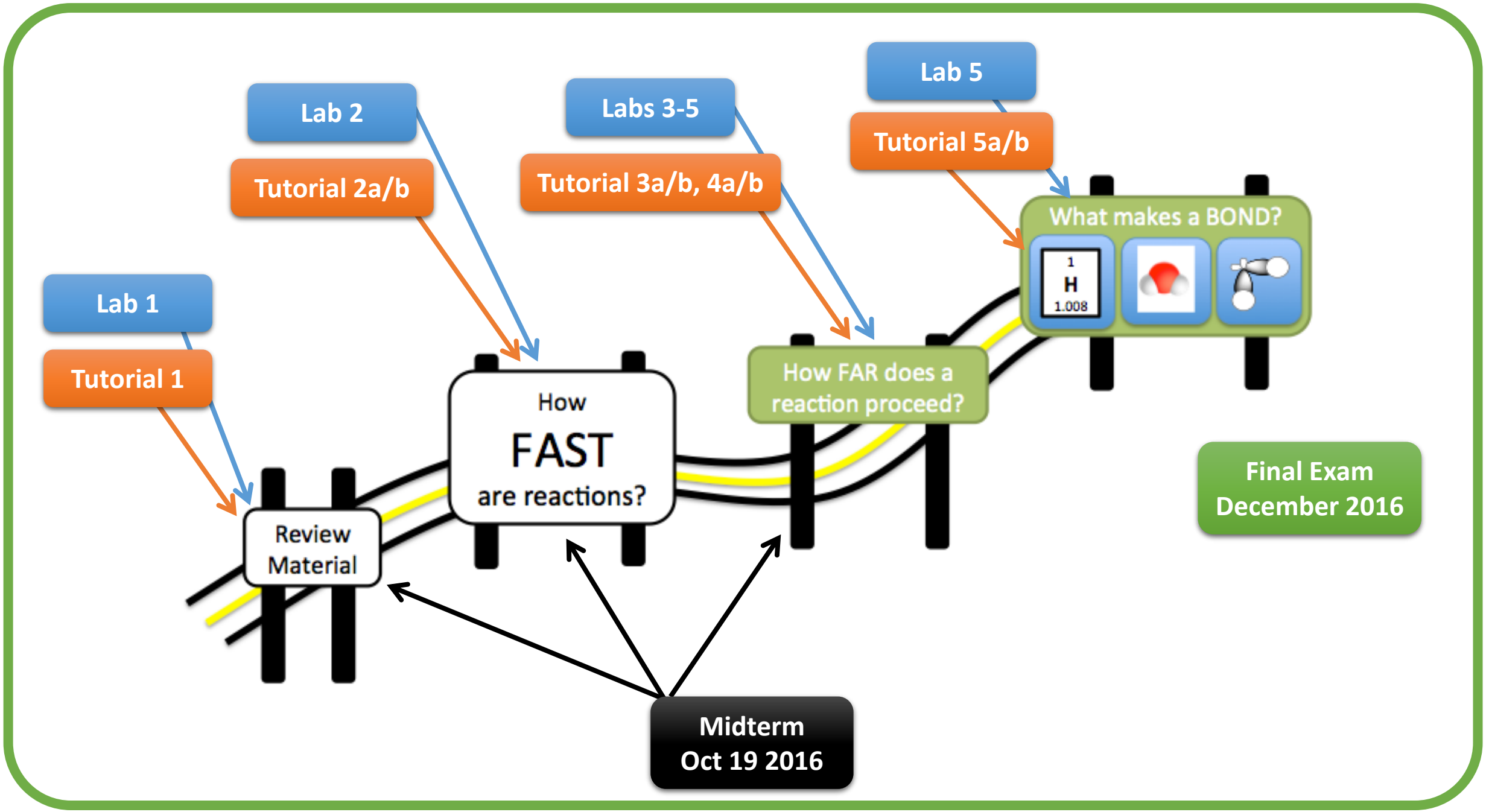
Study Check-in 3

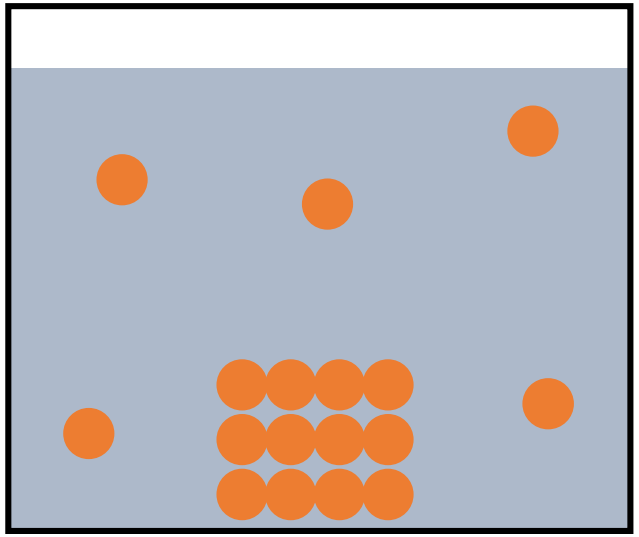
This week you were introduced to class, and started preparing for Tutorial Quiz 1. How did you do it?

