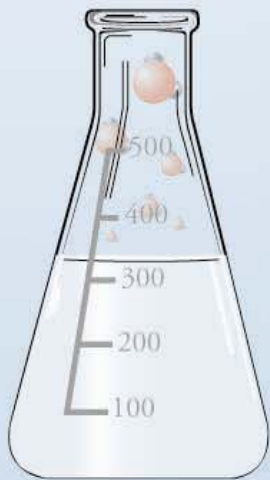
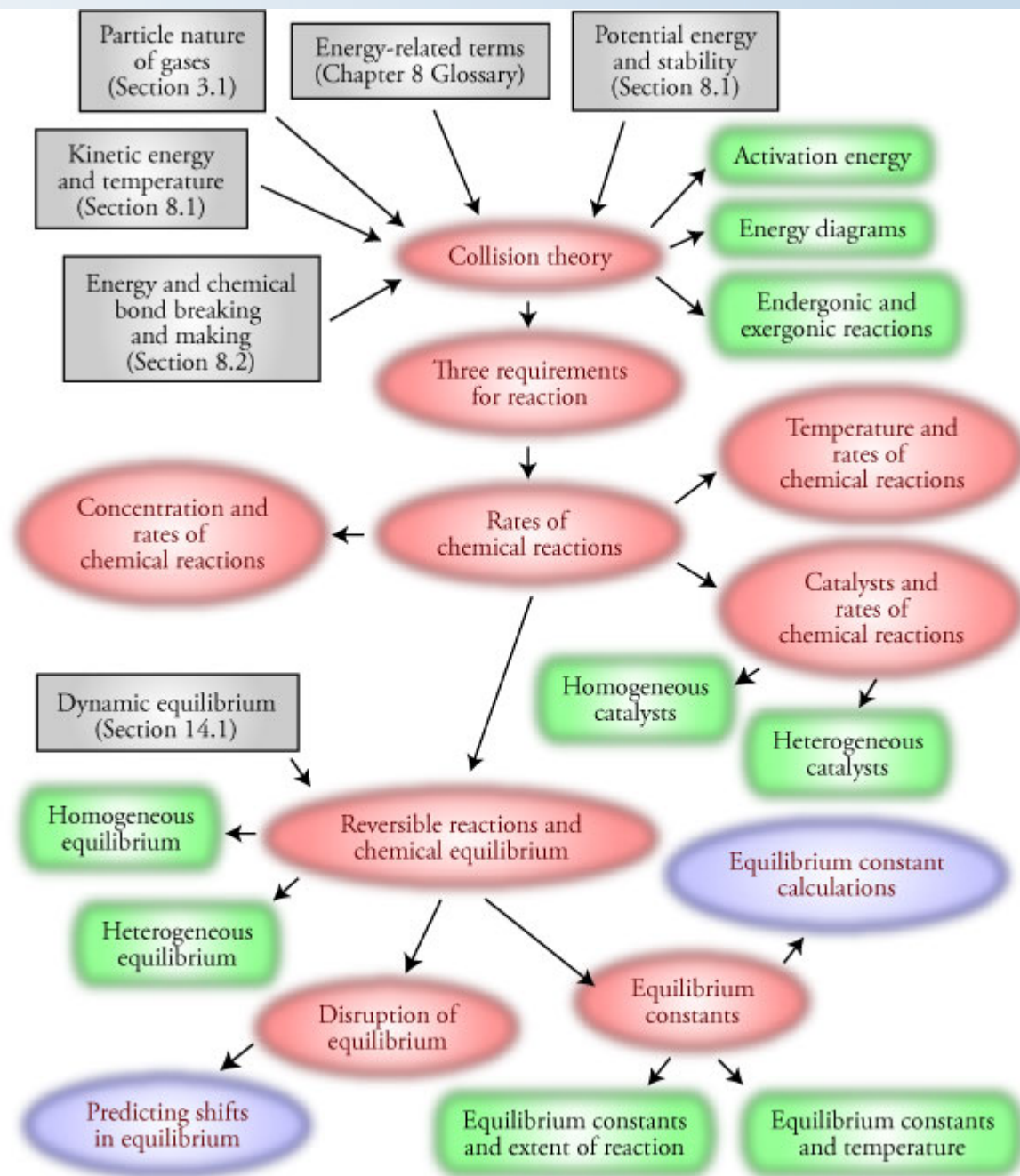


Chapter 16

The Process of Chemical Reactions

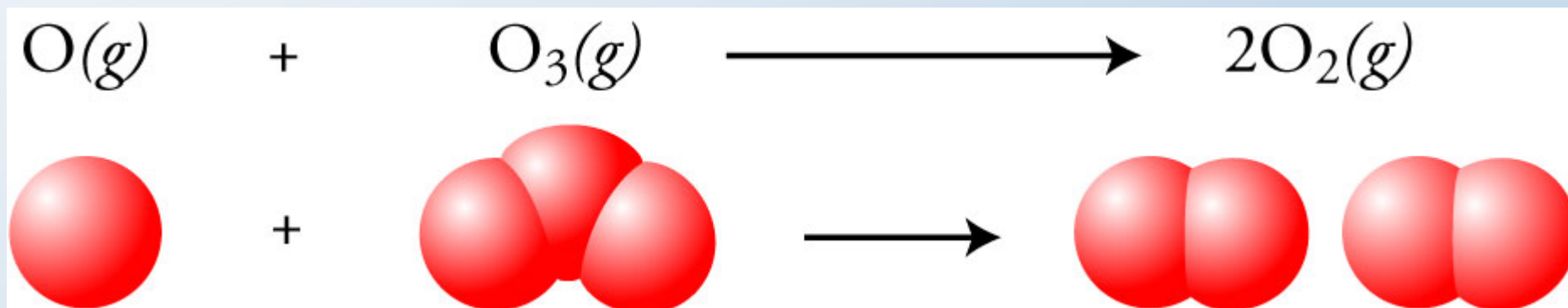


Chapter Map



Collision Theory

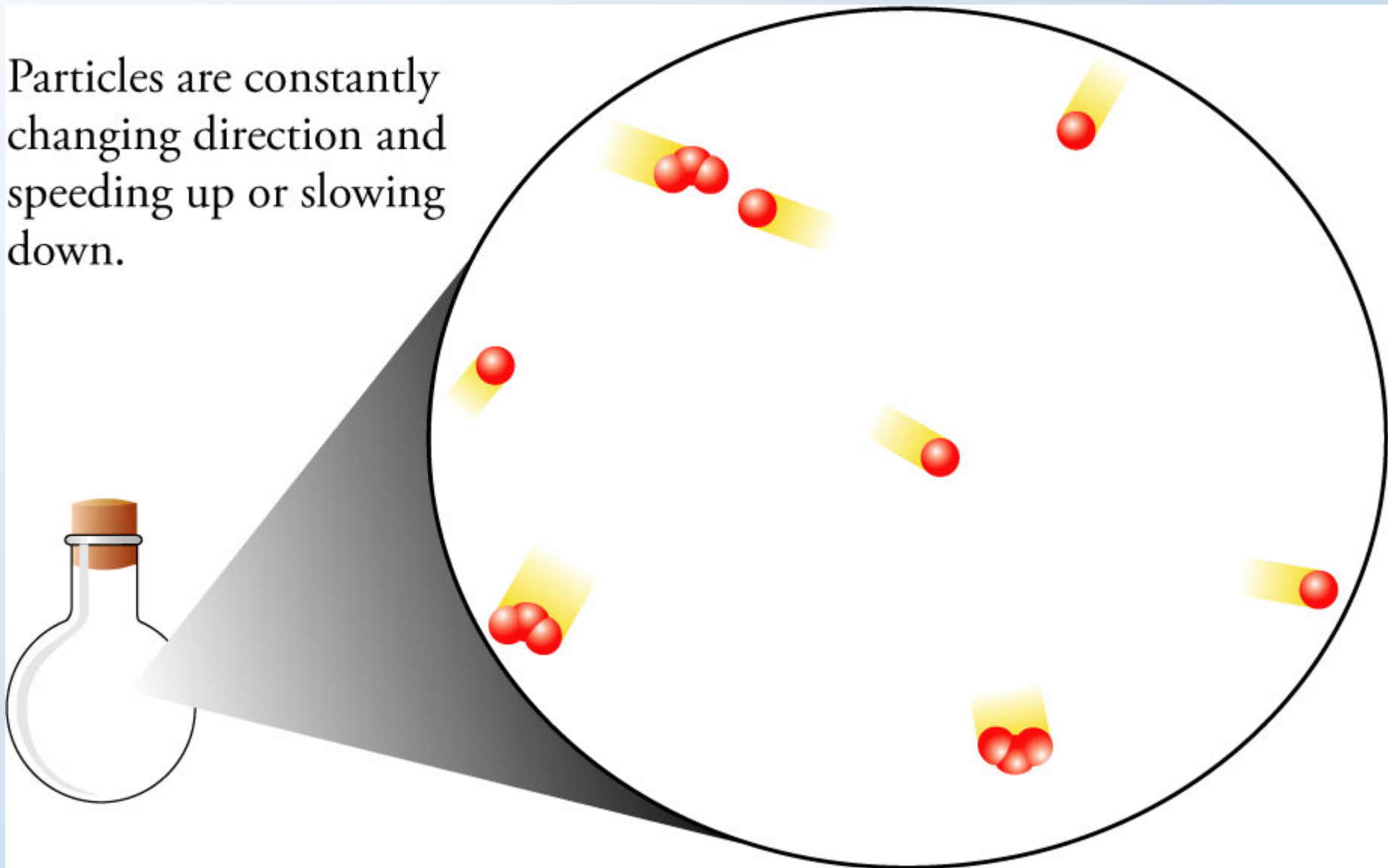
- Reactants must collide



- collision brings contact between reactants
- collision provides energy to break bonds

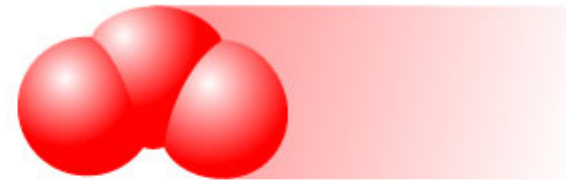


Particles are constantly changing direction and speeding up or slowing down.



