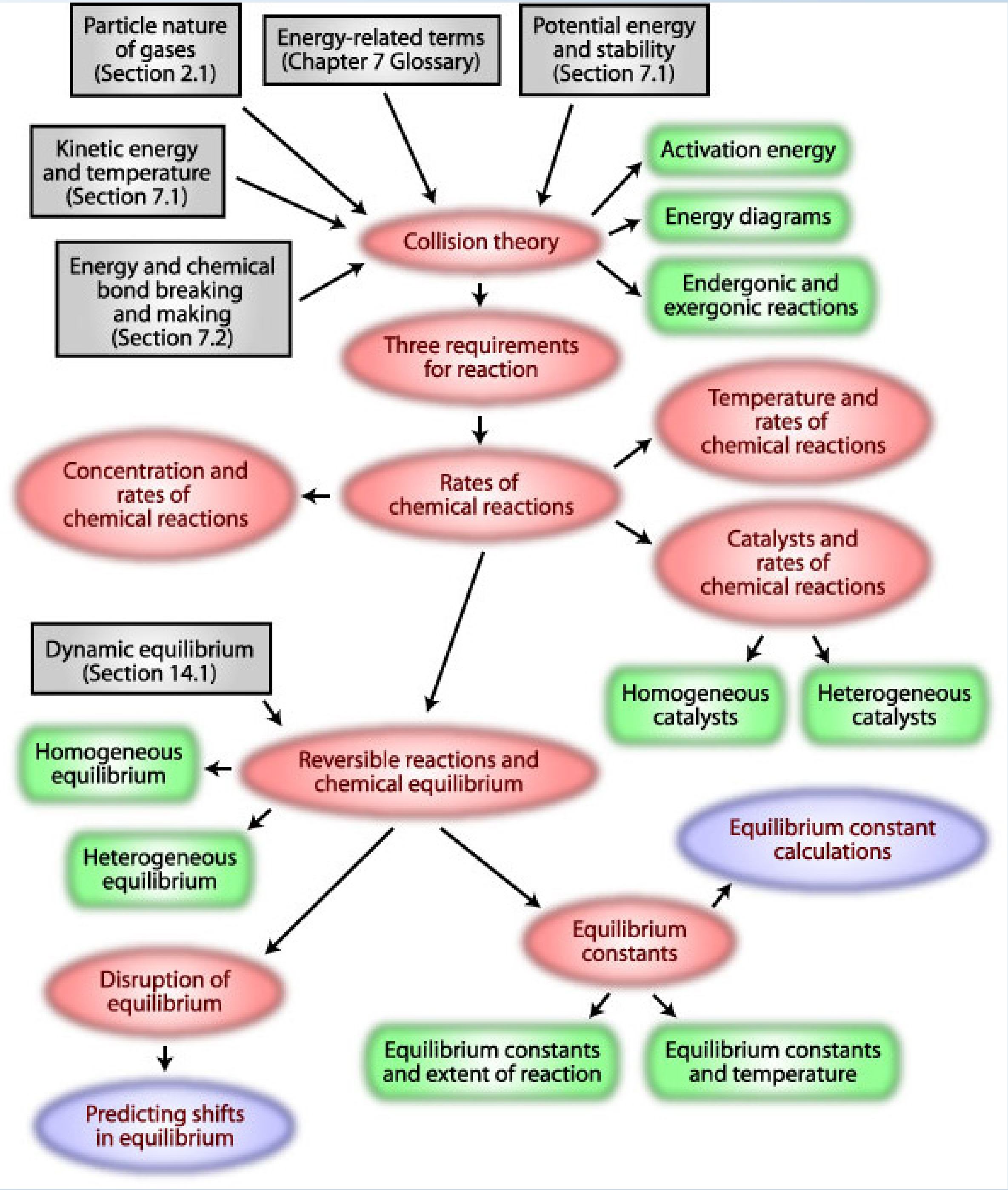
Chapter 16

The Process of Chemical Reactions

Chapter Map



Particle nature of gases (Section 2.1)
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Heterogeneous equilibrium
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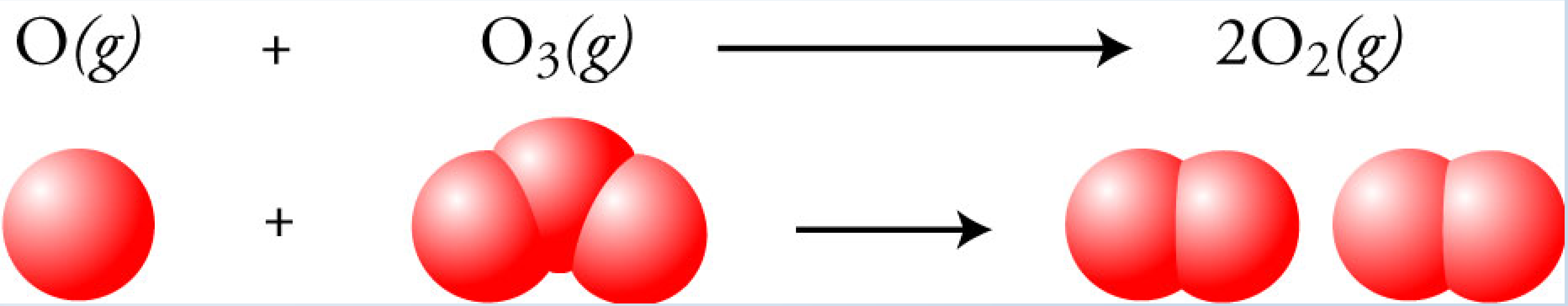
Equilibrium constants and extent of reaction
Equilibrium constants and temperature
Predicting shifts in equilibrium