- Approximately how much time (in hours) did you spend studying for CHEM 209?
  - Text _____*answer* to *647-931-6504*
- Please select the type(s) of studying that you did for CHEM 209 in the past week:

  A: Read textbook **B:** Reviewed notes **C:** Did textbook problems **D:** Studied with other people (in-person) **E:**Studied with other people online (Facebook, WhatsApp, Skype, or similar) **F:** Watched videos (YouTube, Khan Academy, etc) **G:** Worked with a tutor (private or through SU / DARC) **H:** Something not listed here, or nothing
  - Text _____ *answers* to *647-931-6504*
- What is something from this week's studying that is going well?
  - Text _____ *answer* to *647-931-6504*
- What is something from this week's studying that you're struggling with?
  - Text _____ *answer* to *647-931-6504*

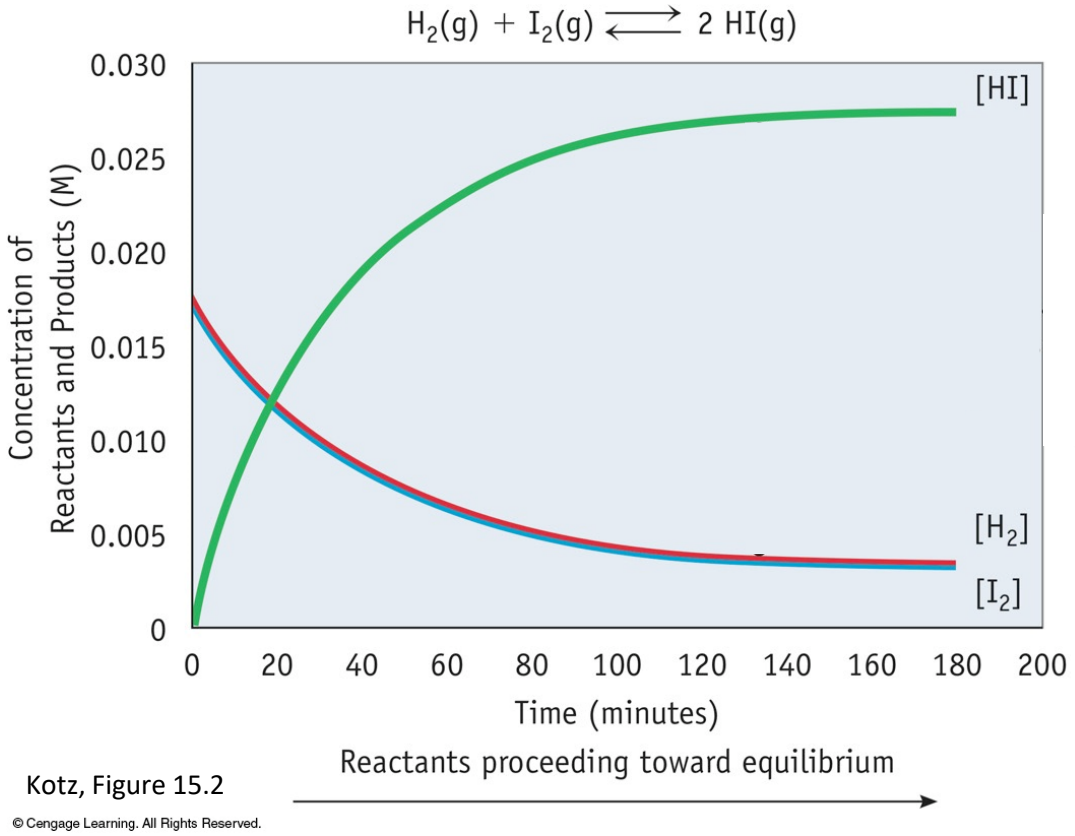

Lab 5
Tutorial 5a/b
Lab 2
Tutorial 2a/b
Labs 3-5
Tutorial 3a/b, 4a/b
What makes a BOND?
1
H
1.008
Lab 1
Tutorial 1
How
FAST
are reactions?
How FAR does a reaction proceed?
Review Material
Final Exam
December 2016
Midterm
Oct 19 2016

What is Equilibrium?



✓ Qualitatively describe chemical equilibrium.

Equilibrium and Concentration



Kotz, Figure 15.2

✓ Generate and manipulate expressions for K and Q for reactions using concentrations or partial pressures, based on a given reaction or set of related reactions.

Equilibrium Constant, *K*

For the generic reaction:

$$a\,A + b\,B \rightleftharpoons c\,C + d\,D$$

- K_C (in terms of concentrations)
-

- K_P (in terms of partial pressure)

-

- Note: **K is unitless**

✓ Generate and manipulate expressions for K and Q for reactions using concentrations or partial pressures, based on a given reaction or set of related reactions.

How are K_C and K_P related?

For the generic reaction:

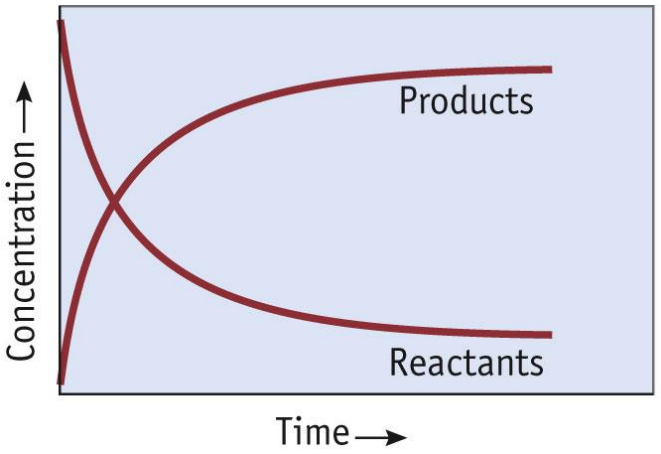
$$a\,\mathrm{A} + b\,\mathrm{B} \rightleftharpoons c\,\mathrm{C} + d\,\mathrm{D}$$

✓ Generate and manipulate expressions for K and Q for reactions using concentrations or partial pressures, based on a given reaction or set of related reactions.

