15.2 The Equilibrium Constant, K

Manipulating Equilibrium Constant Expressions

a) Multiply by a constant
b) Reverse the reaction.
c) Combining reactions.

a) Multiple by a constant.

1. $SO_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons SO_3(g)$
2. $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

$$K_1 = \frac{[SO_3]}{[SO_2][O_2]^{1/2}} \qquad K_2 = \frac{[SO_3]^2}{[SO_2]^2[O_2]}$$

Rxn 2. = 2 × Rxn 1.

$$\boxed{K_2 = K_1^2}$$

b) Reverse the reaction.

1. $2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$
2. $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

$$K_1 = \frac{[SO_2]^2[O_2]}{[SO_3]^2} \qquad K_2 = \frac{[SO_3]^2}{[SO_2]^2[O_2]}$$

Rxn 2. = -1 × Rxn 1.

$$\boxed{K_2 = K_1^{-1}}$$

c) Combining reactions.

1. $C(s) + \frac{1}{2}O_2(g) \rightleftharpoons CO(g)$
2. $\underline{C(s) + \frac{1}{2}O_2(g) \rightleftharpoons CO(g)}$
3. $2C(s) + O_2(g) \rightleftharpoons 2CO(g)$

$$K_1 = \frac{[CO]}{[O_2]^{1/2}} \qquad K_2 = \frac{[CO]}{[O_2]^{1/2}} \qquad K_3 = \frac{[CO]^2}{[O_2]}$$

Rxn 3. = Rxn 1. + Rxn 2.

$$\boxed{K_3 = K_1 \times K_2}$$

15.2 The Equilibrium Constant, K

Manipulating Equilibrium Constant Expressions

The equilibrium constant, **Kc**, for the following reaction is 0.25 at 500K

$2\ PCl_5(g) \Leftrightarrow 2\ PCl_3(g) + 2\ Cl_2(g)$

Calculate **Kc** at this temperature for:

$PCl_3(g) + Cl_2(g) \Leftrightarrow PCl_5$

Kc = ?.0

a) 1
b) 2 ✓
c) 3
d) 4
e) 3

Compare : $PCl_3(g) + Cl_2(g) \Leftrightarrow PCl_5(g)$

To : $2\ PCl_5(g) \Leftrightarrow 2\ PCl_3(g) + 2\ Cl_2(g)$

The reaction of interest is :-

a) Reversed
b) Multiplied by ½

$$K_c = (0.25)^{-1 \times \frac{1}{2}}$$
$$= (0.25)^{-\frac{1}{2}}$$
$$= \frac{1}{\sqrt{0.25}}$$
$$= 2$$

