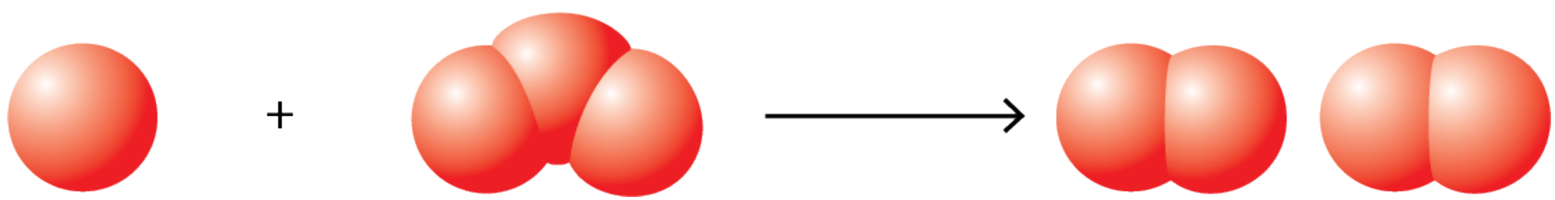
Rates of Chemical Reactions

$$\text{rate of reaction} = \frac{\text{number of moles of product formed}}{\text{liter} \cdot \text{second}}$$

$$O(g) \quad + \quad O_3(g) \longrightarrow 2O_2(g)$$



$$\text{rate of reaction} = \frac{\text{mol } O_2 \text{ formed}}{\text{L} \cdot \text{s}}$$

Collision Theory

- According to collision theory, for a reaction to take place,
  - the reactants must collide,
  - with the correct orientation to make the new bonds as the old bonds are broken,
  - and with enough energy to reach the activated complex.
- Anything that speeds the rate at which any of these three things happen, increases the rate of reaction.

Factors that Affect Rates of Chemical Reactions

- Temperature
- Concentrations of reactants
- Catalysts

Temperature and Rate of Reaction

Increased temperature

Increased average velocity of particles → Increased number of collisions between reactants per second

Increased average kinetic energy of particles → Increased fraction of collisions between reactants with the minimum energy to react

Increased rate of reaction

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

↓

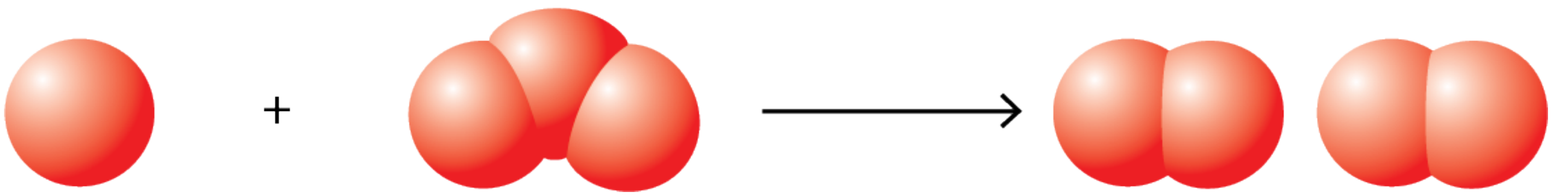
Increased number of particles fulfilling the requirements for reaction

