Equilibrium

At what point is a reversible reaction "completed"?

Why?

Most of the reactions that we have studied this year have been "forward" reactions—once the reactant has changed into the product it stays that way. We can assume that eventually the reaction will "finish" when the limiting reactant runs out. However, in a reversible reaction (one that can take place in both directions), once the product is formed it can turn back into the reactant and a continuous cycle occurs. When do reactions such as these "finish?" Is there ever an end, and can we predict how much reactant or product will be present when the reaction is "done?"

Model 1 – A Reversible Reaction

$$\mathbf{A(g) \rightleftarrows B(g)}$$

1. What is the reactant in the reaction in Model 1?

2. What is the product in the reaction in Model 1?

3. What is the significance of the double arrow in the equation in Model 1?

4. Imagine that the reaction in Model 1 starts with 100 molecules of A and zero molecules of B. Explain why the concentration of substance A will never reach zero.

5. Imagine the reaction in Model 1 starts with zero molecules of A and 100 molecules of B. Will the concentration of substance B increase or decrease as the reaction proceeds? Explain.

6. Consider an initial concentration of 5.00 moles of A and zero moles of B for the reaction in Model 1. If 60% of the available A molecules react each minute, calculate the concentration of A and B after one minute. Fill in the table below with your answers. Be prepared to discuss your method of calculation with the class.

	A		B	
Initial Starting moles of A	5.00 moles		0.00 moles	**Initial** Starting moles of B
Change Forward Moles of A reacted	–	⟶	+	**Change Forward** Moles of B made
End Moles of A after 1 minute	=		=	**End** Moles of B after 1 minute

7. Did you use the mole ratio between substance A and substance B in Question 6? If not, make a correction.

8. Consider an initial concentration of 5.00 moles of A and 2.00 moles of B for the reaction in Model 1. If 60% of the available A molecules react each minute, and 20% of the available B molecules also react each minute, calculate the concentrations of A and B after one minute. Fill in the table below with your answers. *Hint:* Since the forward and reverse reactions happen simultaneously, calculate the "change reverse" based on the initial 2.00 moles of B.

	A		B	
Initial Starting moles of A	5.00 moles		2.00 moles	**Initial** Starting moles of B
Change Forward Moles of A reacted	–	⟶	+	**Change Forward** Moles of B made
Change Reverse Moles of A made	+	⟵	–	**Change Reverse** Moles of B reacted
End Moles of A after 1 minute	=		=	**End** Moles of B after 1 minute

STOP

9. Obtain a set of starting conditions from the instructor. Enter the initial moles of A and B in Model 2 as well as the percent of A molecules that react each minute (over the first forward arrow) and the percent of B molecules that react each minute (over the first reverse arrow).

Model 2 – Reaching Equilibrium

		A		B
1 minute	**Initial**			
	Change Forward	–	⟶	+
	Change Reverse	+	⟵	–
	End	=		=
2 minutes	**Change Forward**	–	⟶	+
	Change Reverse	+	⟵	–
	End	=		=
3 minutes	**Change Forward**	–	⟶	+
	Change Reverse	+	⟵	–
	End	=		=
4 minutes	**Change Forward**	–	⟶	+
	Change Reverse	+	⟵	–
	End	=		=
5 minutes	**Change Forward**	–	⟶	+
	Change Reverse	+	⟵	–
	End	=		=
6 minutes	**Change Forward**	–	⟶	+
	Change Reverse	+	⟵	–
	End	=		=
7 minutes	**Change Forward**	–	⟶	+
	Change Reverse	+	⟵	–
	End	=		=
8 minutes	**Change Forward**	–	⟶	+
	Change Reverse	+	⟵	–
	End	=		=
9 minutes	**Change Forward**	–	⟶	+
	Change Reverse	+	⟵	–
	End	=		=

10. Complete the calculations required for Model 2. Round your answers to the nearest hundredth of a mole. Take turns doing the calculations and check each other's work.

Read This!

Reversible reactions never come to an end: they just reach **equilibrium**. That is, they reach a point where there is no further change in concentration of any species in the reaction. The forward and reverse reactions continue to happen, but the moles of any species in the reaction that are produced or used in a specific time period are the same, so the overall quantities of all the reactants and products remain constant.

11. Identify the time in Model 2 at which your reaction reached equilibrium.

12. When equilibrium was reached, how did the moles of A lost and the moles of A gained in one minute compare?

13. Calculate the moles of product to moles of reactant ratio at equilibrium for your reaction in Model 2.

$$\frac{\text{Moles product}}{\text{Moles reactant}}$$

Model 3 – Comparing Equilibrium Conditions

	Initial moles A	Initial moles B	Percent reacted forward	Percent reacted reverse	Equilibrium moles A	Equilibrium moles B	Ratio of product to reactant
A	10.00	0.00	60.0%	20.0%			
B	5.00	5.00	60.0%	20.0%			
C	0.00	10.00	60.0%	20.0%			
D	8.00	0.00	60.0%	20.0%			
E	0.00	4.00	60.0%	20.0%			
F	10.00	0.00	25.0%	50.0%			
G	5.00	5.00	25.0%	50.0%			
H	0.00	10.00	25.0%	50.0%			
I	8.00	0.00	25.0%	50.0%			
J	0.00	4.00	25.0%	50.0%			

14. Fill in the Table in Model 3.
    a. Enter your data from Model 2 in the appropriate row.
    b. Send a representative from your group to other groups in the class to gather data for other sets of initial conditions. *Note:* Depending on class size, not all of the conditions may have been explored by a group.
15. Based on the data in Model 3, does the reaction reach equilibrium when the moles of A are equal to the moles of B in the container?