15.3 Using Equilibrium Constants in Calculations

Determining Whether a System Is at Equilibrium – Q

Q = Reaction Quotient

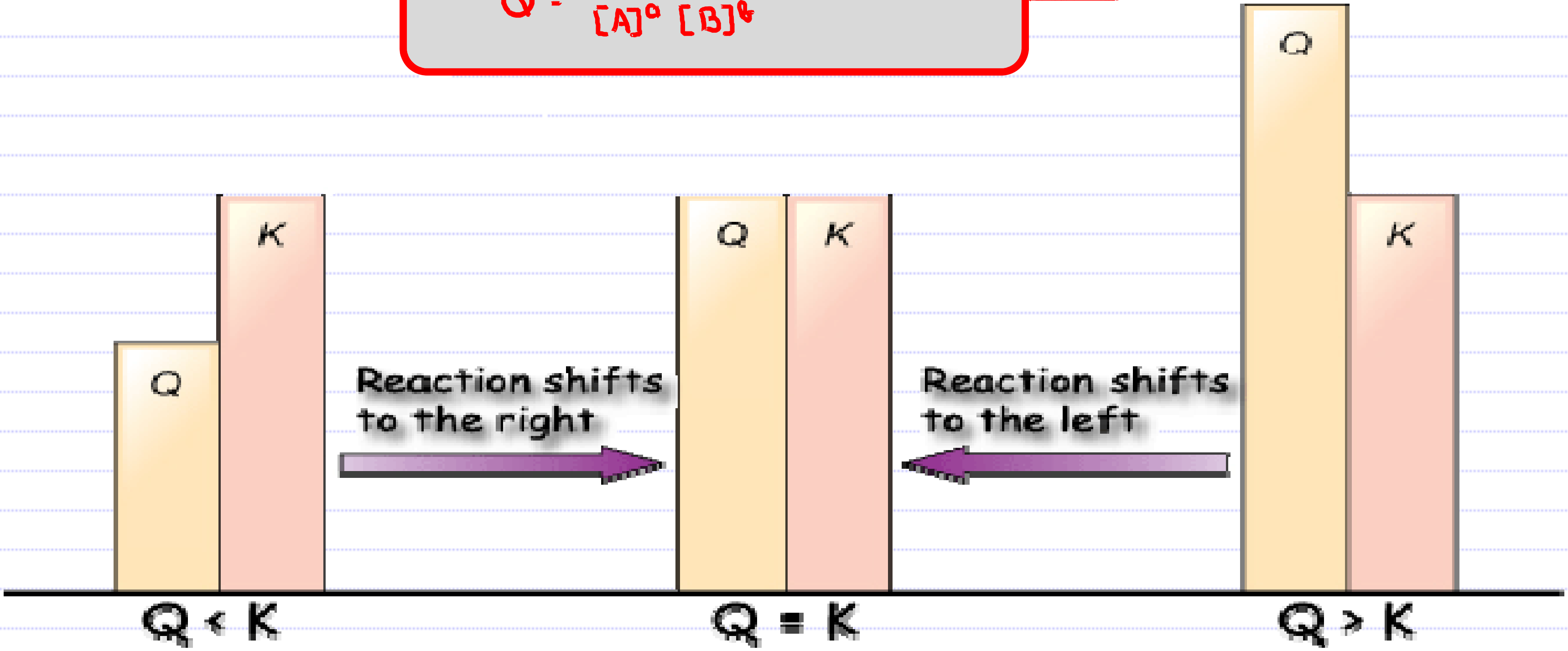
$$aA + bB \Leftrightarrow cC + dD$$

$$Q = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

$\rightarrow Q < K$

