Chapter 9 Rates of Chemical Reactions

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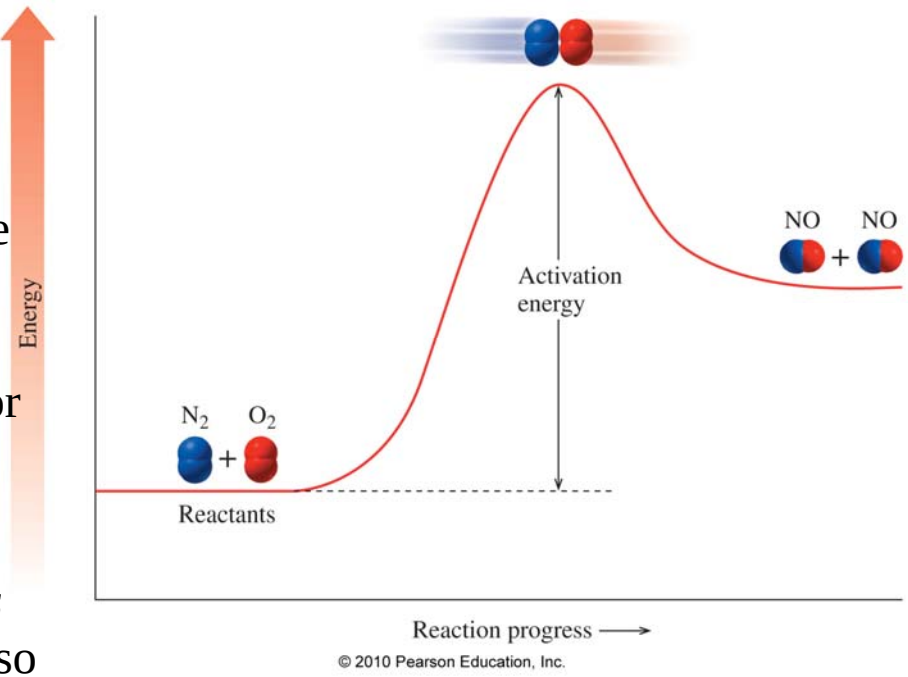
A **chemical reaction** occurs when collisions between molecules have
sufficient energy to break the bonds in the reactants;
molecules collide with the proper orientation

The **activation energy** is the minimum energy needed for a reaction to take place upon proper collision of reactants