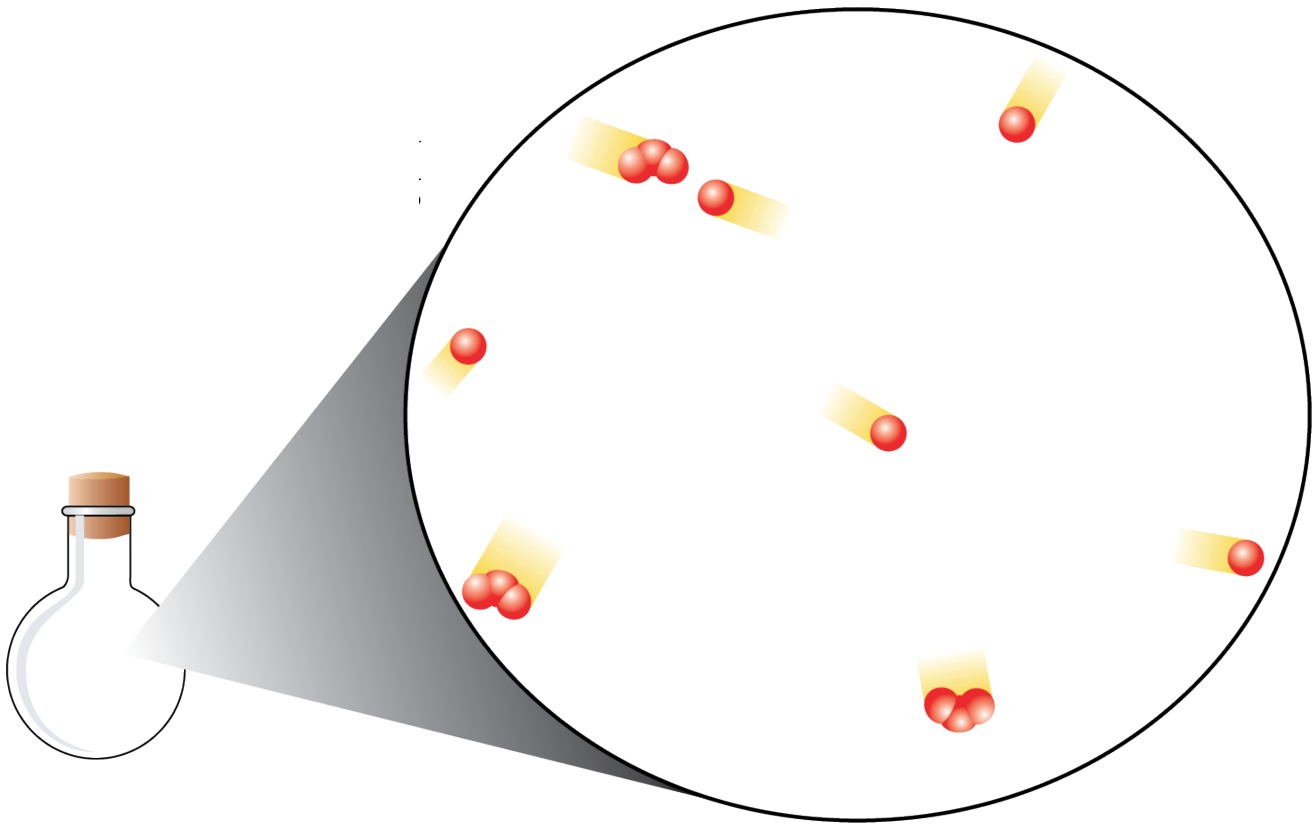
↓

Increased rate of reaction

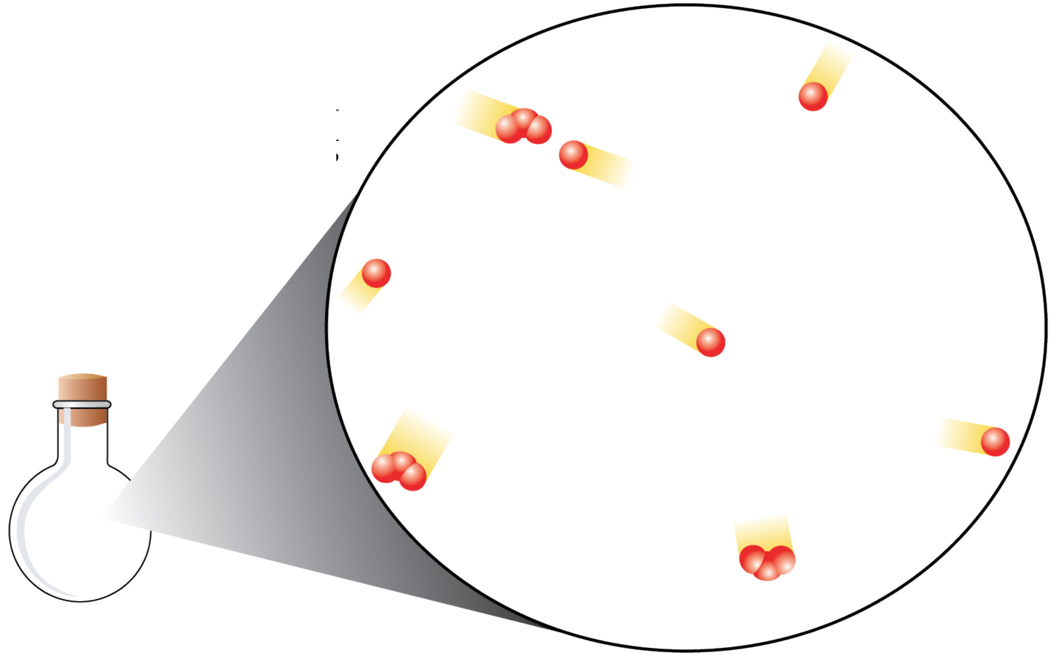
Example Reaction

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

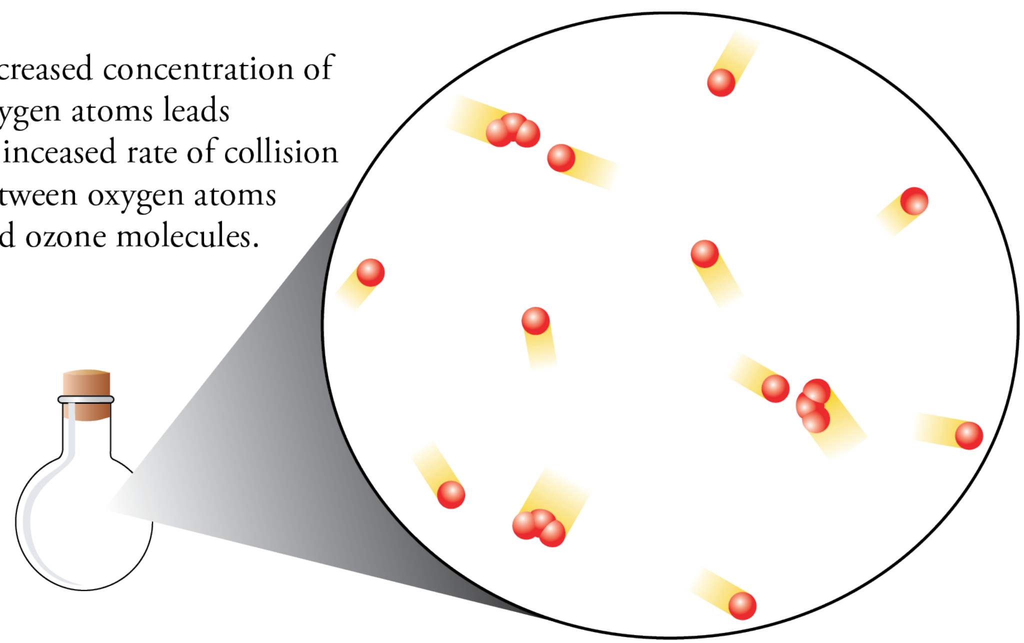




Increased Concentration of one Reactant



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



Catalysts and Rates of Reactions

- A ***catalyst*** is a substance that speeds a chemical reaction without being permanently altered itself.

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

Example

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

- Activation energy = 17 kJ
- At 25 ºC, 0.1% of the collisions have the activation energy or more.
- This does not mean that 0.1% of the collisions leads to products.
- Only the collisions with the correct orientation to make the new bonds at the same time as breaking the old bonds can get to products with the activation energy.