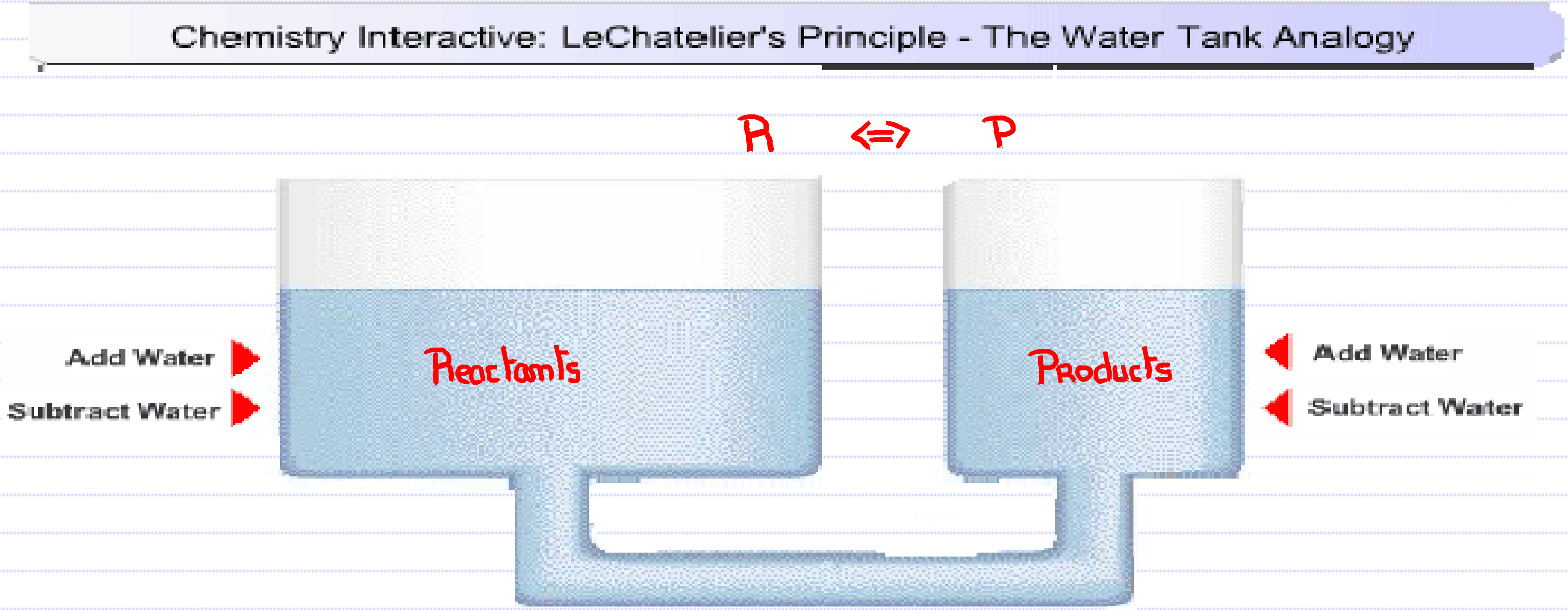
$\rightarrow Q > K$

$\rightarrow Q = K$



15.4 Disturbing a Chemical Equilibrium: Le Chatelier's Principle

Addition or Removal of a Reactant or Product



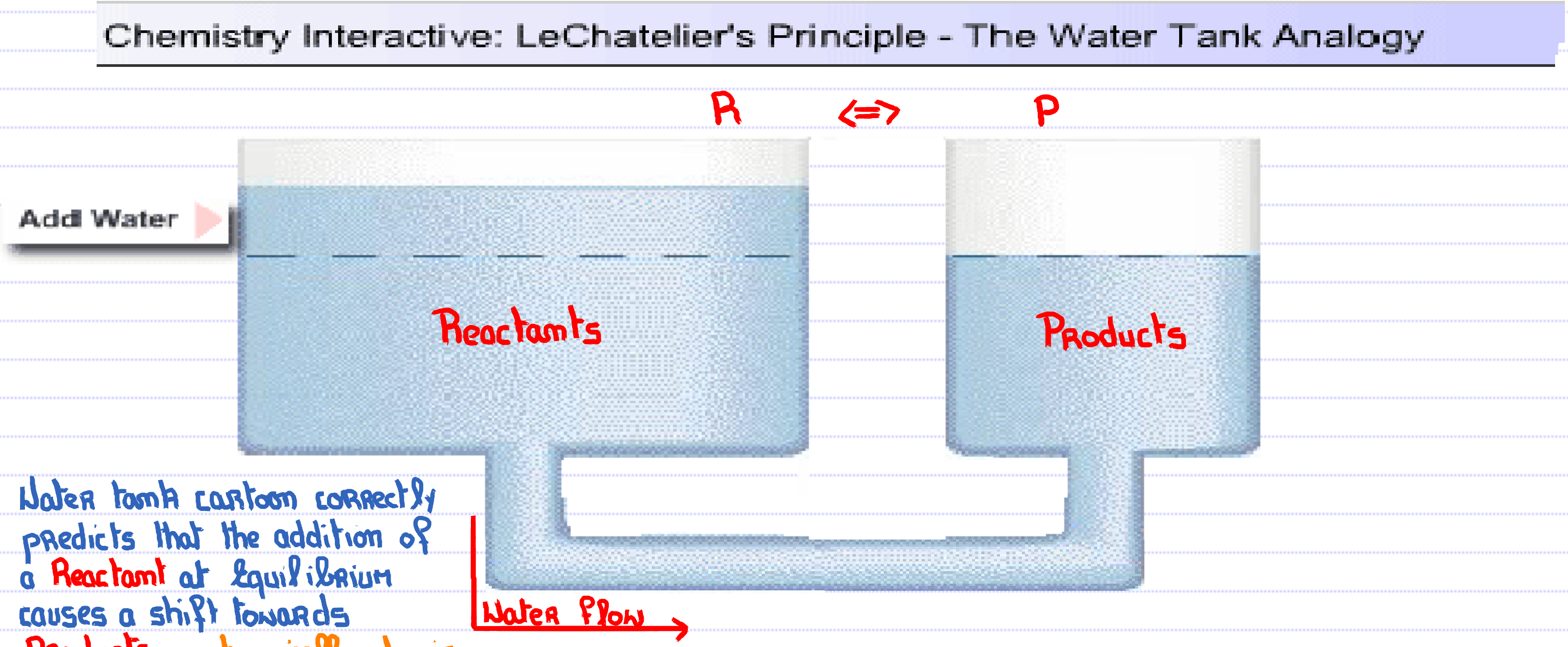
Chemistry Interactive: LeChatelier's Principle - The Water Tank Analogy

