EXPERIMENT 3
EQUILIBRIUM GAMES

PURPOSE:

1. To illustrate three chemical equilibria by using three physical systems as models.
2. To understand how the concentration of reactants and products change with time as equilibrium is achieved.

PRINCIPLES:

A previous experiment demonstrated that reaction rates increase as the concentration of reactants increases, and reaction rates decrease as the concentration of reactants decreases.

Consider the reaction in which reactant A changes into product B:

$$\mathbf{A} \longrightarrow \mathbf{B} \qquad \textbf{Forward Reaction}$$

In the forward reaction, the concentration of A gradually decreases and the concentration of B gradually increases. As a result:

- The rate of the forward reaction decreases,
- B can change back into A and a reverse reaction may occur.

Consider the reaction in which product B changes into reactant A (reverse reaction):

$$\mathbf{A} \longleftarrow \mathbf{B} \qquad \textbf{Reverse Reaction}$$

In the reverse reaction, the concentration of A gradually increases and the concentration of B gradually decreases. As a result:

- The rate of the reverse reaction decreases,

At some point, the rate of the reverse reaction becomes equal to the rate of the forward reaction and a **Dynamic Equilibrium** is reached.

Dynamic: implies that both reactions (forward and reverse) occur simultaneously.

Equilibrium: implies that:

- the rate of the forward reaction equals the rate of the reverse reaction, and
- the concentrations of A and B remain constant.
  However, in a dynamic equilibrium, the concentrations of A and B are not necessarily equal to each other.

In summary:

Dynamic equilibrium for a chemical reaction is the condition in which the rate of the forward reaction equals the rate of the reverse reaction and the concentrations of the reactants and products no longer change.

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Shown below is a stepwise illustration of how a reversible reaction reaches equilibrium:

Forward Reaction

$$\mathbf{A} \rightleftharpoons \mathbf{B}$$

Reverse Reaction

STEP 1

A ——————→ B Fast	A ←·········· B No Reaction

STEP 2

A ————→ B Forward Reaction slows down	A ← B Reverse Reaction starts slowly

STEP 3

A ———→ B Forward Reaction slows down further	A ←—— B Reverse Reaction speeds up

STEP 4

A ——→ B Forward Reaction slows down further	A ←——— B Reverse Reaction speeds up further

$$\mathbf{A} \rightleftharpoons \mathbf{B}$$

Rate of Forward Reaction = Rate of Reverse Reaction
The concentrations of A and B no longer change
Dynamic Equilibrium has been reached

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PROCEDURE:
Working with a partner, prepare two 25 mL graduated cylinders.
1. Label one 25 mL graduated cylinder "A"
2. Fill cylinder A with 25 mL of water
3. Label a second 25 mL graduated cylinder "B"
4. Leave cylinder B empty
5. Obtain two glass tubes with different diameters

In the procedure that follows, three physical models will illustrate three different chemical equilibria.

Model 1
Use the wider diameter glass tube to transfer water from cylinder A to cylinder B.
Use the narrower diameter glass tube to transfer water from the cylinder B to cylinder A.
1. One student shall insert the wider diameter tube in cylinder A (with water).
2. The other student shall insert the narrower diameter tube in cylinder B. (empty, at first)
3. Once the tubes reach the bottom of the cylinders, the top end of the glass tubes must be covered with an index finger to suction hold the water in the tubes.
4. Carefully transfer the contents of the two tubes to the other cylinder and allow the water (if any) to drain into the other cylinder. (i.e. wider diameter tube holding water from cylinder A will transfer that water the cylinder B, and vice versa)
5. Record the volumes in both cylinders (nearest 0.1 mL)
6. Continue this double water transferring process, from one cylinder to the other, and record the volume of each cylinder after each transfer, until equilibrium is reached.
    a. Expect 20 – 30 transfers.
    b. Careful not to mix glass tubes.
7. Once equilibrium is reached, perform five more transfers, still recording the volumes after each transfer.

Model 2
Use the narrower diameter tube to transfer water from cylinder A to cylinder B.
Use the wider diameter tube to transfer water from cylinder B to cylinder A.
1. One student shall insert the narrower diameter tube in cylinder A (with water).
2. The other student shall insert the wider diameter tube in cylinder B. (empty, at first)
3. Once the tubes reach the bottom of the cylinders, the top end of the glass tubes must be covered with an index finger to suction hold the water in the tubes.
4. Carefully transfer the contents of the two tubes to the other cylinder and allow the water (if any) to drain into the other cylinder.
5. Record the volumes in both cylinders (nearest 0.1 mL)
6. Continue this double water transferring process, from one cylinder to the other, and record the volume of each cylinder after each transfer, until equilibrium is reached.
    a. Expect 20 – 30 transfers.
    b. Careful not to mix glass tubes.
7. Once equilibrium is reached, perform five more transfers, still recording the volumes after each transfer.

