Extension 21: An Equation for Multiple Extraction

1. Prerequisites

The ideas required to understand this section are:

Topic	Book page
Solvent extraction	378
Reasoning behind multiple extractions	380

2. Equation for multiple extractions

Aqueous industrial effluent often contains substances which may be separated out using organic solvents. Recovery of the substances may take several stages. The following equation can be used to calculate the mass of a substance left in the aqueous solvent after several extractions:

$$m = m_0 \left[\frac{V_{aq}}{K_d.V + V_{aq}}\right]^n$$

Where:

m_0 = the mass (in g) of the substance to be recovered before extraction begins;
m = the mass (in g) of the substance left in the effluent after n extractions;
K_d = the distribution ratio of the substance to be recovered between the organic solvent and water;
V = the volume of organic solvent used in each stage of the extraction (in cm^3). (*Note that it must always be the same*);
V_{aq} = the volume of the aqueous effluent (in cm^3); and
n = number of extractions

Using the equation for the worked example in Box 21.4, p. 380.

For two extractions using ethoxyethane:
m_0 = 10.0 g
m = ? g
K_d = 4
V = 50 cm^3
V_{aq} = 100 cm^3
n = 2

$$m = 10.0 \left[\frac{100}{(4 \times 50) + 100}\right]^2$$

or m = 1.1 g (or 10.0 − 1.1 = 8.9 g is the mass extracted)
(which agrees with the answer obtained in Box 21.4!)

EXERCISE 21A

Using the equation for multiple extractions

See if you can use the equation for multiple extractions to obtain the answer to the following: The distribution ratio of an organic compound X between toluene (methylbenzene) and water is 7.0. An aqueous mixture (100 cm^3) contains 1.0 g of X. The mixture is extracted twice using 100 cm^3 of toluene each time. What mass of X is extracted into the organic layer?

Revision questions

1. Which mixture would be the most difficult to separate, and why?

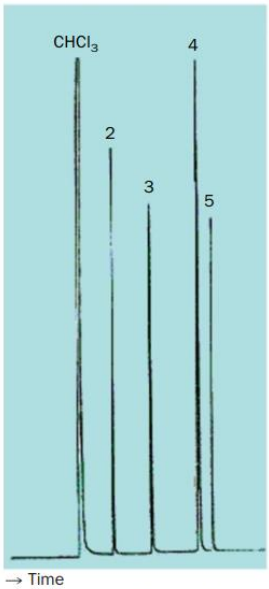
(i) Benzene (boiling point 80°C) and cyclohexane (boiling point 78°C)

(ii) Benzene (boiling point 80°C) and 1,4-dimethylbenzene (boiling point 138°C)

2. A mixture of hydrocarbons was dissolved in trichloromethane and separated by gas chromatography through a column at a temperature of 150°C. The constitutents of the initial mixture and the resulting gas chromatogram are shown below.

(i) Assign the hydrocarbons responsible for peaks 2-5.

(ii) Which hydrocarbon is not shown on the chromatogram (shown on the right), and why?



Gas chromatogram of mixture

Constituents of hydrocarbon mixture

Compound	Boiling point/°C	Molecular weight/u	Formula
Trichloromethane	61	119.5	$CHCl_3$
Benzene	80	78	C_6H_6
Ethylbenzene	136	106	C_8H_{10}
Propylbenzene	159	120	C_9H_{12}
Toluene	110	92	C_7H_8
1,2-dimethylbenzene	144	106	C_8H_{10}

3. You are required to separate a mixture of benzoic acid and charcoal. Benzoic acid is soluble in hot water, but insoluble in cold water. Charcoal is insoluble in both cold and hot water. Describe how you would separate the mixture.

4. Lemongrass oil contains contains citral, an oily substance that is used in the manufacture of vitamin A. Lemongrass oil boils at 229°C, but it decomposes/polymerizes at temperatures near boiling. What method might you be able to use to extract citral?

5. Use the equation for multiple extractions to calculate the number of extraction stages needed to extract 95% by mass of a substance from 1000 cm^3 of aqueous layer (which initially contains 100 g of substance to be extracted) using 100 cm^3 of solvent in each stage (K_d = 10).

Answers

Exercises

Exercise 21A

$$m = 1\left[\frac{100}{(7 \times 100) + 100}\right]^2$$

m = 0.02 g

Revision questions

1. Benzene and cyclohexane would be the most difficult to separate by distillation because they have boiling points that are very close.

2.

(i) The hydrocarbons move through the column according to their volatility. The most volatile (lowest boiling point) has the least retention time. The order therefore is: 2 is benzene; 3 is toluene; 4 is ethylbenzene; and 5 is 1,2-dimethylbenzene.

(ii) Propylbenzene has a boiling point of 159°C and the temperature of the column is 150°C, so it will stay on the column.

3. Recrystallization. Stir the mixture in hot water so that the benzoic acid will dissolve. Filter quickly (Buchner filtration) to remove the charcoal. Allow the hot solution to cool and benzoic acid will precipitate. Filter once more to obtain the purified acid.

4. Steam distillation is useful here, since distillation can take place at a much lower boiling point.

5. After 95% extraction, 5 g of the substance is left:

$$5 = 100\left[\frac{1000}{(10 \times 100) + 1000}\right]^n$$

or 5/100 = 0.05 = $(1/2)^n$

$(1/2)^n$ = 0.03 for n = 5

therefore, for n = 5, over 95% has been extracted.