

**What Does the Equilibrium
Constant Tell Us?**

Predicting the Direction of a Reaction

The reaction quotient (Q) is a useful tool to analyze what must happen in order for a system to reach equilibrium

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$$Q_c = \frac{[\text{products}]^x}{[\text{reactants}]^y}$$

$Q_c = K_c$ reaction is at equilibrium

$Q_c > K_c$ products revert to reactants to achieve equilibrium

$Q_c < K_c$ reactants form products to achieve equilibrium

Practice Exercise



(a) How will system shift when

$$[\text{N}_2] = 0.0711 \text{ M}$$

$$[\text{H}_2] = 9.17 \times 10^{-3} \text{ M}$$

$$[\text{NH}_3] = 1.83 \times 10^{-4} \text{ M}$$



$$K_c = 1.2$$

$$Q = \frac{[\text{NH}_3]^2}{[\text{N}_2] [\text{H}_2]^3}$$

$$Q = \frac{(1.83 \times 10^{-4})^2}{(0.0711) (9.17 \times 10^{-3})^3}$$

$$= 0.611$$

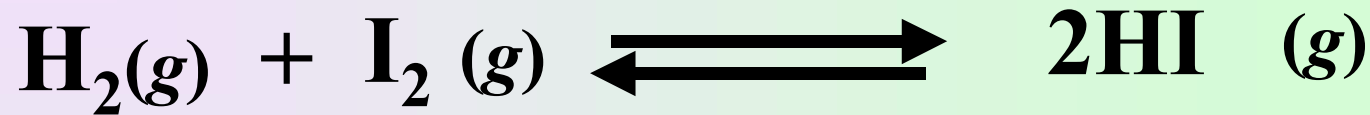
if Q is smaller than K the concentration of the products increases

Calculating Equilibrium Concentrations

Practice Exercise

Calculate the concentrations at equilibrium.

$$K_c = 54.3 \text{ at } 430^\circ\text{C}$$



$$\text{Init:} \quad 0.50 \text{ M} \quad 0.50 \text{ M} \quad 0.00 \text{ M}$$

$$\text{final:} \quad -x \quad -x \quad +2x$$

$$0.50 - x \quad 0.50 - x \quad 2x$$

$$\frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]} = \frac{(2x)^2}{(0.50 - x)(0.50 - x)} = 54.3$$

$$\frac{[\text{HI}]^2}{[\text{H}_2] [\text{I}_2]} = \frac{(2x)^2}{(0.50 - x)(0.50 - x)} = 54.3$$

Taking the square root of both sides

$$\frac{2x}{0.50 - x} = 7.37$$

$$x = 0.393$$

At equilibrium, the concentration are

$$[\text{H}_2] = (0.50 - 0.393) \text{ M} = 0.107 \text{ M}$$

$$[\text{I}_2] = (0.50 - 0.393) \text{ M} = 0.107 \text{ M}$$

$$[\text{HI}] = (2 \times 0.393) \text{ M} = 0.786 \text{ M}$$

$$\frac{(x)^2}{(1.00 - x)} = 1.8 \times 10^{-5}$$

Small K

Approximation $1.00 - x \approx 1.00$

$$\frac{x^2}{1.00} = 1.8 \times 10^{-5}$$

$$100\% \times \frac{0.0042}{1.00} = .42\%$$

$$[H^+] = x = 0.0042 M$$

assumption is valid

Practice Exercise

$$[\text{H}_2] = 1.000 \text{ M}$$

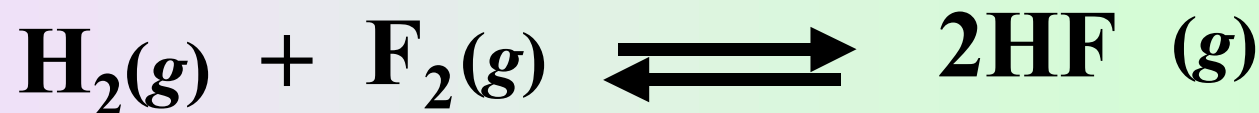
$$[\text{F}_2] = 2.000 \text{ M}$$



$$K_c = 115 \text{ at } 430^\circ\text{C}$$

Calculate the equilibrium concentrations of all species present.

