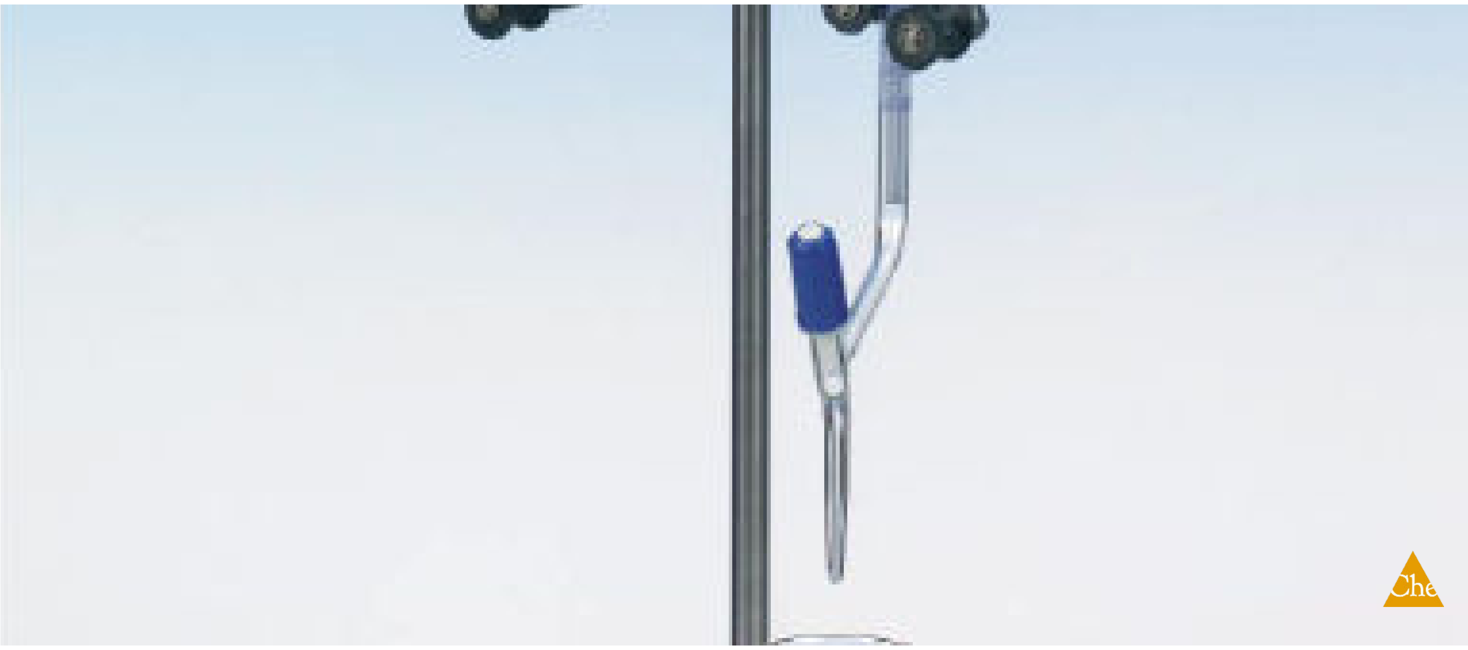
Complex formation equilibrium / equilibrium constant



Many metals, in particular transition elements, can form complexes with charged or neutral ligands. Complex formation reactions are equilibrium reactions. The stability of these complexes is described by the complex formation constant.

Chemistry > General Chemistry > Substances mixtures & separation

Chemistry > General Chemistry > Chemical reactions > Chemical balance

Difficulty level	Group size	Preparation time	Execution time
easy	2	10 minutes	10 minutes

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General information

Application

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Experimental setup

Many metals, in particular transition elements, can form complexes with charged or neutral ligands. Complex formation reactions are equilibrium reactions.

The stability of these complexes is described by the complex formation constant, which the students will get to know in this experiment.

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Other information (1/2)

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Prior knowledge

The Students should already be familiar with the complex formation equilibrium in theory.

They should know, how to calculate the equilibrium concentrations - take the total volume of the respective solution into account – including the potassium bromide solution used.

Scientific principle

The stability of complex formation reactions is described by the complex formation constant.

Other information (2/2)

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Learning objective

The students get to know complex formation equilibrium in practice.

Tasks

The students are to determine the number of ligands of the silver amine complex with a precipitation titration from a silver salt solution.

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Safety instructions

- Wear protective gloves/protective clothing/eye protection/face protection.
- For the H- and P-phrases please refer to the corresponding safety data sheets.
- The general instructions for safe experimentation in science education apply to this experiment.

Theory

Complexes are chemical compounds which consist of a central atom and a definite number of ligands. The central atom is normally a metal ion, transition metals in particular frequently form complexes. The ligands can be charged ions (anions) or neutral molecules. The formation of a complex can be perceived to be a Lewis acidbased reaction.

The ligands, with their free pairs of electrons, represent the Lewis bases, while the central atom with its free orbitals functions as an acid.

A complex is formed with atomic bonds between the ligands and the central atom, whereby the pairs of electrons only come from one partner, the ligand.

