Rafa Muñoa
Lizardi Institutua
Zarautz

Why do chemical reactions reach equilibrium?

Forward rate

The rate of a forward reaction can be expressed as

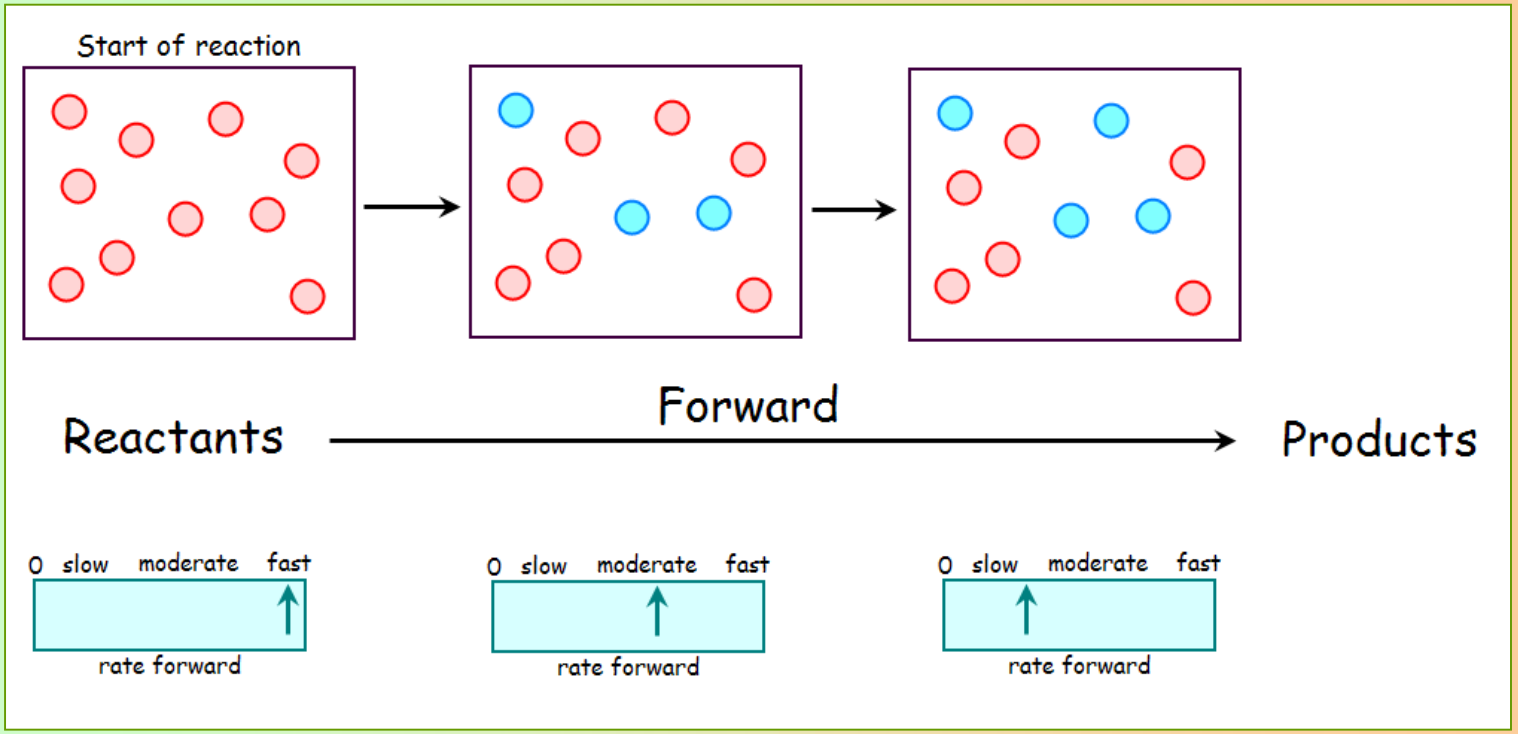
$$\text{Reactants} \xrightarrow{\text{Forward}} \text{Products}$$

$$\text{Rate}_{\text{forward}} = k_{\text{forward}} * [\text{Reactants}]^{\text{orders}}$$

We assume that the temperature remains constant during the reaction.

The rate constant k doesn't change at a given temperature. But the concentrations of the reactants decrease as the reaction proceeds.

Consequently, the rate of the forward reaction decreases as the reaction proceeds.



