

Microscale Experiments in Chemistry – The Need of the New Millenium

5. Organic Qualitative Analysis and Mixture Separation on Microscale

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In each of the four parts¹ of this series, we stressed the need for implementing microscale techniques in chemistry laboratories and described various experiments for employment on smaller scale. In this article, we wish to emphasize on the introduction of this technique for some widely performed experiments in organic chemistry laboratories at various academic levels.

Conversion from the macroscale synthetic preparations to microscale is not at all difficult. As a matter of fact, all one has to do is to calculate the stoichiometric ratios of the reactants and reagents and follow the same reaction conditions – be it on macro- or microscale. If preliminary techniques such as transfer in place of pouring, use of Pasteur/Beral pipettes, Hickmann heads, etc., described in earlier articles are followed properly, students could easily and comfortably use as little as 250 mg of the starting materials for even a 2- or 3-step synthesis.

Microscale Separations

One of the most extensively performed experiments in organic laboratory laboratories is the separation of 2 or 3 components from a mixture. As a prelude to it, in the first or second year, the students are introduced to the identification of a *single* compound. This leads to a two-component mixture separation in the third year. The scheme is extended to a three-component mixture separation using ether extraction in the postgraduate level. It is one of those experiments which helps develop several skills in the student and teaches them several principles of chemistry.

In single component identification the usual tests include the

determination of solubility in organic and inorganic solvents; purification by crystallization or distillation; determination of melting or boiling points; determination of type (acid, phenol, base or neutral); detection of N, S and halides by Lassaigne's test (commonly known as sodium fusion test); and identification of other functional groups. Even if a student is given 0.5-1 g or even less of any substance, (s)he should be able to perform the experiments efficiently (current practice is to provide about 5 g), since most of the reactions/tests can be done in capillaries. A recent article by us explains² this innovative use. The method for doing this has been explained in Part 1 of the series. Alternately, an aromatic primary amine, 1M HCl, a solution of NaNO₂ and 2-naphthol dissolved in NaOH are spotted on a filter paper (at the same location) with the help of open-ended capillaries. An orange colour develops instantaneously. Tests done in this way could be performed with greater certainty. It is a common experience that the test done in the conventional manner fails frequently. If done on filter paper, cooling of the solutions is not required and only micrograms or microliters of the test substance and reagents are used. The identification of primary, secondary and tertiary amines is very easy in this manner. Besides saving chemicals to a significant extent, this procedure makes the students feel more confident.

In many laboratories, the amount of 2- or 3-component mixture commonly given to the students is usually in excess of 20 g. We felt the need for changing this and decided to give not more than 1 g or 1 ml of each component. After explaining the scheme by which acids, phenols and bases could be separated from a neutral substance by successive extraction with 8-10% sodium bicarbonate, 2M sodium hydroxide and dilute hydrochloric acid, respectively, we asked the students a simple question – “Assuming that the given mixture contains 1 g of benzoic acid, what should be the quantity of 10% sodium bicarbonate required for extracting it completely?” They would obviously come out with the answer of 7 ml. They were then told to verify the statement: “Any other water insoluble acid with a higher molecular weight, commonly available in college laboratory would require lesser amounts of bicarbonate

Part 1. Newer Ways of Teaching Laboratory Courses with New Apparatus, *Resonance*, Vol.5, No.10, p. 24, 2000.

Part 2. Experiments which Bring Theory Closer to Laboratories, *Resonance*, Vol.5, No.12, p.6, 2000.

Part 3. Microscale Inorganic Qualitative Analysis and New Methods of Titrations for Introduction at All Levels in Chemistry Laboratories, *Resonance*, Vol.6, No.2, p.14, 2001.

Part 4. Physical Chemistry Experiments on Microscale, *Resonance*, Vol.6, No.4, p.15, 2001.

² S L Kelkar, D D Dhavale and B G Mahamulkar, *J. Chem. Ed.*, 365, 2000.