Collision Theory

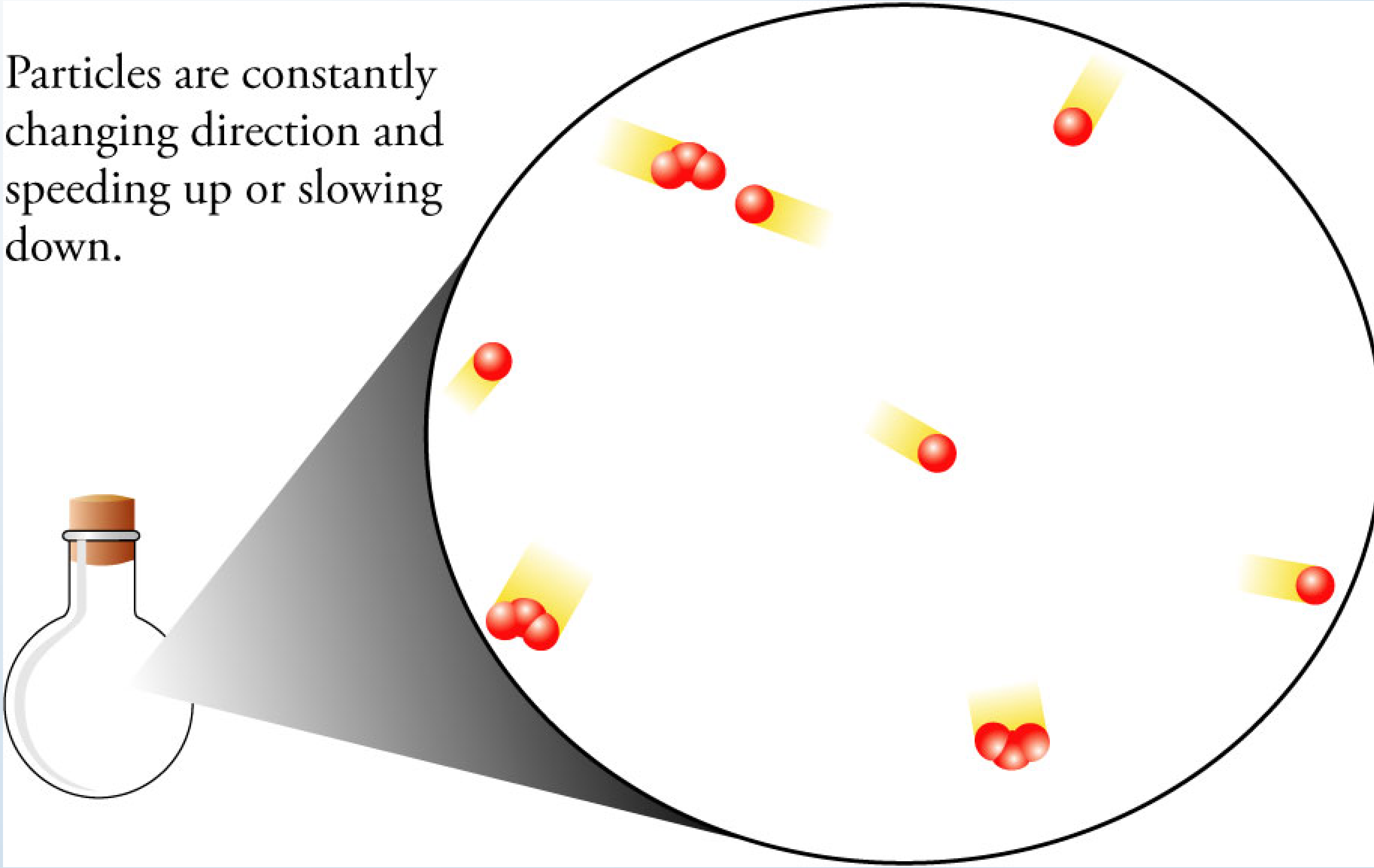
- Reactants must collide



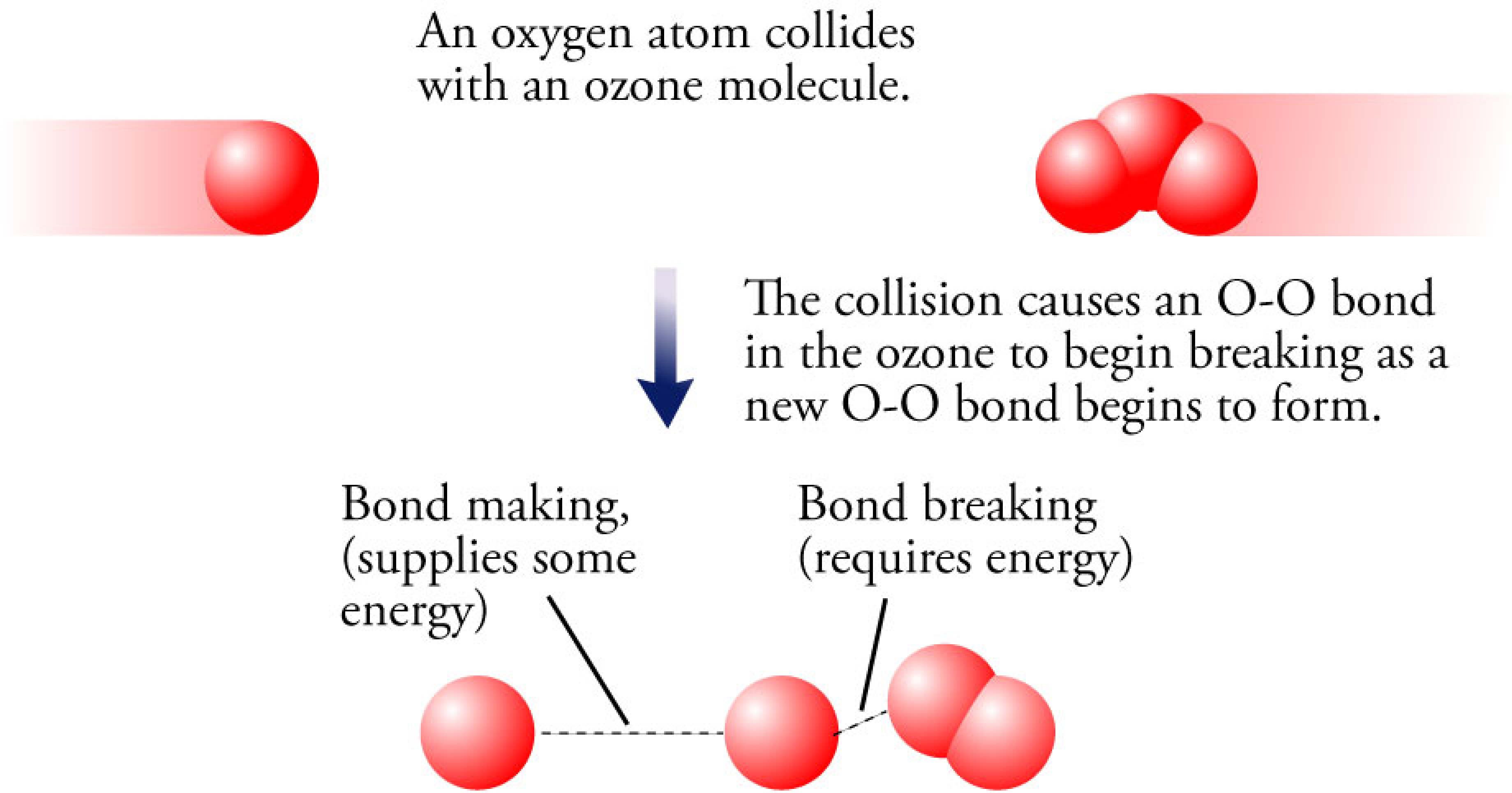
  - collision brings contact between reactants
  - collision provides energy to break bonds

$$O(g) + O_3(g) \rightarrow 2O_2(g)$$

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

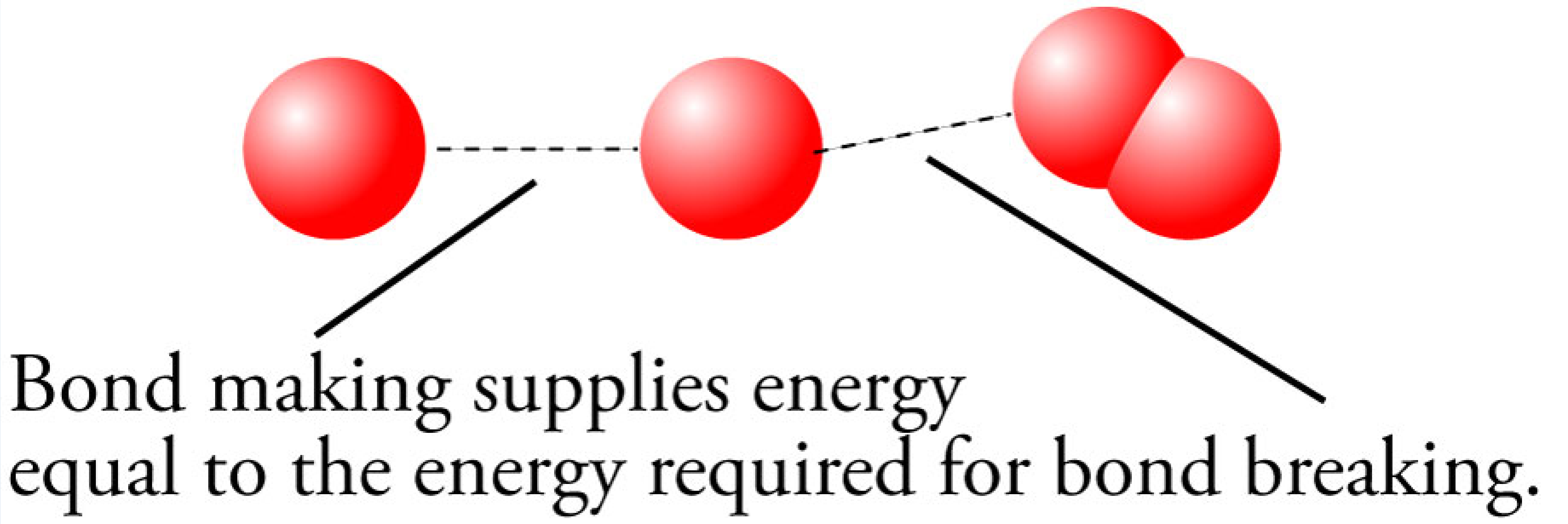


Bond Breaking and Making

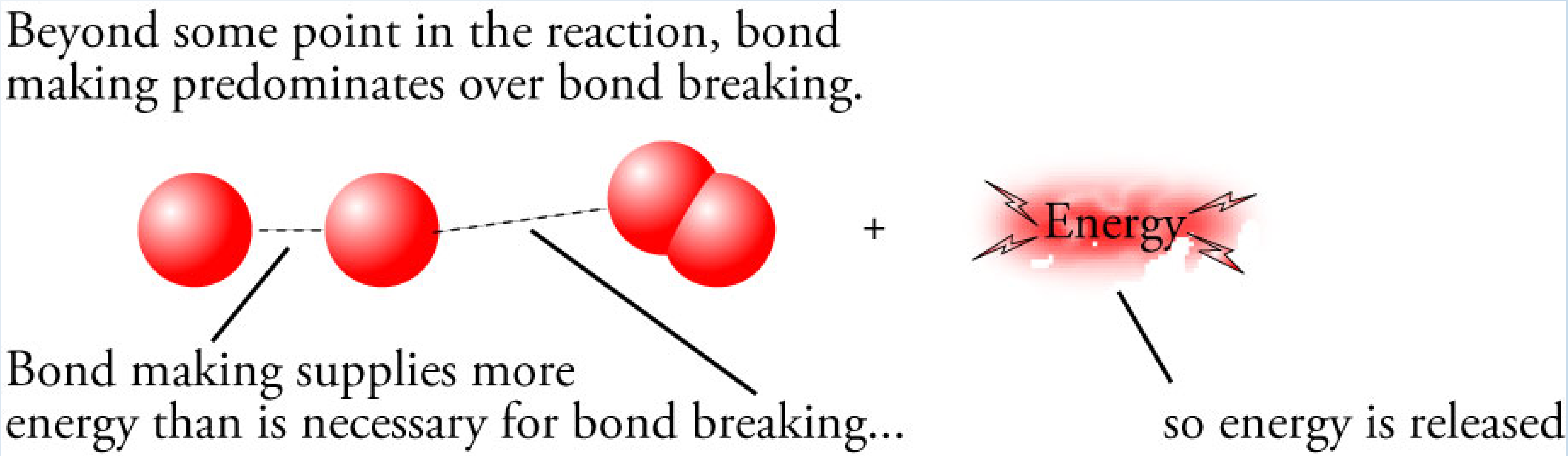


Initially, the energy required for bond breaking is greater than the energy supplied from bond making. The extra energy necessary for the reaction comes from the kinetic energy of the colliding particles.