Bond Breaking and Making

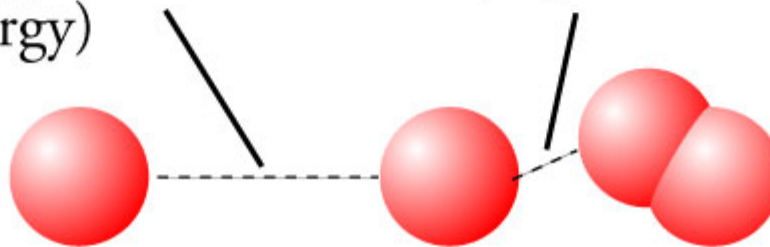
An oxygen atom collides with an ozone molecule.



The collision causes an O-O bond in the ozone to begin breaking as a new O-O bond begins to form.

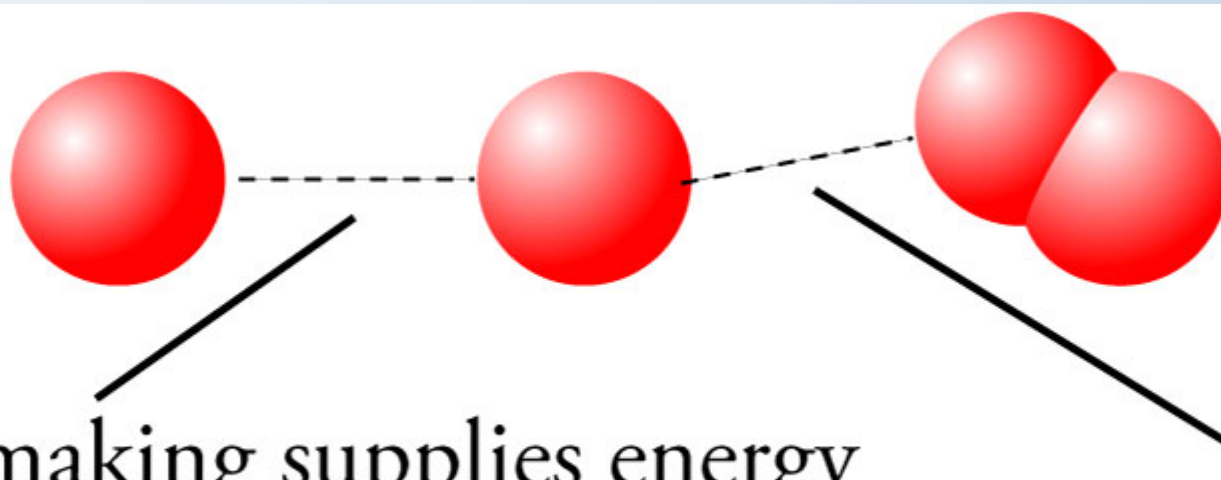
Bond making,
(supplies some
energy)

Bond breaking
(requires energy)



Initially, the energy required for bond breaking is greater than the energy supplied from bond making. The extra energy necessary for the reaction comes from the kinetic energy of the colliding particles.

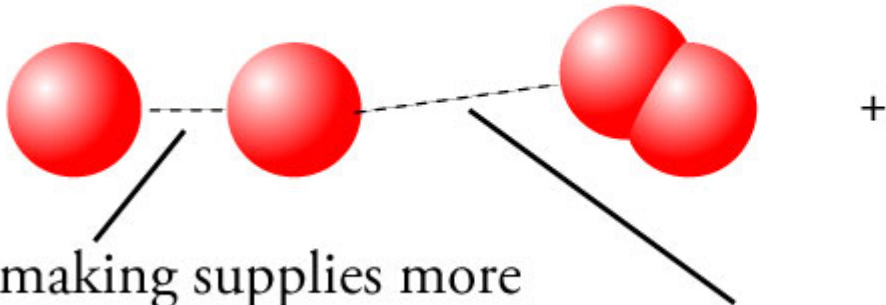
Formation of Activated Complex



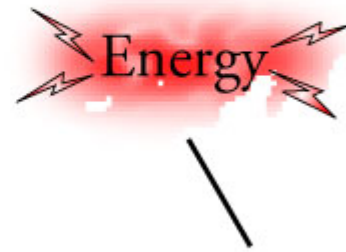
Bond making supplies energy equal to the energy required for bond breaking.

Formation of Product

Beyond some point in the reaction, bond making predominates over bond breaking.



+

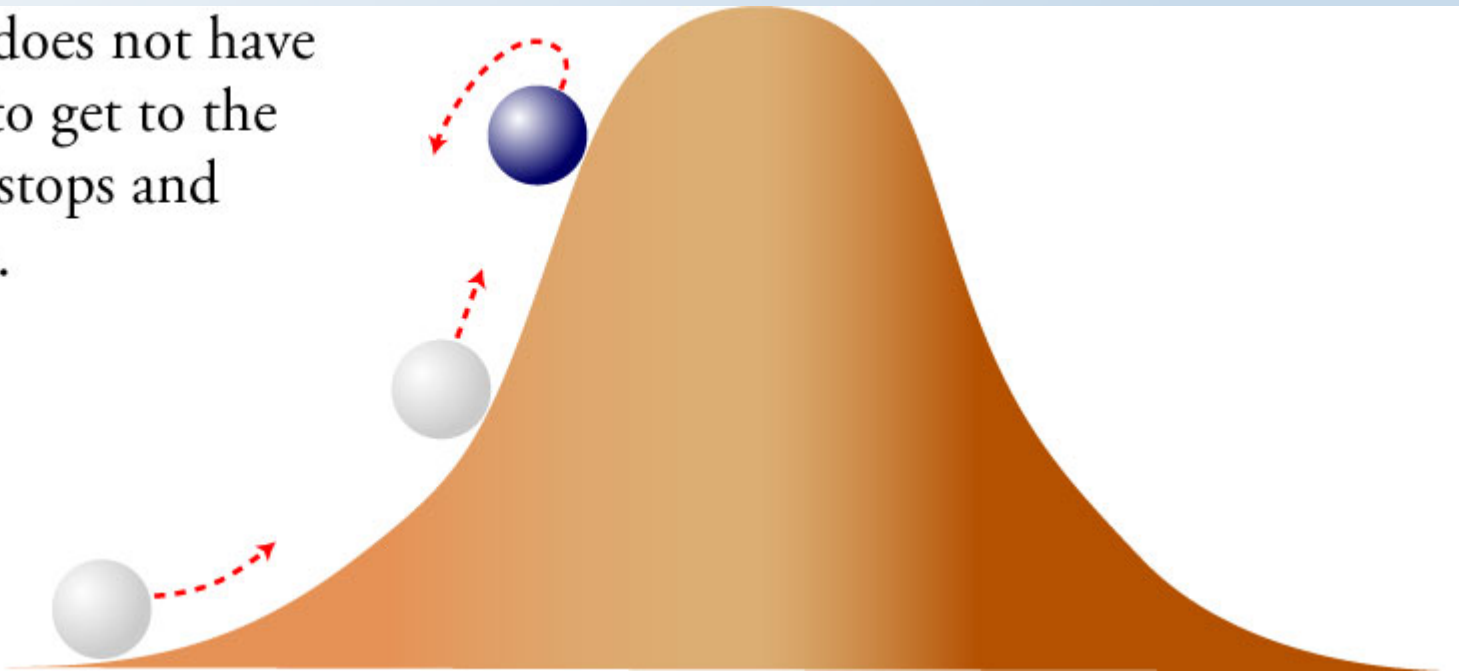


Bond making supplies more energy than is necessary for bond breaking...