After the acids, phenols or bases are extracted using dilute solutions of sodium bicarbonate, sodium hydroxide and hydrochloric acid, respectively, we suggest that the neutralization of these be done using concentrated solutions such as 6M hydrochloric acid or 10M sodium hydroxide.

for extraction, than this amount". This would also imply that when they take about 0.2 g of a mixture for determination of the type of the mixture, less than 2 ml of 10% bicarbonate solution would be actually required to separate the acid component, if present. This gives the students the concept of controlling the volumes of the solutions at every stage. They were then asked the second question. *"How much 6M hydrochloric acid is required to neutralize this 8 to 9 ml of sodium bicarbonate so that the insoluble organic acid would precipitate?"* It is easy to see that only 1.5 ml will be needed. It may be stressed through such questions that the total volume of solutions needed to separate the acid from a mixture should not exceed 12 to 15 ml under any circumstances. A similar exercise can help them understand how much of 2M aq. NaOH or 2M aq. HCl will be needed to dissolve a given quantity of a phenol or an organic base, respectively. The students can then plan their own experiments and control the volumes of the extracting media in a better manner. They may also be instructed to use this required volume in three parts for the initial extraction (i.e., use 3-4 ml thrice). The advantages of doing multiple extractions with smaller volumes may be explained to them at this stage.

After the acids, phenols or bases are extracted using dilute solutions of sodium bicarbonate, sodium hydroxide and hydrochloric acid, respectively, we suggest that the neutralization of these be done using concentrated solutions such as 6M hydrochloric acid or 10M sodium hydroxide. We also suggest that the addition of these be done with a glass rod dipped in the reagent and then touching its tip to the top of the test tube containing the solution to be neutralized. The reagent is allowed to trickle down the walls of the test tube and the students can observe the precipitate forming at the surface. This would normally dissolve immediately on shaking or stirring, but they would know for sure that the acid (or phenol or base) is present. This observation assures them that the substance *can* be precipitated. The more dreaded separation of amino acids such as anthranilic or *p*-aminobenzoic acids, done in this manner, assures maximum recovery. Alternately, the addition of reagents could be



done with easily available Beral pipettes, as the volume of the drop coming out from it is typically 0.03-0.04 ml. The entire process of type-determination and separation of the mixture may be done in this manner. With smaller volumes, operations like the filtration, drying, crystallization, and extractions are performed much more quickly and using smaller amounts of reagents.

The separation of components from a ternary mixture is usually more complicated than with a binary mixture. Usually this would involve both physical and chemical separations. Insolubility in ether or low boiling point of one of the components is a major criterion in this experiment. After taking into consideration these physical methods, the remaining separation is carried out chemically as described above, with the only modification that the mixture is initially dissolved in ether. We stress that ether should be used even in the 2-component mixture separation. It is usually avoided in undergraduate laboratories because of its higher cost and higher volatility. With reduction in the scale of the experiments, the total consumption of ether for about 20 students doing a 2-component mixture separation could be merely 200 ml or about 10 ml per student per component.

Once separated and purified, each component is subjected to Lassaigne's test for the detection of elements. One of the usual mistakes committed by the students in this experiment is that the sodium fusion extract is not concentrated before adding the reagents. Now that the tests on the extract are conducted in capillaries, the volume of the extract could be reduced to as low as 0.5 ml. The tests for the presence of nitrogen, sulfur or halides can now be performed in capillaries as described in Part 1 of this series, effecting saving sodium nitroprusside and more expensive silver nitrate. Based on the elements detected, the functional group tests may then be performed on the original compounds, again mostly in capillaries. Even though the amount obtained by the students after separation may be less than 0.5 g, they can perform all the tests using microgram quantities each time.

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Microscale Synthesis

The aim of taking up microscale experiments in the undergraduate laboratory goes beyond economy or ecology. We are introducing several new experiments in organic laboratory to explain the theoretical principles to the students. For example, using only 0.250 g of acetanilide, cinnamic acid and *p*-toluic acid, the students are asked to carry out bromination using solutions of bromine in acetic acid, CCl_4 and NBS, respectively. They would know from structures that they have performed aromatic substitution, addition and side-chain bromination. Treating the products separately with KOH would bring about hydrolysis (of the amide) in first case; HBr elimination in the second and nucleophilic substitution in the third. All these newly suggested experiments could easily be done in two laboratory periods of 4 hours each. During this time the student would perform 6 different types of reactions, which (s)he has learnt in the theory classes. We are implementing several such experiments and are planning many more. It should be noted that if not done on a microscale, it would not be possible to demonstrate all these results in the 8 hour period.