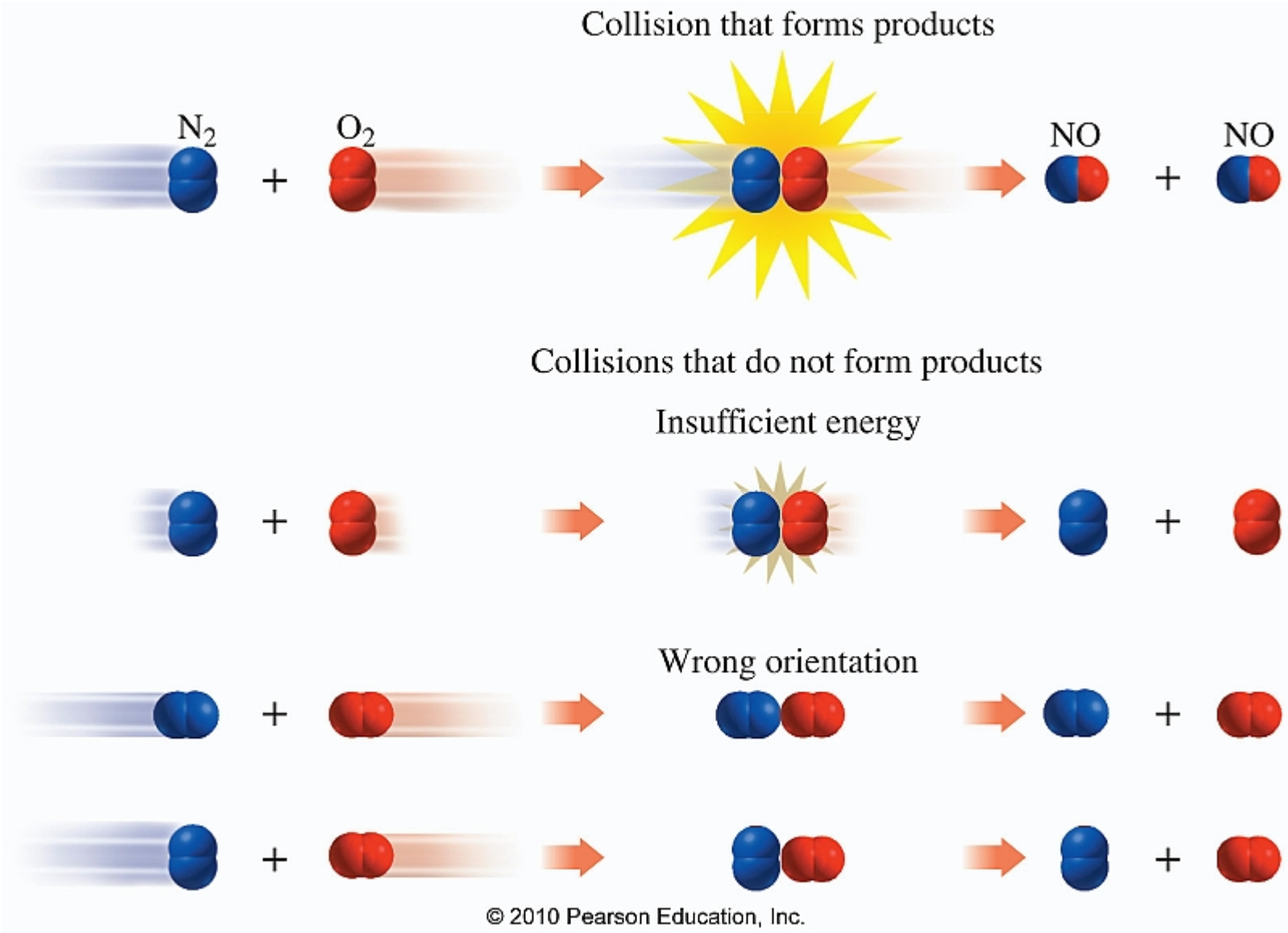
The **Reaction rate** is the speed at which reactant is used up and product forms;

increases when temperature rises because reacting molecules move faster, thereby providing more colliding molecules with sufficient energy to react (rate doubles for every 10 °C increase, approximately)

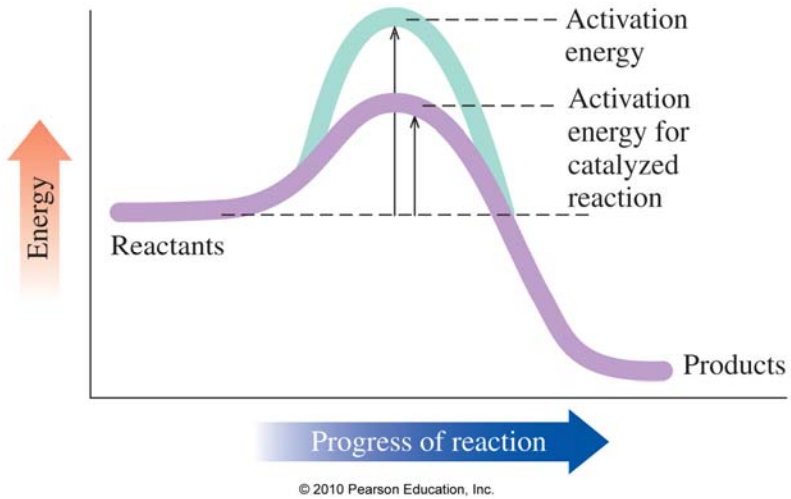
Increasing the *concentration of reactants* increases the number of collisions and also increases the reaction rate