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Reverse rate

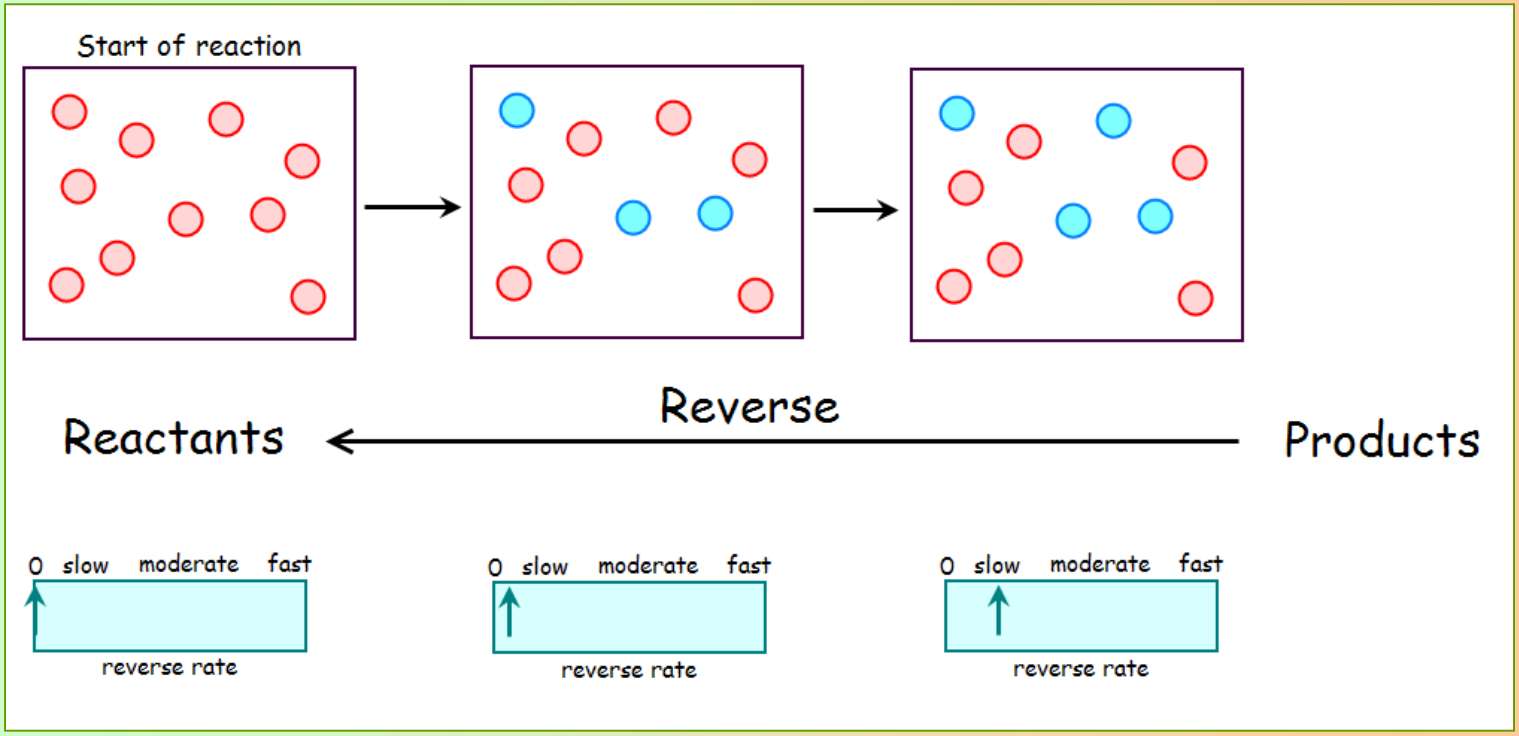
The rate of the reverse reaction can be expressed as

$$\text{Reactants} \xleftarrow{\text{Reverse}} \text{Products}$$

$$\text{Rate}_{reverse} = k_{reverse} * [\text{Products}]^{orders}$$

We assume that the temperature remains constant during the reaction.

The reverse reaction starts with 0 rate (we assume that there is no product at the beginning) and as the concentration of product increases, the reverse rate also increases.