Example

- Chlorine atoms catalyze the reaction between ozone molecules and oxygen atoms in the stratosphere.
- One proposed mechanism for this is

$$O_3(g) + Cl(g) \rightarrow ClO(g) + O_2(g)$$

$$O(g) + ClO(g) \rightarrow Cl(g) + O_2(g)$$

- The net equation is the same as the equation for the uncatalyzed reaction.

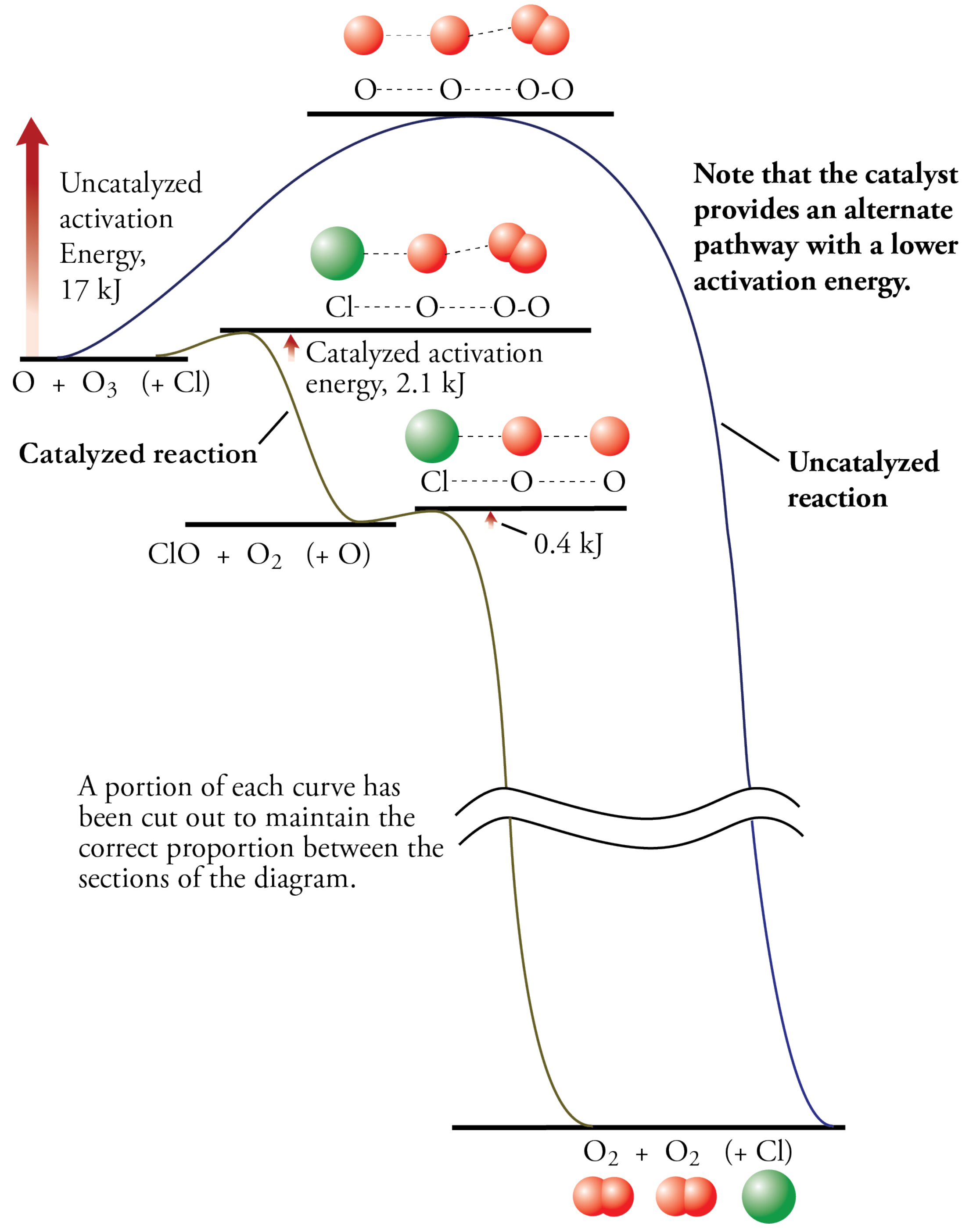
$$O_3(g) + O(g) \xrightarrow{Cl} 2O_2(g)$$