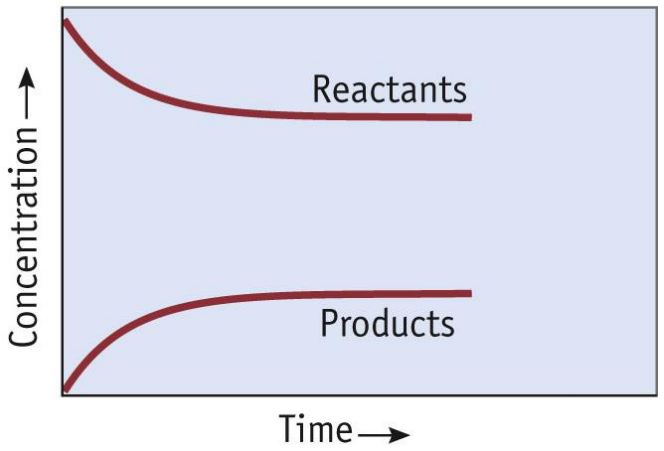
Equilibrium constant & extent of reaction

reactants ⇄ *products*

Reaction 1



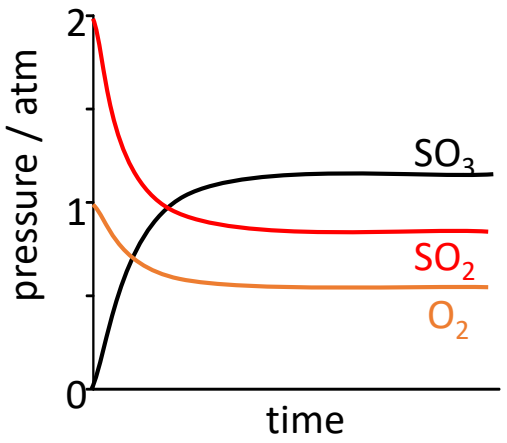
Reaction 2



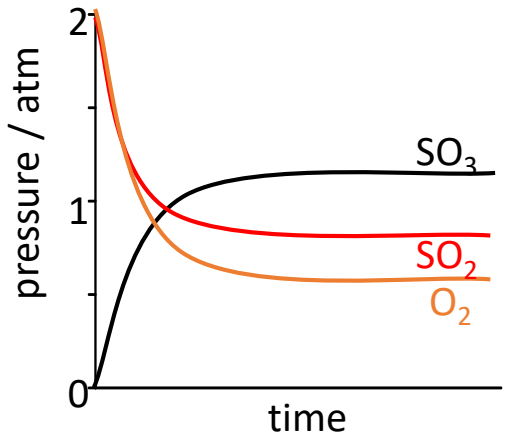
- Small K (< 1):
- Large K (> 1):
- Very large K (> about 10^{10}):
- Very small K (< about 10^{-10})

For the reaction of sulfur dioxide with oxygen, which of the following plots of pressure versus time is correct?
You shouldn't need a calculator.

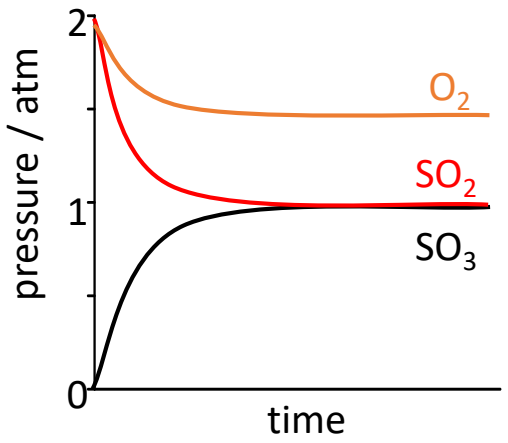
$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad K_P = 3.4$$



1.



2.



3.

✓ Determine either K, initial concentration, or equilibrium concentration, given the other two values.

Does K change if you look at the reaction differently?

Reaction equation 1: $N_2\,(g) + 3\,H_2\,(g) \rightleftarrows 2\,NH_3\,(g)$

$K_{C1} =$

Reaction equation 2: $2\,NH_3\,(g) \rightleftarrows N_2\,(g) + 3\,H_2\,(g)$

$K_{C2} =$

Reaction equation 3: $2\,N_2\,(g) + 6\,H_2\,(g) \rightleftarrows 4\,NH_3\,(g)$

$K_{C3} =$

✓ Generate and manipulate expressions for K and Q for reactions using concentrations or partial pressures, based on a given reaction or set of related reactions.

Finding *K* from related reactions

Dealing with multiple equilibria

Step 1: $H_2C_2O_4\,(aq) \rightleftharpoons H^+\,(aq) + HC_2O_4^-\,(aq)$ $\quad K_1 = 5.90 \times 10^{-2}$

Step 2: $HC_2O_4^-\,(aq) \rightleftharpoons H^+\,(aq) + C_2O_4^{2-}\,(aq)$ $\quad K_2 = 6.40 \times 10^{-5}$

Overall reaction: $\quad K_{overall} =$

✓ Generate and manipulate expressions for K and Q for reactions using concentrations or partial pressures, based on a given reaction or set of related reactions.

Given the information below, predict K for the overall reaction:

$$\tfrac{1}{2}\,N_{2(g)} + \tfrac{1}{2}\,O_{2(g)} \leftrightarrow NO_{(g)} \qquad K_1 = 6.6 \times 10^{-13}$$

$$2NO_{(g)} + O_{2(g)} \leftrightarrow 2NO_{2(g)} \qquad K_2 = 2.6 \times 10^{8}$$