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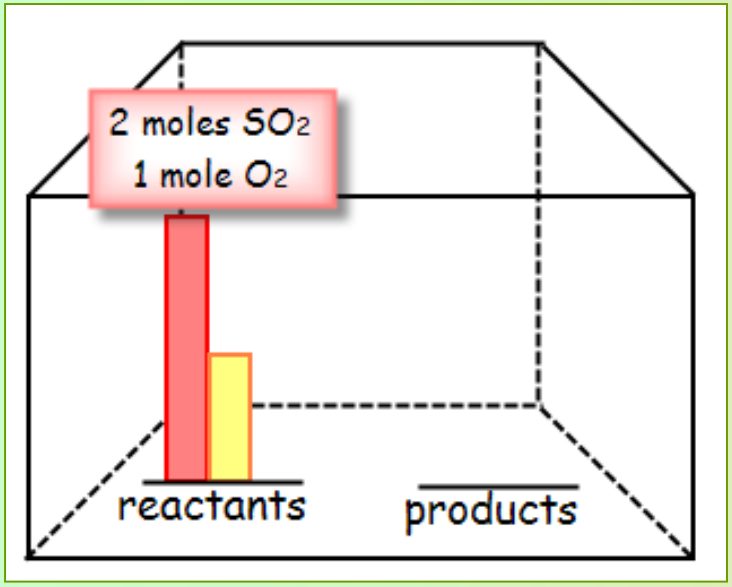
Example

Let's study the following equation:

$$2\ SO_2 + O_2 \rightarrow 2\ SO_3$$

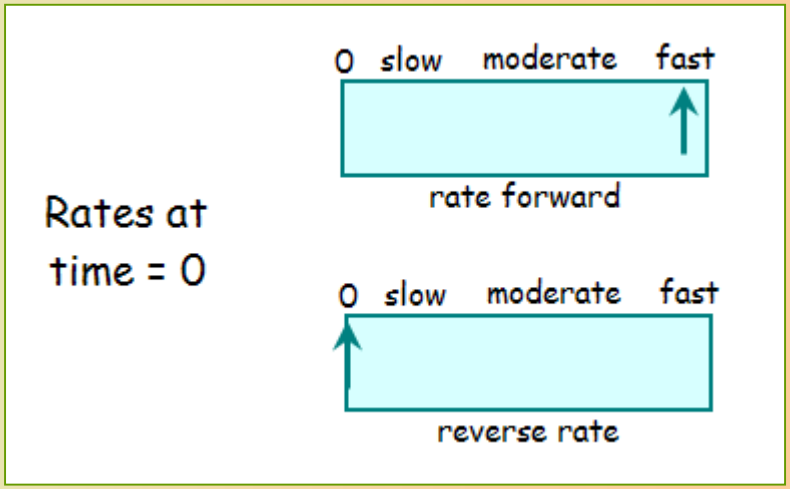
Suppose that at the start we have 2 moles of SO_2 and 1 mole of O_2.



At time zero there is no product; only reactants are present.

$$2\ SO_2\ (g) + O_2\ (g) \xrightarrow{\text{Forward}} 2\ SO_3\ (g)$$
$$2\ SO_2\ (g) + O_2\ (g) \xleftarrow{\text{Reverse}} 2\ SO_3\ (g)$$

At time zero, the rates of both reactions are different:



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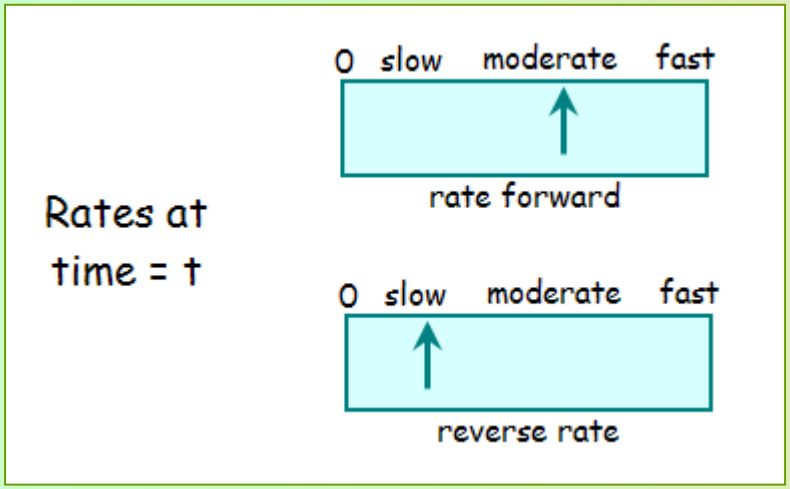
As time passes, the concentration of reactants decreases and the concentration of products increases.

As a result, the rates of reactions change and both values approach.



The forward reaction keeps slowing down while the reverse reaction keeps speeding up.