$R \Leftrightarrow P$

See Class Web Site

15.4 Disturbing a Chemical Equilibrium: Le Chatelier's Principle

Addition of a Reactant.



Water tank cartoon correctly predicts that the addition of a Reactant at Equilibrium causes a shift towards Products ... chemically why is this prediction correct ?

$$Q = \frac{[\text{Products}]}{[\text{Reactants}]}$$ } @ Equilibrium Q = K

Addition of a Reactant causes Q ↓, thus now

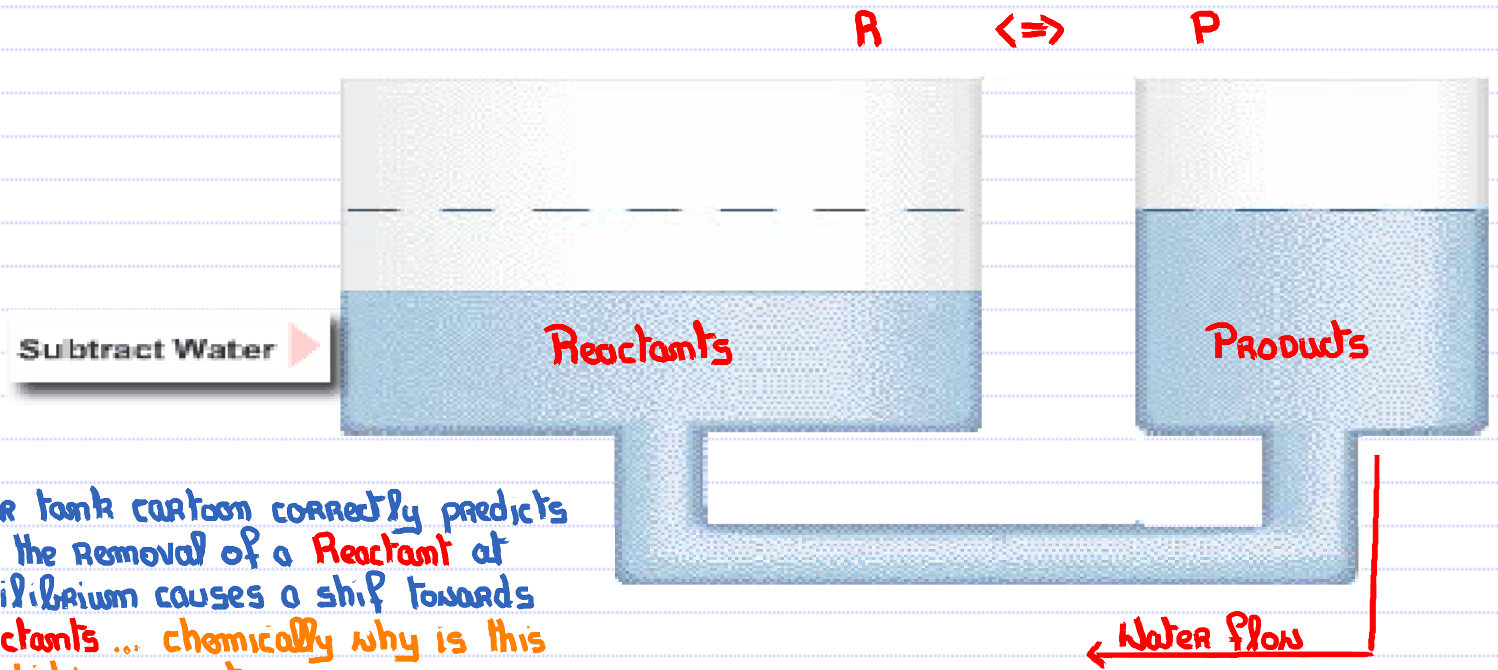
$\underline{Q < K}$