$$N_{2(g)} + 2O_{2(g)} \leftrightarrow 2NO_{2(g)} \qquad K = ?$$

a) 1.1×10^{-16}

b) 9.2×10^{-5}

c) 1.72×10^{-4}

d) 3.4×10^{7}

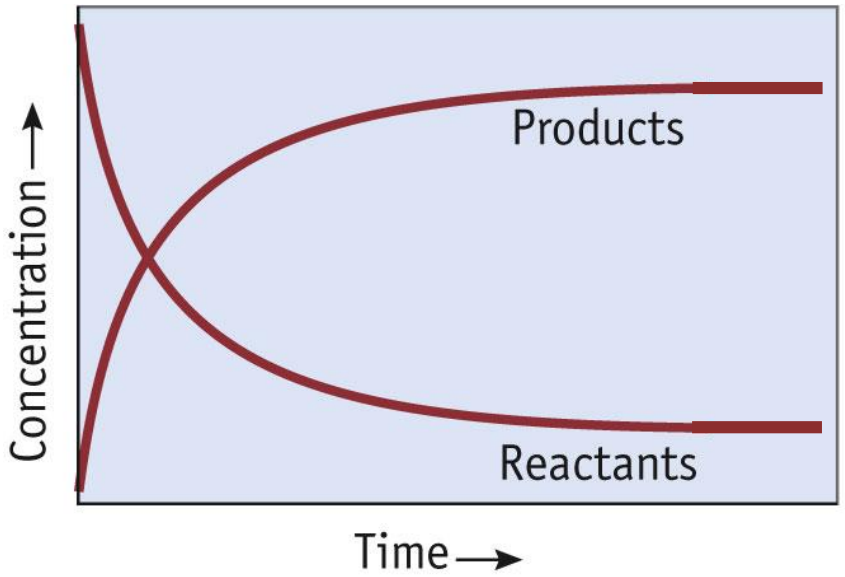
e) 2.6×10^{8}

✓ Generate and manipulate expressions for K and Q for reactions using concentrations or partial pressures, based on a given reaction or set of related reactions.

Predicting Reaction Progress

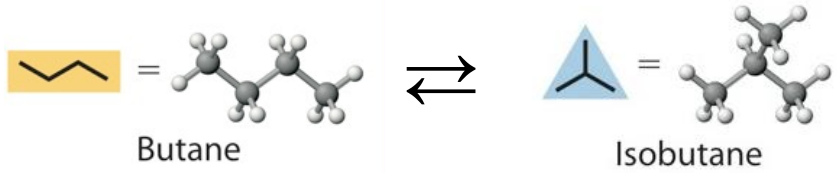
- Reaction quotient, *Q*:

- Equilibrium constant, *K*:



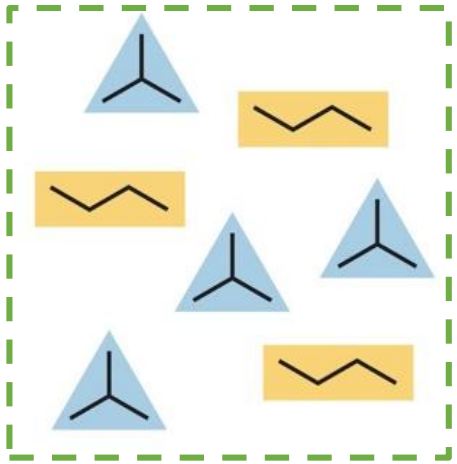
✓ Generate and manipulate expressions for K and Q for reactions using concentrations or partial pressures, based on a given reaction or set of related reactions.

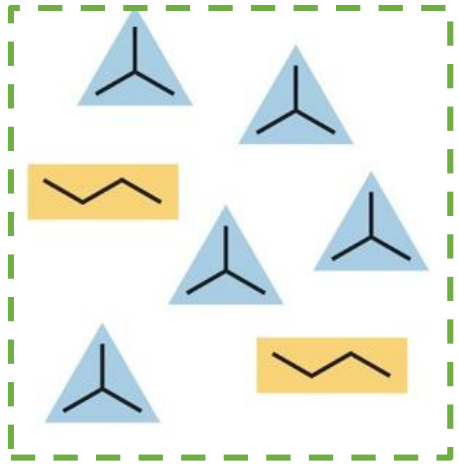
Q vs *K*: *In which direction is the reaction going?*

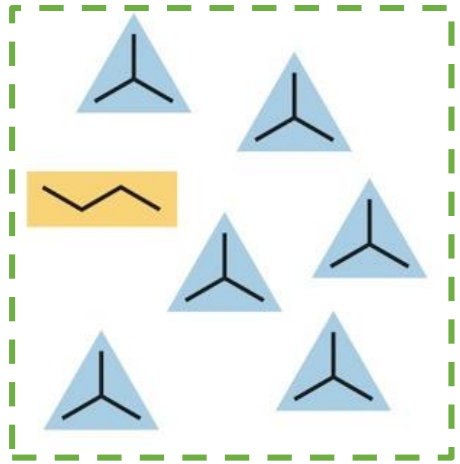


$K = 2.5$

(measured in "picture units")







✓ Determine the direction in which a reaction will proceed using values of K and Q.

For the reaction:

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

$K_c = 0.21$ at 100°C. At one point during the reaction, $[N_2O_4] = 0.12$ mol/L and $[NO_2] = 0.55$ mol/L. Which option below correctly describes the reaction at this moment?

a) The reaction is at equilibrium

b) The reaction is not at equilibrium, and is proceeding to the right

c) The reaction is not at equilibrium, and is proceeding to the left

d) The reaction is not at equilibrium, but we need more information to determine the direction

Calculations with K

1: Finding *K* from Equilibrium Concentrations

A researcher fills an evacuated 2.00 L flask with 0.200 mol of HI gas and allows the reaction below to proceed at 453°C. At equilibrium, [HI] = 0.078 mol/L. Calculate K_c.

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$$

✓ Determine either K, initial concentration, or equilibrium concentration, given the other two values.

2: Predicting Concentrations at Equilibrium

An evacuated flask with a small amount of graphite and gaseous CO_2 is heated to 1080 K, at which point the pressure in the flask is 0.458 atm. Over time, as the temperature is held constant, CO forms. K_P for this reaction is 2.25. What is the partial pressure of CO at equilibrium?

✓ Determine either K, initial concentration, or equilibrium concentration, given the other two values.

Simplifying Calculations: the *"small K"* approximation

For the reaction below, determine the concentrations of N_2O_4 and NO_2 at equilibrium:

$N_2O_4\ (g) \rightleftharpoons 2\ NO_2\ (g)$ $\qquad K = 0.00077$ at 273K

Initial concentrations: 0.100 M 0.00 M

✓ Determine either K, initial concentration, or equilibrium concentration, given the other two values.