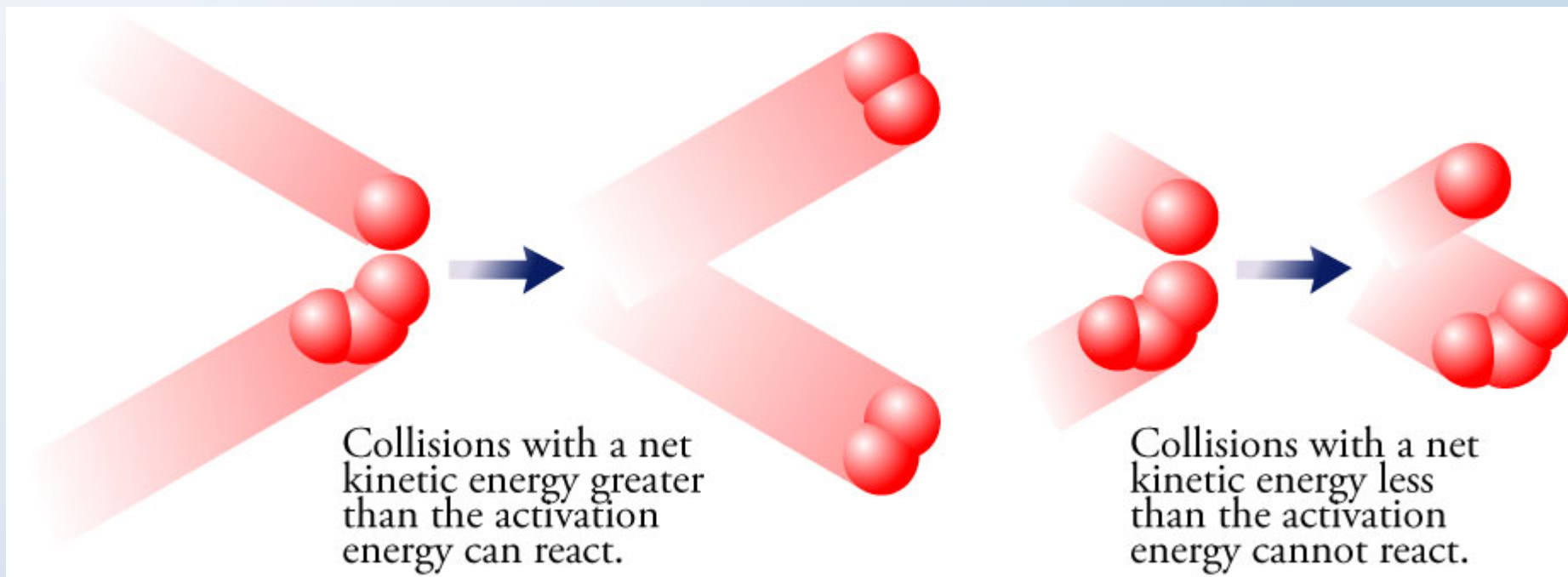
so energy is released

Reactions must have a minimum activation energy...if too little, no change

If a rolling ball does not have enough energy to get to the top of a hill, it stops and rolls back down.

