

# Hands-on Inquiry-Based Qualitative Identification of Metals in Coins Utilizing Atmospheric Pressure Chemical Ionization Mass Spectrometry

Jonathan G. Moloney, Craig D. Campbell, Andrew F. Worrall,\* and Malcolm I. Stewart



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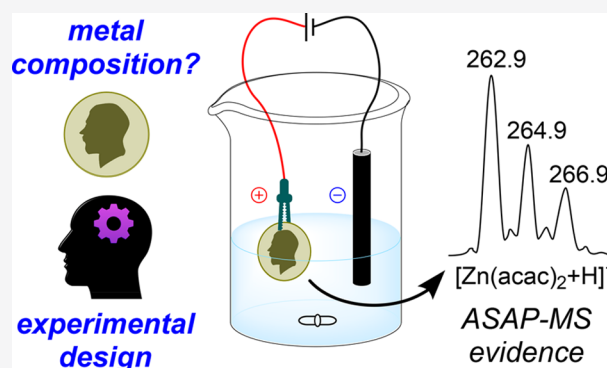


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**ABSTRACT:** This paper describes the application of an accessible, benchtop mass spectrometer using an Atmospheric Solids Analysis Probe (ASAP) for easy sample introduction, coupled with Atmospheric Pressure Chemical Ionization (APCI) as a soft ionization technique, to the inquiry-based identification of the metal composition of alloys, including coins. Students experience the preparation of metal acetylacetonates via traditional salt metathesis and electrochemical methods. They are then encouraged to immediately apply these newly acquired skills to a novel research problem. The discovery aspect of the practical demonstrates opportunities to develop experimental design early in the undergraduate curriculum.



**KEYWORDS:** First-Year Undergraduate/General, Analytical Chemistry, Inorganic Chemistry, Laboratory Instruction, Inquiry-Based/Discovery Learning, Problem Solving/Decision Making, Coordination Compounds, Electrochemistry, Mass Spectrometry, Metals, Qualitative Analysis

## INTRODUCTION

Transition metal acetylacetonate (acac) compounds have long been used as a tool in chemistry teaching laboratories for the introduction of inorganic complex synthesis by salt metathesis, and consequently formation of these compounds is well understood.<sup>1–4</sup> Historically, these synthetic techniques have been taught through expository exercises.<sup>5</sup> Given the emphasis on following fully scaffolded protocols rather than allowing the students to understand the underlying chemistry, such “cookbook” experiments have been shown to develop students’ practical skills in a limited sense.<sup>6,7</sup> While these conventional preparations are important for the development of early, simple practical skills, such as glassware setup, heating under reflux, recrystallization, and the use of a hot plate/stirrer, it was felt that this well-established chemistry could be further developed to illustrate alternative practical techniques and then provide a vehicle for student-led experimental design. Practicals where students get to design their own procedures are believed to lead to better student engagement because of a sense of empowerment and ownership.<sup>8</sup> The employment of active learning, guided enquiry, and experimental design, alongside small research-based projects, allows students an insight into real-world of research chemistry.<sup>7</sup> There are many examples of these types of lab sessions in the literature, but they usually occur in the later years of the undergraduate curriculum.<sup>8</sup> We are actively trying to incorporate oppor-

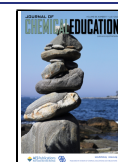
tunities for experimental design into the first-year teaching laboratory. Considering that experimental design and inquiry-based practicals require significant scaffolding and support, this article demonstrates a further application of such a pedagogical approach:<sup>9–11</sup> the introduction of fully scaffolded expository practical protocols, followed by the posing of a “research” question which students have to consider and investigate.