Example

$$O_3(g) + Cl(g) \rightarrow ClO(g) + O_2(g)$$
$$O(g) + ClO(g) \rightarrow Cl(g) + O_2(g)$$

- The activation energy of the first step is 2.1 kJ/mol, which means that 43% of the collisions between O_3 and Cl have an energy equal to or higher than the activation energy.
- The activation energy for the second step is only 0.4 kJ/mol, which means 85% of the collisions between O and ClO have an energy equal to or higher than the activation energy.
- This leads to a significantly greater rate of reaction.

Catalyzed O/O_3 Reaction



Two Categories of Catalysts

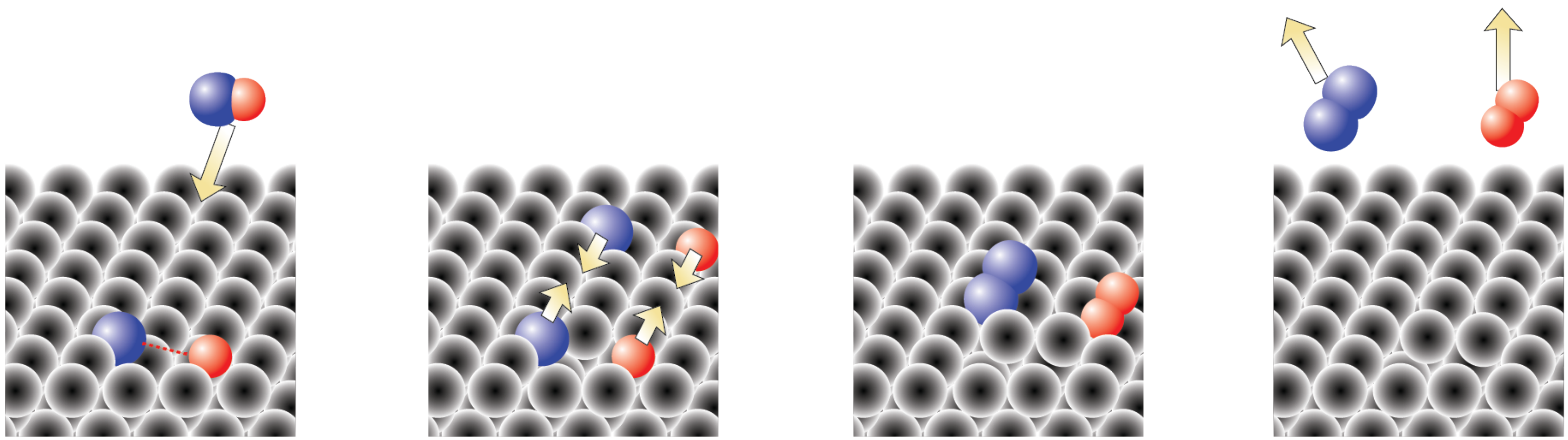
- If the reactants and the catalyst are all in the same state (all gases or all in solution) the catalyst is a ***homogeneous catalyst***.
  - Because Cl atoms are in the gaseous state just like the O_3 molecules and the O atoms, the Cl is a homogeneous catalyst.

Two Categories of Catalysts

- If the catalyst is not in the same state as the reactants, the catalyst is called a ***heterogeneous catalyst***.
  - There are solid catalysts in the catalytic converters in cars that catalyze the conversion of nitrogen monoxide gas to nitrogen and oxygen.

$$2NO(g) \rightarrow N_2(g) + O_2(g)$$

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.