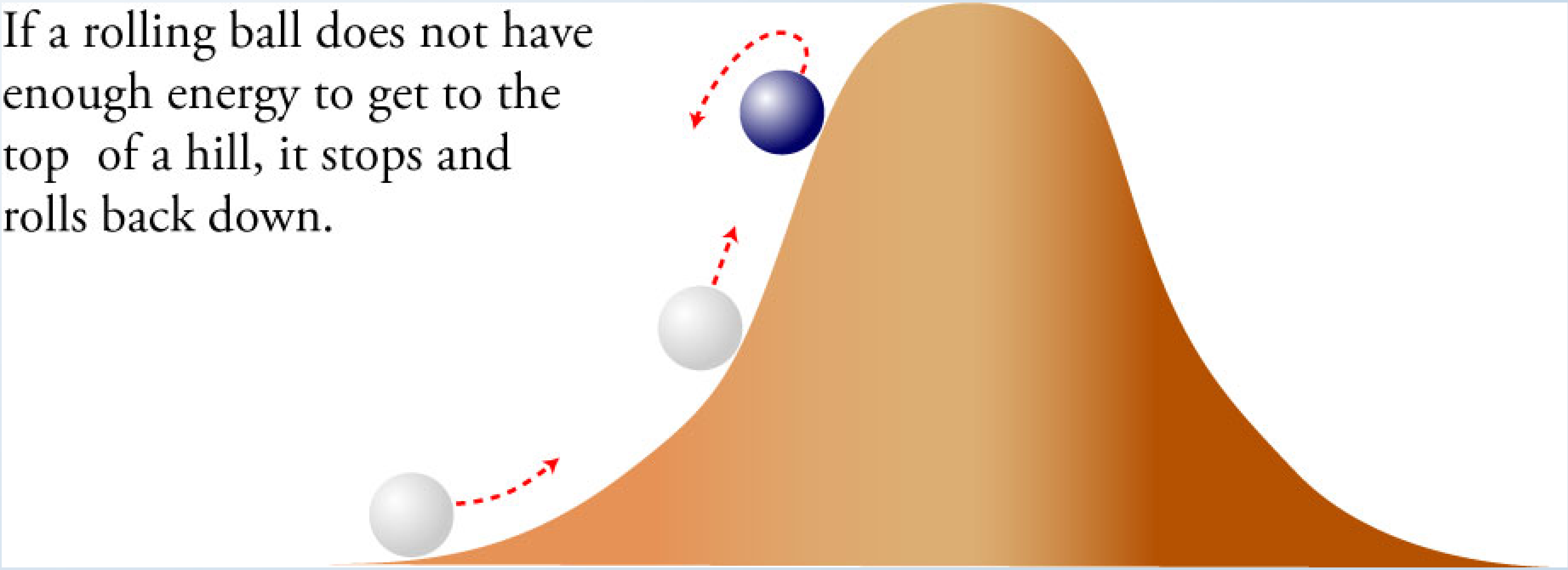
Formation of Activated Complex



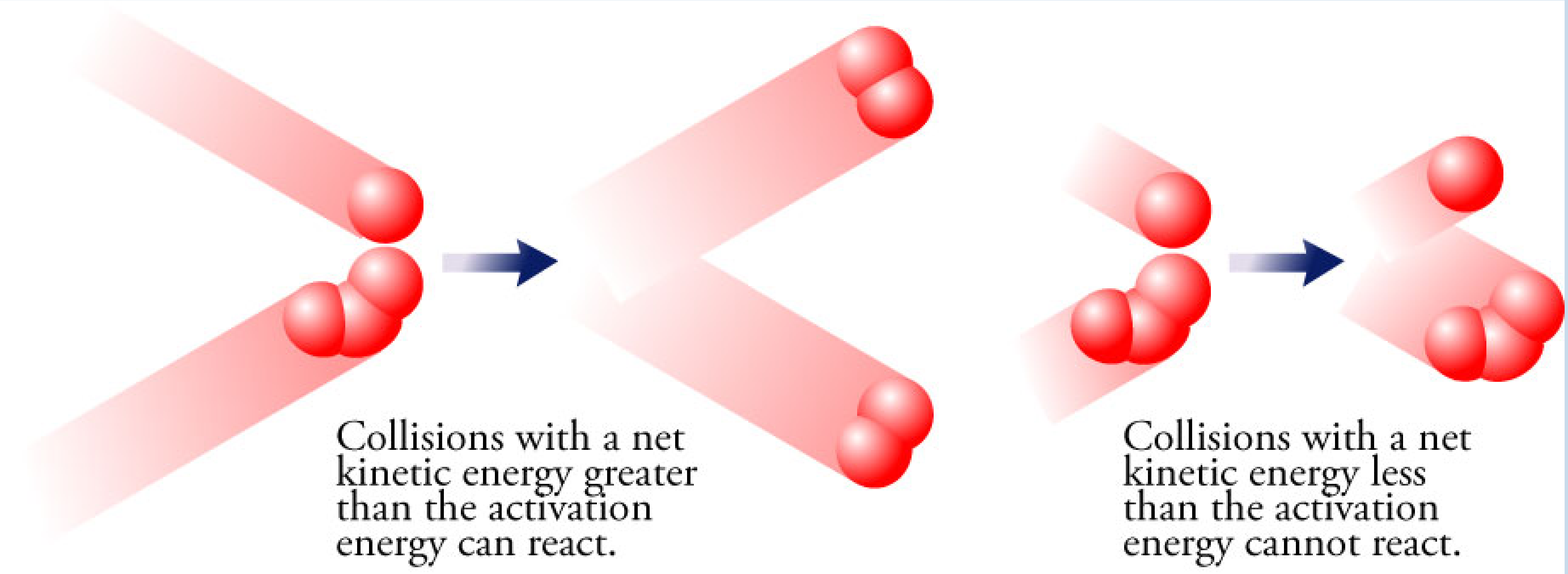
Formation of Product



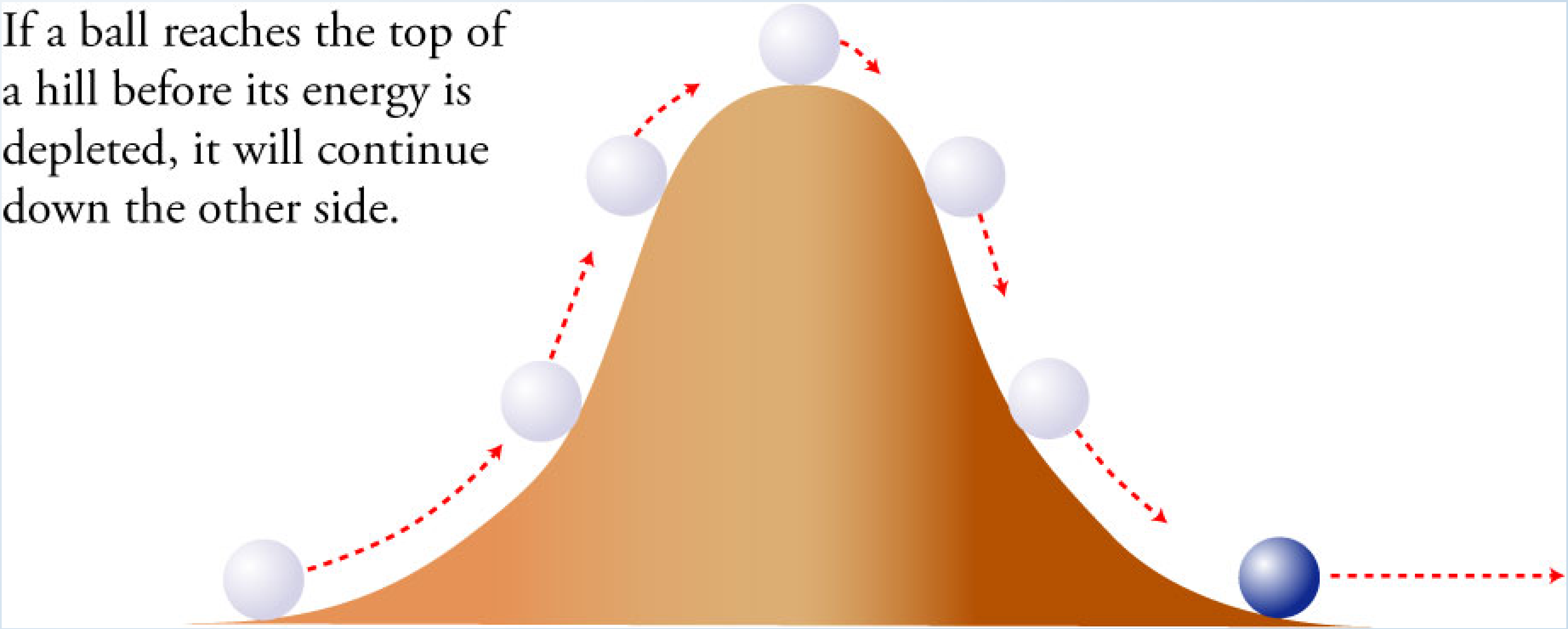
Reactions must have a minimum activation energy…if too little, no change