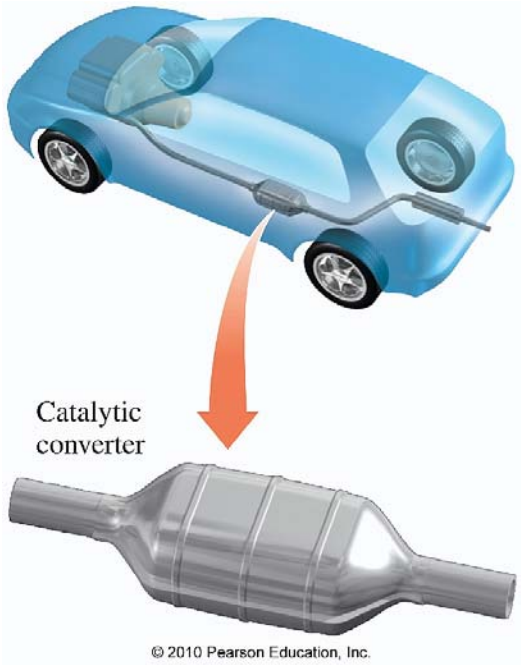


Factors affecting the formation of NO from N_2 and O_2



A **catalyst** speeds up the rate of a reaction by lowering the energy of activation and is generally not used up during the reaction



