16–18 years

A practical investigation of *cis-trans* isomerism in transition metal complexes

ROYAL SOCIETY OF CHEMISTRY

Education
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Introduction

Transition metal complexes can form both ***cis-trans* isomers** and **optical isomers**.

In this activity, you will synthesise the *cis*- and *trans*-isomers of the complex copper(II) aminoethanoate, $Cu(H_2NCH_2COO)_2$.

First, you will isolate the *cis*-isomer. Then you will isomerise some of your sample to form the *trans*-isomer.

Before starting the practical activity complete the **Pre-lab questions** on the next slide.

Pre-lab questions

1. In water, the Cu^{2+} ion forms the $[Cu(H_2O)_6]^{2+}$ complex ion which is turquoise blue.
   a. Give the electron configuration of a Cu^{2+} ion.
   b. Use the electron configuration of Cu^{2+} to explain why transition metal complex ions are coloured.

2. In this experiment, you will make $Cu(H_2NCH_2COO)_2$ by replacing water ligands in the $[Cu(H_2O)_6]^{2+}$ complex with glycinate ligands.
   a. Glycine is an amino acid. It has the formula H_2NCH_2COOH.
      Draw the displayed structural formula of glycine.
   b. In alkaline conditions the carboxylic acid group is deprotonated to form a glycinate ion.
      Draw the displayed structural formula of a glycinate ion.
   c. Use your diagram to explain why the glycinate ion can act as a bidentate ligand.

3. $Cu(H_2NCH_2COO)_2$ is a square planar complex and can exist as *cis*- and *trans*-isomers.
   a. Draw the structure of the *cis*- and *trans*-isomers of $Cu(H_2NCH_2COO)_2$.
   b. Label one *cis*-$Cu(H_2NCH_2COO)_2$ and the other *trans*-$Cu(H_2NCH_2COO)_2$.

Pre-lab answers

1. In water, the Cu^{2+} ion forms the $[Cu(H_2O)_6]^{2+}$ complex ion which is turquoise blue.

   a. Give the electron configuration of a Cu^{2+} ion.

   Cu atom $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1\ 3d^{10}$

   Cu^{2+} ion $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^9$

   b. Use the electron configuration of Cu^{2+} to explain why transition metal complex ions are coloured.

   Transition metal ions have d-orbitals which are partially full.

   When ligands surround the central metal ion the d-orbitals have slightly different energies (3 with lower energy and 2 with higher energy).

   Energy in the visible region of the spectrum is absorbed when an electron is promoted from a lower to a higher d sub orbital.

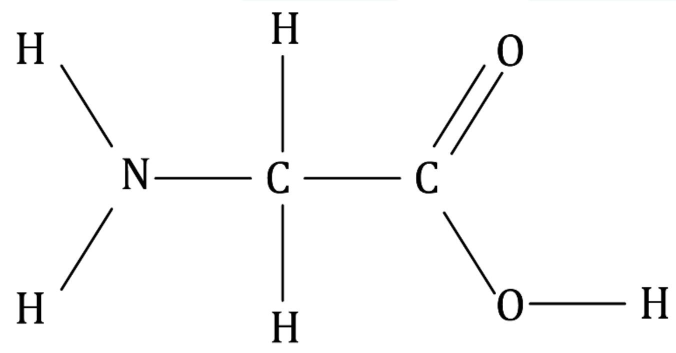
   The colour absorbed is therefore missing from the spectrum and the complementary colour is transmitted.

Pre-lab answers (continued)

2. In this experiment you will make $Cu(H_2NCH_2COO)_2$ by replacing water ligands in the $[Cu(H_2O)_6]^{2+}$ complex with glycinate ligands.

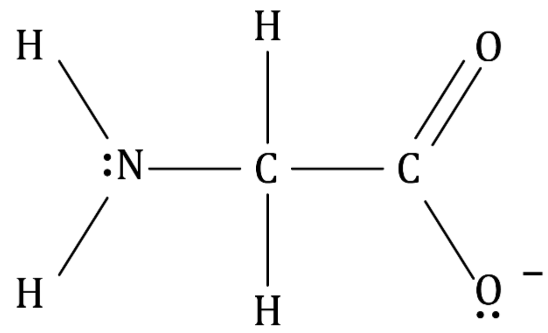
   a. Glycine is an amino acid. It has the formula H_2NCH_2COOH.

   Draw the displayed structural formula of glycine.



   b. In alkaline conditions the carboxylic acid group is deprotonated to form a glycinate ion.