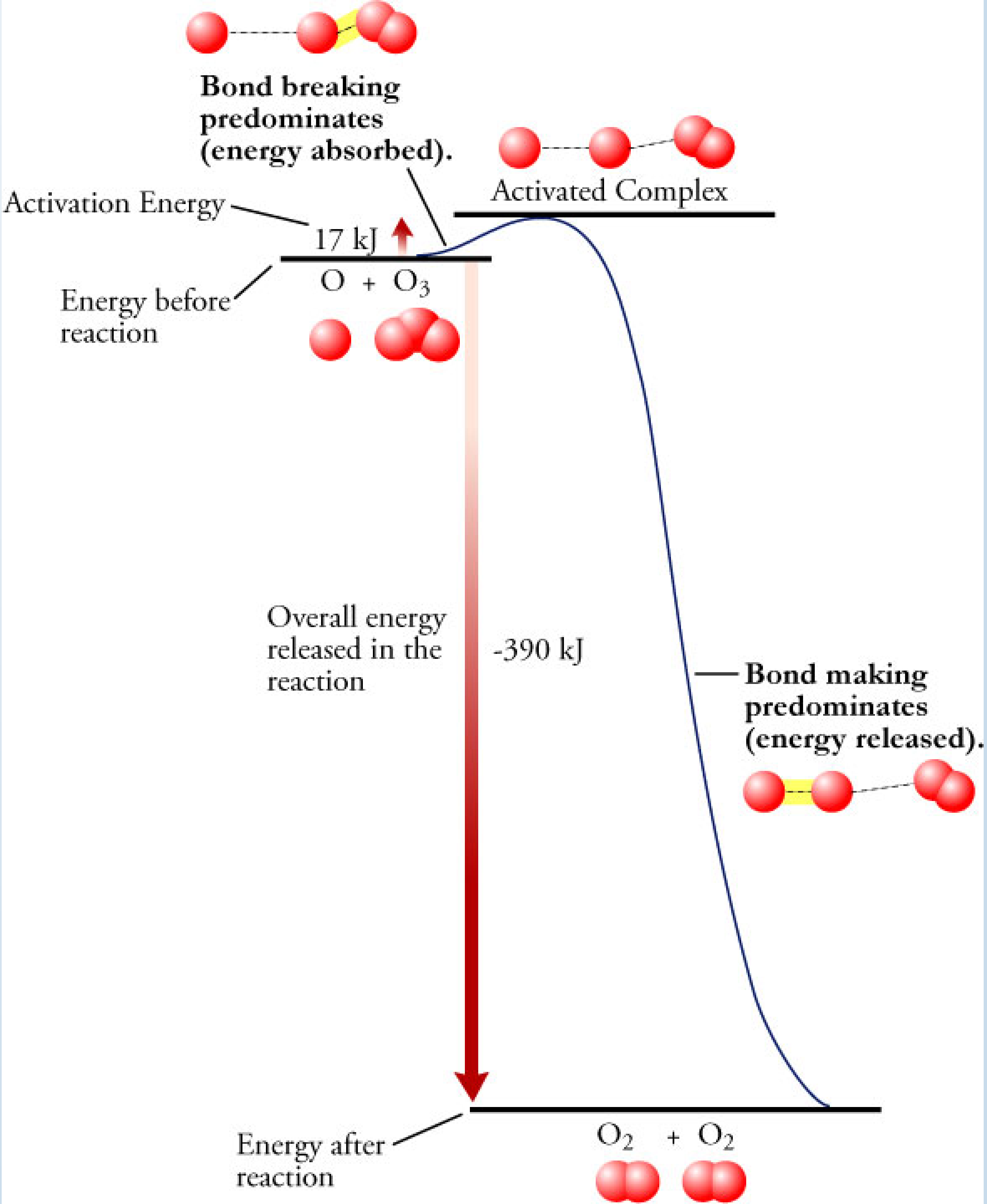
Collision Energy and Activation Energy



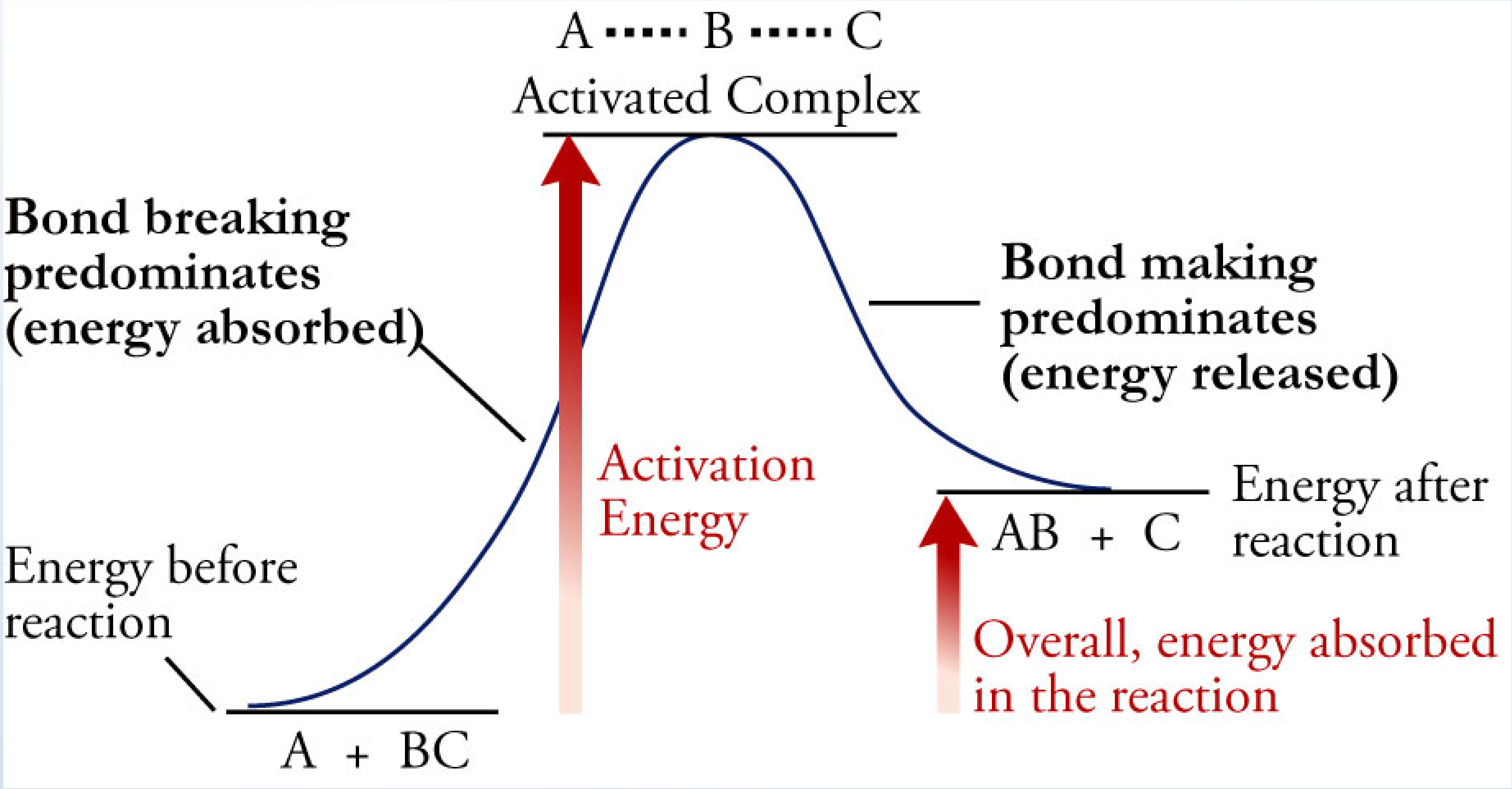
Reactions must have a minimum activation energy…if enough, change



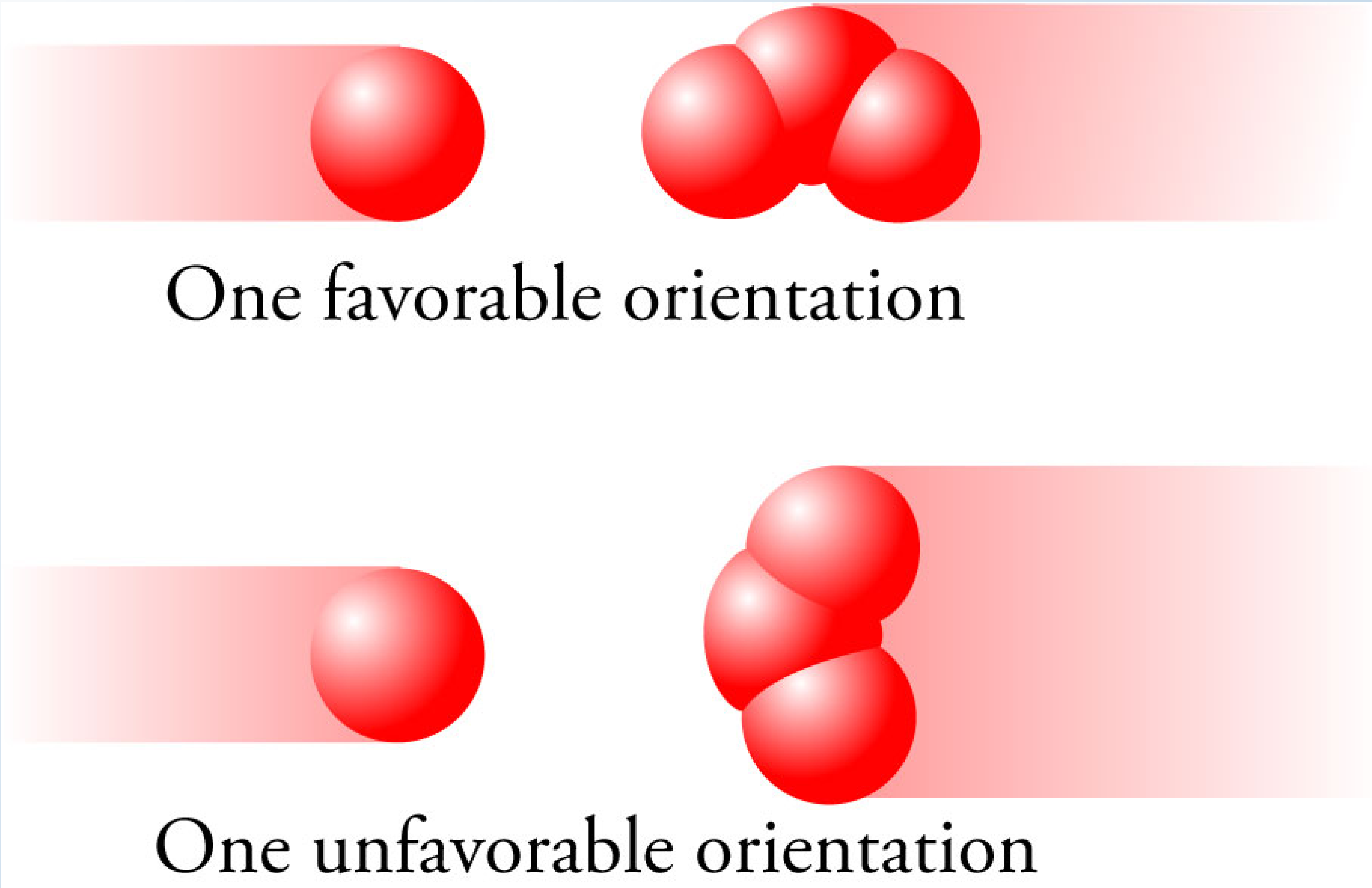
Energy Diagram for O/O_3 Reaction



Endogonic Reactions



Orientation



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.

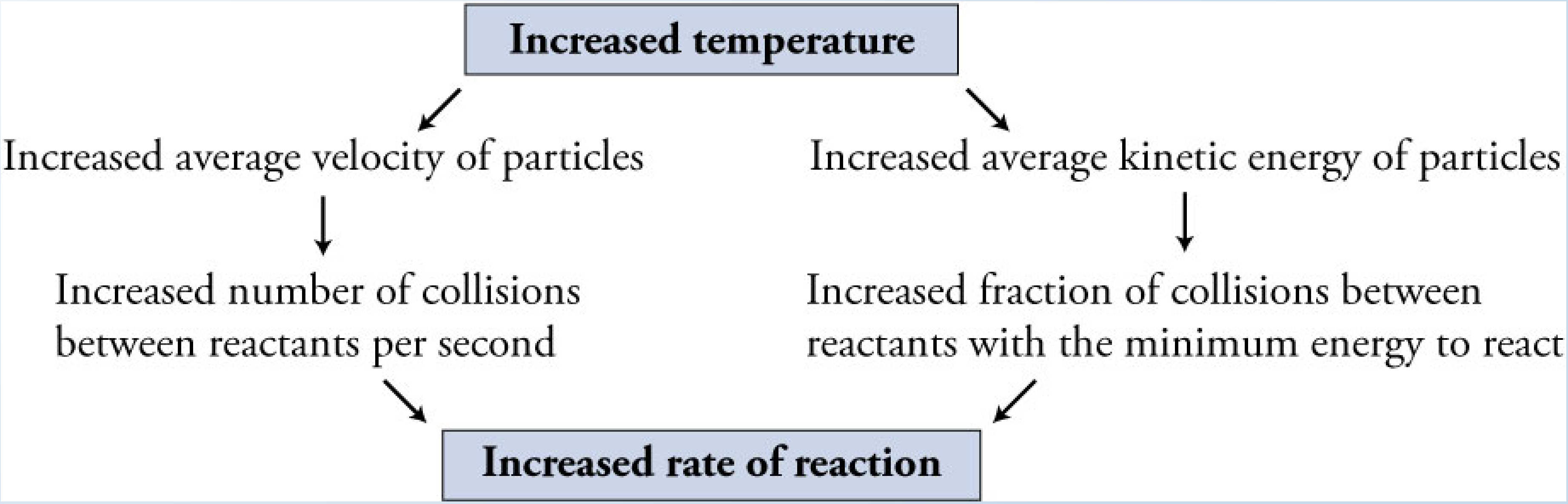
Summary (part 2)

- **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.