Practice Exercise



Init: **1.000 M** **2.000 M** **0.000 M**

final: **-x** **-x** **+ 2x**

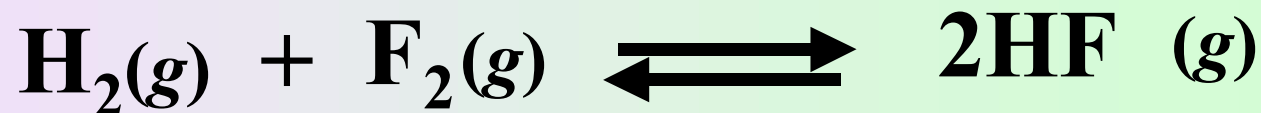
$$115 = \frac{[\text{HF}]^2}{[\text{H}_2][\text{F}_2]}$$

$$115 = \frac{(2x)^2}{(1.000-x)(2.000-x)}$$

assume x is
small compared
to 1.000 and
2.000 and solve

If x is 5% or less than
the original quantity
our assumption is valid

Practice Exercise



Init: **1.000 M** **2.000 M** **0.000 M**

final: **-x** **-x** **+ 2x**

$$115 = \frac{[\text{HF}]^2}{[\text{H}_2][\text{F}_2]}$$

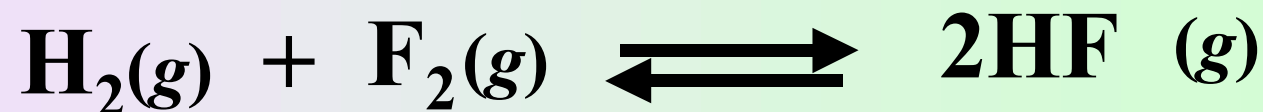
$$115 = \frac{(2x)^2}{(1.000-x)(2.000-x)}$$

$$115 = \frac{(2x)^2}{(1.000)(2.000)}$$

$$x = 7.58$$

$$\frac{7.58}{2.000} \times 100 = 379\%$$

Practice Exercise



Init: **1.000 M** **2.000 M** **0.000 M**

final: **-x** **-x** **+ 2x**

$$115 = \frac{(2x)^2}{(1.000-x)(2.000-x)}$$

$$115(1.000-x)(2.000-x) = 4x^2$$

$$115(x^2) - 3.000(115)x + 2.000(115) = 4x^2$$

$$111x^2 - 345x + 230 = 0$$

Practice Exercise

Quadratic equation

$$ax^2 + bx + c = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$111x^2 - 345x + 230 = 0$$

$$x = \frac{345 \pm \sqrt{-345^2 - 4(111)(230)}}{2(111)}$$

~~$x = 2.14$~~ $x = 0.968$

Practice Exercise



Init:

final:

1 - .968

2 - .968

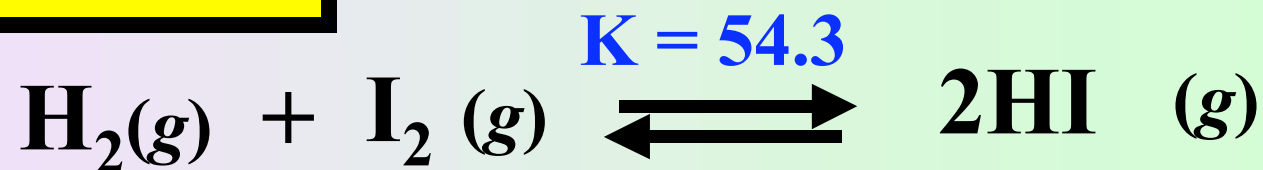
2(0.968)

0.032 M

1.032M

1.936 M

Practice Exercise

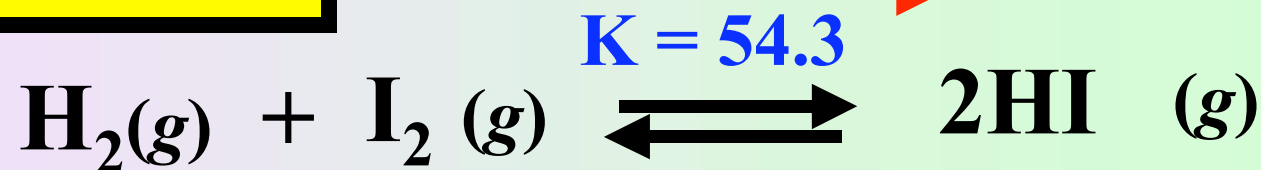


Init: **0.00623 M** **0.00414M** **0.0224 M**

How will the reaction shift ?