   Draw the displayed structural formula of a glycinate ion.



   c. Use your diagram to explain why the glycinate ion can act as a bidentate ligand.

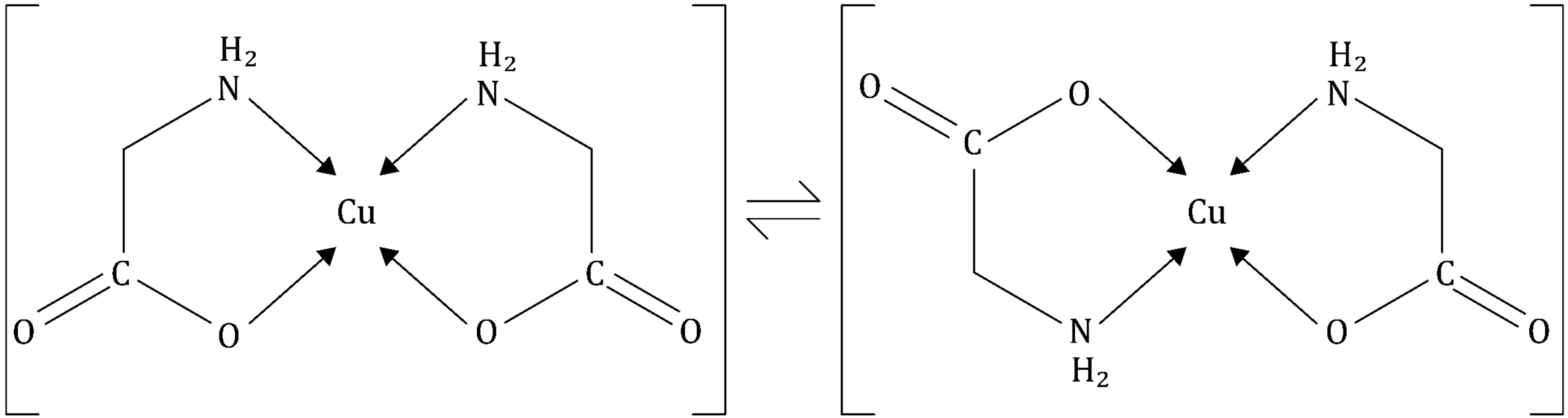
   The glycinate ion has two lone pairs of electrons that can form coordinate bonds with the transition metal ion.

Pre-lab answers (continued)

3. $Cu(H_2NCH_2COO)_2$ is a square planar complex and can exist as *cis–trans* isomers.

   Draw the structure of the *cis–trans* isomers of $Cu(H_2NCH_2COO)_2$.

   Label one *cis*-$Cu(H_2NCH_2COO)_2$ and the other *trans*-$Cu(H_2NCH_2COO)_2$.



cis-$Cu(H_2NCH_2COO)_2$ *trans*-$Cu(H_2NCH_2COO)_2$

Synthesis of copper(II) aminoethanoate

In this experiment you will prepare copper(II) aminoethanoate via a ligand substitution reaction:

$$[Cu(H_2O)_6]^{2+}(aq) + 2H_2NCH_2COO^-(aq) \rightarrow Cu(H_2NCH_2COO)_2(s) + 6H_2O(l)$$