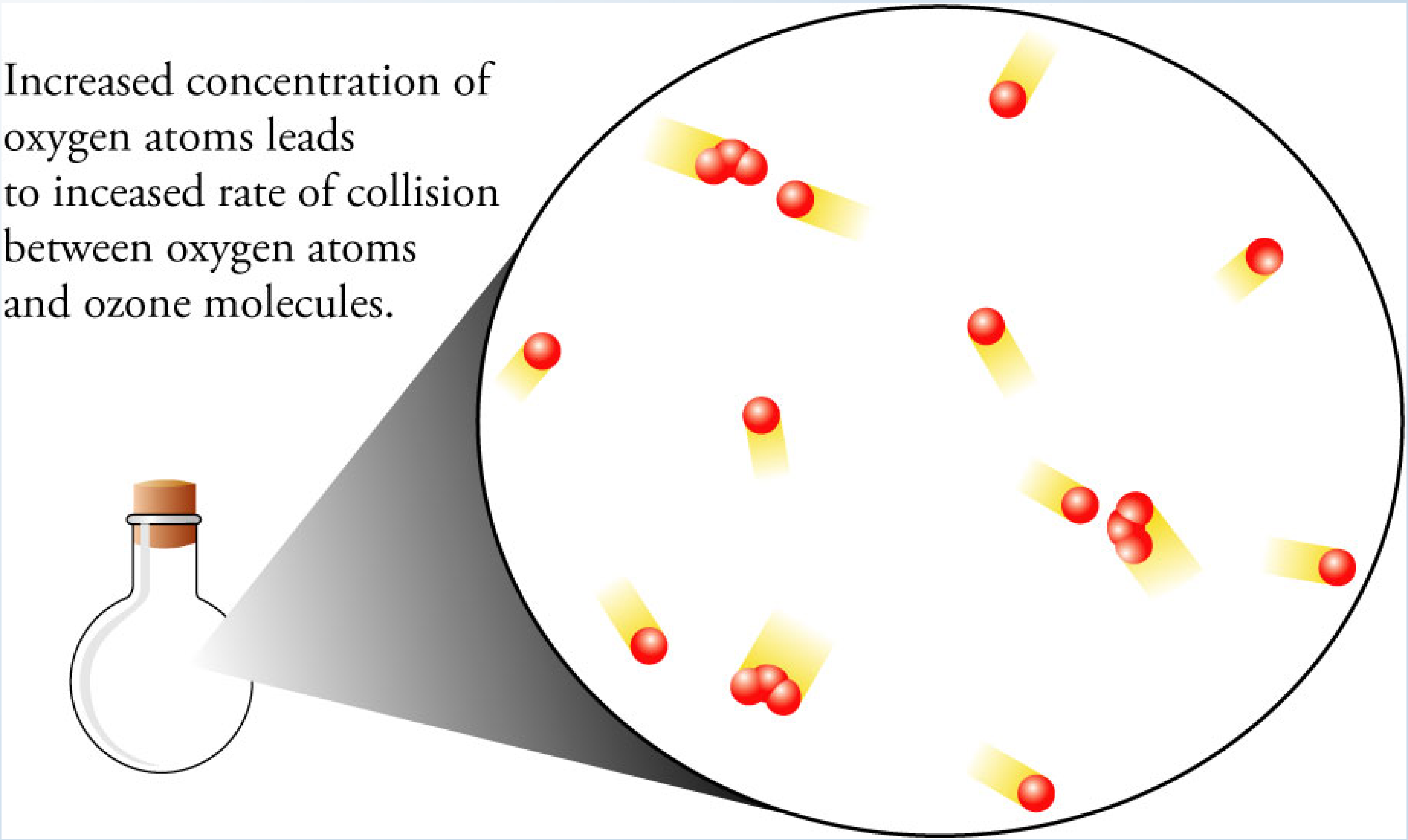
Summary (part 3)

- **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



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

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Increased number of collisions between reactants per liter per second

↓

Increased number of particles fulfilling the requirements for reaction

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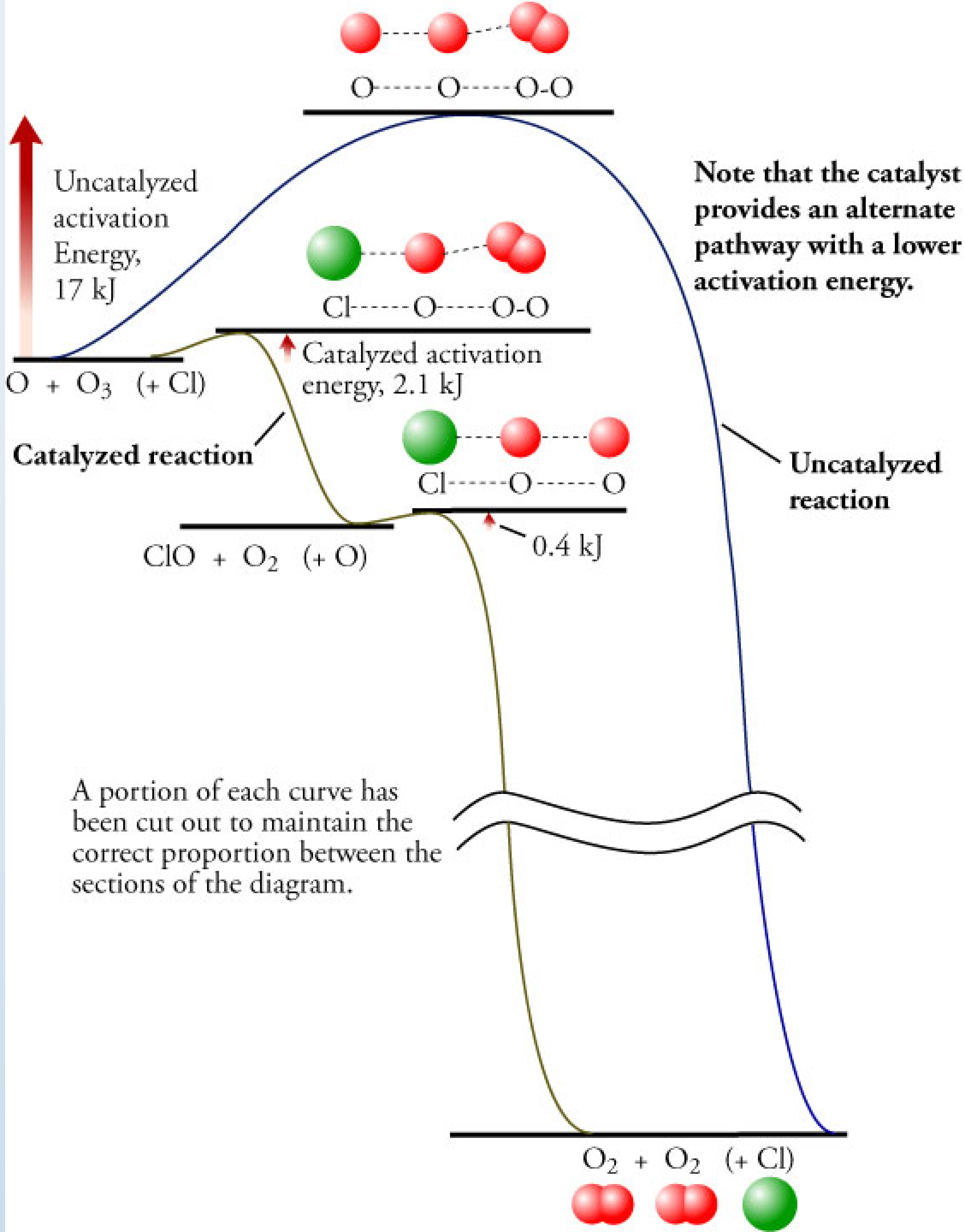
Increased rate of reaction

Catalyzed O/O_3 Reaction



Catalysts and Rate of Reactions

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

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A greater fraction of collisions have the activation energy.

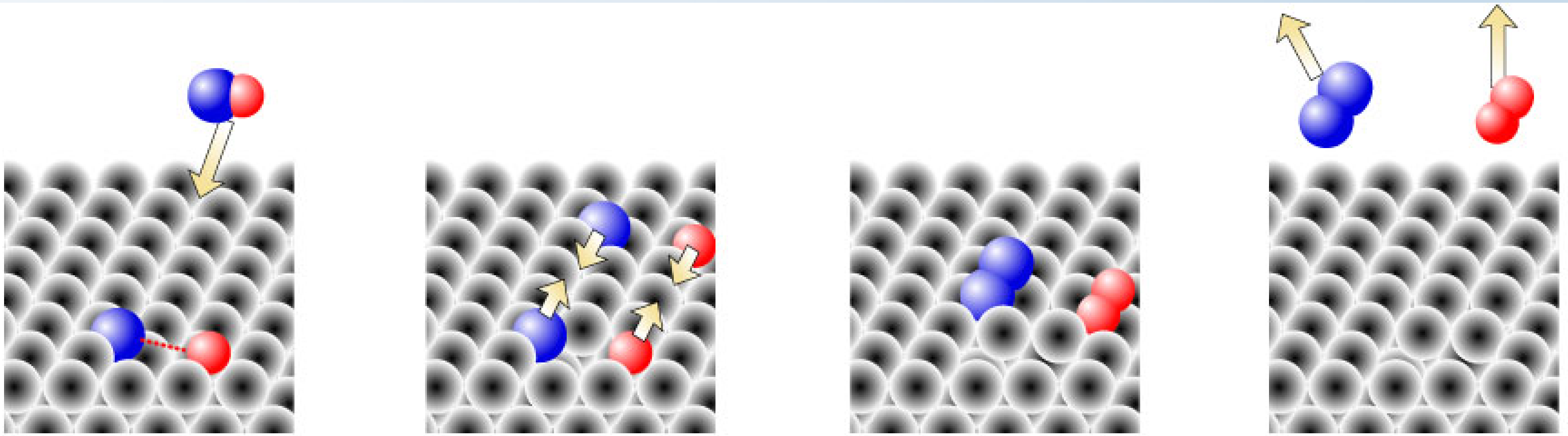
↓

A greater fraction of collisions lead to products.