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Equipment

Position	Material	Item No.	Quantity
1	Burette, lateral stopcock, Schellbach, 25 ml	MAU-24022021	1
2	Burette clamp, roller mount., 2 pl.	37720-00	1
3	Retort stand, h = 750 mm	37694-00	1
4	Magnetic stirrer without heating, 3 ltr., 230 V	35761-99	1
5	Magnetic stirring bar 30 mm, cylindrical	46299-02	2
6	Graduated pipette 25 ml	36602-00	1
7	Volumetric pipette, 5 ml	36577-00	1
8	Volumetric pipette, 10 ml	36578-00	1
9	Volumetric pipette, 20 ml	36579-00	2
10	Pipettor	36592-00	1
11	Pipette dish	36589-00	1
12	Erlenmeyer flask, borosilicate, wide neck, 250 ml	46152-00	5
13	Volumetric flask, Borosilicate, 100 ml, IGJ12/21	36548-00	4
14	Volumetric flask 250 ml, IGJ14/23	36550-00	3
15	Funnel, glass, top dia. 50 mm	34457-00	3
16	Weighing dishes, square shape, 84 x 84 x 24 mm, 500 pcs.	45019-50	1
17	Spoon, special steel	33398-00	1
18	Wash bottle, plastic, 500 ml	33931-00	1
19	Pasteur pipettes, 250 pcs	36590-00	1
20	Rubber caps, 10 pcs	39275-03	1
21	Silver nitrate, cryst. 25 g	30222-04	1
22	Potassium bromide, 100 g	30258-10	1
23	Ammonia solution, 25% 1000 ml	30933-70	1
24	Water, distilled 5 l	31246-81	1

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Setup and procedure

Setup (1/2)

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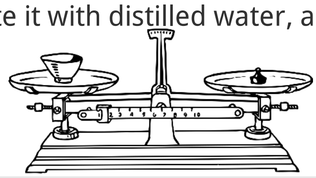
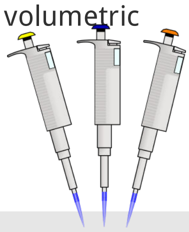
Set up the experiment as shown in the figure on the second page.
Prepare the solutions required for the experiment as follows:

- 0.01 molar silver nitrate solution: Weigh 0.425 g of silver nitrate in a 250 ml volumetric flask, dissolve it in approximately 100 ml of distilled water and fill up to the calibration mark with distilled water.
- 0.01 potassium bromide solution: Weigh 0.298 g of potassium bromide in a 250 ml volumetric flask, dissolve it in approximately 100 ml of distilled water, and fill up to the calibration mark with distilled water.
- 2 molar ammonia solution: Pipette 37.5 ml of 25 % molar ammonia solution into a 250 ml volumetric flask, dilute it with distilled water, and fill up to the calibration mark with distilled water.





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Setup (2/2)

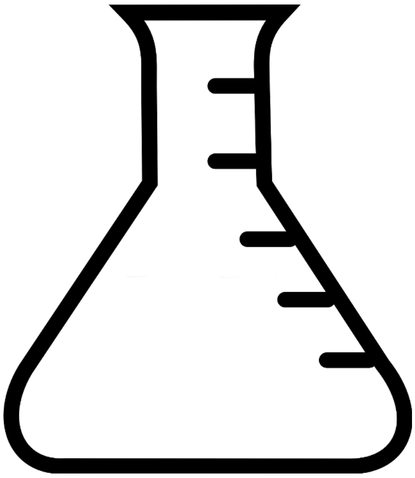
Use four measuring flasks and four Erlenmeyer flasks

Pipette 20 ml of the 0.01 M silver nitrate solution into each of the four 100 ml flasks.

Add 10 (flask 1), 15 (flask 2), 20 (flask 3) and 30 ml (flask 4) respectively of 2 molar ammonia solution into the flasks

Fill the flasks up to the calibration mark with distilled water.

Transfer each of these four solutions into a separate (four) 250 ml Erlenmeyer flask.



Transfer these four solutions into a separate Erlenmeyer flask

Procedure

Experiment setup

Take the 250 ml Erlenmeyer flask and successively titrate each of them with 0.01 molar potassium bromide solution until the solution becomes slightly cloudy (compare it with pure water).

To calculate the equilibrium concentrations, take the total volume of the respective solution into account – including the potassium bromide solution used.

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Evaluation

Evaluation (1/9)

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Evaluation part 1

Complex formation can be described by the following equation:

$$M + nL \rightleftharpoons [ML_n]$$

where n Number of ligands.

