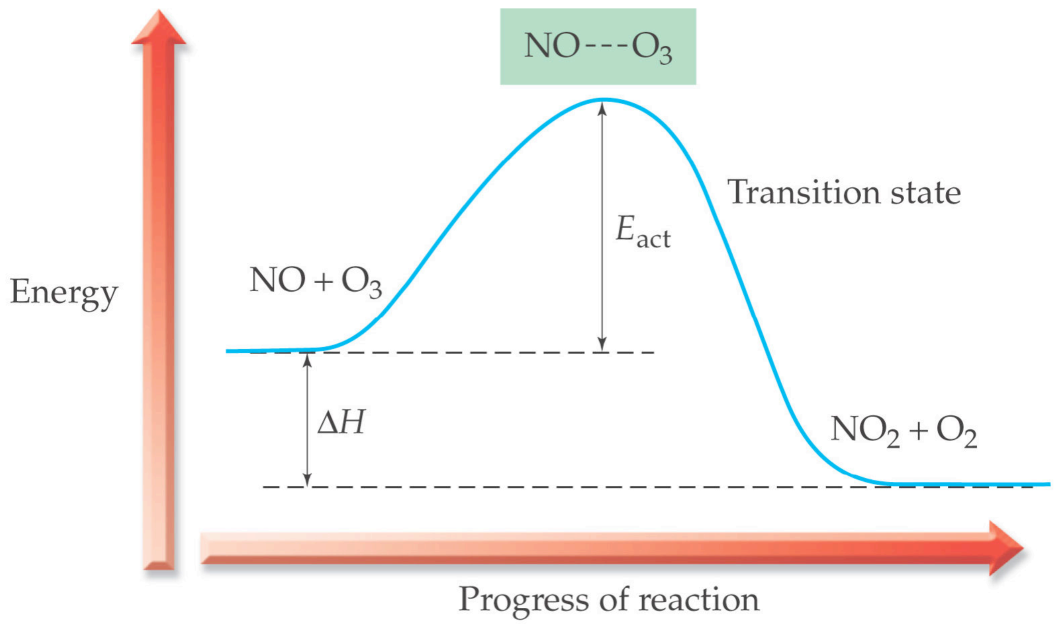
<   >   =

Ex 3. If you are holding a beaker where an endothermic reaction occurs, the beaker will feel ___________ following the reaction.

hotter   colder   about the same

Exothermic Reaction Profiles

Fig. 16.3 on p. 434 shows the energy profile for an **exothermic reaction**.



Example 1: Write a chemical equation to represent the reaction shown in the energy profile above, including heat as a reactant or product.

– Note that in an ***exothermic reaction***, the reactants are higher in energy than the products, so the reaction releases energy usually as heat
  ⇒ heat of the reaction (or ***ΔH***) ***is negative***.
  - Thus, ***exothermic reactions*** release heat to the surroundings, making the surroundings feel hotter
    ⇒ Heat can be considered a product in an exothermic reaction.

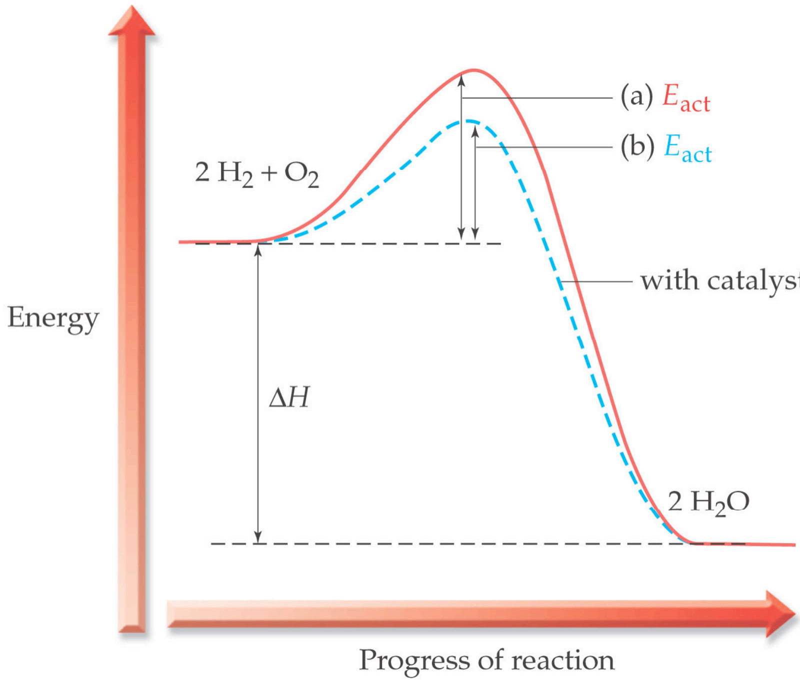
Ex 2. In an exothermic reaction, the energy of the reactants is ________ than the energy of the products.

$<$ $>$ $=$

Ex 3. If you are holding a beaker where an exothermic reaction occurs, the beaker will feel ___________ following the reaction.

hotter colder about the same

Ex. 2 Consider the reaction between hydrogen and oxygen below:



a. Write a chemical equation to represent the reaction shown in the energy profile above, including heat as a reactant or product.

b. This reaction is __________. (Circle one) exothermic endothermic

c. The difference in energy between the reactants and products is _______. (Circle one)

the activation energy ΔH the catalyst

d. The activation energy (E_{act}) of the reaction with a catalyst is ________ compared to the reaction without a catalyst. (Circle one)

< > =

e. The heat of reaction (ΔH) with a catalyst is ________ compared ΔH for the reaction without a catalyst. (Circle one)

< > =

16.3 Chemical Equilibrium Concept

A chemical reaction proceeds in the forward direction, with reactants being converted to products. When enough products are formed, the reaction can also proceed in the reverse direction, so more reactants are formed from products:

$$\text{reactants} \rightleftharpoons \text{products}$$

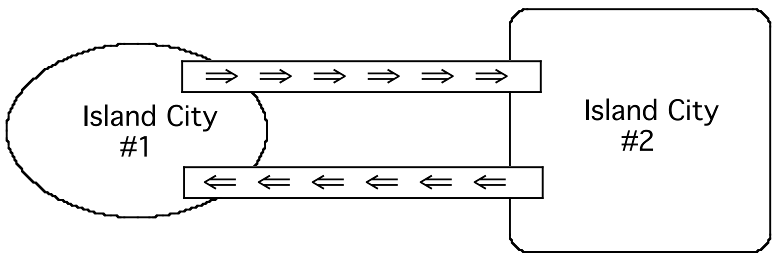
Given enough time, the reaction will reach ***equilibrium***

equilibrium: state where forward and reverse reactions occur at same rate

At equilibrium, since concentrations of reactants and products are not changing, it may appear that everything has stopped. This is not true!

Traffic Analogy

Consider two island cities connected by two one-way bridges:



Suppose the traffic flow on the bridges is equal in both directions.

– The total number of cars on each island doesn't change, but there is constant motion (as evidenced by the cars moving on the bridges).
  ⇒ a reaction at equilibrium is a ***dynamic, reversible process***

Consider the number of cars on each island if the traffic on both bridges is equal:

Question 1: Is the number of cars on island #1 changing? Yes No

Question 2: Is the number of cars on island #2 changing? Yes No

Question 3: Do the number of cars on each island have to be equal for them to not be changing? Yes No

Similarly, **at equilibrium**,

rate of the forward reaction = rate of the reverse reaction

The concentrations of reactants and products are constant but may not be equal!