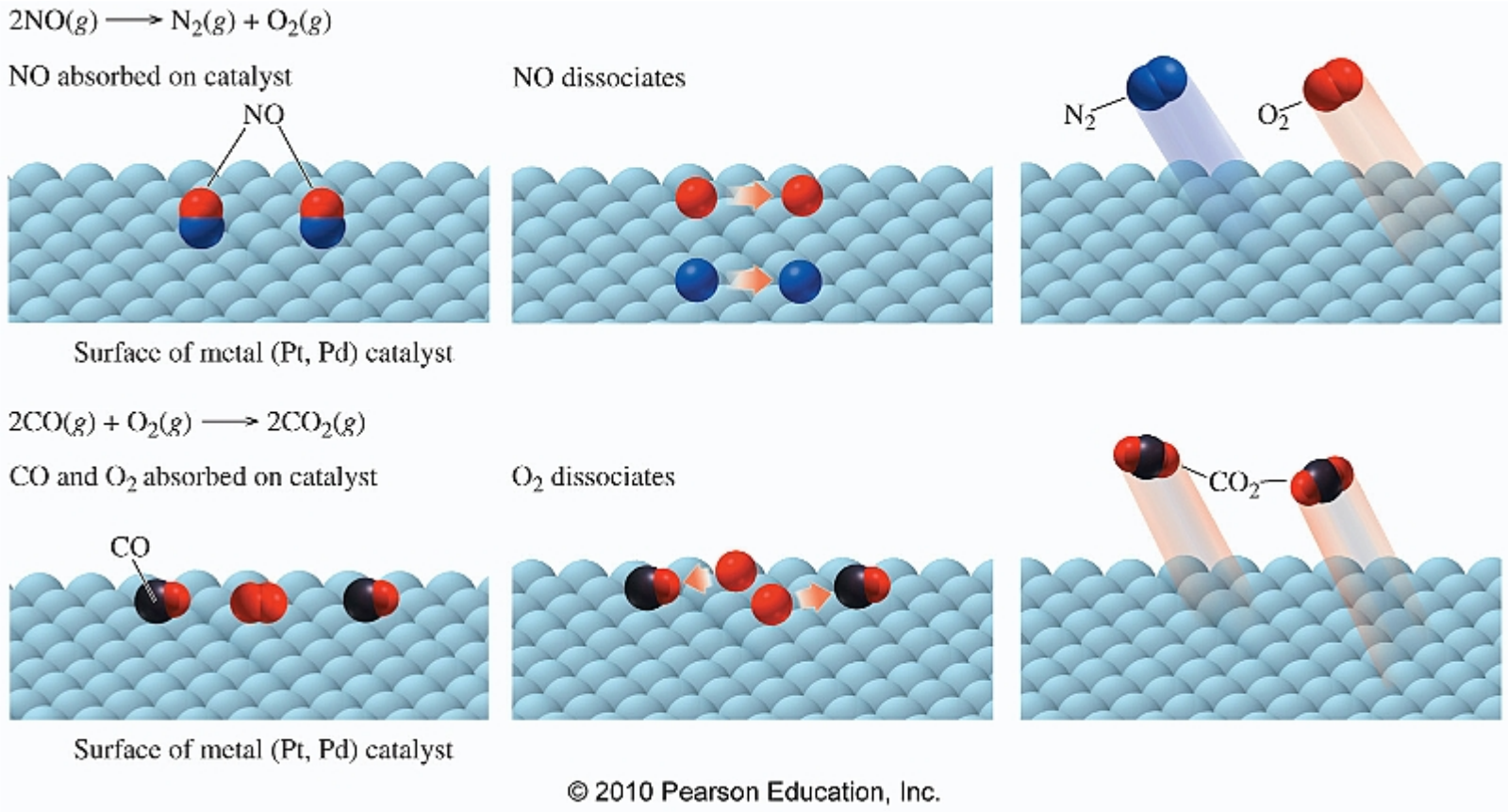


The catalytic converter in your car is used to remove CO and NO and unburned fuel

$2CO + O_2 = 2CO_2$

$2\ NO = N_2 + O_2$

C_8H_{18}



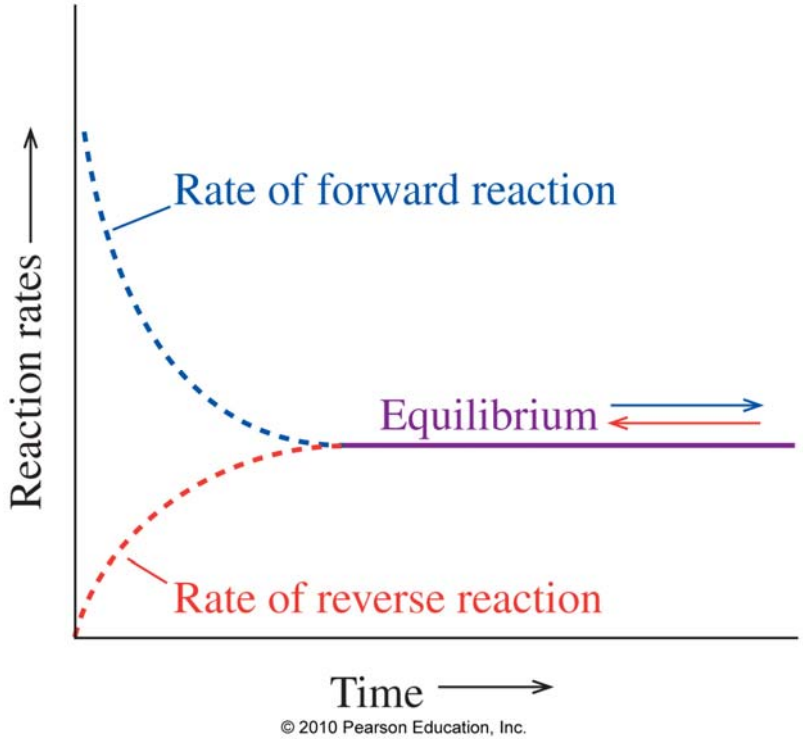
A catalytic converter consists of solid-particle catalysts, such as platinum (Pt) and palladium (Pd), on a ceramic honeycomb that provides a large surface area and facilitates contact with pollutants. As the pollutants pass through the converter, they react with the catalysts. Today, we all use unleaded gasoline because lead interferes with the ability of the Pt and Pd catalysts in the converter to react with the pollutants. The lead was used previously to increase the octane rating of gasoline. Today an methyl t-butyl ether, ethyl t-butyl ether or toluene is used.