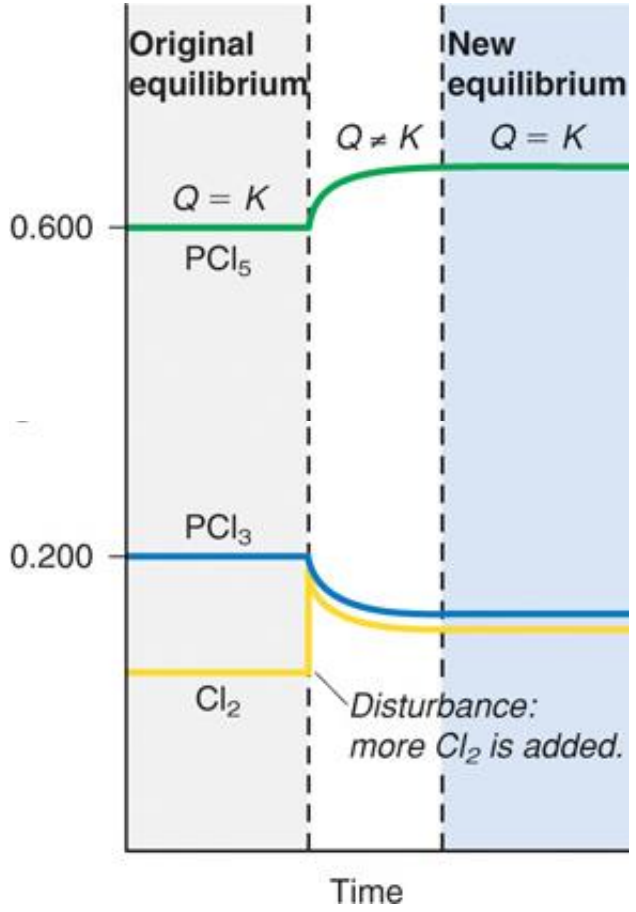
Perturbing Equilibria

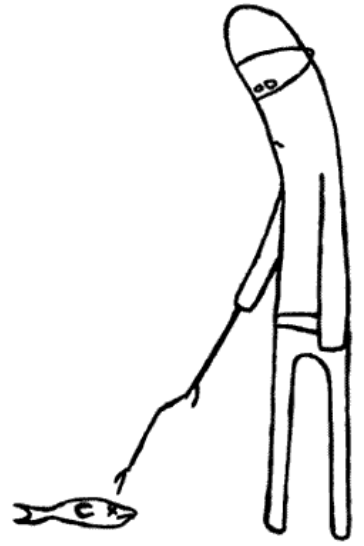
1. Changing Concentration

In aqueous solution, adding or removing reagents in the mixture will result in the reaction "adjusting" to restore equilibrium:

e.g. $PCl_3 + Cl_2 \rightleftharpoons PCl_5$

If this reaction is allowed to come to equilibrium, then Cl_2 is added:





✓ Describe (qualitatively and quantitatively) the effect of changes in concentration, partial pressures, and volume on equilibrium.

In the reaction:

$$Co(H_2O)_6^{2+}\ (aq)\ +\ 4\ Cl^-\ (aq)\ \rightleftharpoons\ CoCl_4^{2-}\ (aq)\ +\ 6\ H_2O\ (l)$$

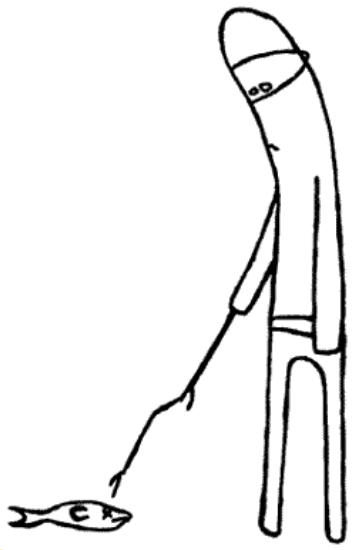
If the initial solution is **purple** (i.e. containing some pink $Co(H_2O)_6^{2+}$ and some blue $CoCl_4^{2-}$) and some **HCl** is added, what color will the resulting mixture be?

a. Unchanged (purple) – HCl is not part of this reaction.

b. More pink – Adding the HCl will shift the reaction towards the reactants.

c. More blue – Adding the HCl will shift the reaction towards the products.

d. We need to know K before we can answer this question.



✓ Describe (qualitatively and quantitatively) the effect of changes in concentration, partial pressures, and volume on equilibrium.

In the reaction:

$$Co(H_2O)_6^{2+}\ (aq)\ +\ 4\ Cl^-\ (aq)\ \rightleftharpoons\ CoCl_4^{2-}\ (aq)\ +\ 6\ H_2O\ (l)$$

If the initial solution is **purple** (i.e. containing some pink $Co(H_2O)_6^{2+}$ and some blue $CoCl_4^{2-}$) and some **water** is added, what color will the resulting mixture be?

a. Unchanged (purple) – water is a pure liquid and won't affect the reaction.

b. More pink – Adding water will shift the reaction towards the reactants, since it is a product.

c. More blue – Adding water will shift the reaction towards the products.

✓ Describe (qualitatively and quantitatively) the effect of changes in concentration, partial pressures, and volume on equilibrium.

Perturbing Equilibria

2. Changing Pressure

Changing pressure in a gaseous reaction is similar to changing concentration in aqueous reactions:

- Increasing partial pressure of a single reactant or product will cause the reaction to shift against this change.

- Changing the volume of the container changes all partial pressures simultaneously, similarly to how adding water affected the cobalt example earlier.
  - Increasing volume (reducing the partial pressures) shifts the reaction towards the side of the reaction with the most moles of gas.
  - Decreasing volume (increasing the partial pressures) shifts the reaction towards the side of the reaction with the fewest moles of gas.

- Adding an inert gas (or a nonreacting gas) changes the total pressure but does not affect the partial pressures – so it does not shift the reaction!

✓ Describe (qualitatively and quantitatively) the effect of changes in concentration, partial pressures, and volume on equilibrium.