↳ Shift towards Products until again Q = K

15.4 Disturbing a Chemical Equilibrium: Le Chatelier's Principle

Removing an Reactant.

Chemistry Interactive: LeChatelier's Principle - The Water Tank Analogy



Water tank cartoon correctly predicts that the removal of a Reactant at equilibrium causes a shif towards Reactants ... chemically why is this prediction correct.

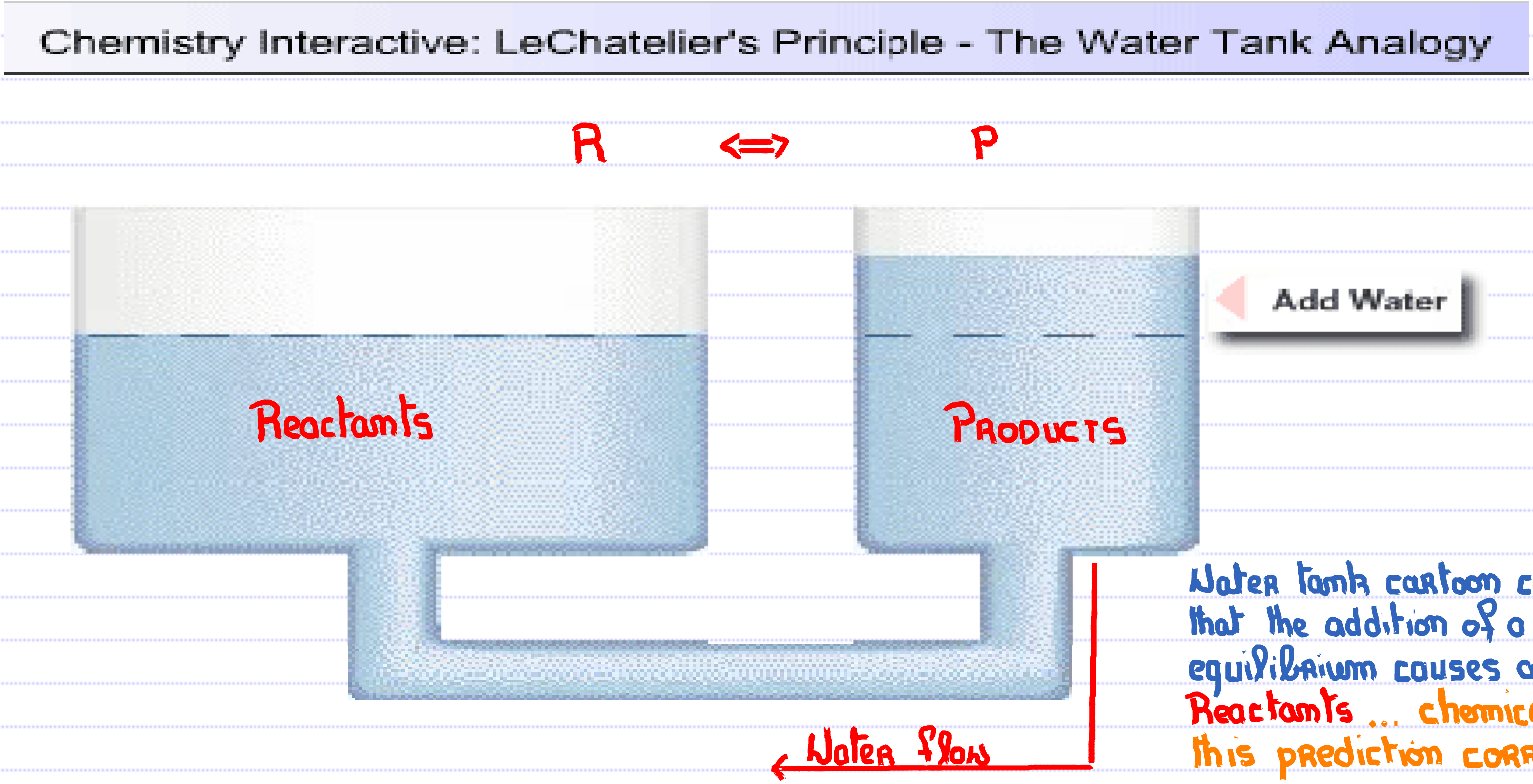
$$Q = \frac{[\text{Products}]}{[\text{REACTANTS}]} \Big\} \text{ @ Equilibrium, } Q = K$$