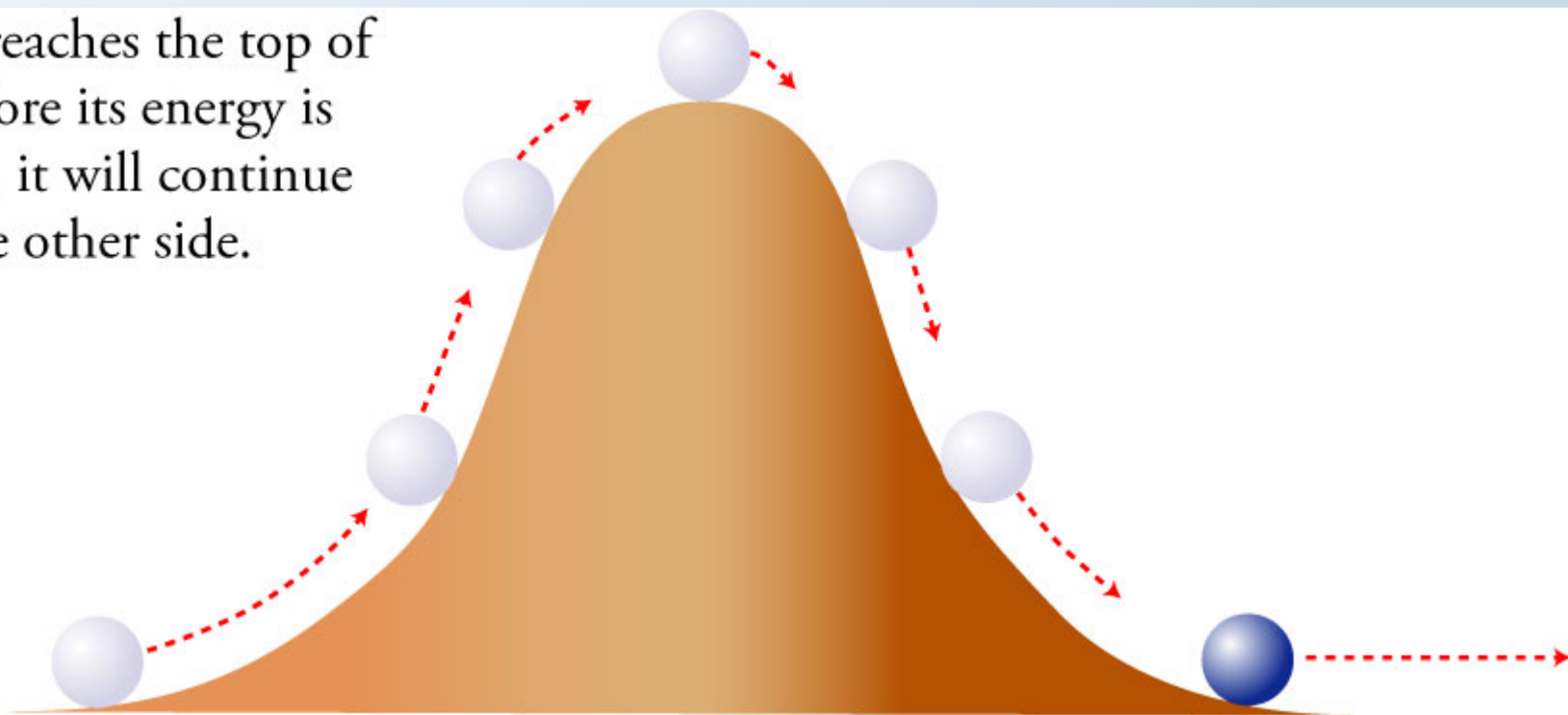


Collision Energy and Activation Energy

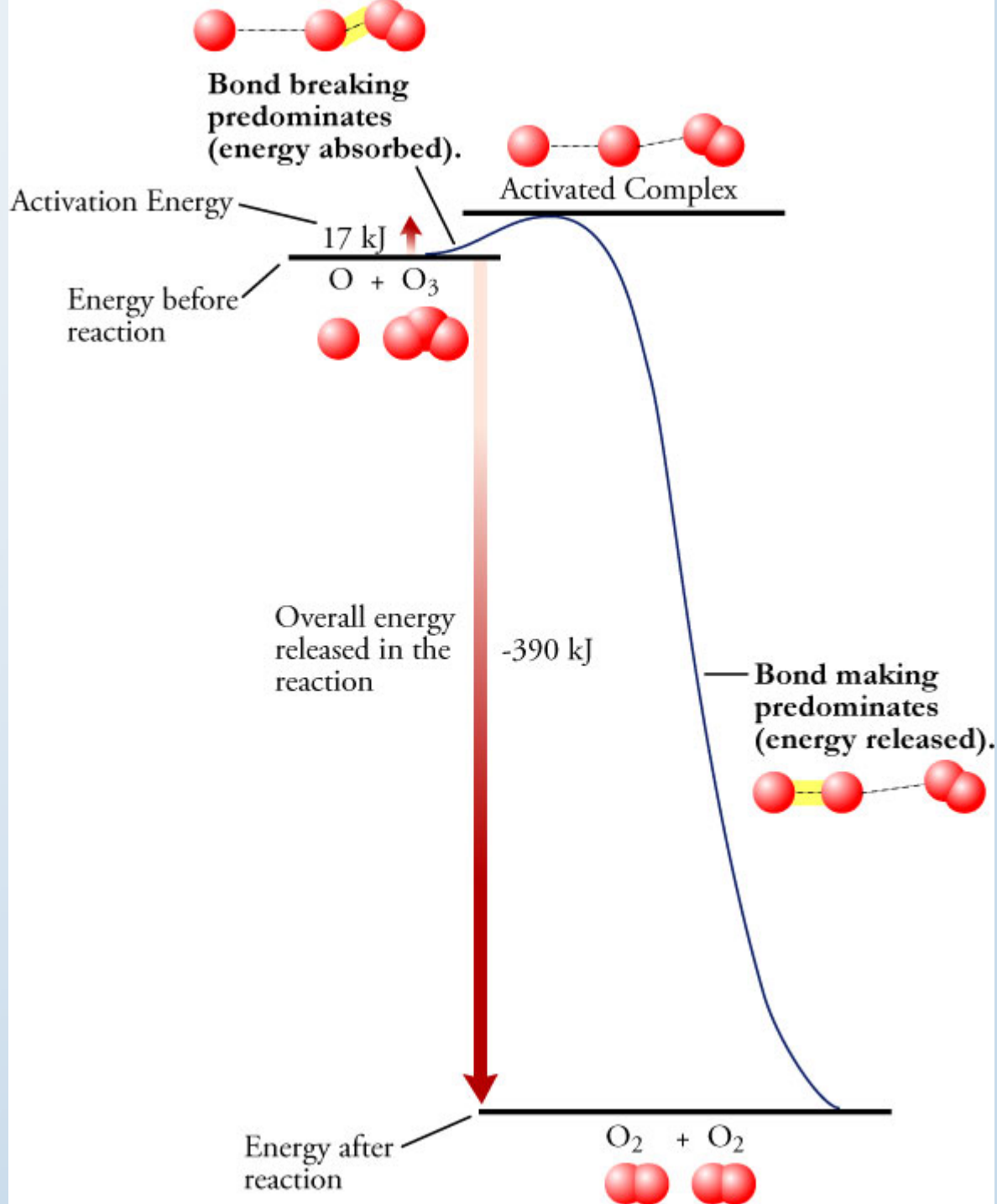


Reactions must have a minimum activation energy...if enough, change

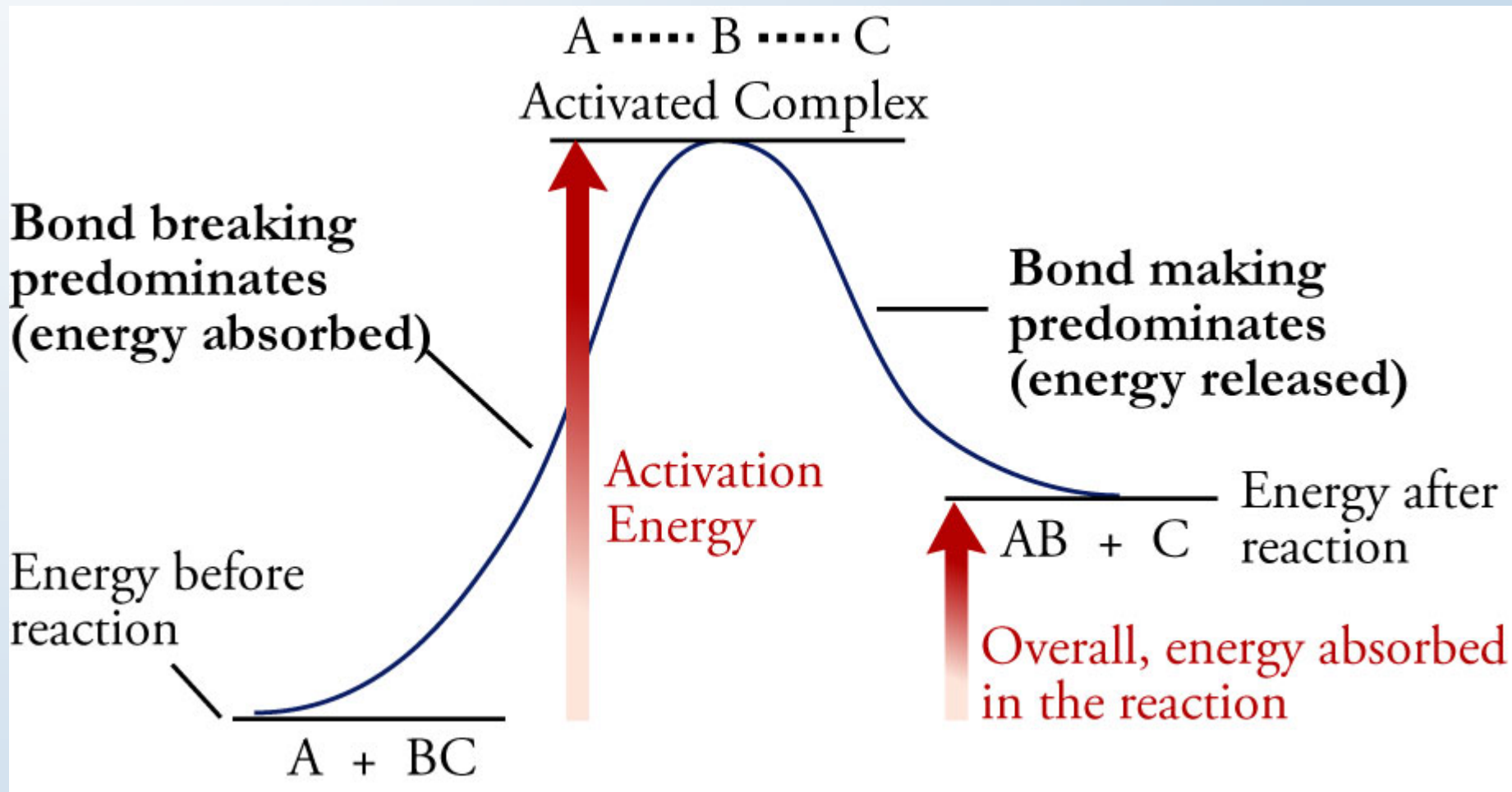
If a ball reaches the top of a hill before its energy is depleted, it will continue down the other side.



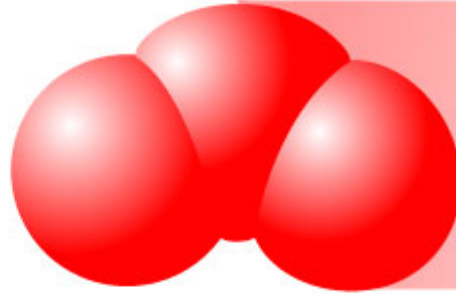
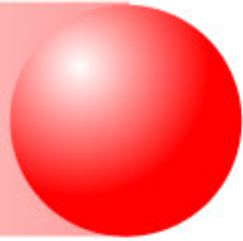
Energy Diagram for O/O_3 Reaction



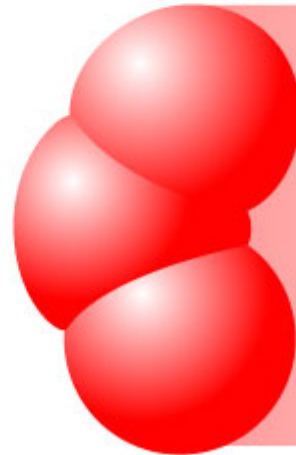
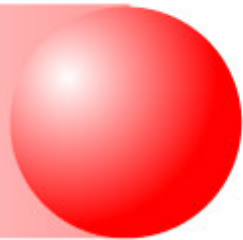
Endogonic Reactions



Orientation



One favorable orientation

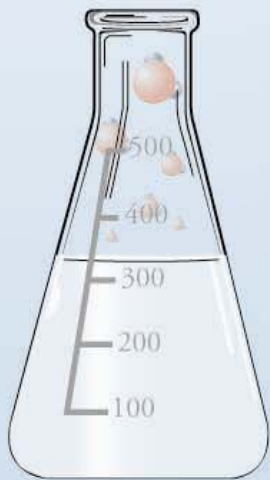


One unfavorable orientation

A vertical column of water molecules (H₂O) is shown on the left side of the slide. Each molecule consists of one red oxygen atom and two smaller black hydrogen atoms. The molecules are arranged in a descending staircase pattern from the top left towards the bottom left.

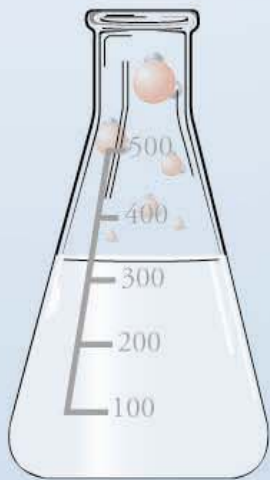
Summary (part 1)

- **The reactant particles must collide.**
 - The collision brings together the atoms that will form the new bonds, and the kinetic energy of the particles provides energy for the reaction to proceed.



Summary (part 2)

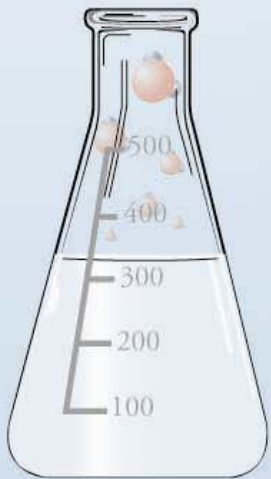
- **The collision must provide at least the minimum energy necessary to produce the activated complex.**
 - It takes energy to initiate the reaction by converting the reactants into the activated complex. If the collision does not provide this energy, products cannot form.



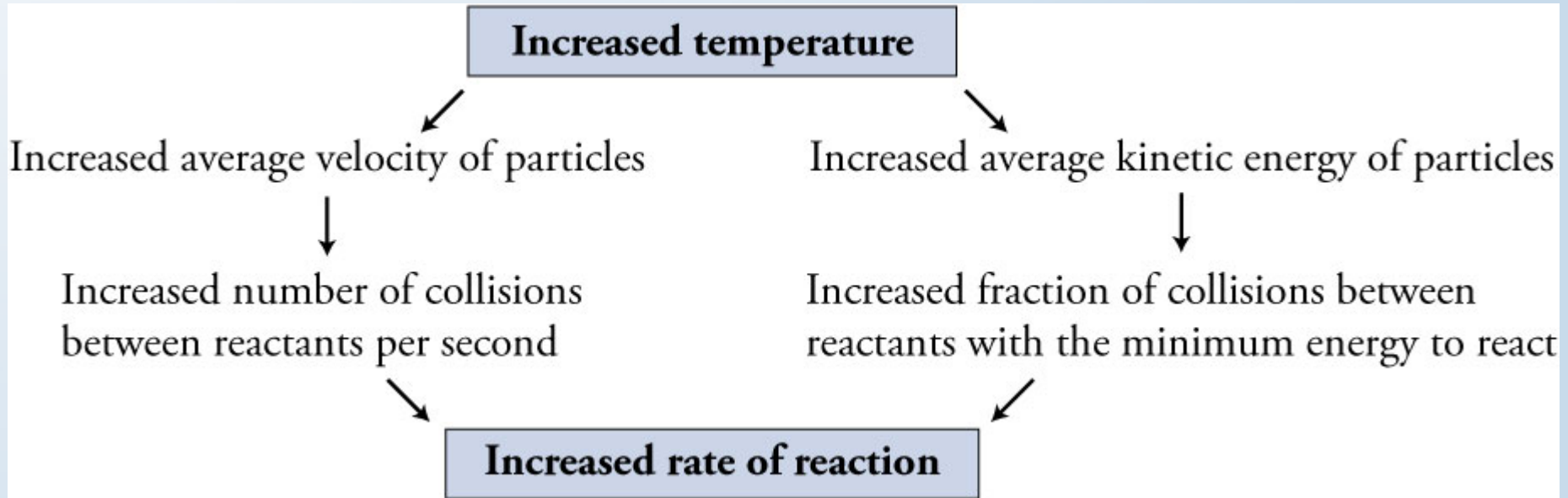
A vertical column of water molecules (H₂O) is positioned on the left side of the slide. Each molecule consists of a large red sphere (oxygen) and two smaller black spheres (hydrogen) bonded to it. The molecules are arranged in a descending staircase pattern from the top left towards the bottom left.