Eventually, apoint is reached where their rates become equal: dynamic equilibrium has been reached.

$$Rate_{forward} = Rate_{reverse}$$

$$k_{forward} * [Reactants]^{orders} = k_{reverse} * [Products]^{orders}$$

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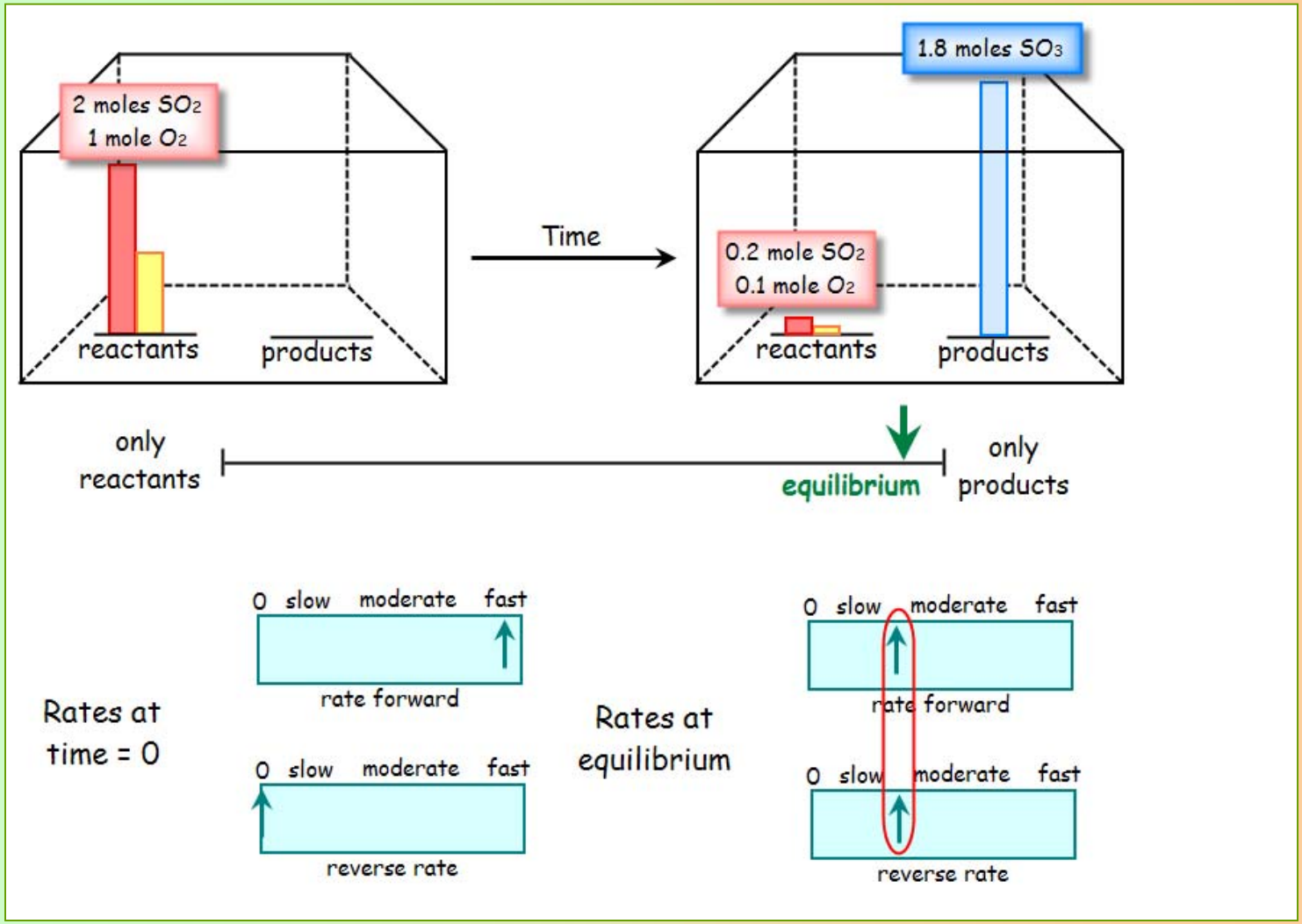
Here we can see the process:



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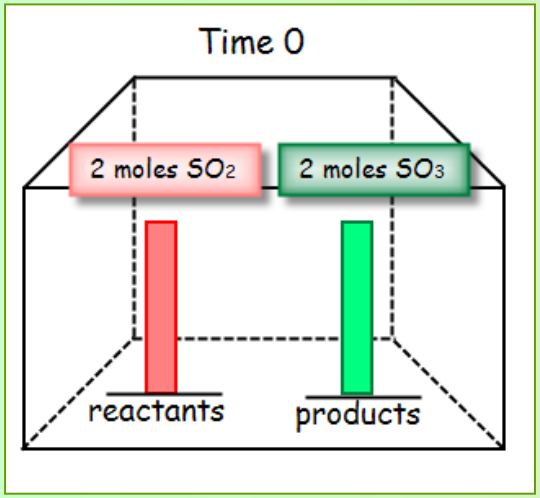
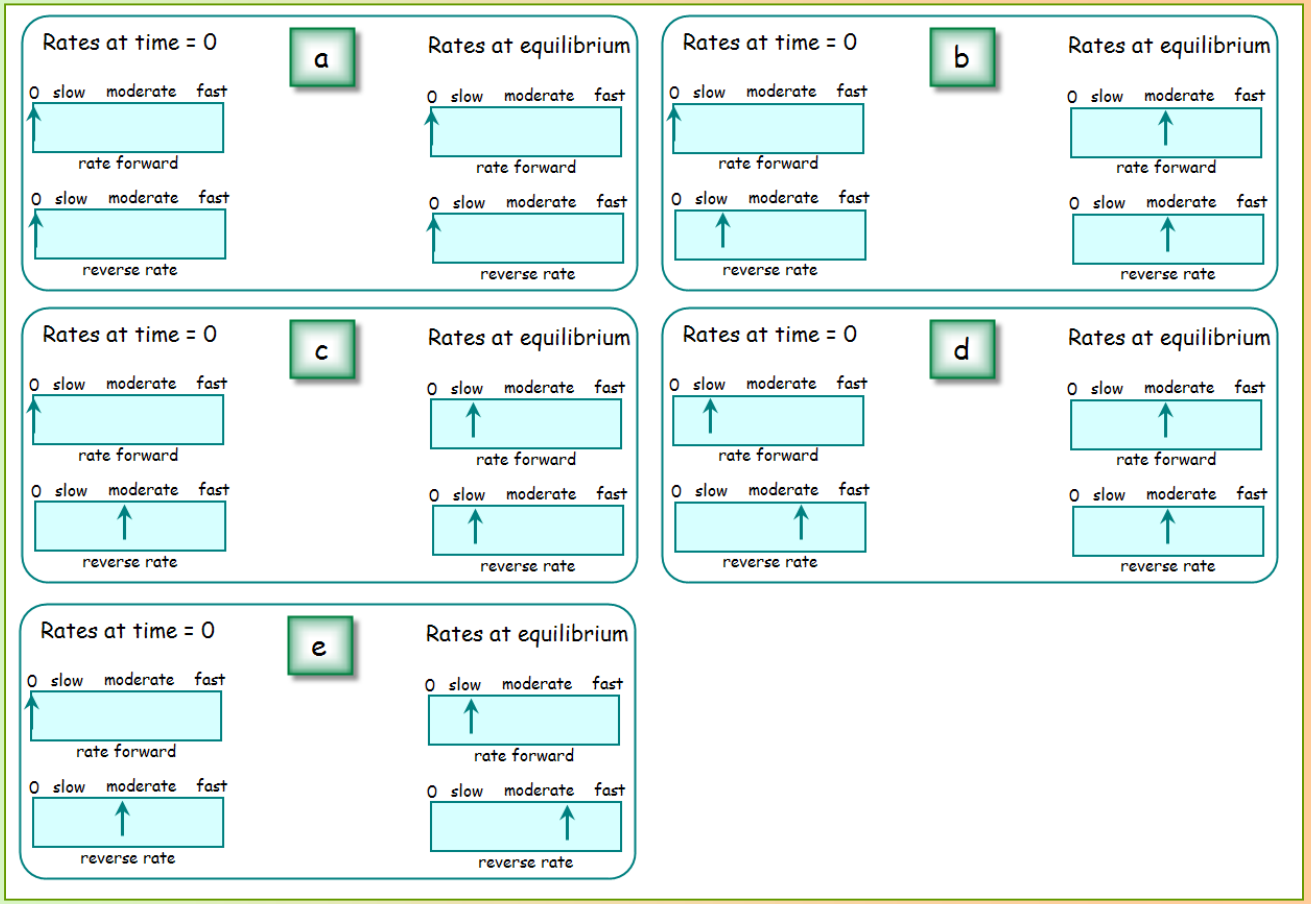
Exercise

Given a reaction vessel with the initial conditions shown below, which set of rate meters describes the situation best?

Explain your choice, and then explain why the other choices are incorrect.

$$2\ SO_2 + O_2 \rightarrow 2\ SO_3$$





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Solution

Choice “a”. Wrong. The initial value of rate of the reverse reaction cannot be 0.

Choice “b”. Wrong. The final value (at equilibrium) of rate of the reverse reaction cannot be greater than the initial value.

Choice “c”. Correct. One of the reactants is missing, so the initial rate of forward reaction has to be zero.

Choice “d”. Wrong. Initial rate of forward reaction has to be zero.

Choice “e”. Wrong. At equilibrium both rates have to be equal.