Removal of a Reactant causes Q↑, thus now $Q > K$

↳ Shift towards Reactants until $Q = K$ again.

15.4 Disturbing a Chemical Equilibrium: Le Chatelier's Principle

Adding a Product.



Chemistry Interactive: LeChatelier's Principle - The Water Tank Analogy

Water tank cartoon correctly predicts that the addition of a Product at equilibrium causes a shift towards Reactants ... chemically why is this prediction correct?

$$Q = \frac{[\text{Products}]}{[\text{Reactants}]} \Big\} \text{ @ Equilibrium, } Q = K$$

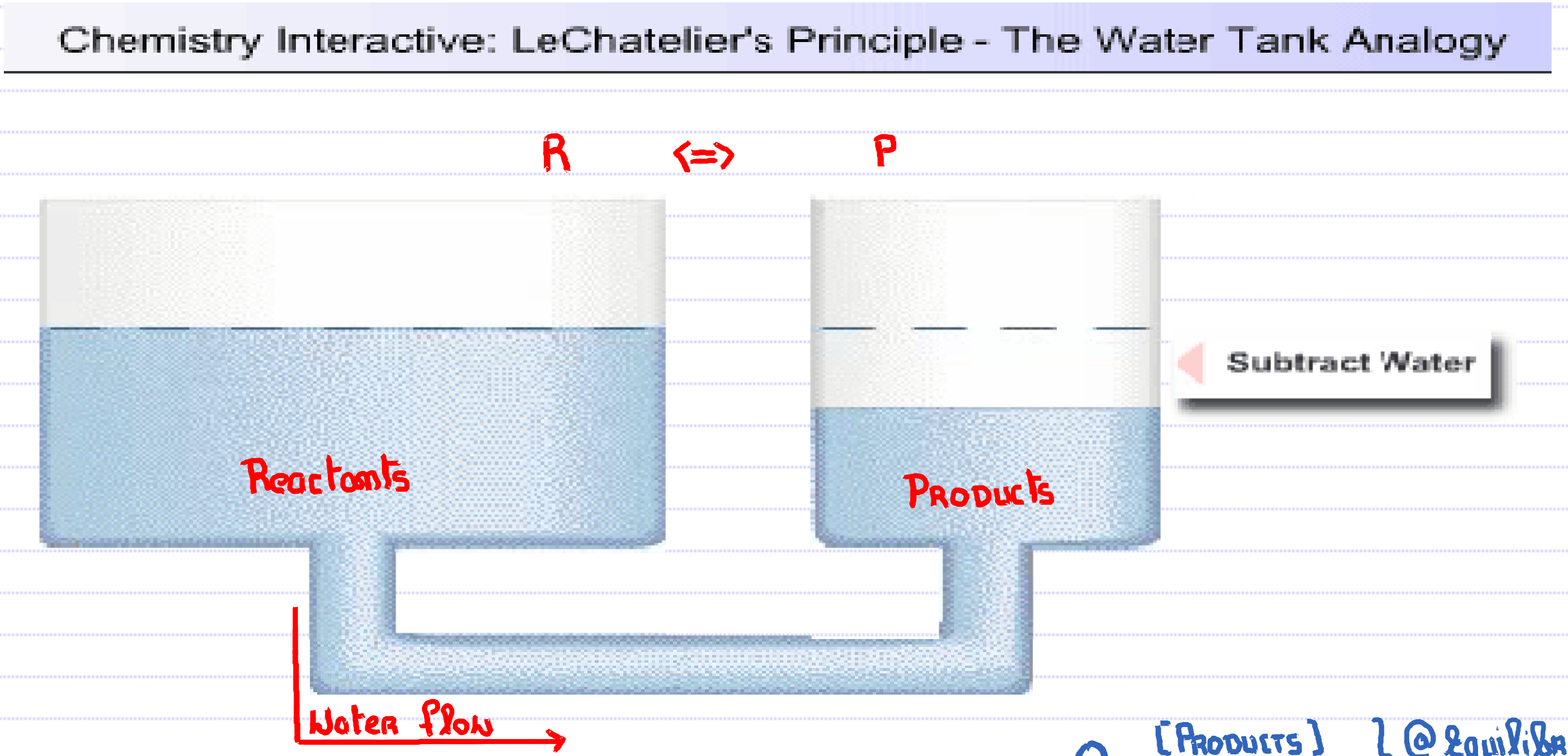
Addition of Product causes Q ↑

Q > K

↳ Shift towards Reactants until Q = K again

15.4 Disturbing a Chemical Equilibrium: Le Chatelier's Principle

Removing a Product.



Chemistry Interactive: LeChatelier's Principle - The Water Tank Analogy

The water tank cartoon correctly predicts that the removal of a Product at Equilibrium causes a shift towards Products ... chemically why is this prediction correct ?

$Q = \frac{[\text{PRODUCTS}]}{[\text{REACTANTS}]}$ } @ Equilibrium, $Q = K$

Removing a Product causes $Q\downarrow$

$Q < K$ → Shift towards Products until $Q = K$ again.

15.4 Disturbing a Chemical Equilibrium: Le Chatelier's Principle

Addition or Removal of a Reactant or Product