Summary (part 3)

- **The orientation of the colliding particles must favor the formation of the activated complex, in which the new bond or bonds are able to form as the old bond or bonds break .**
 - Because the formation of the new bonds provides some of the energy necessary to break the old bonds, the making and breaking of bonds must occur more or less simultaneously. This is only possible when the particles collide in such a way that the bond-forming atoms are close to each other.

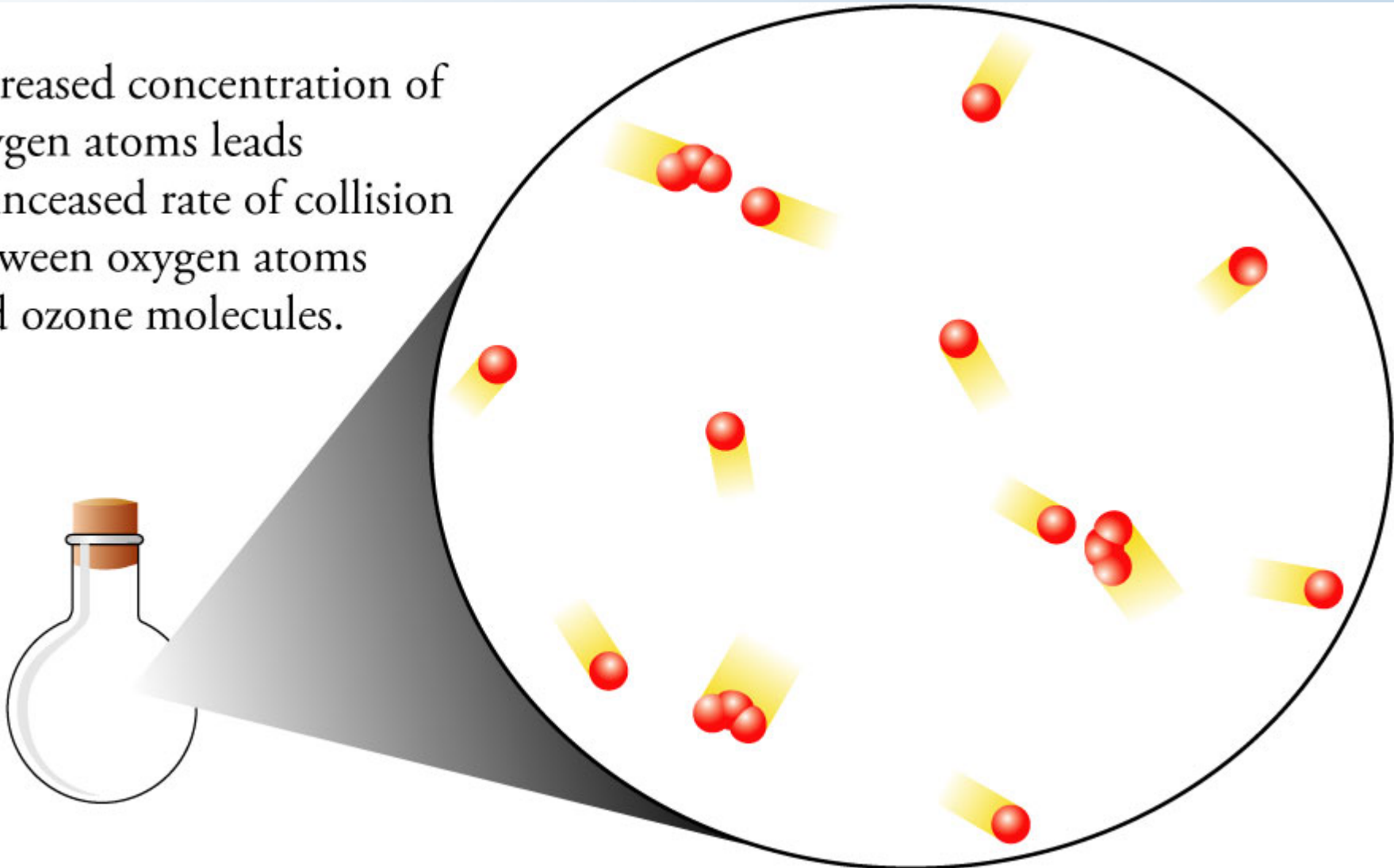


Temperature and Rate of Reaction



Increased Concentration of One Reactant

Increased concentration of oxygen atoms leads to increased rate of collision between oxygen atoms and ozone molecules.



Concentration and Rates of Reaction

**Increased concentration of reactant
(Increased number of particles per unit volume)**



Decreased average distance between particles and decreased volume available in which to move without colliding



Increased number of collisions between reactants per liter per second

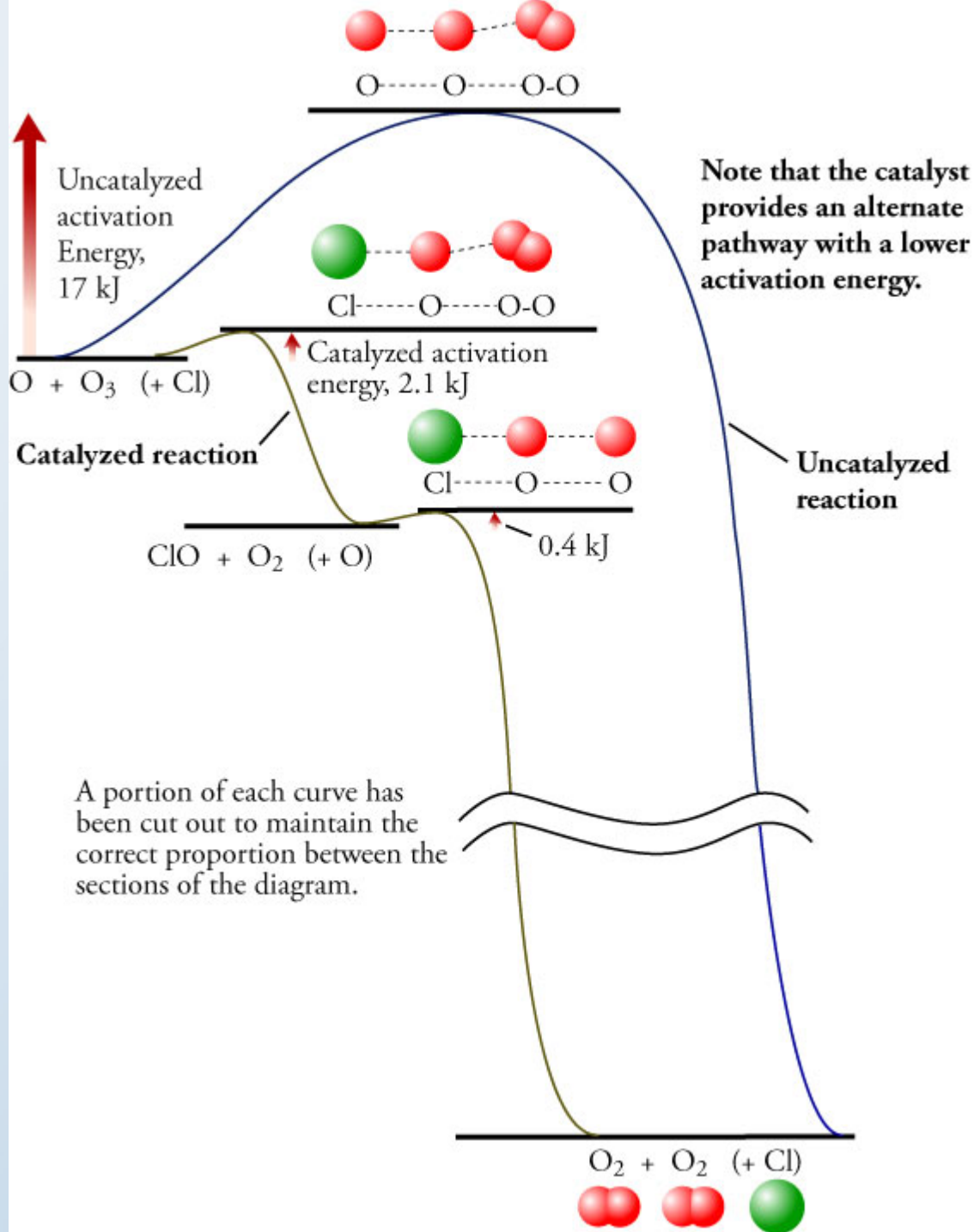


Increased number of particles fulfilling the requirements for reaction



Increased rate of reaction

Catalyzed O/O_3 Reaction



Catalysts and Rate of Reactions

The catalyst provides an alternate pathway with a lower activation energy.



A greater fraction of collisions have the activation energy.