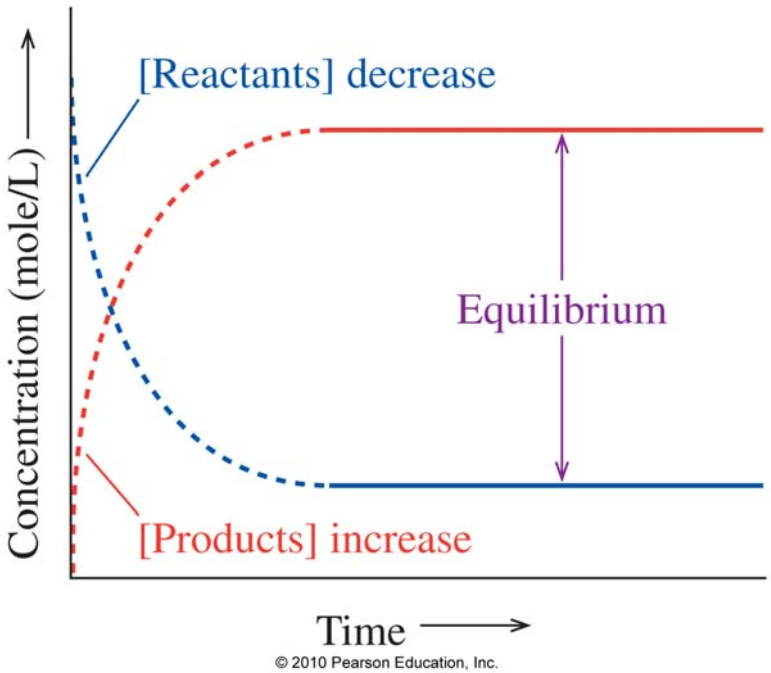
Chemical Equilibrium

At **equilibrium**, the rate of the forward reaction becomes equal to the rate of the reverse reaction;

the forward and reverse reactions continue at equal rates in both directions

molecules/sec





When equilibrium is reached,
there is no further change in the amounts of reactant and product

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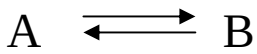
This means that for the following reaction,



$[A]/[B] = \text{constant}$

The magnitude of the constant tells us something about the position of equilibrium of the reaction

what is found experimentally is

$[A]^2/[A_2] = \text{constant}$

Information conveyed by the magnitude of the equilibrium constant

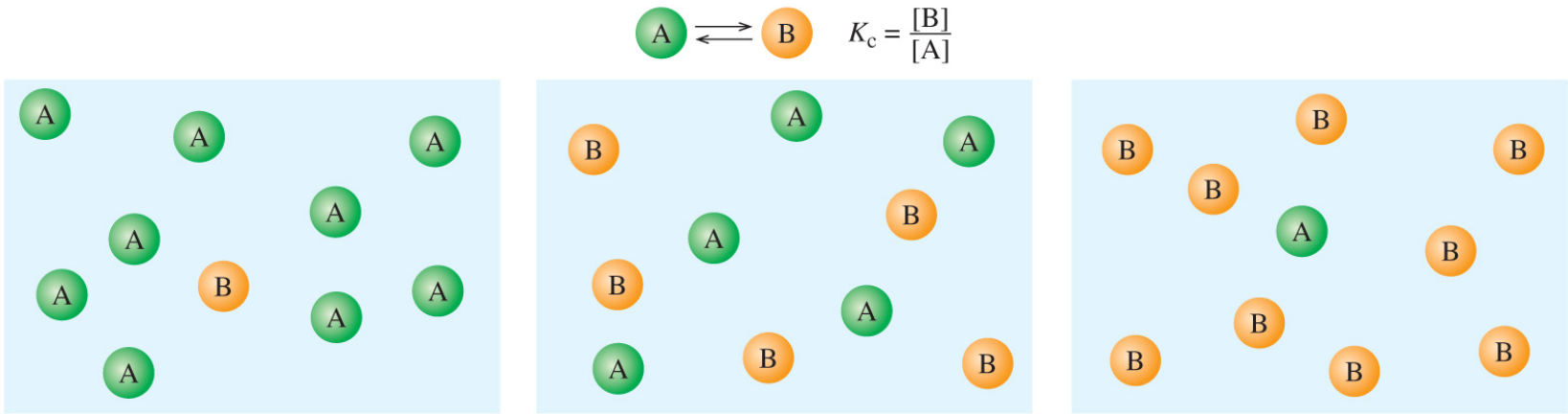


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TABLE 9.3 Examples of Reactions with Large and Small K_c Values