HCN is a weak acid –

$HCN(aq) + H_2O(l) \Leftrightarrow H_3O^+ + CN^-$ Kc = 4.0×10^{-10} @ 25°C

Removal of H_3O^+ from this equilibrium will cause the $[CN^-]$ to

a) Increase ✓ c) Remain unchanged

b) Decrease d) Impossible to determine

$$Q = \frac{[\text{Products}]}{[\text{Reactants}]}$$

Removal of a Product (H_3O^+), causes Q↓, $\underline{Q < K}$

↳ Shift towards Products (which produces more $[N^-)$ until $Q = K$ again.

15.4 Disturbing a Chemical Equilibrium: Le Chatelier's Principle

Addition or Removal of a Reactant or Product

HCN is a weak acid –

$HCN(aq) + H_2O(l) \Leftrightarrow H_3O^+ + CN^-$ Kc = 4.0×10^{-10} @ 25°C

Addition of OH^- to this equilibrium will cause the $[CN^-]$ to

a) Increase ✓

b) Decrease

c) Remain unchanged ?

d) Impossible to determine

At first glance it looks like c) : as OH^- is neither a product or a reactant !

$HCN(aq) + H_2O(l) \Leftrightarrow \underline{H_3O^+} + CN^-$

$\hookrightarrow + OH^- = 2\,H_2O(l)$

Net result is the removal of a products ... Q becomes < K thus a shift towards products (producing more CN^-) until Q once more equals K.

Beware of secondary reaction that can affect an equilibrium by indirectly removing a reactant or product.