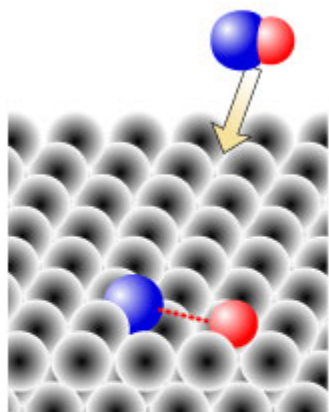


A greater fraction of collisions lead to products.

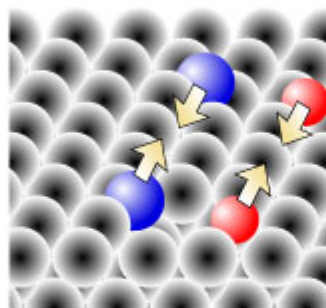


Increased rate of reaction

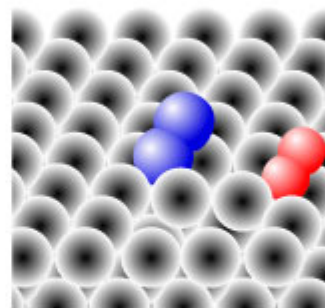
Heterogeneous Catalysis



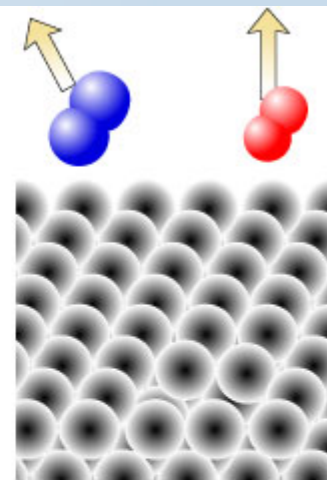
Step 1 - The reactant molecules are adsorbed, and the bonds are weakened.



Step 2 - The atoms migrate across the catalyst.



Step 3 - New bonds form.



Step 4 - The products leave the catalyst.

Production and Uses of Hydrogen Gas

Chemical plants make a mixture of hydrogen gas and carbon monoxide gas called synthesis gas.

A shift converter converts carbon monoxide and water into more hydrogen gas and carbon dioxide.

Ammonia for fertilizers, explosives, plastics, and fibers

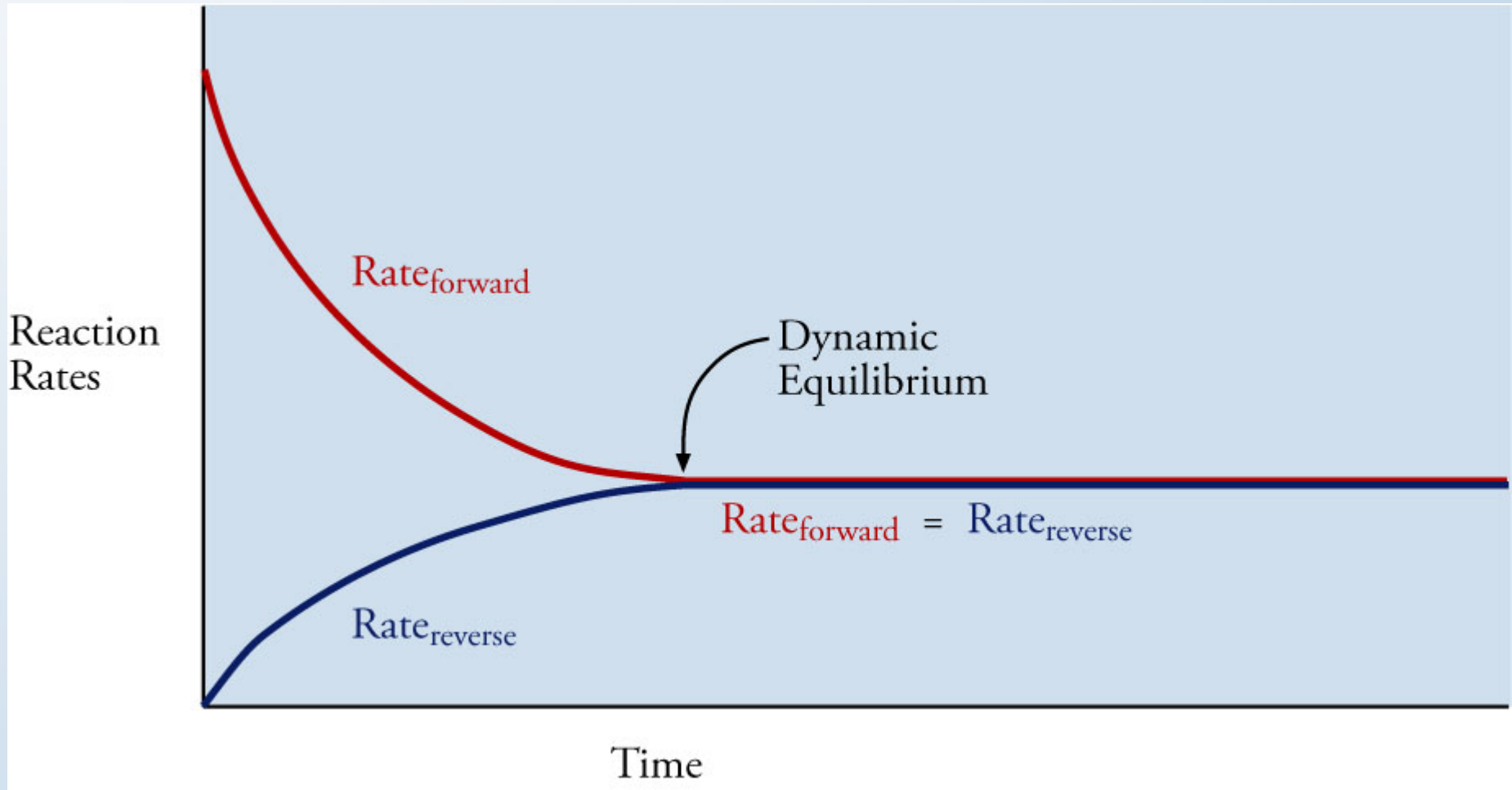
Reduction of metal oxides to form pure metals



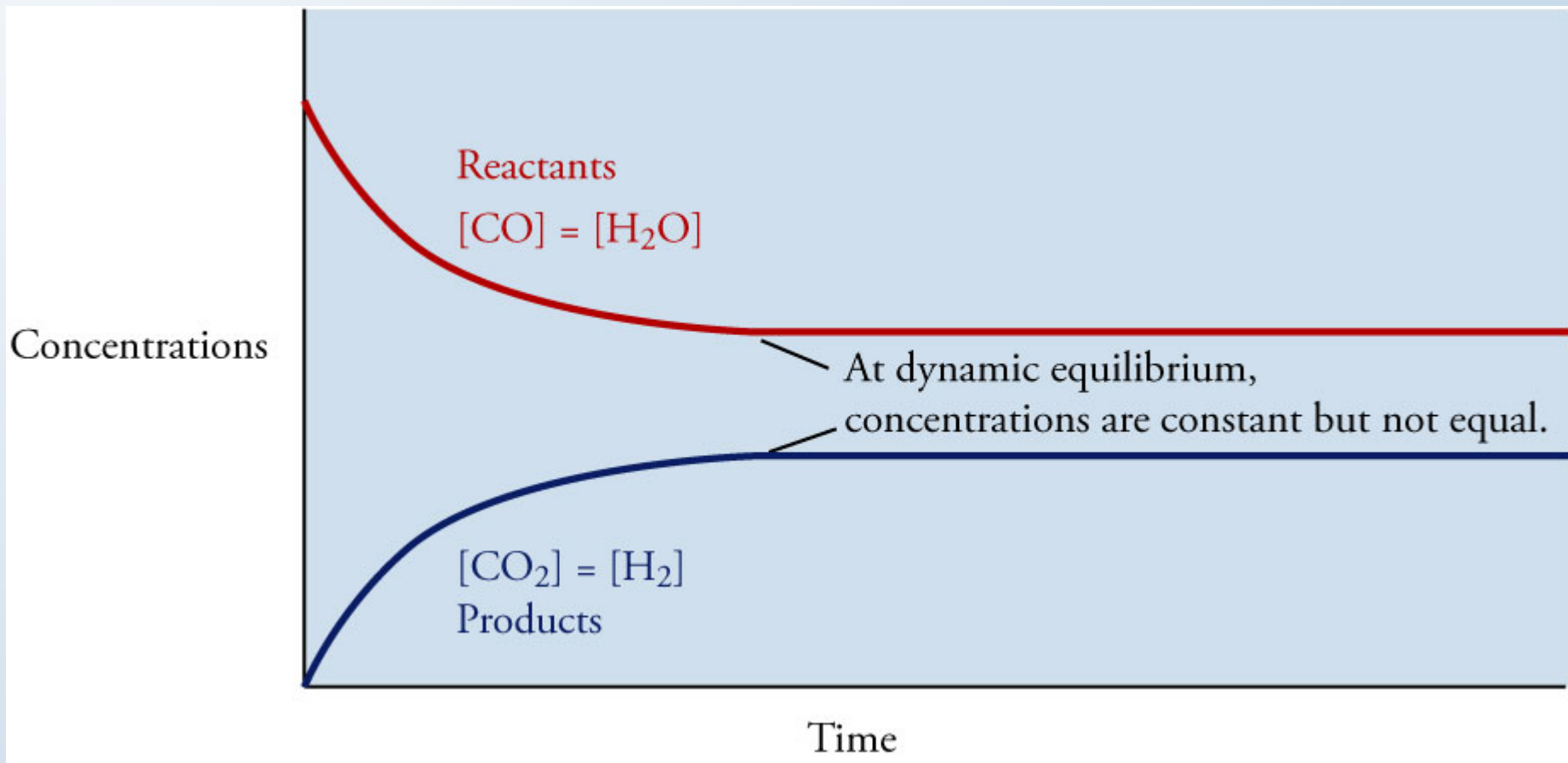
HCl for cleaning metals acidifying oil wells, food processing, and the manufacture of many other chemicals

Methanol, used to make formaldehyde, acetic acid, MTBE, and many other chemicals

Rates of Reaction for Reversible Reactions

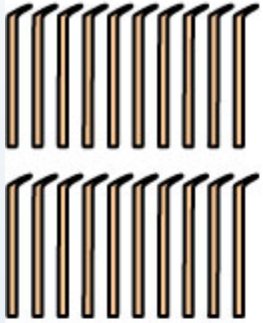


Changes in Concentrations for a Reversible Reaction



Ski Shop Analogy for Equilibrium

Early morning



5 pairs of skis leave per hour

No skis on the slope

Initially, there are 20 skis in the shop.