Perturbing Equilibria

3. Changing Temperature

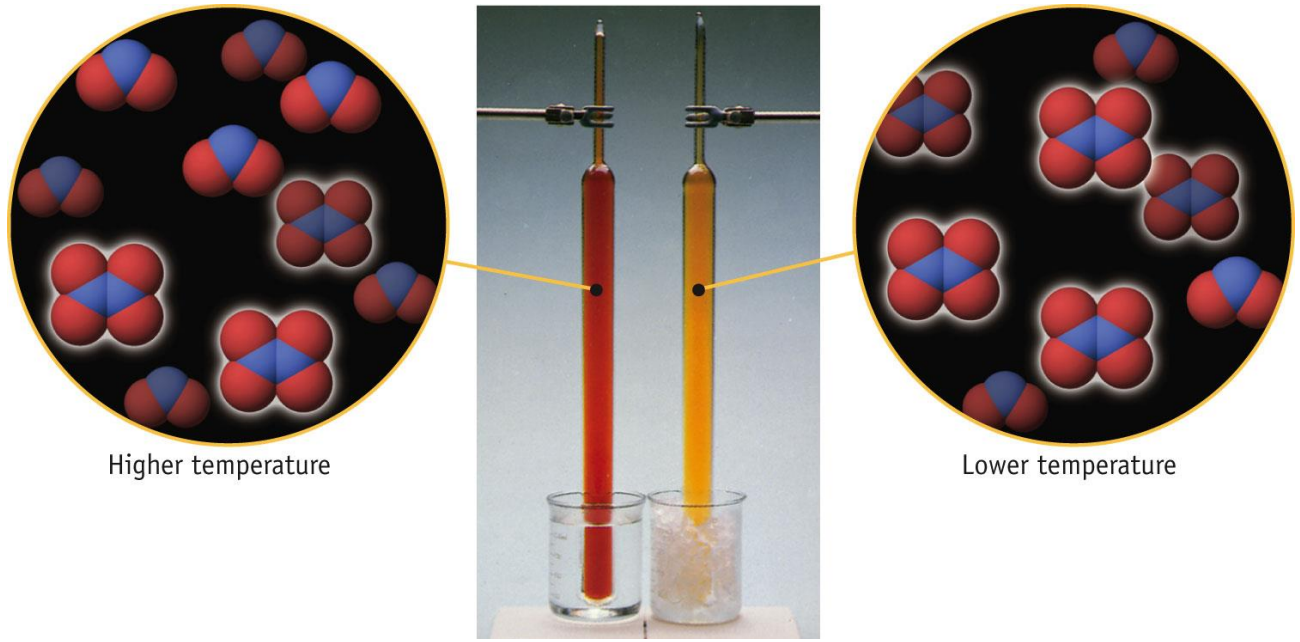
Changing temperature also affects the equilibrium of a reaction … but T doesn't appear in the expression for *K*! So Le Chatelier and comparing Q doesn't work.

Changing temperature actually changes the value of K for the reaction.

This is why you always include T in your 'conditions' when you are reporting a K value.

$$N_2O_4\ (g) \rightleftharpoons 2\ NO_2\ (g)$$

K value	Temperature
0.00077	273 K
0.0059	298 K



✓ Describe (qualitatively and quantitatively) the effect of changes in temperature on equilibrium.

How much – and in what direction – K changes with T depends on the energetics (endothermic / exothermic) of the reaction, and is found using the **Van't Hoff Equation:**

$$\ln\left(\frac{K_2}{K_1}\right) = \left(\frac{\Delta H}{R}\right)\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

For an **endothermic** reaction:

For an **exothermic** reaction:

✓ Describe (qualitatively and quantitatively) the effect of changes in temperature on equilibrium.

For the exothermic reaction:

$$NaHCO_3(aq) + H_2O(l) \rightleftharpoons NaOH(aq) + CO_2(g) + H_2O(l)$$

Which of the following modifications will result in a shift in the reaction that creates more products?

a. Increase the pressure of CO_2 in the reaction chamber

b. Add potassium bicarbonate to the solution

c. Increase the pressure of nitrogen gas in the reaction chamber

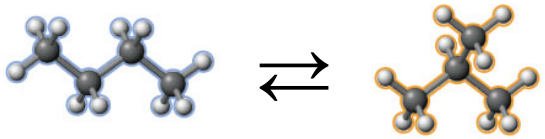
d. Add more water to the mixture

e. Heat the reaction mixture

f. Add a catalyst to the reaction mixture

- ✓ Describe (qualitatively and quantitatively) the effect of changes in temperature on equilibrium.
- ✓ Describe (qualitatively and quantitatively) the effect of changes in concentration, partial pressures, and volume on equilibrium.

