# Extraction of Caffeine from Tea Leaves

Extraction is a common technique used in organic chemistry to separate or isolate a desired compound from a mixture. The two major types of extractions used in the organic laboratory are solid-liquid extraction and liquid-liquid extraction. Solid-liquid extraction is often used to isolate a natural product from its biological source, such as the leaves or bark of a tree. For example, the anti-cancer drug paclitaxel (Taxol®) can be isolated from the bark of the Pacific yew tree by solid-liquid extraction with methanol. Liquid-liquid extraction is the most common extraction technique, and involves partitioning a solute between two immiscible liquid phases (layers), usually an aqueous phase and an organic solvent phase. The relative concentration of solute in each phase depends on the solubility of the solute in each phase and is given by the partition coefficient (K):

[g/100 mL] in organic phase

Partition coefficient (K) =

[g/100 mL] in aqueous phase

In this experiment, you will use extraction to isolate caffeine from tea leaves. Caffeine is an *alkaloid* (a class of naturally occurring compounds containing nitrogen and exhibiting the properties of an alkali, hence the term *alkaloid*) which is found in many sources, such as tea and coffee. The amount found in tea usually ranges from 2 – 5%.



**Caffeine**

You will first use an aqueous medium (sodium carbonate in water) to extract caffeine (along with tannins, gallic acid, flavonoid pigments, and other trace substances) from tea leaves using solid-liquid extraction. These compounds are soluble in this alkaline medium, but the main component of tea leaves – cellulose – is not. You will then perform a liquid-liquid extraction of the tea solution with an organic solvent, dichloromethane, to remove the caffeine from the basic tea solution. Since caffeine is more soluble in dichloromethane than in water, it partitions primarily into the organic layer, separating it from the acidic tannins and gallic acid. These acidic compounds are converted to water soluble salts by the sodium carbonate, and remain in the aqueous layer during the extraction. Since the other components of tea are not very soluble in dichloromethane, the extraction of tea solution removes virtually no other compound but caffeine. The solid caffeine can be then be isolated by evaporation of the low-boiling dichloromethane and identified by its melting point and mass spectrum.

**Required Reading (Padias):**

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| **Topic** | **2nd Edition** | **3rd Edition** |
| Extraction | pp. 128 – 137 | pp. 130 – 139 |
| Drying the Organic Fraction | pp. 137 – 140 | pp. 139 – 142 |
| Mass Spectrometry | pp. 106 – 114 | pp. 109 – 116 |

**Safety:**

Dichloromethane is a somewhat toxic solvent; handle it as much as possible in a hood and avoid spills.

**Procedure:**

Preparation of Tea

Place about 30 mL of water into a 100 mL beaker (use the beaker markings to estimate the volume). Cover the beaker with a watch glass and heat the water to a gentle boil. Remove the watch glass and place a tea bag (the weight of the tea in the bag will be provided) into the boiling water so that it is covered as completely as possible. Note the approximate level of the liquid in the beaker at this point. Replace the watch glass and continue gently boiling the mixture for about 15 minutes. Water may evaporate during this step; you may add water to maintain the liquid level. Occasionally push down (GENTLY!) on the tea bag with the closed end of a test tube to maintain contact of the tea in the bag with the solution. After the 15 minute boiling period, remove the beaker from the hot plate and use a test tube to squeeze any excess liquid out of the tea bag by rolling the bag against the side of the beaker. Remove the tea bag, squeeze out the excess liquid into the beaker and add 1.1 g of sodium carbonate (Na2CO3). Stir the hot solution with a stir rod until the sodium carbonate is dissolved and allow the solution to cool to room temperature. ***Be sure the solution has cooled to room temperature before you proceed to the next section!***