0 pairs of skis return per hour

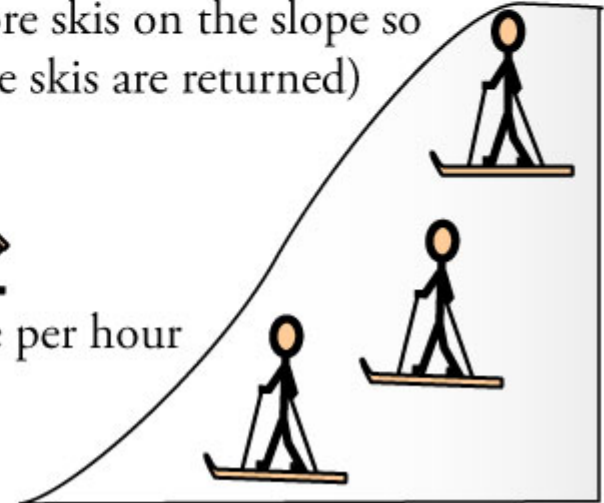
Later in the day

(Fewer skis available so fewer are rented per hour)



3 pairs of skis leave per hour

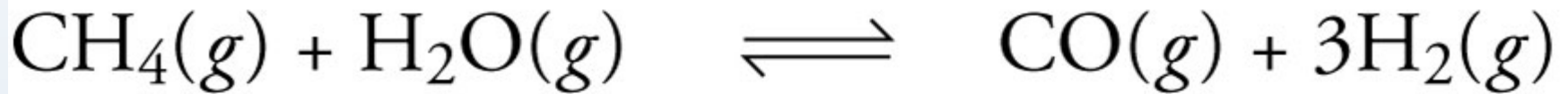
3 pairs of skis on the slope
(More skis on the slope so more skis are returned)



3 pairs of skis return per hour

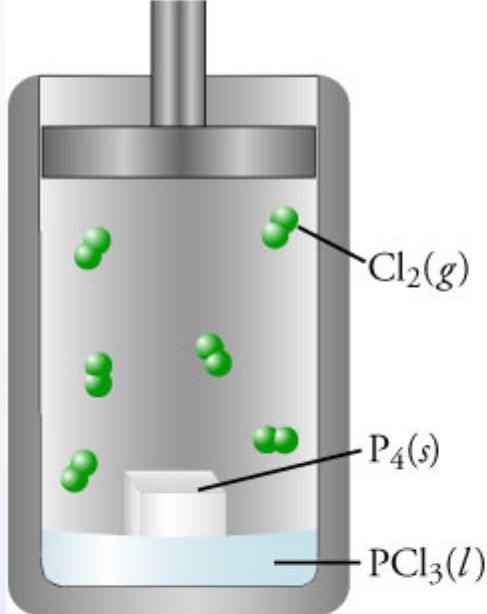
Equilibrium (No change in the number of skis in the shop and on the slope)

Equilibrium Constant Expression



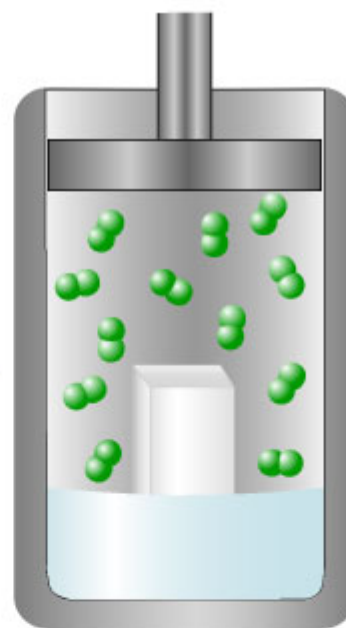
The coefficient before H_2 is 3, so we raise the concentration or pressure to the third power.

$$K_C = \frac{[\text{CO}] [\text{H}_2]^3}{[\text{CH}_4] [\text{H}_2\text{O}]} \qquad K_P = \frac{P_{\text{CO}} P_{\text{H}_2}^3}{P_{\text{CH}_4} P_{\text{H}_2\text{O}}}$$



Double the moles of
 P_4 , Cl_2 , and PCl_3

Constant volume



Concentration of gas
doubles.

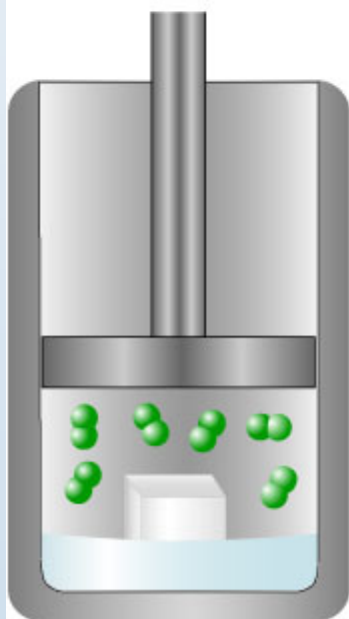
$$\text{Double } \frac{\text{mol Cl}_2}{L}$$

Concentrations
of solid and liquid
remain constant.

$$\text{Same } \frac{\text{mol P}_4}{L}$$

$$\text{Same } \frac{\text{mol PCl}_3}{L}$$

Half volume,
with no change
in moles



Concentration of gas
doubles.

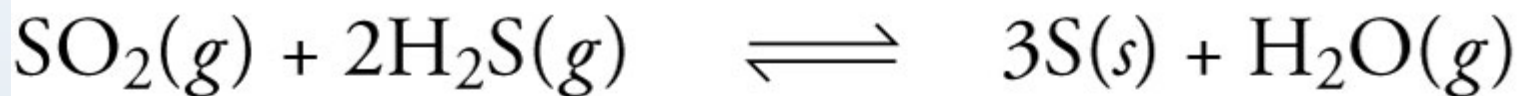
$$\text{Double } \frac{\text{mol Cl}_2}{L}$$

Concentrations
of solid and liquid
remain constant.

$$\text{Same } \frac{\text{mol P}_4}{L} \text{ and } \frac{\text{mol PCl}_3}{L}$$

Heterogeneous Equilibrium

Equilibrium Constant Expressions for Heterogeneous Equilibria



The solid does not appear in the K_C and K_P expressions.

$$K_C = \frac{[\text{H}_2\text{O}]}{[\text{SO}_2] [\text{H}_2\text{S}]^2}$$

$$K_P = \frac{P_{\text{H}_2\text{O}}}{P_{\text{SO}_2} P_{\text{H}_2\text{S}}^2}$$