Equilibrium Concepts Practice



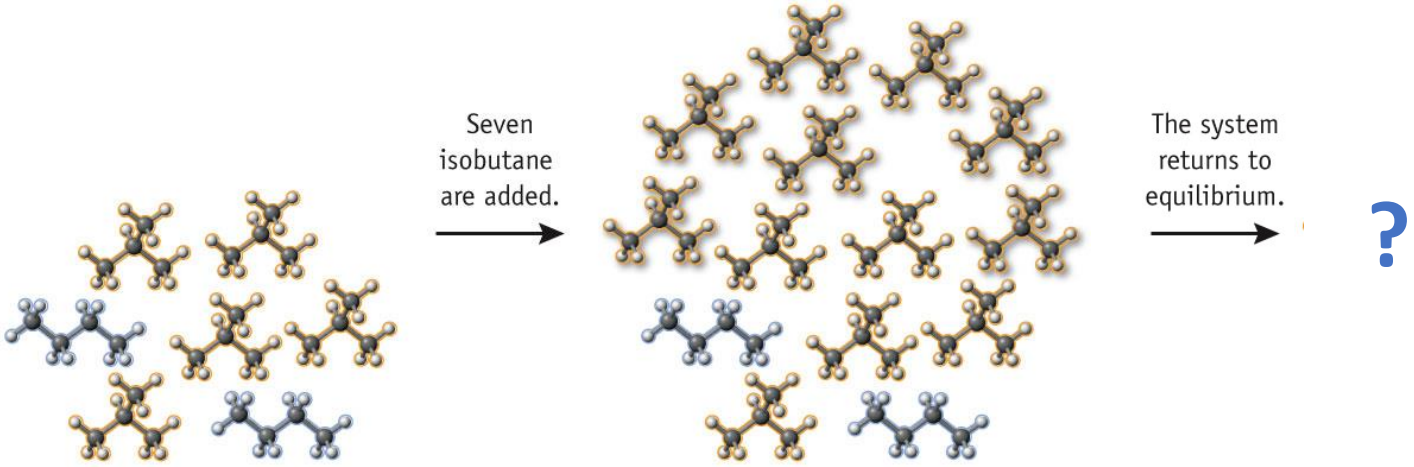
$K = 2.5$

This system is at equilibrium (in a.), then 7 isobutane are added (in b.). What are the new equilibrium conditions?

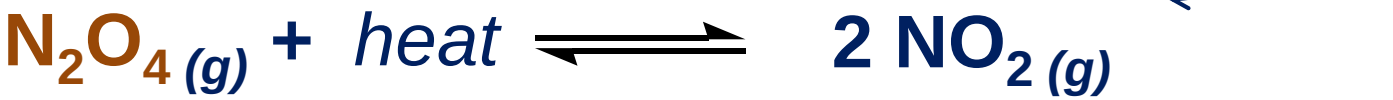
New **I**nitial:

Change:

New **E**quilibrium:

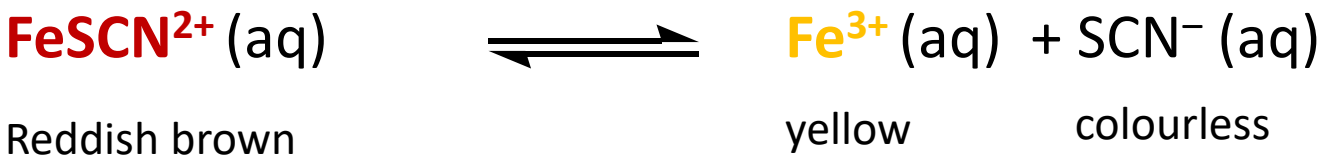


colourless



What happens to this system if ...

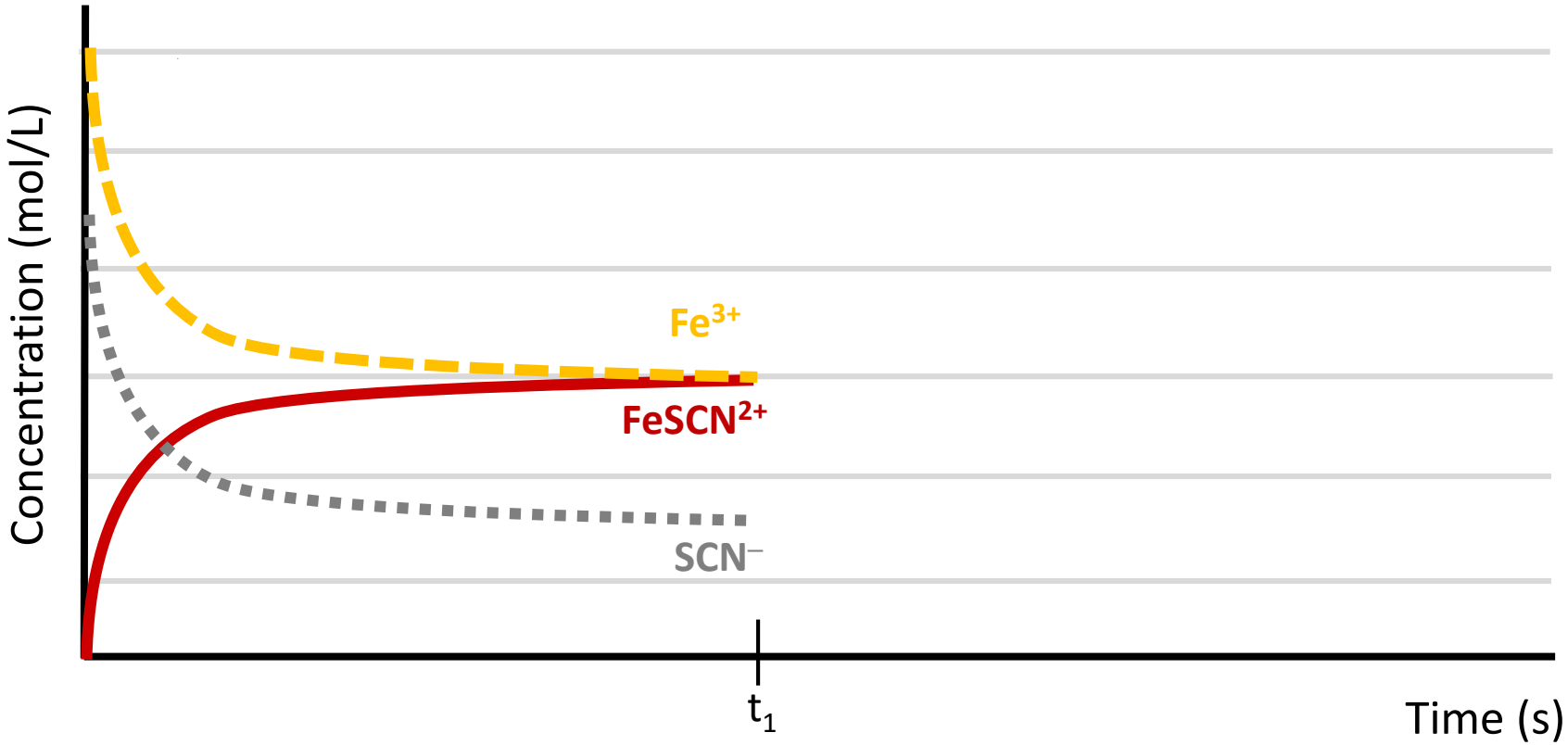
- Temperature is increased?
- Temperature is decreased?
- The container volume is increased?
- N_2 (g) is added to the container?