Calculate the equilibrium concentrations of all species present.

Practice Exercise



Init: 0.00623 M 0.00414 M 0.0224 M

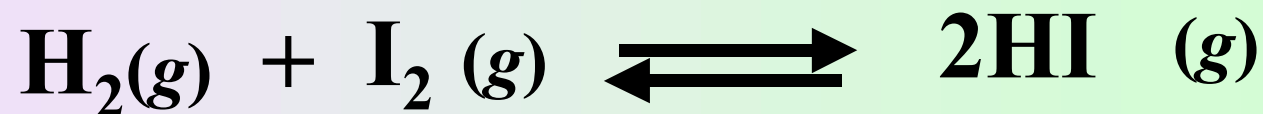
$$Q = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]}$$

$$Q = \frac{(0.0224)^2}{(0.00623)(0.00414)}$$

$$= 19.45$$

if Q is smaller than K the concentration of the products increases

Practice Exercise



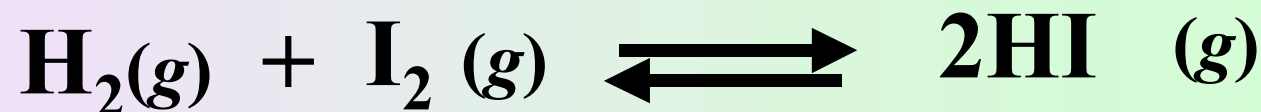
Init: **0.00623 M** **0.00414M** **0.0224 M**

final: **0.00623 - x** **0.00414M -x** **0.0224 + 2x**

$$54.3 = \frac{[\text{HI}]^2}{[\text{H}_2] [\text{I}_2]}$$

$$54.3 = \frac{(0.0224 + 2x)^2}{(0.00623-x)(0.00414-x)}$$

Practice Exercise



Init: **0.00623 M** **0.00414M** **0.0224 M**

final: **0.00623 - x** **0.00414M -x** **0.0224 + 2x**

$$54.3 = \frac{(0.0224 + 2x)^2}{(0.00623 - x)(0.00414 - x)}$$

$$54.3 (2.58 \times 10^{-5} - 0.0104x + x^2) =$$

$$5.02 \times 10^{-4} + 0.0896x + 4x^2$$

$$50.3 x^2 - 0.654 x + 8.98 \times 10^{-4} = 0$$

Practice Exercise

Quadratic equation

$$ax^2 + bx + c = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$50.3 x^2 - 0.654 x + 8.98 x 10^{-4} = 0$$