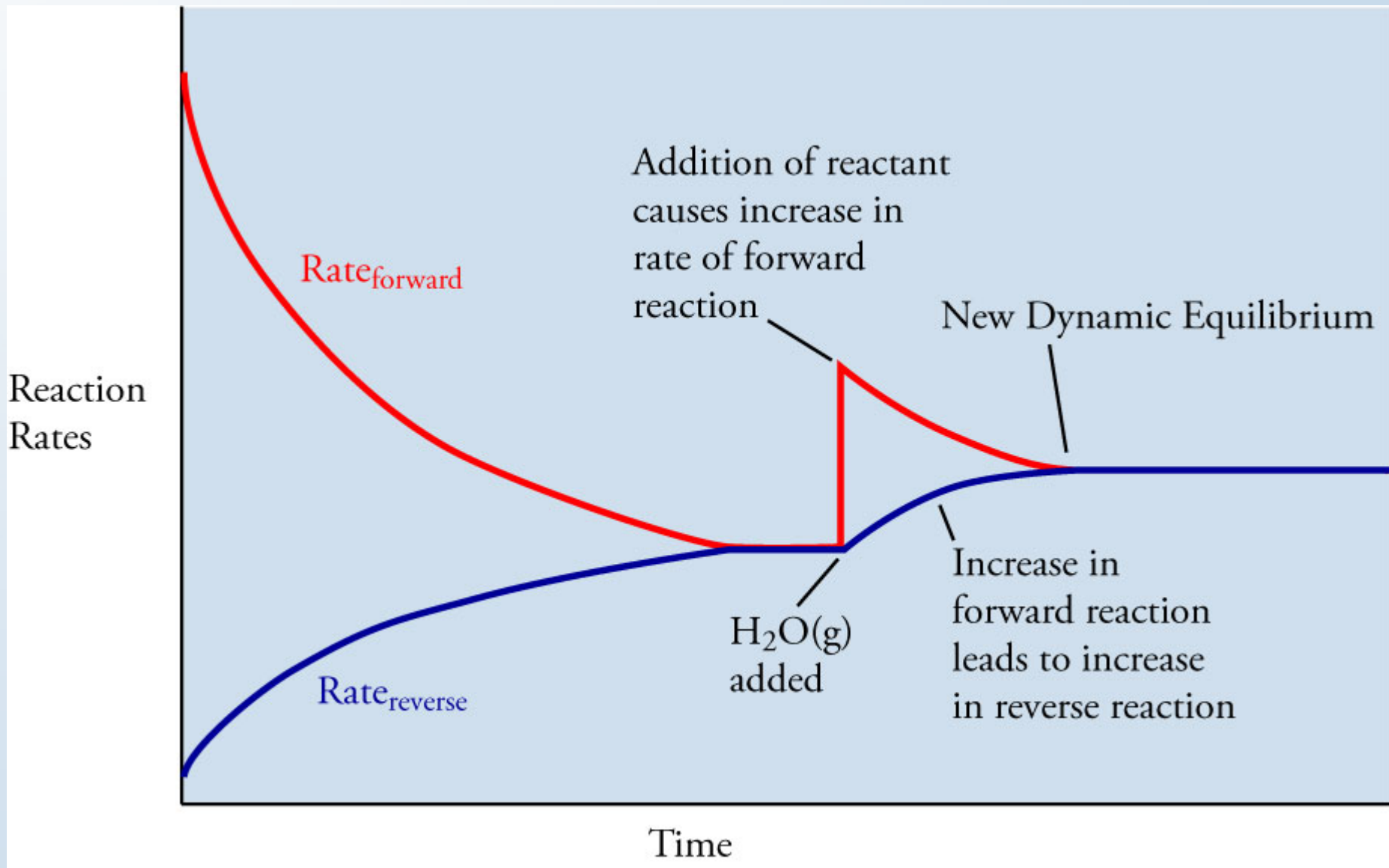
Effect of Increased Concentration on Equilibrium

Increased concentration of reactant for a system at equilibrium with $\text{Rate}_{\text{forward}} = \text{Rate}_{\text{reverse}}$

↓
Increased $\text{Rate}_{\text{reverse}}$
↓
 $\text{Rate}_{\text{forward}} > \text{Rate}_{\text{reverse}}$
↓

System shifts toward products

Change in Rates When Reactant Added



Ski Shop Analogy 2

Before buying more skis

There are 12 skis in the shop.



12 skis in the shop.

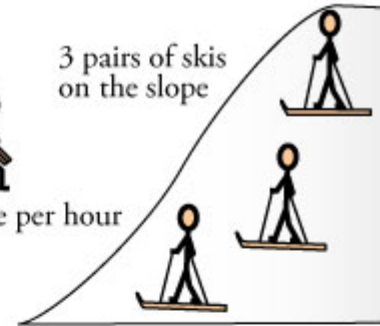


3 pairs of skis return per hour

3 pairs of skis leave per hour



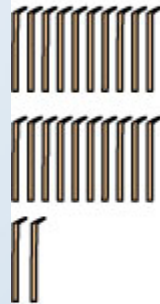
3 pairs of skis on the slope



Equilibrium (No change in the number of skis in the shop and on the slope)

Immediately after buying more skis

There are 22 skis in the shop. (With more skis in the shop, more are rented per hour.)

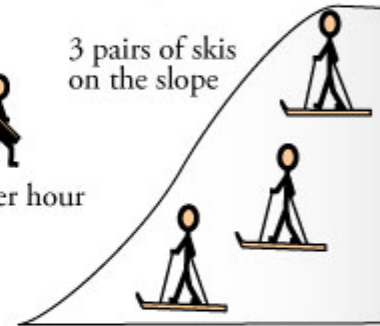


3 pairs of skis return per hour

5 pairs of skis leave per hour



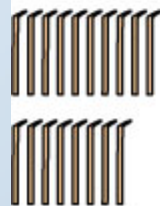
3 pairs of skis on the slope



More skis leave than return, so the equilibrium is disrupted.

Later

There are 18 skis in the shop. (This is more skis than before the purchase but fewer than immediately after the purchase.)

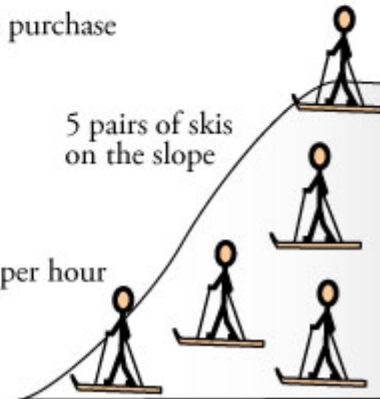


4 pairs of skis return per hour

4 pairs of skis leave per hour



5 pairs of skis on the slope



New equilibrium (No change in the number of skis in the shop and on the slope)

Effect of Decreased Concentration on Equilibrium

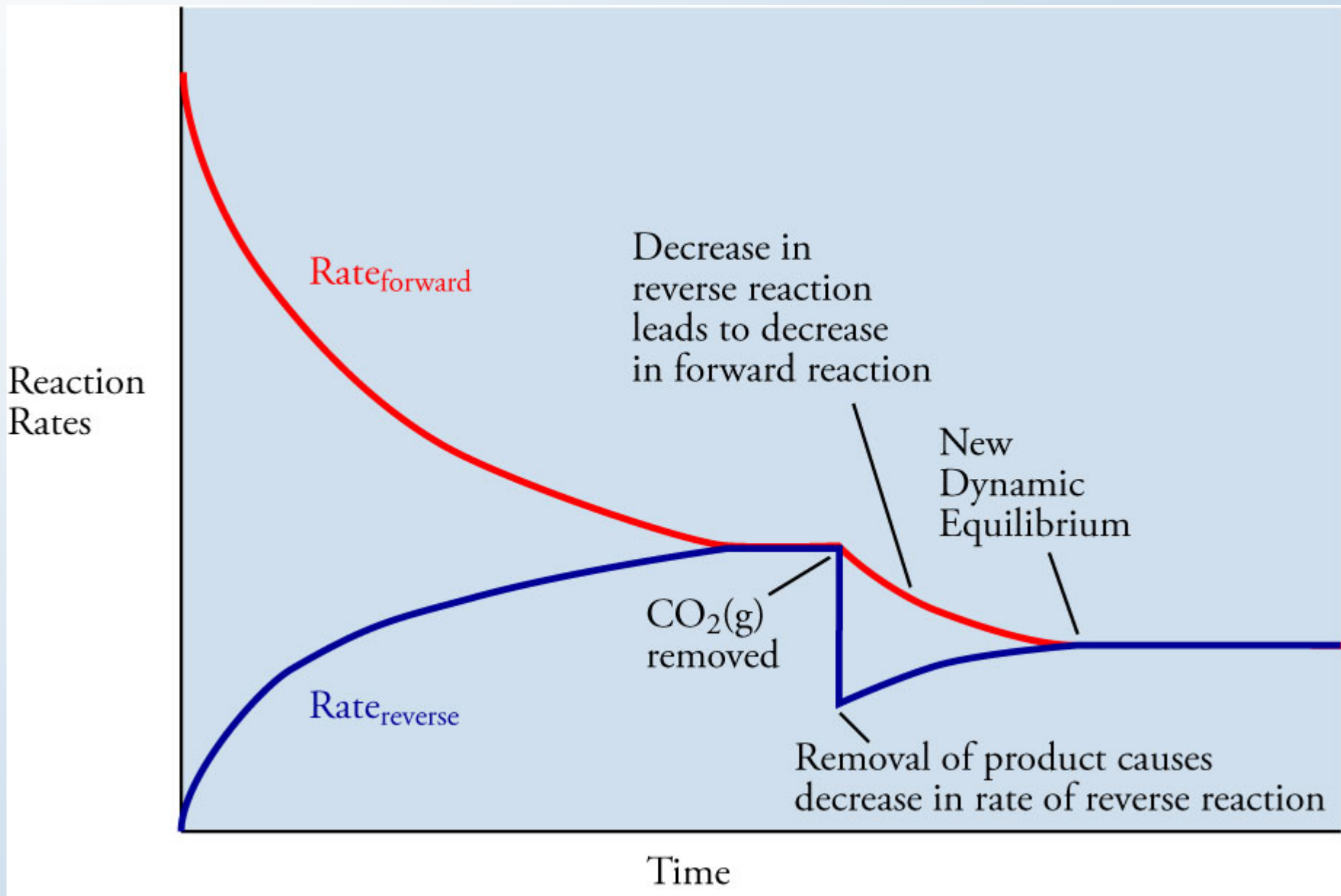
Decreased concentration of one product for a system at equilibrium with $\text{Rate}_{\text{forward}} = \text{Rate}_{\text{reverse}}$

↓
Decreased $\text{Rate}_{\text{reverse}}$

↓
 $\text{Rate}_{\text{forward}} > \text{Rate}_{\text{reverse}}$

↓
System shifts toward products

Change in Rates When Product Removed





Le Chatelier's Principle

- If a system at equilibrium is altered in a way that disrupts the equilibrium, the system will shift in such a way as to counter the change.