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Model 3
Use wide diameter tubes for both cylinder A and cylinder B.

1. One student shall insert a wide diameter tube in cylinder A. (with water)
2. The other student shall insert an identical wide diameter tube in cylinder B (empty, at first).
3. Once the tubes reach the bottom of the cylinders, the top end of the glass tubes must be covered with an index finger to suction hold the water in the tubes.
4. Carefully transfer the contents of the two tubes to the other cylinder and allow the water (if any) to drain into the other cylinder.
5. Record the volumes in both cylinders (nearest 0.1 mL)
6. Continue this double water transferring process, from one cylinder to the other, and record the volume of each cylinder after each transfer, until equilibrium is reached.
    a. Expect 20 – 30 transfers.
    b. Careful not to mix glass tubes.
7. Once equilibrium is reached, perform five more transfers, still recording the volumes after each transfer.

ANALYSIS:
The three physical models use the following analogies:

Physical Model	Analogous to
Volume in Cylinder "A"	Concentration of Reactants
Volume in Cylinder "B"	Concentration of Products
Change in volume (ΔV_A) in cylinder "A"	Change in concentration (ΔC_R) of Reactant
Change in volume (ΔV_B) in cylinder "B"	Change in concentration (ΔC_P) of Product
Number of Transfers	Time
$\frac{\Delta V_A \text{ or } \Delta V_B)}{\Delta \# \text{ transfers}}$ (The slope of the plot of any given transfer)	$\frac{\Delta C_{REACTANT} \text{ or } \Delta C_{PRODUCT}}{\Delta \text{ time}}$
$\frac{\text{Volume of water in cylinder B}}{\text{Volume of water in cylinder A}}$ at the point the system reached equilibrium	The Equilibrium Constant (K)

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Guidelines for completing your Report Form

- Fill in all data tables in the Report Form with your recorded data.
- Construct three graphs, one for each model, all three on one sheet of graph paper.
  A **sample** graph is included on page 10..
- Use the following guidelines to construct the graphs:
  - ➢ Do not use the **sample** graph to plot your data.
    Use instead a blank sheet of graph paper of the same type as the sample graph.
    The required type of graph paper (20 squares to the inch) is available in the laboratory.
  - ➢ Plot the “Number of Transfers” on the X axis.
  - ➢ Plot the “Volume of Water” on the Y axis
  - ➢ Join each set of points with a smooth curve.
  - ➢ Label:
    - ✓ Each graph as Model 1, Model 2 and Model 3,
    - ✓ Each axis, and
    - ✓ All six smooth curves (two for each model), “A” and “B” respectively.

- After you constructed your graphs, answer the questions of Table 4.
- When submitting your report form, remove the sample graph and replace it with your own graph.

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REPORT FORM

Name: ______________________ Date: _____________ Partner: ______________________

DATA TABLE 1
MODEL 1

Number of Transfers	Volume in A (mL)	$\Delta V_{(A)}$ (mL)	Volume in B (mL)	$\Delta V_{(B)}$ (mL)
0	**25.0**	**0**	**0.0**	**0**
1				
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DATA TABLE 2
MODEL 2

Number of Transfers	**Volume in A (mL)**	**$\Delta V_{(A)}$ (mL)**	**Volume in B (mL)**	**$\Delta V_{(B)}$ (mL)**
0	**25.0**	**0.0**	**0.0**	**0.0**
1				
2				
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DATA TABLE 3
MODEL 3