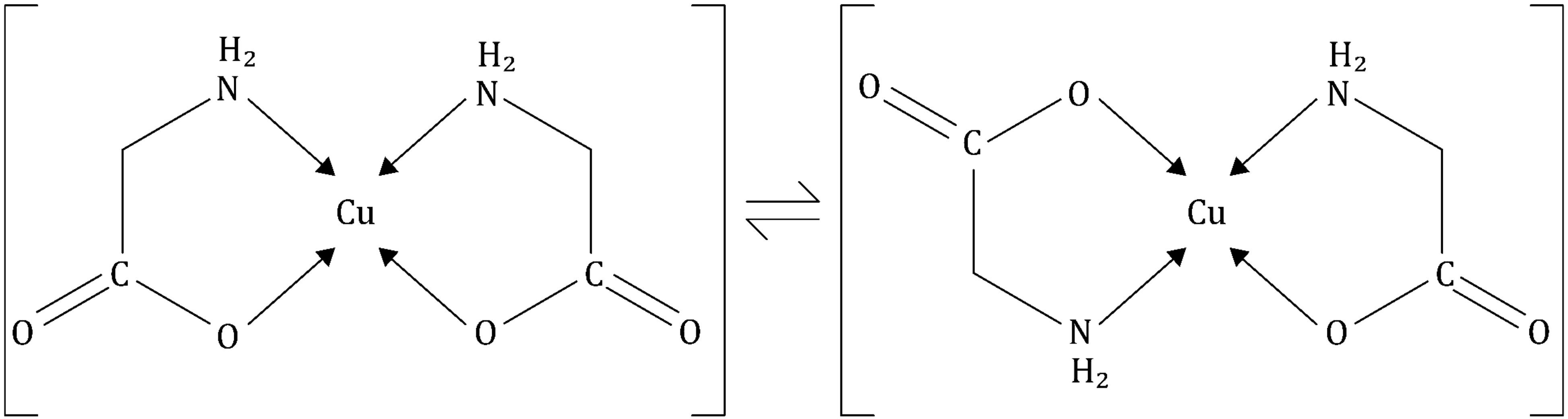
copper(II) aminoethanoate

In the reaction, three moles of reactant species are converted to seven moles of product species causing a significant increase in entropy.

This significant increase in entropy drives the reaction to the right.

Isomerisation

The *cis*- and *trans*-isomers of $Cu(H_2NCH_2COO)_2$ exist in equilibrium:



The *cis*-isomer **crystallises faster**

The *trans*-isomer is **thermodynamically more stable** and **less soluble**

By heating the mixture for longer we can form the *trans*-isomer which is less soluble and comes out of solution.

Calculating percentage yield

$$[Cu(H_2O)_6]^{2+}(aq) + 2H_2NCH_2COO^-(aq) \rightarrow Cu(H_2NCH_2COO)_2(s) + 6H_2O(l)$$

0.01 mol 0.02 mol

1. Use the equation to deduce the amount in mol of $Cu(H_2NCH_2COO)_2$ that could theoretically be formed from the reaction.

2. The complex is isolated as the monohydrate, $Cu(H_2NCH_2COO)_2.H_2O$.

   Calculate the molar mass of $Cu(H_2NCH_2COO)_2.H_2O$ and use this value with your answer to Question 1 to calculate the theoretical mass of $Cu(H_2NCH_2COO)_2.H_2O$ that could be formed.

3. Calculate your percentage yield using the equation:

$$\textbf{Percentage yield} = \frac{\textbf{actual mass}}{\textbf{theoretical mass}} \times 100$$

   If you didn't complete the practical, assume an actual mass obtained of 1.38 g.

4. Based on your practical method and knowledge of the reaction, give two reasons why your yield is less than 100%.

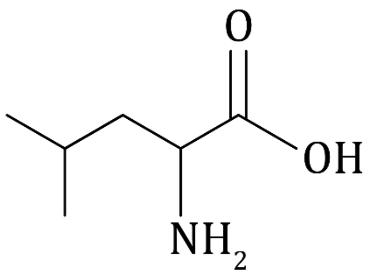
Post-lab synoptic questions

1. Give the full IUPAC name for glycine.

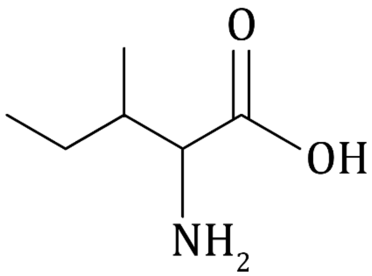
2. Glycine is the only amino acid that is not chiral. All other amino acids have a chiral carbon atom in the *alpha* position (C-2) and exist as **optical isomers**.
   a. Draw the two enantiomers of alanine, $H_2NCH(CH_3)COOH$.
      Show the three-dimensional shape of the chiral carbon atom in your diagrams.
   b. Draw the displayed structural formula for an isomer of alanine which has a different functional group.

3. The image shows the skeletal formulas of leucine and isoleucine.

leucine



isoleucine



   Name the type of **structural isomerism** shown by these two amino acids.