Reactants	Products	K_c	Equilibrium Favors
$2CO(g) + O_2(g)$	$\rightleftharpoons 2CO_2(g)$	2×10^{11}	Products
$2H_2(g) + S_2(g)$	$\rightleftharpoons 2H_2S(g)$	1.1×10^{7}	Products
$N_2(g) + 3H_2(g)$	$\rightleftharpoons 2NH_3(g)$	1.6×10^{2}	Products
$PCl_5(g)$	$\rightleftharpoons PCl_3(g) + Cl_2(g)$	1.2×10^{-2}	Reactants
$N_2(g) + O_2(g)$	$\rightleftharpoons 2NO(g)$	2×10^{-9}	Reactants

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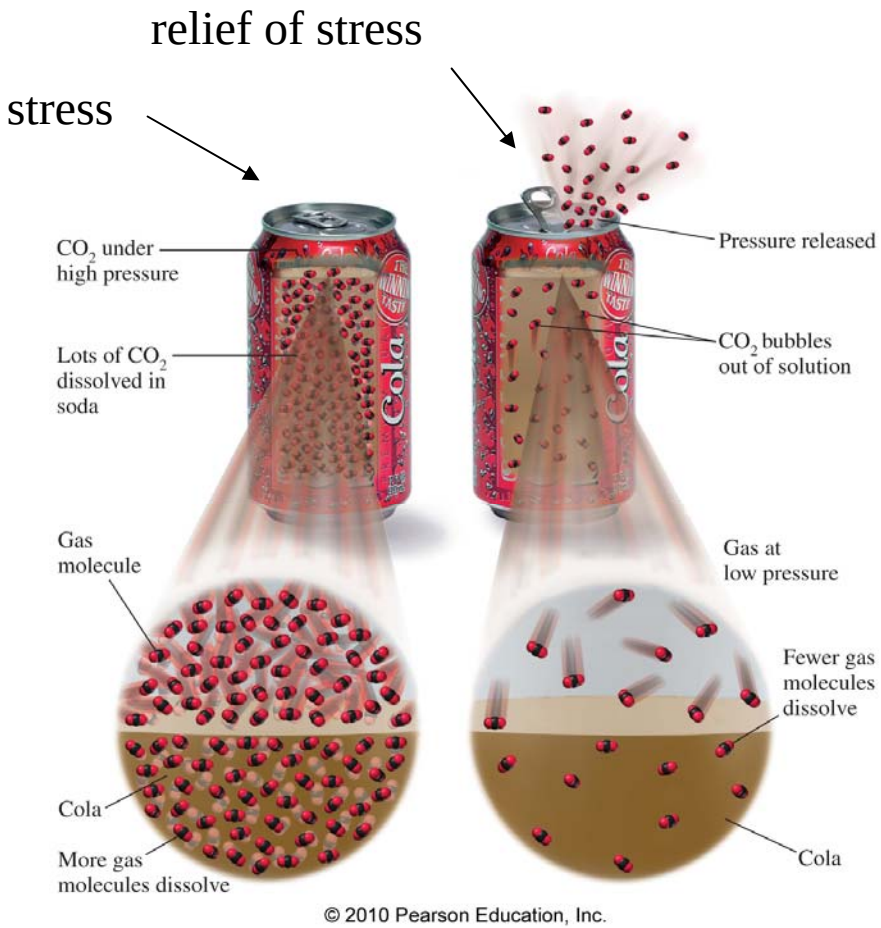
$$CH_4(g) + 2H_2S(g) \rightleftharpoons CS_2(g) + 4H_2(g)$$

The length of the arrow often is a qualitative measure of the position of equilibrium. In this case, arrows indicate more products on the right than on the left