Extraction of Caffeine from the Tea Solution

Pour the tea solution into a 60 mL separatory funnel (***close the stopcock before you add the tea solution!***). Extract the tea solution with 6 mL of dichloromethane (CH2Cl2, also called methylene chloride or DCM). Mix the two layers by inverting the funnel gently several times (do not shake the funnel too hard or an emulsion will form which is very difficult to separate). Vent the funnel frequently to avoid any pressure buildup. Place the funnel in a ring and allow the layers to separate. Drain the lower dichloromethane layer into a **dry** 25 mL Erlenmeyer flask. Avoid draining any of the aqueous layer or emulsion (a green-brown layer between the aqueous and organic layer) into the flask. Perform a second extraction in the same manner with another 6 mL of dichloromethane. Combine this dichloromethane extract with the first one by draining it into the same Erlenmeyer flask. If there are any visible water drops in the dichloromethane solution, pour the extract back into the separatory funnel, allow the layers to separate, then drain the dichloromethane layer into the Erlenmeyer flask. Dry the dichloromethane solution by adding a small amount of granular anhydrous sodium sulfate. Allow the dichloromethane solution to remain over the drying agent for about 10 minutes.

Isolation of the Caffeine

Decant the dried dichloromethane solution into a **dry**, **pre-weighed** 30 mL beaker. Avoid transferring any of the sodium sulfate to the beaker (a Pasteur pipet works well for the transfer). Place the beaker on a hot plate (***UNDER THE HOOD!***) and evaporate the dichloromethane with gentle heating. As soon as you see solid forming in the beaker, remove it from the heat. The residual heat should be enough to complete the evaporation of the dichloromethane. Do not heat the beaker after the solvent has evaporated, otherwise you may sublime the caffeine. Determine the weight and melting point of your caffeine.

Obtaining the Mass Spectrum

Place 1–2 mg of your isolated caffeine in an autosampler vial. Fill the vial to the shoulder with methanol, cap the vial and shake to dissolve. Obtain the mass spectrum of your product (in Room 308).

**References:**

Pavia, D. L.; Lampman, G. M.; Kriz, G. S.; Engel, R. G. *Introduction to Organic Laboratory Techniques, A Microscale Approach;* 3rd ed.; Brooks/Cole: Pacific Grove, CA, 1999; pp. 125 – 127.

Hill, R.; Barbaro, J. *Experiments in Organic Chemistry;* 3rd ed.; Contemporary Publishing Company: Raleigh, NC, 2005; pp. E4-1 – E4-4.

**Extraction of Caffeine from Tea Leaves: Post-Lab Worksheet**

Recovery Data

1. Mass of Tea Leaves: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

2. Mass of Caffeine Recovered: \_\_\_\_\_\_\_\_\_\_\_\_\_\_

3. Percentage Recovery of Caffeine from Tea: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  
(show calculation)

4. How does your answer in Question 3 compare to the amount of caffeine normally found in tea, and why might it be different?

Melting Point Data

5. Melting point of your product: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

6. Literature melting point of caffeine: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

7. If the melting point of your caffeine is different from the literature value, why might it be different?

Mass Spectrometry Data

8. Molecular ion of your product: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

9. Best match from NIST search (along with percentage match): \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

10. Provide a detailed explanation of how you identified your product as caffeine.

**Questions**

**(Fully explain how you arrived at each answer, including all calculations.)**

1. Many organic solvents can be used for extraction of organic materials from aqueous solutions. Some of the more common solvents (other than dichloromethane) are (a) chloroform, (b) toluene, (c) ethyl acetate, and (d) diethyl ether. For each of these solvents, draw the structure and indicate, for an extraction from aqueous medium, whether the solvent will be the top layer or the bottom layer. Explain your answer.
2. In drug discovery, the value “log P” (the log of the octanol-water partition coefficient) is often used as an estimate of the lipophilicity of a potential new drug.

log P = log([solute]octanol/[solute]water)

The log P value for nicotine is 1.09. If 20 mL of 0.10 g/mL nicotine solution in water is extracted with 20 mL of octanol, how much nicotine is removed from the water layer into the octanol layer? If the same water solution is extracted with (2 x 10 mL) of octanol, how much nicotine is removed from the water layer? Both methods employ a total of 20 mL octanol for the extraction, but are they equally effective for removing nicotine from a water solution? Which method is more effective?

1. Outline a separation scheme for a mixture of benzoic acid, aniline, and ethylbenzene. Use a flowchart similar to that shown in Figure 3-8 in *Padías*. Explain the principle behind each of the steps in the separation scheme.