↓

Increased rate of reaction

Heterogeneous Catalysis



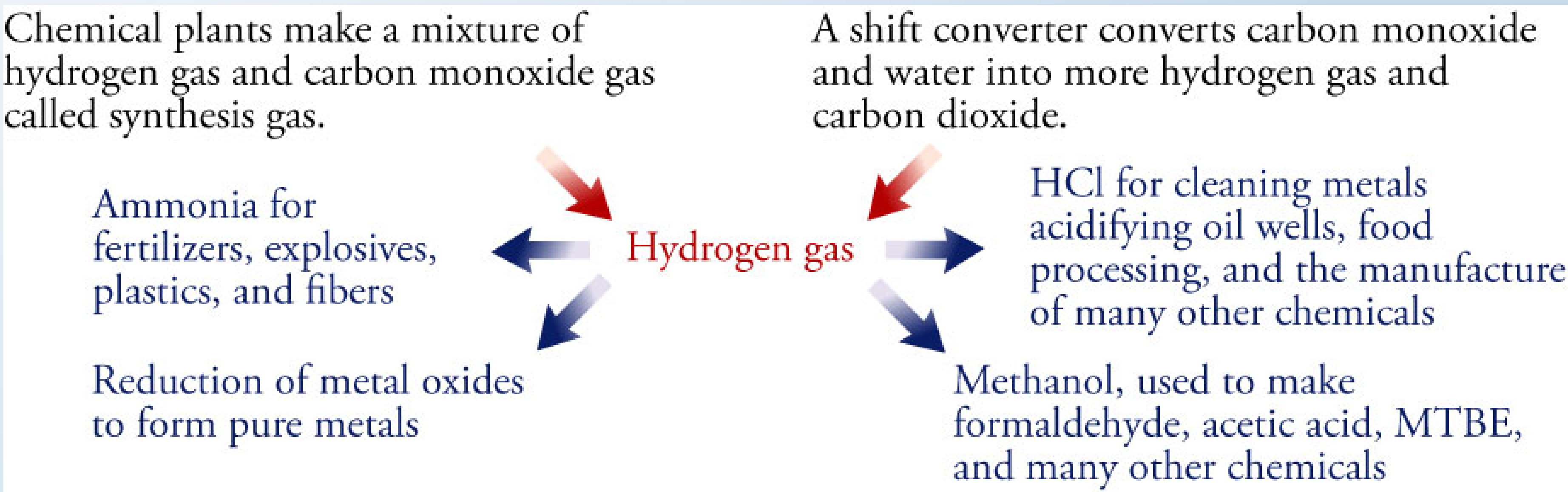
Step 1 - The reactant molecules are adsorbed, and the bonds are weakened.

Step 2 - The atoms migrate across the catalyst.

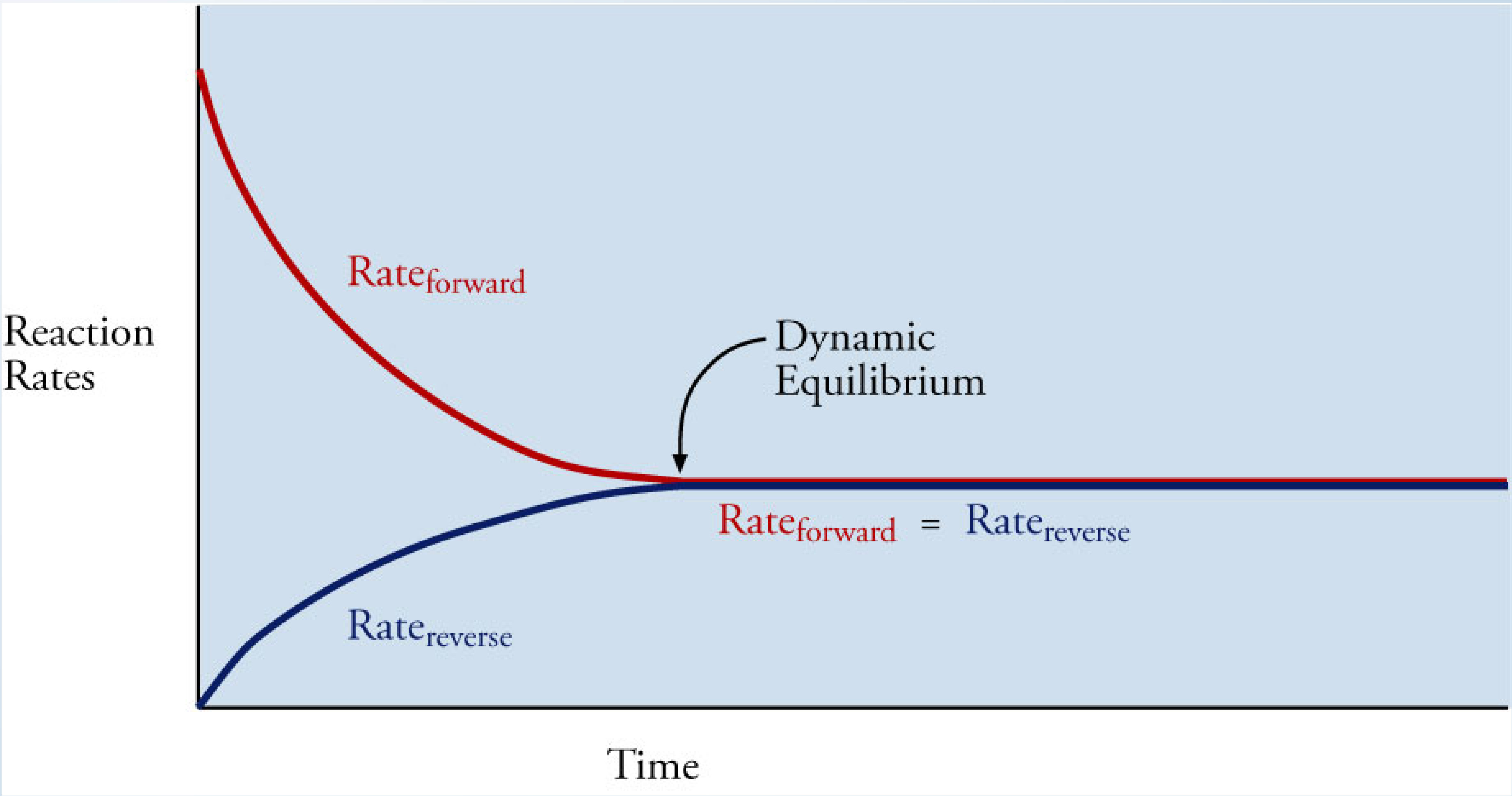
Step 3 - New bonds form.

Step 4 - The products leave the catalyst.