With the assistance from a team of dedicated resource persons we have now taken up the responsibility of training teachers in microscale experiments. We are constantly evolving newer methods of conducting laboratory courses in all branches of chemistry – organic, physical and inorganic. Usually the university postgraduate department or a local college take all the organizational responsibilities for a 4-day workshop, and we carry all the required apparatus with us for the use of all the participants. The teacher participants would perform the experiments pertaining to their university syllabus. This firsthand experience boosts their confidence many fold. After doing this successfully in Pune, Mumbai and Goa and more recently at Solapur for teachers of Shivaji University and at Jalgaon for the North Maharashtra University, we have also conducted workshops for the teachers of Kalyani University in West Bengal and Calicut University at Kozhikode in Kerala. We realized that partici-



pants in the workshops became convinced about the ease of doing the experiments and the equally easy implementation only after having a firsthand experience.

Conclusions

In spite of the obvious advantages of doing chemistry in the microscale, it is our experience that in our typical university/college setup it takes time to implement such a change. However, we are optimistic that educating more college teachers through the organization of more workshops on microscale experiments will surely help change the scenario in the coming years. More direct efforts through the involvement of UGC and DST should also help the implementation.

We do not claim that the last word is said about the adopted techniques. As a matter of fact, it will never be said! However, all the teachers should take up the microscale technique, experiment with it, practise it and then adopt changes that they think are essential and beneficial. It is not necessary that they implement all the techniques and experiments at once. We however suggest that it should be done as if a new law is introduced in the country. Just as the metric system adopted in 1956 got slowly introduced and today nobody even thinks in terms of annas and ounces, microscale can also be popularised. With some experience and obligations, college teachers can come up with better ideas than what we have suggested. They should be the ones who could convince the authorities of their universities to convert to microscale techniques. We have just shown the way and it is up to them to follow.

The revolution in our laboratory practices has already arrived and we are proud to be associated with it. It is our endeavor now to help make other academic institutions a part of this new movement. If the current trend of interest continues and if the authorities of the UGC, DST, NCERT and other financing institutions wake up to the needs of the millennium, we are absolutely certain that the scenario in our chemical laboratories would change entirely and dramatically in the near future.

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Acknowledgments

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$e^{\pi\sqrt{163}}$ is almost an integer – thus spake Ramanujan

This remarkable statement was made by Ramanujan in one of his notebooks. One computes to find that

$$e^{\pi\sqrt{163}} = 262537412640768743.999999999992 \dots (!)$$

Very briefly, here is the explanation.

For any complex number τ on the upper half-plane i.e., for $\text{Im}(\tau) > 0$, the so-called modular j -function is defined as $j(\tau) = \frac{1+240 \sum_{n=1}^{\infty} \sigma_3(n)q^n}{\prod_{n=1}^{\infty} (1-q^n)^{24}}$, where $q = e^{2\pi i\tau}$ and $\sigma_3(n) = \sum_{d|n} d^3$. Look at the Fourier expansion of the j -function

$$j(\tau) = \frac{1}{q} + 744 + 196884q + \dots$$

The j -function is intimately related to the theory of integral quadratic forms in two variables. Let $f(x, y) = ax^2 + bxy + cy^2$ with $a > 0$, $\text{disc}(f) = b^2 - 4ac < 0$ and such that a, b, c have no common factor. A linear change of variables by means of an integral matrix of determinant 1 changes f to a quadratic form with the same properties. It is a beautiful theorem due to Gauss that, upto this equivalence, there is only a finite number $h(d)$ of quadratic forms of a given discriminant d .

It was proved by Weber using the so-called theory of complex multiplication of elliptic functions, that for $\tau = \frac{-b+\sqrt{d}}{2a}$, the number $j(\tau)$ is an algebraic integer i.e., is a root of a monic, irreducible, integral polynomial of degree equal to $h(d)$. There are only nine values of negative d for which $h(d) = 1$; the largest such d is -163 . Thus, $j\left(\frac{1+\sqrt{-163}}{2}\right)$ is an integer. Feeding this in the Fourier expansion and noting that $q = e^{-\pi\sqrt{163}}$, we get that $\frac{1}{q} = e^{\pi\sqrt{163}}$ is very close to the integer $j\left(\frac{1+\sqrt{-163}}{2}\right) + 744$ as the other terms involving positive powers of q give a contribution of $O(10^{-12})$. So much for *almost!*

B Sury