$$x = \frac{.654 \pm \sqrt{(-0.654)^2 - 4(50.3)(8.98 x 10^{-4})}}{2(50.3)}$$

~~$x = 0.0114$~~

$x = 0.00156$

Practice Exercise



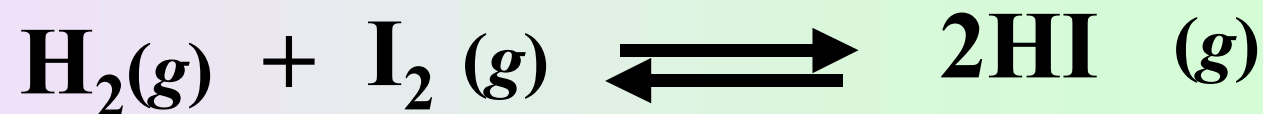
At equilibrium, the concentrations are

$$[\text{H}_2] = (0.00623 - 0.00156) \text{ M} = 0.00467 \text{ M}$$

$$[\text{I}_2] = (0.00414 - 0.00156) \text{ M} = 0.00258 \text{ M}$$

$$[\text{HI}] = [0.0224 + 2(0.00156)] \text{ M} = 0.0255 \text{ M}$$

Practice Exercise



Init: **0.00 M** **0.00 M** **0.04 M**

final: **+ x** **+ x** **0.04 - 2x**

$$54.3 = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]}$$

$$54.3 = \frac{(0.040 - 2x)^2}{(x)(x)}$$

assume $2x$ is
small compared
to 0.04 and solve

If x is 5% or less than
the original quantity
our assumption is valid

Practice Exercise

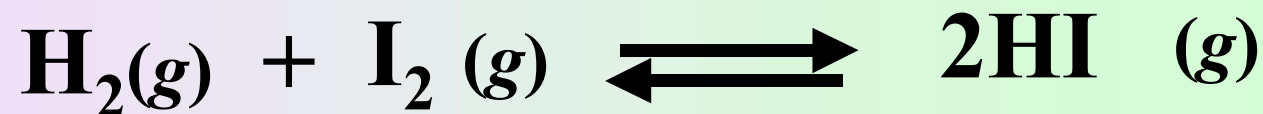
$$[\text{HI}] = 0.040\text{M}$$



$$K_c = 54.3 \text{ at } 430^\circ\text{C}$$

Calculate the equilibrium concentrations of all species present.

Practice Exercise



Init: **0.00 M** **0.00 M** **0.04 M**

final: **+ x** **+ x** **0.04 - 2x**

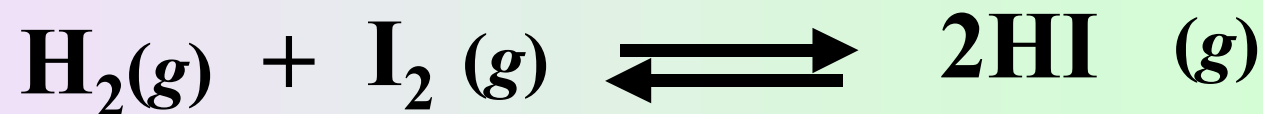
$$54.3 = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]}$$

$$54.3 = \frac{(0.040 - 2x)^2}{(x)(x)}$$

assume $2x$ is
small compared
to 0.04 and solve

If x is 5% or less than
the original quantity
our assumption is valid

Practice Exercise



Init: **0.00 M** **0.00 M** **0.04 M**

final: **+ x** **+ x** **0.04 - 2x**

$$54.3 = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]}$$

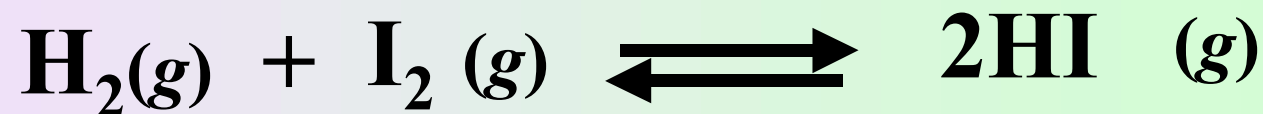
$$54.3 = \frac{(0.04 - 2x)^2}{(x)(x)}$$

$$54.3 = \frac{(0.04)^2}{(x)(x)}$$

~~$x = .0054$~~

$$2x = .0108$$
$$\frac{.0108}{.04} \times 100 = 27\%$$

Practice Exercise



Init: **0.00 M** **0.00 M** **0.040 M**

final: **+ x** **+ x** **0.040 - 2x**

$$54.3 = \frac{(0.040 - 2x)^2}{(x)(x)} \qquad 50.3 x^2 + 0.16 x - 0.0016 = 0$$

$$54.3 x^2 = (0.040 - 2x)(0.040 - 2x)$$

$$54.3 x^2 = 4x^2 - 0.16 x + 0.0016$$

Practice Exercise

Quadratic equation

$$ax^2 + bx + c = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$50.3 x^2 + 0.16 x - 0.0016 = 0$$

$$x = \frac{-.16 \pm \sqrt{.16^2 - 4(50.3)(-.0016)}}{2(50.3)}$$

$$x = 0.0043$$

Practice Exercise



Init:

0.040 M

final:

0.0043 M

0.0043 M

0.040 M - 2(0.0043 M)

0.031 M