16. Based on the data in Model 3, are the equilibrium concentrations of A and B always the same regardless of initial concentrations? *Note:* Compare reactions with the same percentages for the forward and reverse reaction rates.

17. Based on the data in Model 3, does the equilibrium ratio of product to reactant depend on the initial moles of product and reactant? *Note:* Only compare reactions with the same forward and reverse reaction rates. Explain.

18. Based on the data in Model 3, does the equilibrium ratio of product to reactant depend on the percent of the molecules that reacted in the forward and reverse reactions? If yes, describe the relationship.

19. Predict the final product to reactant ratio for the reaction in Model 1 if the initial concentrations of A and B are 15.0 moles and 5.0 moles, respectively, and the percent of molecules reacting in the forward direction is 80.0% while the percent reacting in the reverse direction is 20.0%.

STOP

Read This!

When a reversible reaction reaches equilibrium and the concentrations of the products are significantly higher than those of the reactants, we say the reaction "favors the products." Likewise, if the concentrations of the reactants are higher at equilibrium we say the reaction "favors the reactants."

20. Consider the data collected in Model 3.

   a. Which set of reactions favor the products?

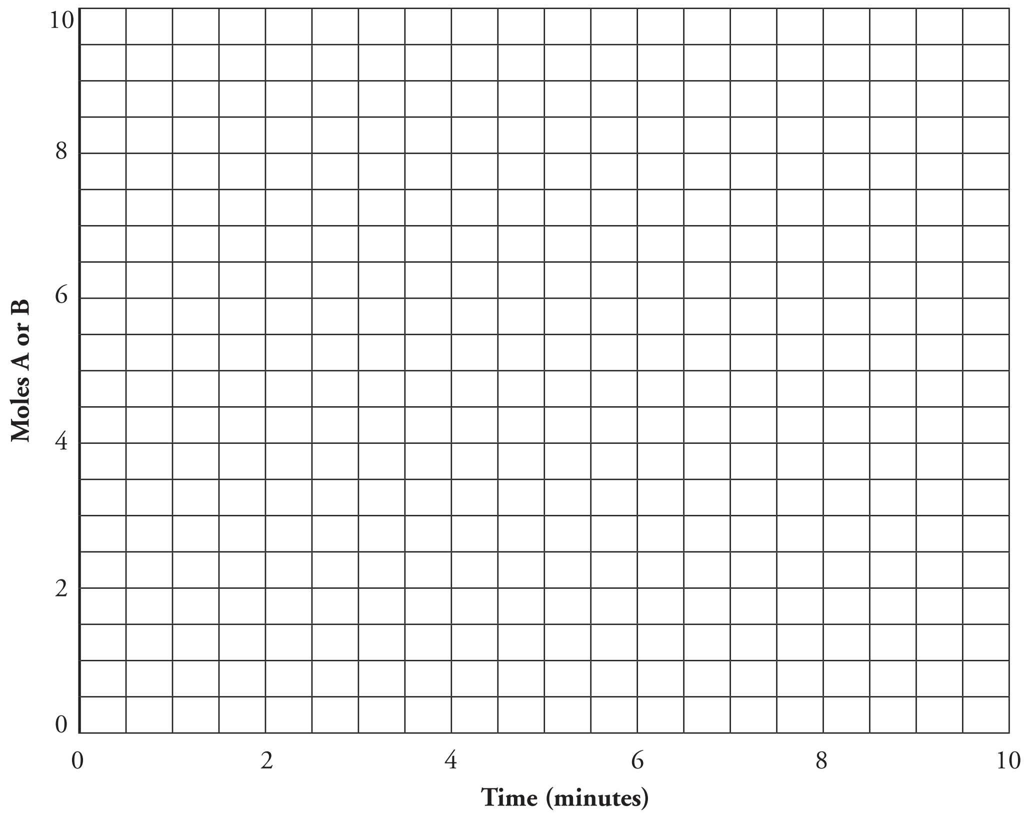
   b. Do reactions that favor the products have a faster forward rate or a faster reverse rate?

   c. Do reversible reactions that favor the products have an equilibrium product to reactant ratio greater than, less than, or equal to one?

21. What is "equal" when a reaction reaches equilibrium?

Extension Questions

23. Using data from Model 2, graph the moles of A and B each minute.



24. How does the shape of the moles vs. time graph communicate that the equilibrium has been established?

25. Predict at least two circumstances (outside influences) that would cause a system in equilibrium to change the concentrations of its reactants or products.