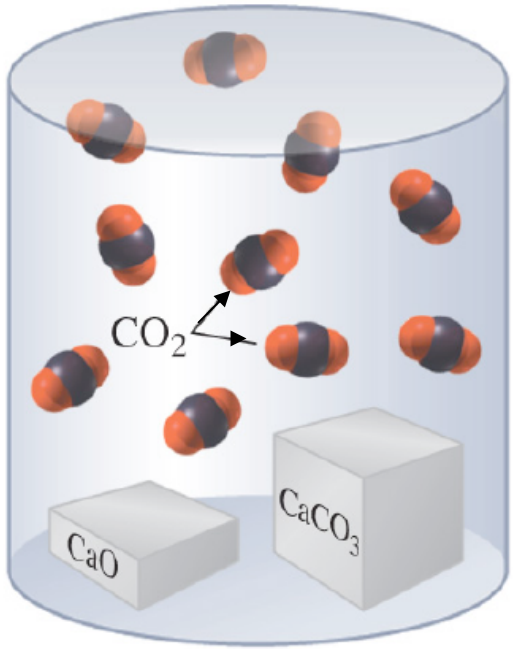
Le Châtelier's principle states that any change in equilibrium conditions upsets the equilibrium of the system;

a system at equilibrium under stress will shift to relieve the stress resulting in a change in the rate of the forward or reverse reaction to return the system to equilibrium

the direction of the shift will depend on the location of the stress

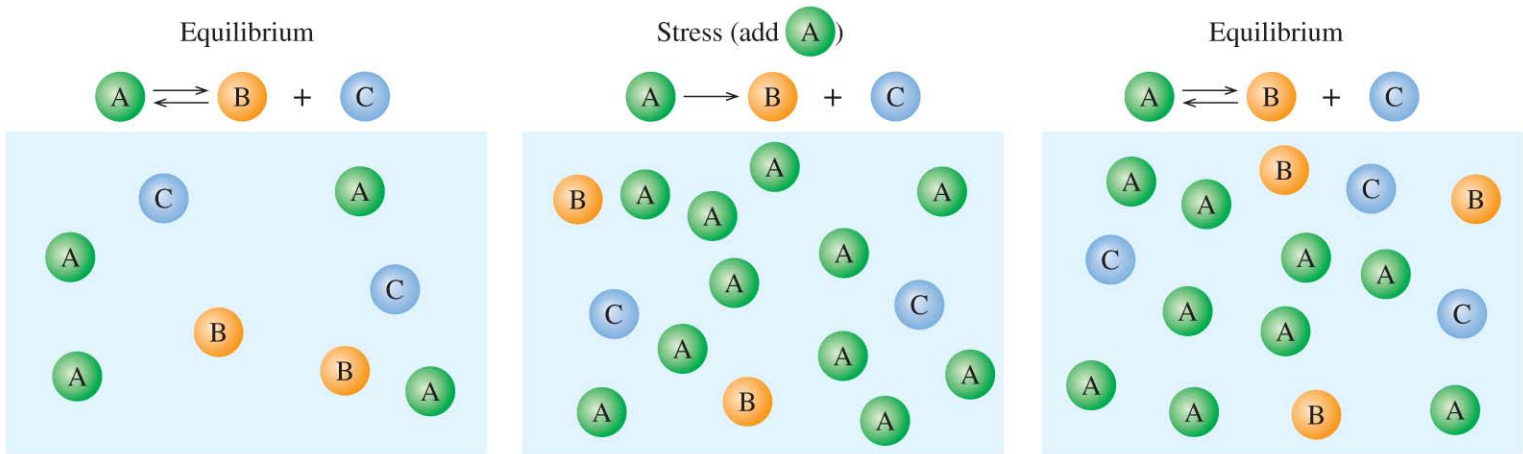


$$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$$



Heating calcium carbonate (limestone) in a closed system results in an equilibrium between calcium carbonate and calcium oxide and carbon dioxide; allowing the CO_2 to escape produces lime (CaO) used in the manufacture of concrete; allowing the CO_2 to escape corresponds in a volume change in the system

For the reaction A $\rightleftharpoons$ B + C at equilibrium, adding more A upsets the equilibrium