4. Copper forms other complexes that show isomerism.
   a. Draw the ***cis***- and ***trans*-isomers** of $[Cu(NH_3)_4(H_2O)_2]^{2+}$
   b. Draw the two **optical isomers** of $[Cu(en)_3]^{2+}$

Post-lab synoptic answers

1. Give the full IUPAC name for glycine.

   2-aminoethanoic acid

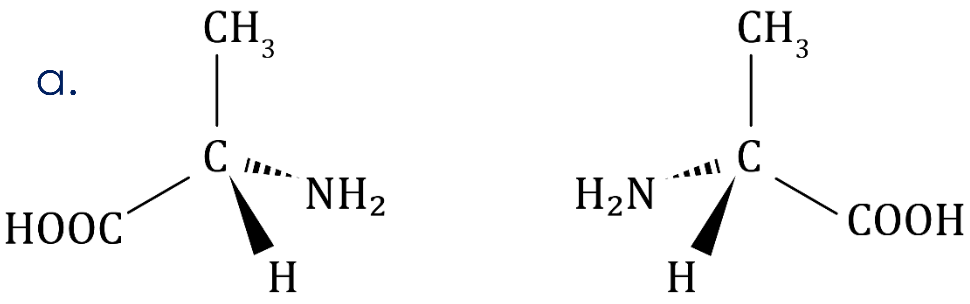
2. Glycine is the only amino acid that is not chiral. All other amino acids have a chiral carbon atom in the *alpha* position (C-2) and exist as **optical isomers**.

   a. Draw the two enantiomers of alanine, $H_2NCH(CH_3)COOH$.

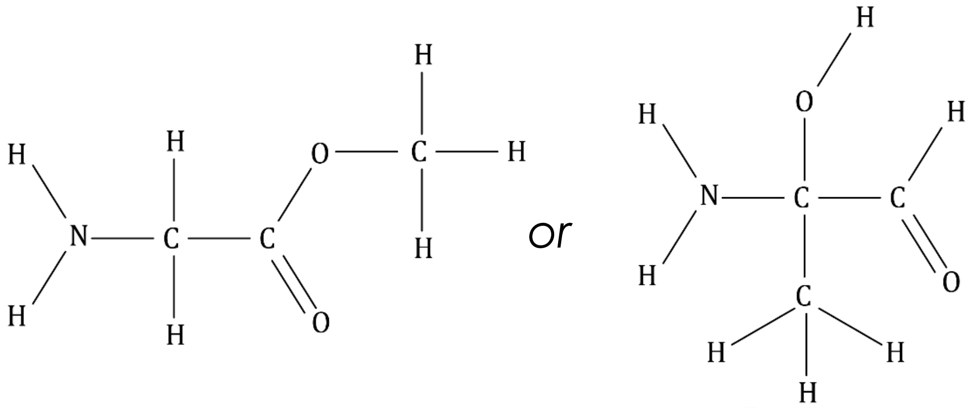
   Show the three-dimensional shape of the chiral carbon atom in your diagrams.

   b. Draw the displayed structural formula for an isomer of alanine which has a different functional group.

a.

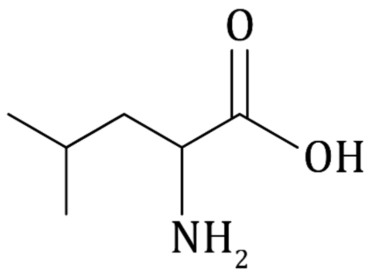
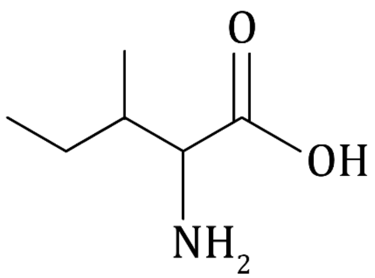


b.



Post-lab synoptic answers (continued)

3. The image shows the skeletal formulas of leucine and isoleucine.

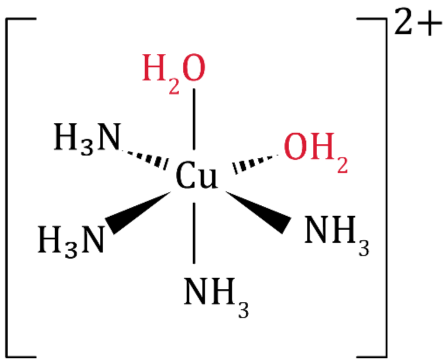
leucine  **isoleucine** 

Name the type of **structural isomerism** shown by these two amino acids.

Chain isomerism, since the methyl group is on C-4 in leucine and C-3 in isoleucine.

Post-lab synoptic answers (continued)

4. Copper forms other complexes that show isomerism.
   a. Draw the ***cis-*** and ***trans*-isomers** of $[Cu(NH_3)_4(H_2O)_2]^{2+}$



   b. Draw the two **optical isomers** of $[Cu(en)_3]^{2+}$