In contrast to the salt metathesis method, the electrochemical synthesis of transition metal acetylacetonates within a teaching laboratory environment has been reported.<sup>12</sup> Electrochemical synthesis has often been overlooked, both in research and in teaching,<sup>13</sup> however, the power of the technique, together with its potentially “green” credentials, has led to a resurgence of interest, the relative operational simplicity being particularly attractive.<sup>14</sup> From our experience of UK schooling, students’ understanding of the concepts and application of electrochemistry has often proven weak, at both the A-level and first-year undergraduate level, despite these concepts being covered as part of pre-university syllabi.<sup>15,16</sup> Additionally, given

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the disruptions to learning encountered during the COVID-19 pandemic, many students have indicated that they have had little opportunity to study and explore electrochemical methods pre-university; developing opportunities to explore these in a practical setting would be of significant benefit to their understanding of this conceptually troublesome topic.<sup>17</sup> By carrying out an electrochemical synthesis practically, the ideas introduced at school can be expanded upon. This allows discussion and clarification of key concepts such as anode and cathode redox behavior and the importance of the electrolyte, further cementing students' understanding of this area of chemistry. In addition, the exploration of both conventional and electrochemical syntheses of the same type of compound can lead to conversations about the relative merits of each technique, including a discussion of sustainability within chemistry, a topic of great importance for the next generation of chemists.<sup>18</sup>

Metal acetylacetonate compounds have typically been characterized through a mixture of IR and UV–visible spectroscopy and mass spectrometry (MS);<sup>12,19</sup> however, the theory and reconciliation of the variation in trends between different metal species is complex: for example, the variation in carbonyl bond stretching frequency is a consequence of an interplay of a number of factors, e.g., charge on the metal center, ionic radius, d-electron configuration, the possibility of high and low spin, and complex geometry. Consequently, analyses by IR and UV–visible spectroscopies are considered beyond the scope of a first-year undergraduate course.<sup>20</sup> Mass spectrometry, however, is covered within all pre-university courses in the UK, such as A-levels, the International Baccalaureate, and the Pre-U course, making it an ideal analytical technique accessible to first-year undergraduate students.<sup>21–23</sup> This familiarity allows the students to easily understand the evidence that they collect from the synthesis of various metal acac complexes. In addition, many metals have characteristic isotopic abundance ratios, which leads to patterns of intensity in molecular ions'  $m/z$  values, that are readily interpretable by early year undergraduates.<sup>24</sup>

With the explosion of the use of benchtop NMR spectrometers in the education literature as a convenient option for analysis,<sup>25–27</sup> we sought an equivalent tool for mass spectrometry. The availability of a solids probe as a straightforward method of sample introduction, in conjunction with Atmospheric Pressure Chemical Ionization (APCI), allows rapid, high-quality analysis of the complexes formed.<sup>28</sup> ASAP-MS provides a simple and hands-on approach to mass spectrometry, granting students the opportunity to evaluate their own MS data. The use of APCI as a soft ionization technique minimizes molecular ion fragmentation, thereby often producing simpler spectra; these two features allow students to gain direct experience of the generation of a mass spectrum together with an analysis of their own data.

Once students have gained experience of the production of metal acetylacetonate complexes by conventional salt metathesis and electrochemical methods, together with the analysis of the products by mass spectroscopy, we pose a problem to allow students to further develop their research skills: to design and conduct an experiment to probe the metal composition of a coin. This aims to reinforce the students' understanding of the practical techniques introduced and helps them develop valuable skills such as expressing their experimental plans through dialogue with an experienced chemist and confidence in the planning of practical work.<sup>8</sup> This immediate reinforce-

ment of learned skills fits the spiral nature of learning which characterizes our newly designed practical course.<sup>29</sup>

## DISCUSSION

Logistically, the use of a large number of power packs requires students to work in pairs. Within each pair, the synthesis, isolation, and analysis of two metal acetylacetonate complexes is carried out: one solely by conventional techniques and one both electrochemically and by salt metathesis. Students' MS data are shared with the whole laboratory group to ensure each student acquires data covering the full range of metal acetylacetonates prepared. Students are then set the task of developing and carrying out an experiment to probe the metal composition of a coin. This task was chosen as there are a range of obtainable answers, given the wide variety in coin composition worldwide, and possible differences dependent on when the coins were minted. Additionally, having "identified" the element(s) present in a coin, students would need to consider whether their conclusions are sensible, inasmuch as they indicate the presence of typical coinage metals. Lists of these are easily found on the Internet.