Number of Transfers	**Volume in A (mL)**	**$\Delta V_{(A)}$ (mL)**	**Volume in B (mL)**	**$\Delta V_{(B)}$ (mL)**
0	**25.0**	**0.0**	**0.0**	**0.0**
1				
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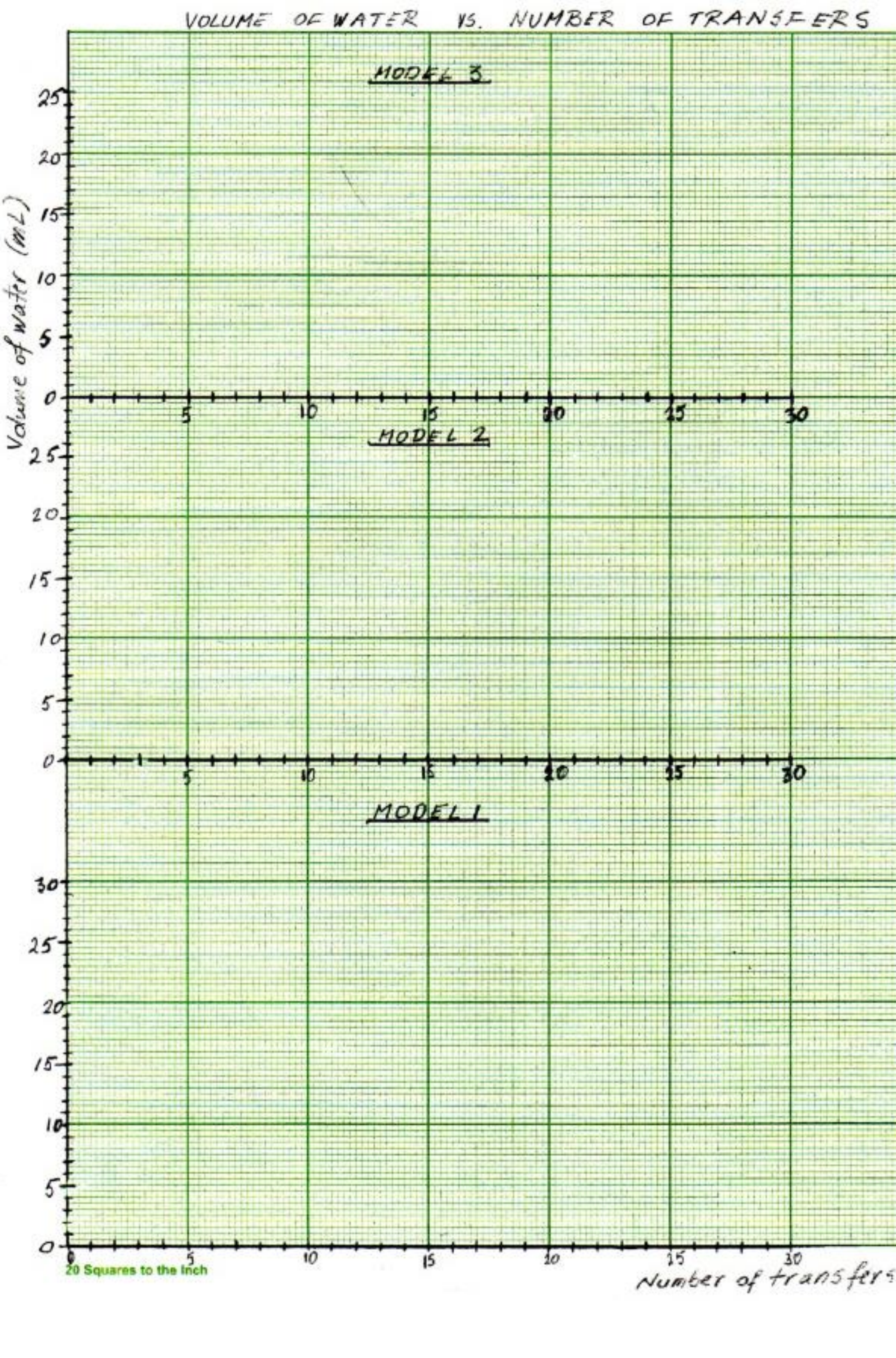

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TABLE 4

Consult your data tables and your graphs to answer the following questions.

		MODEL 1	MODEL 2	MODEL 3
1	Do the volumes of water in the two cylinders ever become equal? (**YES**) or (**NO**)			
2	If your answered **YES** to Question 1 above, how many transfers are required before the volumes become equal? Indicate this on your graphs by drawing the respective vertical line(s) If your answered **NO** to Question 1 above, complete the appropriate box by writing N/A			
3	From your graphs, determine the approximate number of transfers needed to reach equilibrium. Indicate this on your graphs by drawing the respective vertical lines.			
4	Before reaching equilibrium, does the volume of water in cylinder "**A**" **increase**, **decrease** or **remain the same**?			
5	Before reaching equilibrium, does the volume of water in cylinder "**B**" **increase**, **decrease** or **remain the same**?			
6	How do the slopes of curves "**A**" and "**B**" change as number of transfer increases, before equilibrium is reached?			
7	At the point equilibrium has been reached and thereafter, does the volume of water in cylinder "**A**" **increase**, **decrease** or **remain the same**?			
8	At the point equilibrium has been reached and thereafter, does the volume of water in cylinder "**B**" **increase**, **decrease** or **remain the same**?			
9	What are the slopes of the curves "**A**" and "**B**" at equilibrium and thereafter?			
10	What is the volume of water in Cylinder "**A**" at equilibrium?			
11	What is the volume of water in Cylinder "**B**" at equilibrium?			
12	What is the analogous numerical value of the Equilibrium Constant, "**K**" for each model?			

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