What color will the solution become (i.e. more red / more yellow) if:

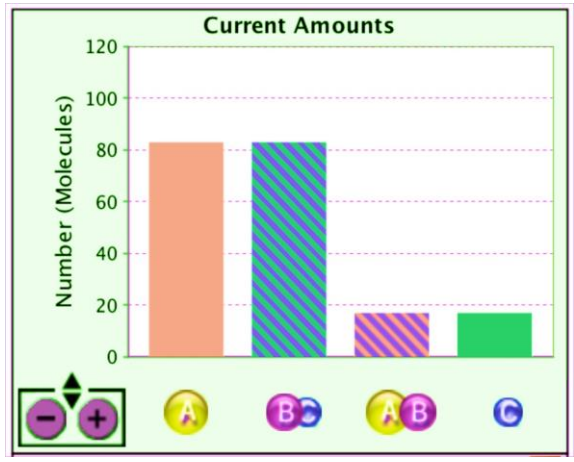
- NaSCN is added?
- Fe^{3+} is removed?
- Water is added?
- Pressure is increased in the reaction container?

Sketch how you expect the concentrations to change over time if more Fe^{3+} is added to the mixture at time t_1:

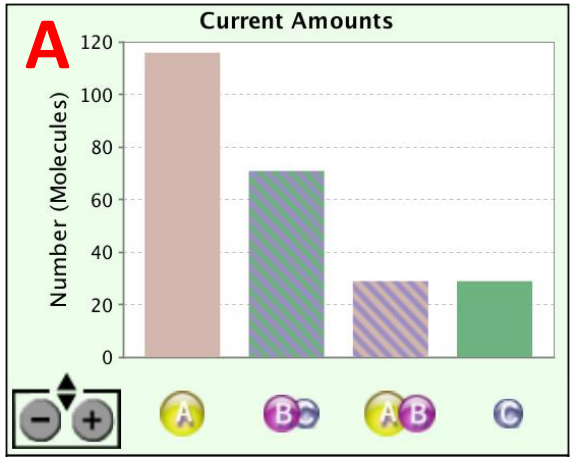


Which of A-E could result from addition of more product(s) to the initial mixture?

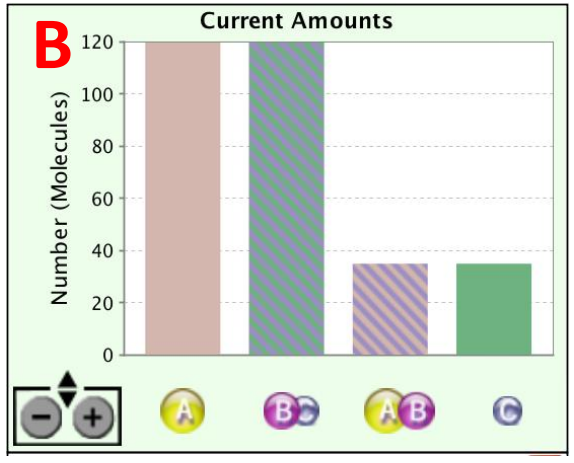
Initial mixture:



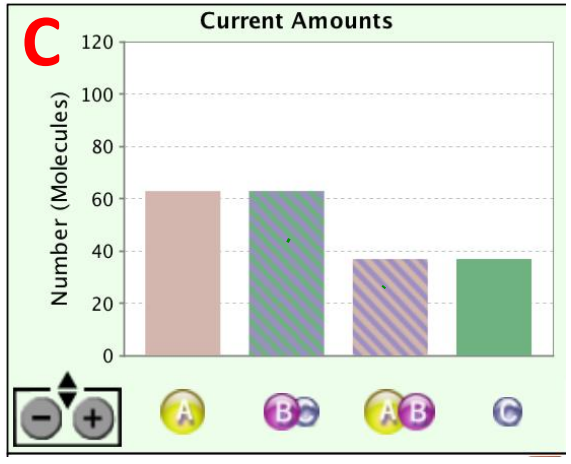
A



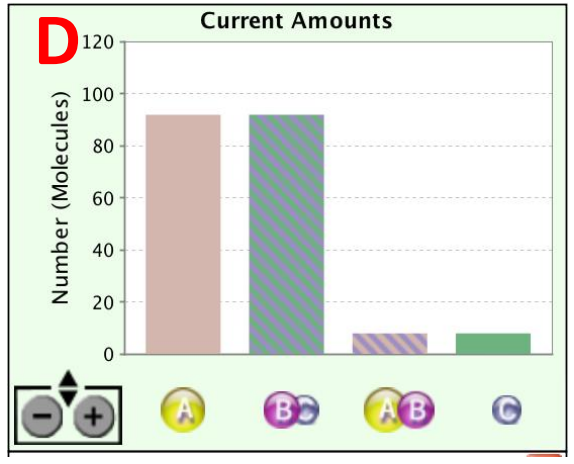
B



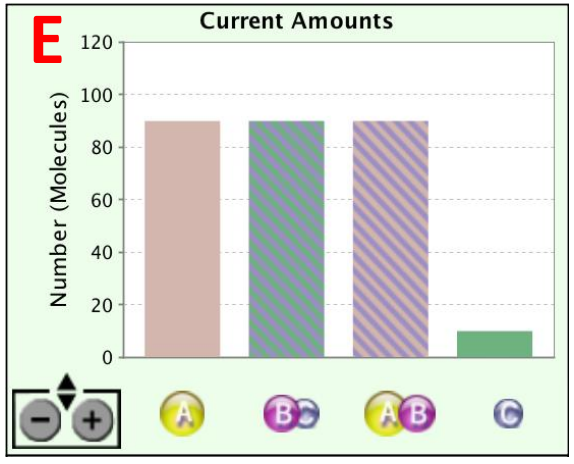
C



D



E



F – None of these apply