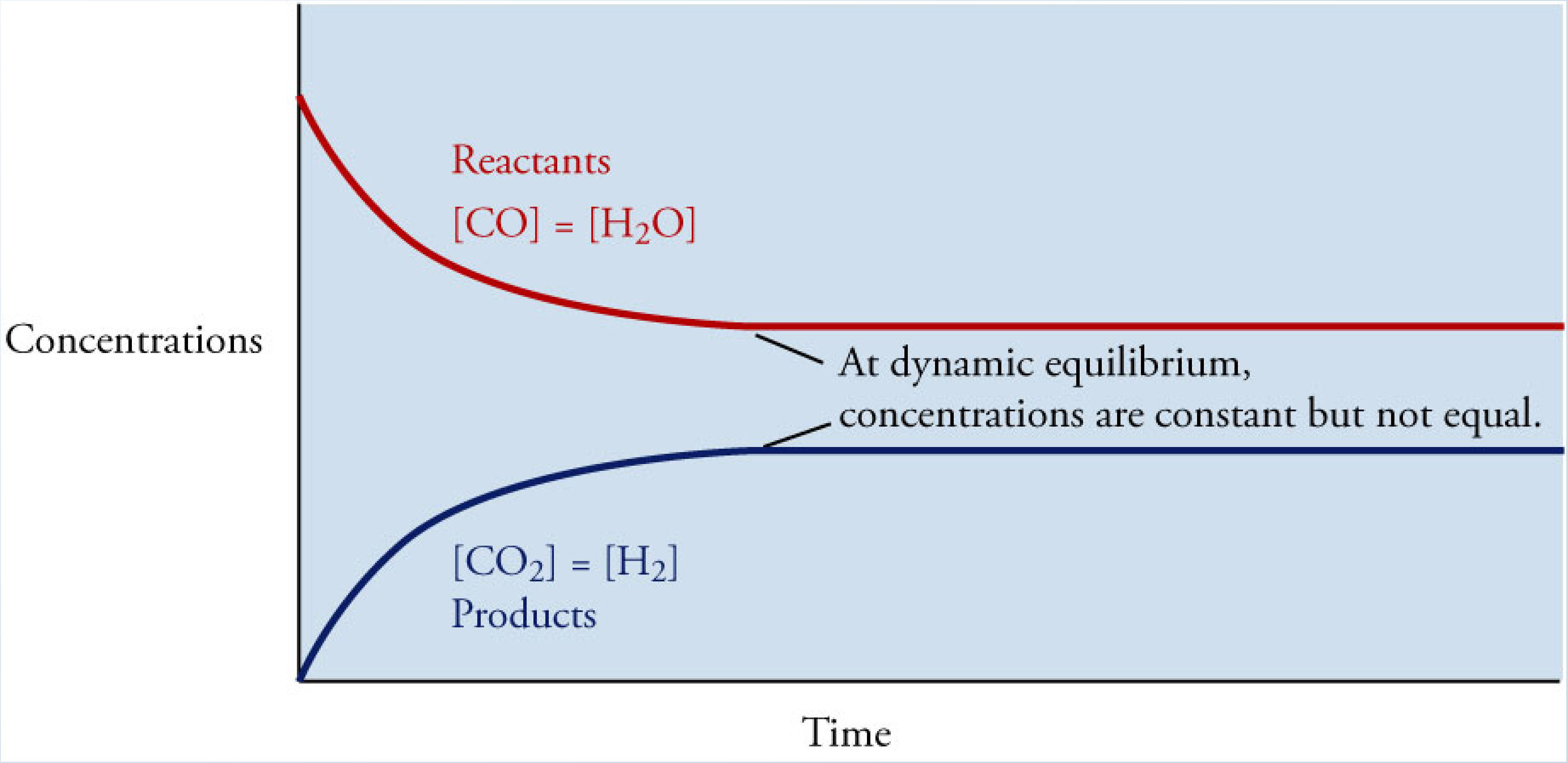
Production and Uses of Hydrogen Gas



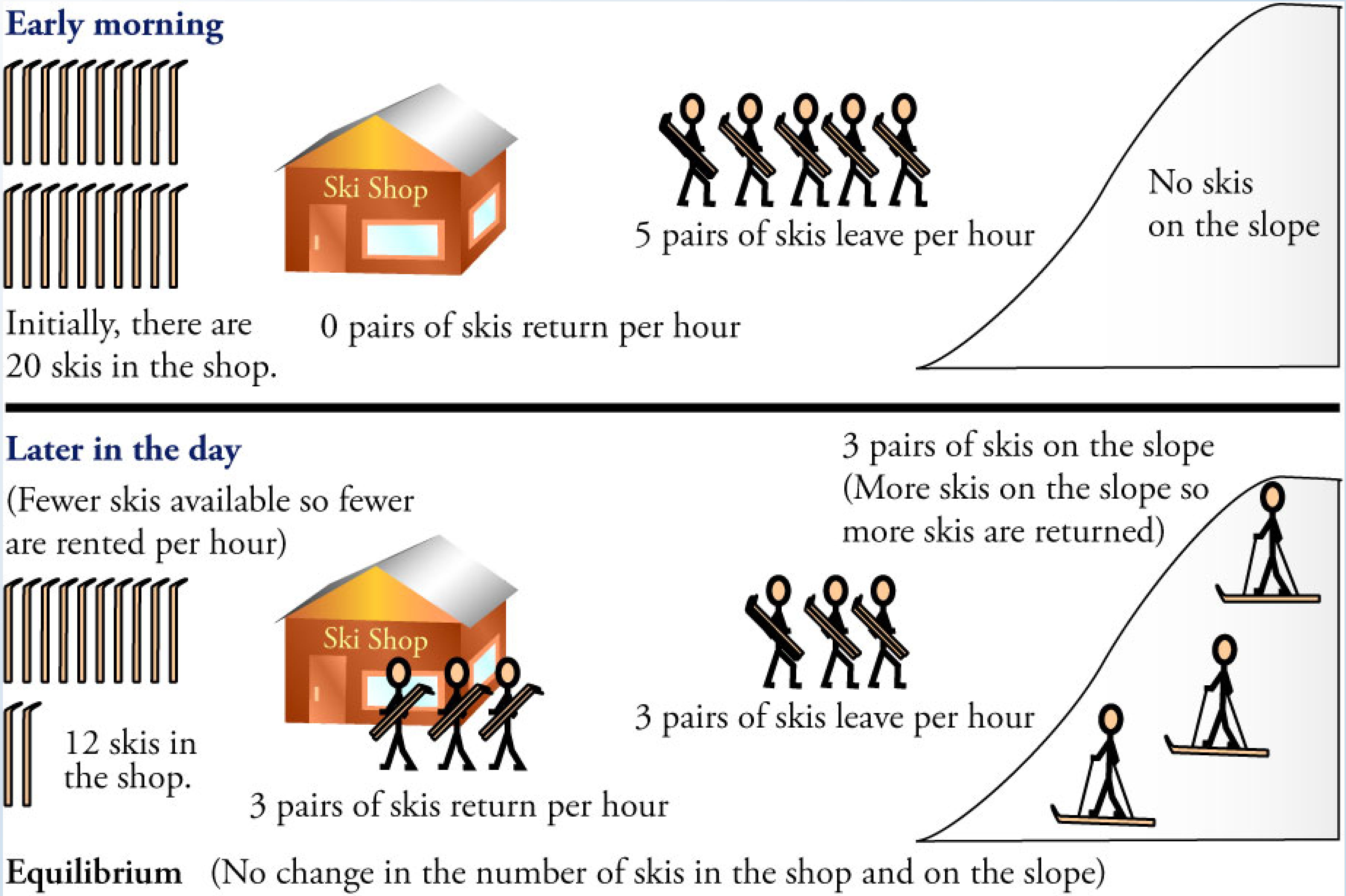
Rates of Reaction for Reversible Reactions



Changes in Concentrations for a Reversible Reaction



Ski Shop Analogy for Equilibrium



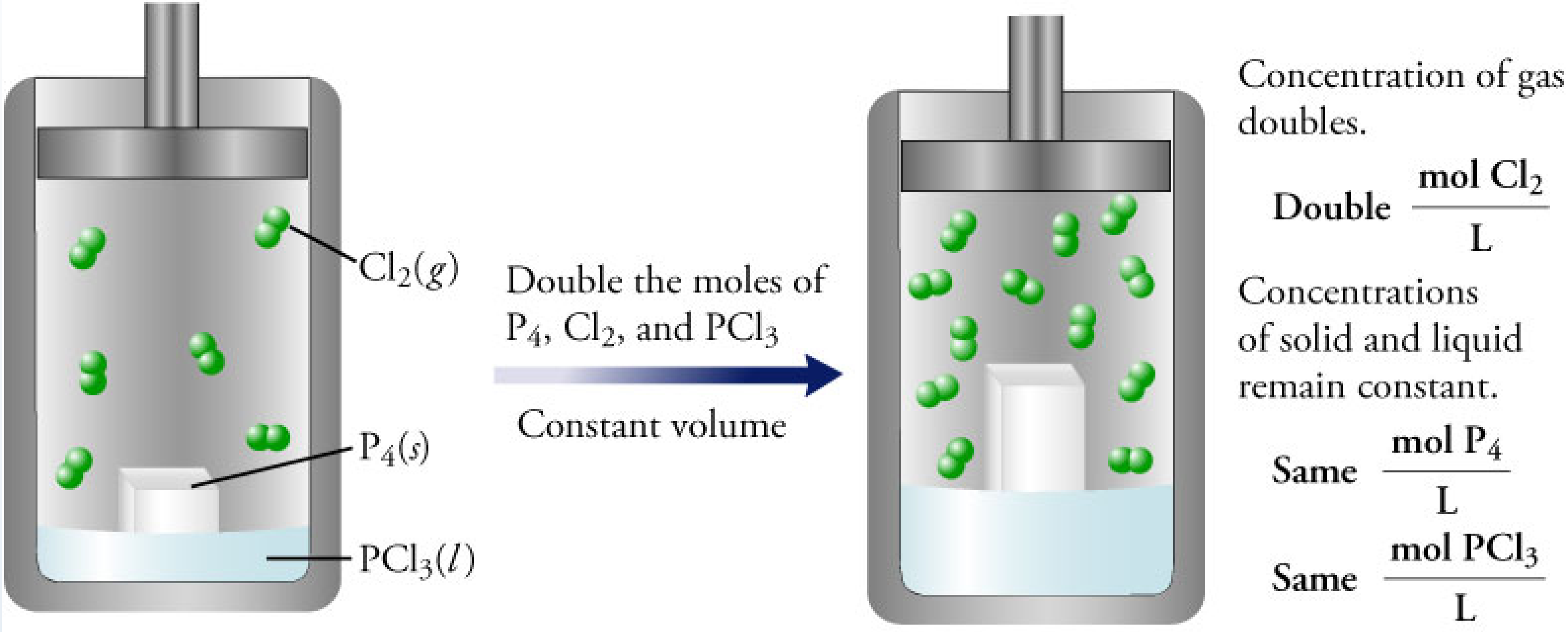
Equilibrium Constant Expression

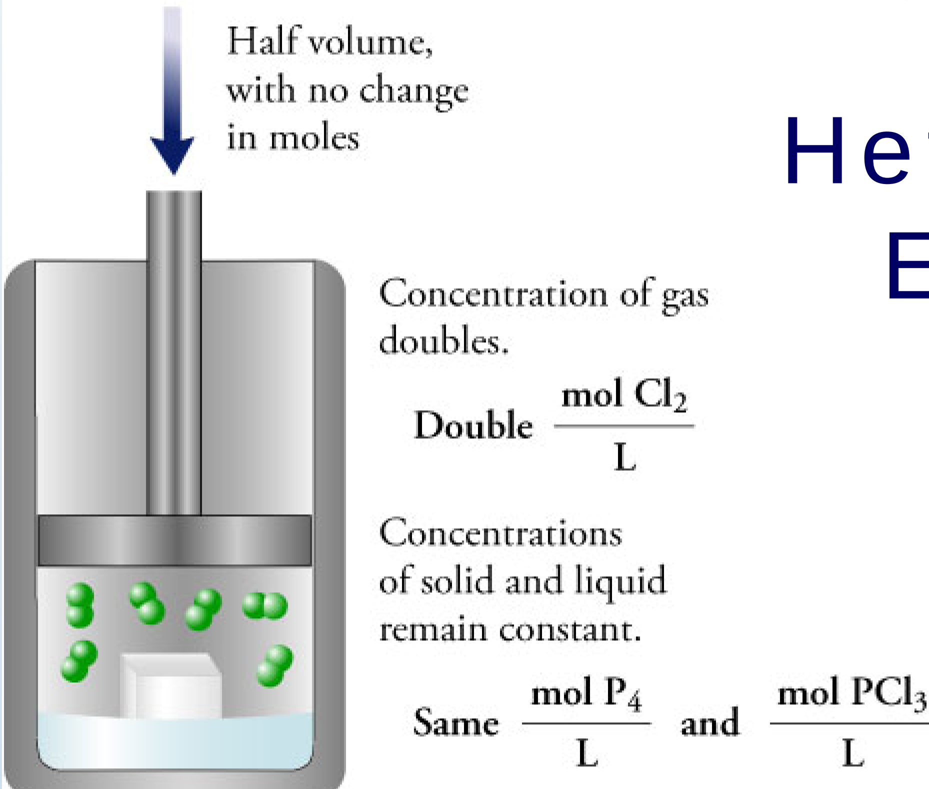
$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$$

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

$$K_C = \frac{[CO]\,[H_2]^3}{[CH_4]\,[H_2O]} \qquad K_P = \frac{P_{CO}\,P_{H_2}^3}{P_{CH_4}\,P_{H_2O}}$$

Heterogeneous Equilibrium





Equilibrium Constant Expressions for Heterogeneous Equilibria

$$SO_2(g) + 2H_2S(g) \rightleftharpoons 3S(s) + H_2O(g)$$

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

$$K_C = \frac{[H_2O]}{[SO_2]\,[H_2S]^2} \qquad K_P = \frac{P_{H_2O}}{P_{SO_2}\,P_{H_2S}^2}$$

Effect of Increased Concentration on Equilibrium

Increased concentration of reactant for a system at equilibrium with $Rate_{forward} = Rate_{reverse}$