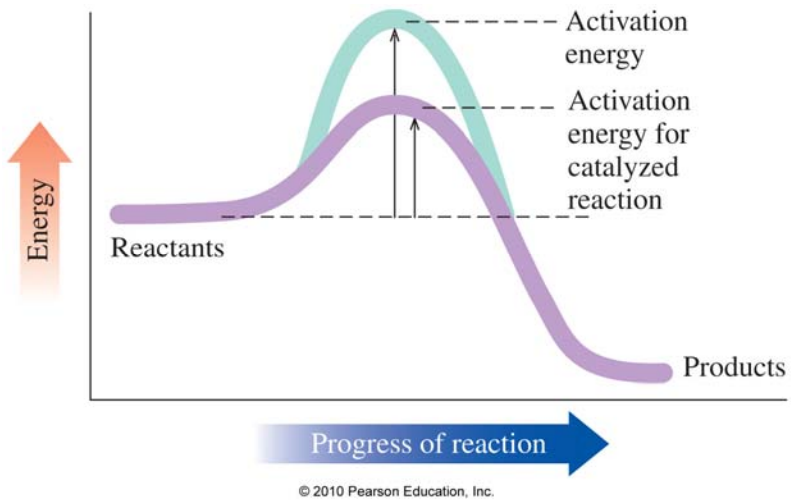
Factors affecting the rate of reaction:

1. temperature
2. concentration reactants
3. catalyst

True or false

Adding a catalyst

lowers the activation energy of the forward reaction
increases the rate of the forward reaction
lowers the activation energy of the reverse reaction
increases the rate of the reverse reaction
decreases the time to reach equilibrium
has no effect on the equilibrium



Factors affecting the position of equilibrium

1. temperature
2. adding excess of a reactant
3. removing one of the products
4. For reactions involving a volume change, pressure

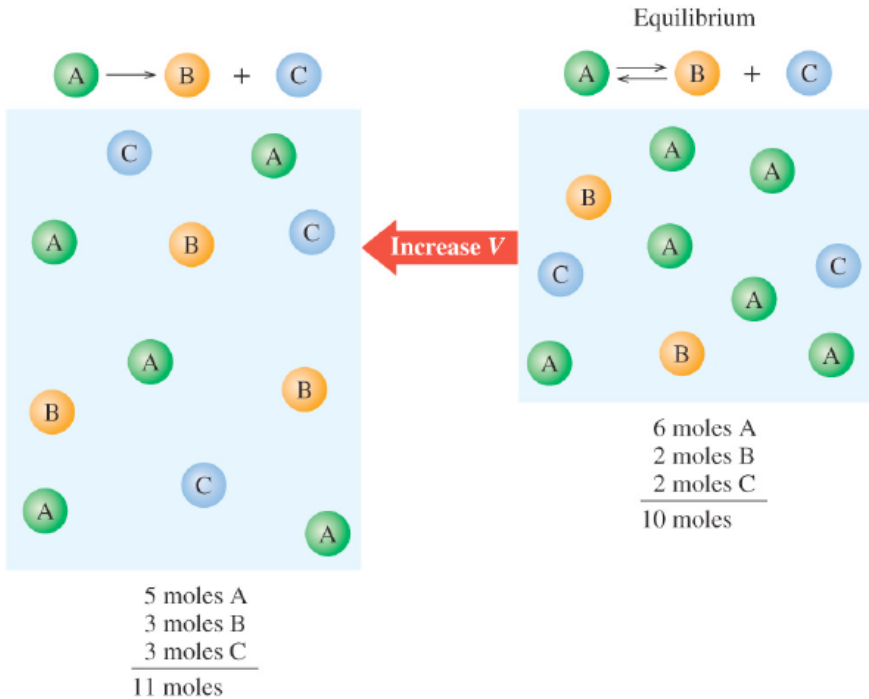


TABLE 9.7 Effects of Condition Changes on Equilibrium

Condition	Change (Stress)	Reaction to Remove Stress
Concentration	Add reactant	Forward
	Remove reactant	Reverse
	Add product	Reverse
	Remove product	Forward
Volume (container)	Decrease	Toward fewer moles in the gas phase
	Increase	Toward more moles in the gas phase
Temperature	**Endothermic reaction**	
	Raise T	Forward, new value for K_c
	Lower T	Reverse, new value for K_c
	Exothermic reaction	
	Raise T	Reverse, new value for K_c
	Lower T	Forward, new value for K_c
Catalyst	Increases rates equally	No effect

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$N_2 + 3H_2 = 2NH_3$

What affect would increasing the pressure have on this reaction taking place in the gas phase in a closed container? Would more or less NH_3 form?