For this experiment the complex formation reaction is

$$Ag^{+} + nNH_3 \rightleftharpoons [Ag(NH_3)_n]^{+} (1)$$

in which the number of ligands is to be determined. The complex formation constant can be calculated according to the law of mass action:

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Evaluation (2/9)

Evaluation part 2

$$K_c = \frac{c([Ag^+(NH_3)_n]^+)}{c(Ag^+) \cdot c^n(NH_3)}(2)$$

Transformed to the logarithmic form, the following results:

$$logc(Ag^+) = -n \cdot logc(HN_3) + log\frac{c([Ag^+(NH_3)_n]^+)}{K_c}(3)$$

Because ammonia is added in excess to the four silver nitrate solutions, the concentration of ammonia is much higher than the concentration of silver nitrate:

$$c(NH_3) \Rightarrow \ c(AgNO_3)(4)$$

Evaluation (3/9)

Evaluation part 3

According to this we can assume that the concentration of the silver complex is nearly equal to the total concentration of silver ions in the solution and further, that the concentration of free ammonia after the complex formation reaction is nearly equal to the total concentration of ammonia:

$$[Ag(NH_3)_n]^+ \approx \ c(Ag^+)_{total}(5)$$

$$c(Ag^+)_{total} = [c(AgNO_3)(6)$$

$$c(NH_3) \approx \ [c(NH_3)_{total}(7)$$

With equations (5), (6) and (7), equation (3) simplifies to

$$logc(Ag^+) = -n \cdot \ logc(NH_3)total + \frac{c(AgNO_3)^+)}{K_c}(8)$$

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Evaluation (4/9)

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Evaluation part 4

After the complex formation reaction some of the silver ions remain in the solution as free silver ions (without ammonia ligands). The amount of these free silver ions can be determined by titration with potassium bromide solution. The titration is stopped when the solution begins to become cloudy (onset of precipitation, some solid silver bromide is formed). At this moment the maximum solubility of the silver bromide is reached. This is described by the solubility product:

$$K_s(AgBr) = c(Ag^+) \cdot \ c(Br)(9)$$

Combining (8) and (9), we obtain:

$$log c(Br^-) = n \cdot \ log c(NH_3) total + log \frac{K_c \cdot \ K_s(AgBr)}{c(AgNO_3)}(10)$$

Evaluation (5/9)

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Evaluation part 5

The concentration of silver nitrate is constant in the four solutions:

$$c(AgNO_3) = const.(11)$$

So it follows

$$log \frac{K_c \cdot \ K_s(AgBr)}{const} = const.(12)$$

Combining equations (10) and (12), we obtain:

$$log c(Br) = n \cdot \ log c(NH_3)_{total} + const.(13)$$

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Evaluation (6/9)

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Evaluation part 6

Example for a measurement series on the right figure. The slope of the curve is 2.07, hence coordination number for silver is 2.

If ammonia is added to a silver nitrate solution, therefore, the water molecules which are bound to the silver ion (aquo complex) are displaced by ammonia molecules and a silver diamine complex is formed:

$$[Ag(H_2O)_2]^+ + 2NH_3 \rightleftharpoons [Ag(NH_3)_2]^2 + 2H_2O$$

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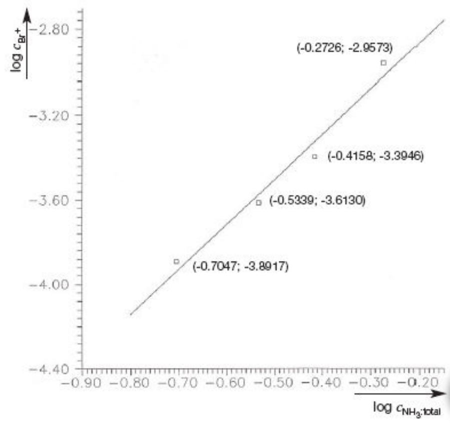

Determination of the number of ligands bound in the complex

Evaluation (7/9)

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What happens if ammonia is added to a silver nitrate solution?

- ○ None of the answers is correct.
- ○ If ammonia is added to a silver nitrate solution, therefore, the water molecules which are bound to the silver ion (aquo complex) are displaced by ammonia molecules and a silver diamine complex is formed.
- ○ If ammonia is added to a silver nitrate solution, therefore, the water molecules which are bound to the silver ion (aquo complex) are absorbed by ammonia molecules and a silver absobtion complex is formed.

Überprüfen

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Evaluation (8/9)

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By which equation can complex formations be described?

- By the equation: $M + nL - H_2O \rightleftharpoons [ML_n] - H_2O$
- None of the answers is correct.
- By the equation: $M + nL \rightleftharpoons [ML_n]$
- By the equation: $M + nL + H_2O \rightleftharpoons [H_2OML_n]$

Überprüfen

Evaluation (9/9)

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Summeray ot the experiment!

Complexes are chemical ______ which consist of a central atom and a definite number of ______. The central atom is normally a ______ ion, transition metals in particular frequently form complexes. The ligands can be ______ ions (anions) or neutral molecules. The formation of a complex can be perceived to be a Lewis acidbased reaction. The ligands, with their free pairs of electrons, represent the Lewis bases, while the central atom with its free orbitals functions as an acid.

- ligands
- metal
- charged
- compounds

Überprüfen

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Folie	Punktzahl / Summe
Folie 19: Ammonia and silver nitrate	**0/1**
Folie 20: Equation	**0/1**
Folie 21: Summery of the experiment	**0/4**

Gesamtsumme **0/6**

Lösungen Wiederholen

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