↓

Increased $Rate_{forward}$

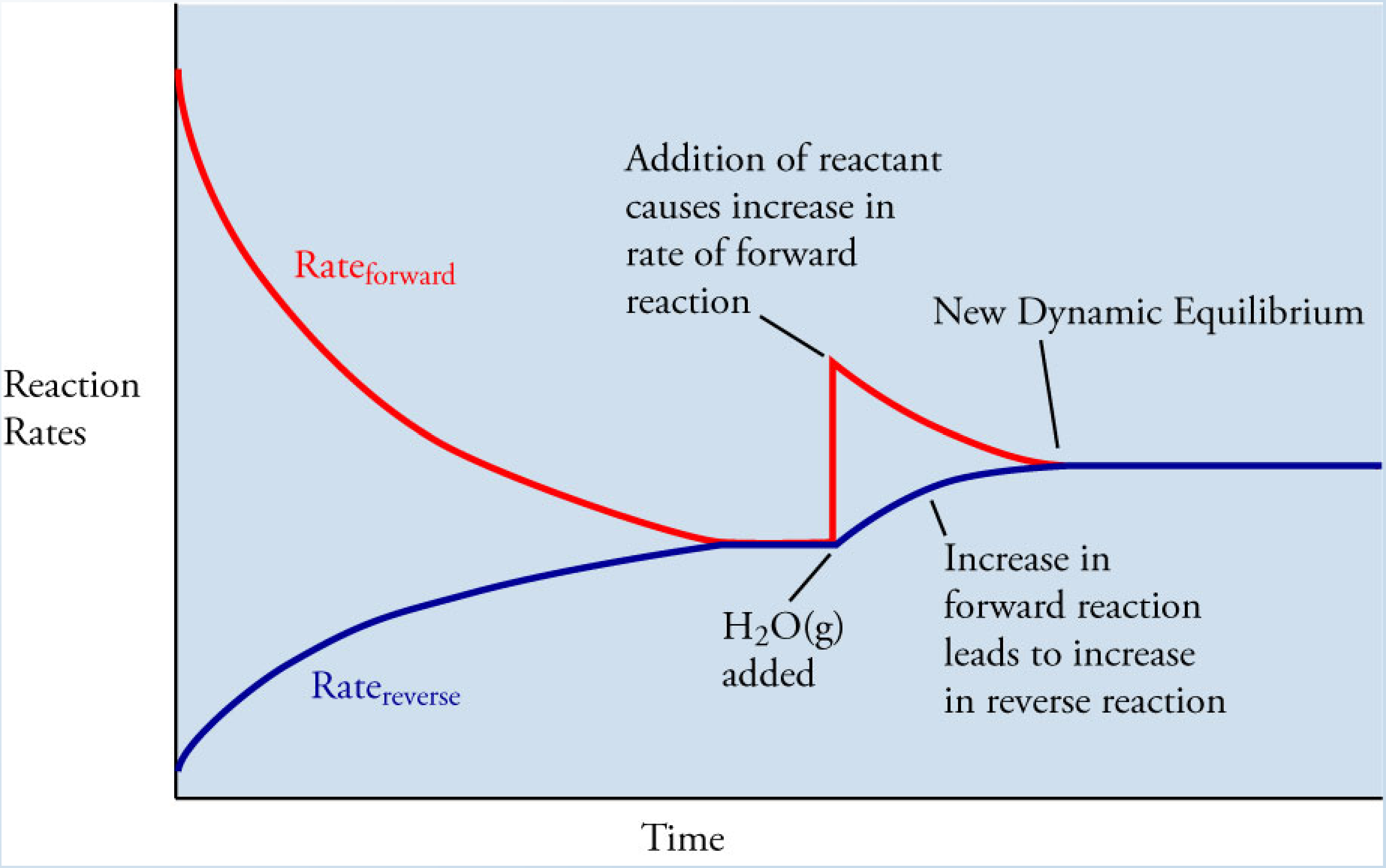
↓

$Rate_{forward} > Rate_{reverse}$

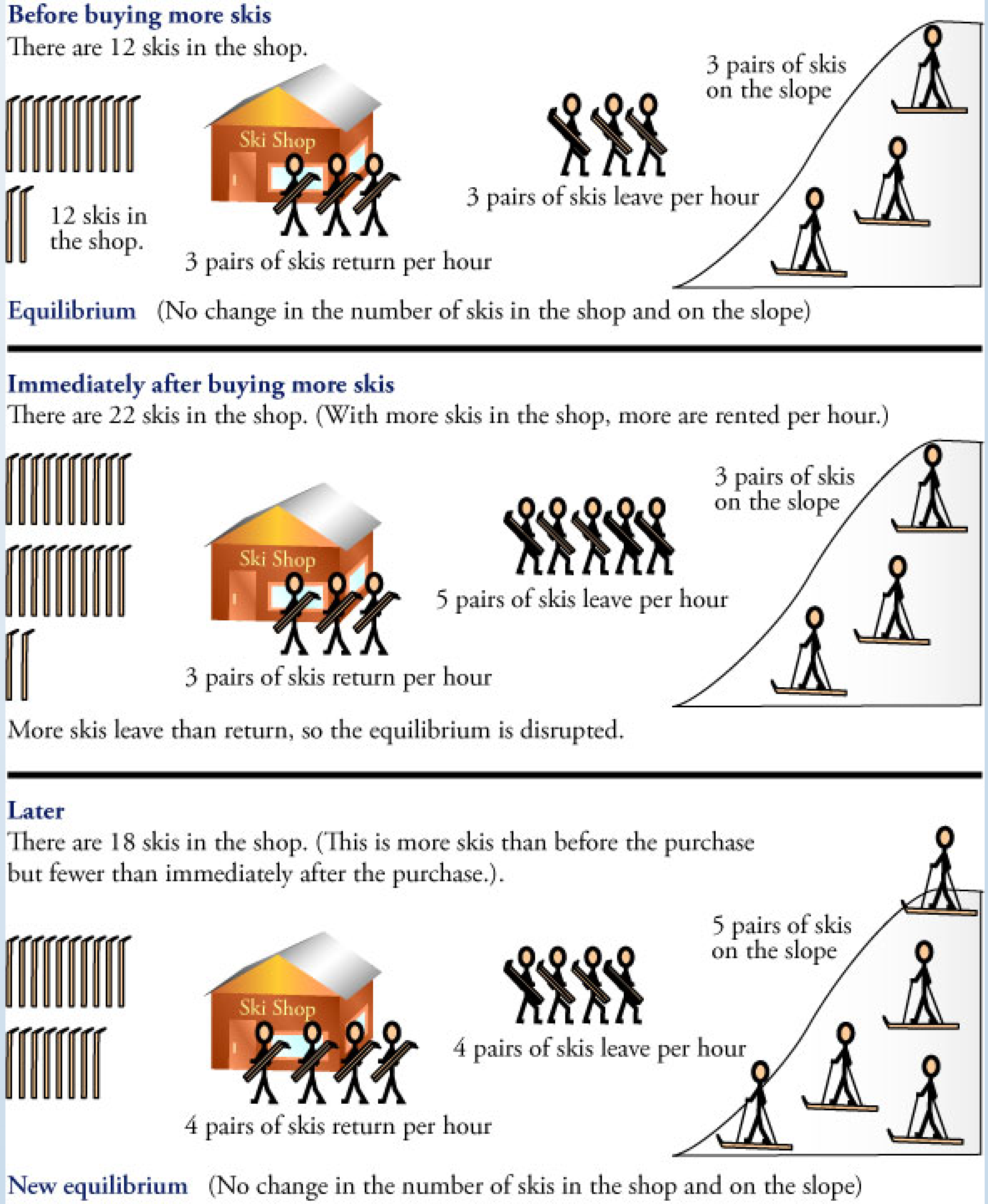
↓

System shifts toward products

Change in Rates When Reactant Added



Ski Shop Analogy 2



Effect of Decreased Concentration on Equilibrium

Decreased concentration of one product for a system at equilibrium with $Rate_{forward}$ = $Rate_{reverse}$

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Decreased $Rate_{reverse}$

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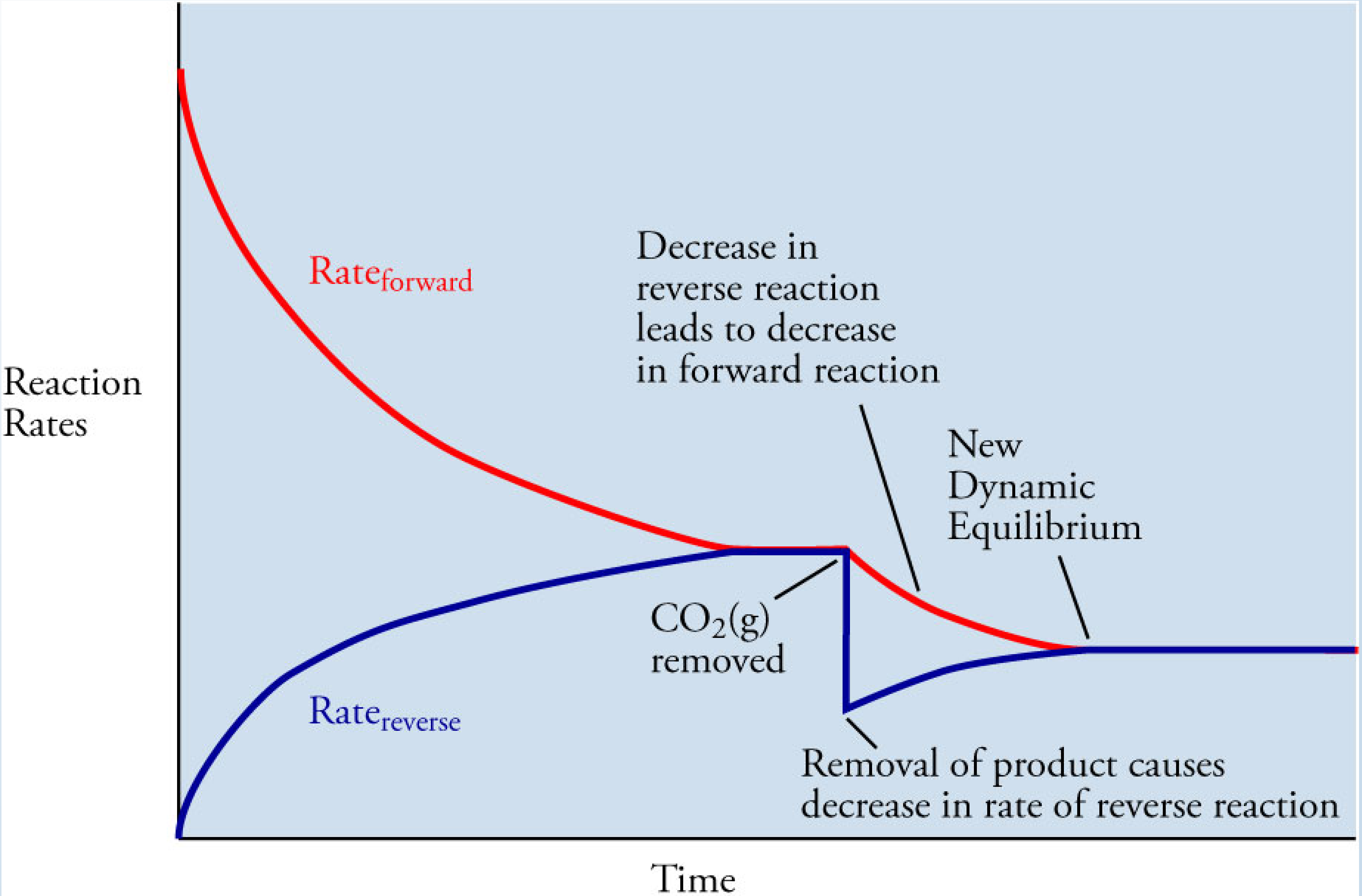
$Rate_{forward} > Rate_{reverse}$

↓

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.