This practical has, so far, been successfully undertaken by approximately 600 undergraduates since 2018. The whole practical is carried out over the course of two 6-h sessions. The first 6-h session is dedicated to expository teaching, allowing students to acquire knowledge of the synthetic and analytical techniques required for the formation of transition metal acetylacetonates. The second 6-h session is much less scaffolded, with approximately 30 min devoted to designing the experiment and the rest of the time to its execution, allowing students the freedom to explore their proposals, following discussion with a graduate teaching assistant (details of this process are provided below in the [Mass Spectrometric Analysis of Coins](#) section).

### Conventional Syntheses

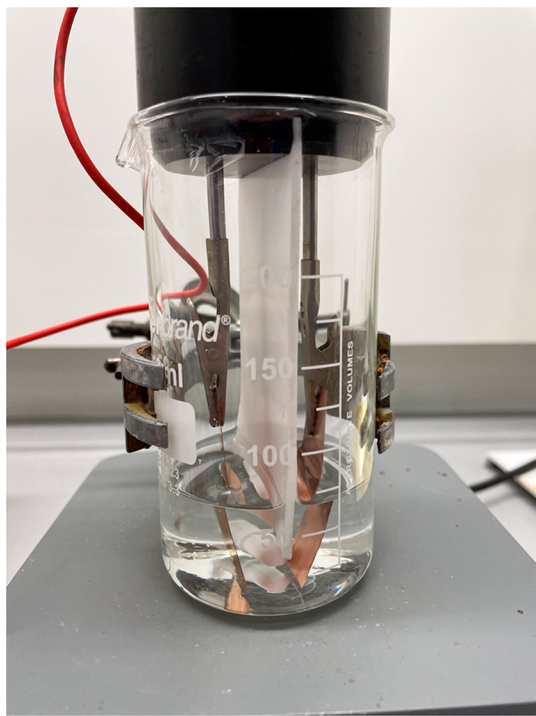
The conventional syntheses of metal acetylacetonate complexes follow a variety of methods (see [Supporting Information](#)), the choice of which is determined by a number of factors such as the availability of starting materials, the air sensitivity of particular metal oxidation states, and the need for careful pH control to avoid precipitation of metal hydroxides.<sup>30</sup> To ensure that all students get experience of a variety of methods, each pair is instructed to prepare a sample of two metal acetylacetonate complexes, one of  $V(acac)_3$ ,  $Cr(acac)_3$ , or  $Mn(acac)_3$  and one of  $Fe(acac)_3$ ,  $Cu(acac)_2$ , or  $Zn(acac)_2$ . The remainder of the metals in the first transition metal series were not considered, either because of reasons of toxicity ( $Ni(acac)_2$  and  $Co(acac)_2$ ), safety ( $Ti(acac)_3$  is made from spontaneously flammable  $TiCl_3$ ), or a lack of a suitable, published synthesis ( $Sc(acac)_3$ ).

In general, undergraduates were comfortable carrying out these syntheses, having had previous experience of conventional synthesis; however, yields varied greatly, with the success of the recrystallization step having the largest impact, while incomplete drying led to reported yields greater than 100%. With these metal acetylacetonate complexes completed, the electrolytic syntheses were attempted.

### Electrosynthesis of Copper(II), Zinc, and Iron(III) Acetylacetonates

The students' initial investigation into the electrochemical synthesis of transition metal acetylacetonates focused on the formation of one of three  $M(acac)_x$  compounds,  $Cu(acac)_2$ ,

$\text{Zn}(\text{acac})_2$ , or  $\text{Fe}(\text{acac})_3$ . These were chosen because of the availability of metals in a form suitable for making electrodes at a reasonable price. It was decided to use two electrodes of the same metal, even though only the anode provides the metal ions for the formation of the acac complex. Presumably, an inert electrode (e.g., graphite) as the cathode would give similar results, but we took the opportunity to discuss the different roles of the two electrodes in the cell in the hope that this would feed into the later experimental design, when students needed to choose their own electrodes. After discussion about the necessary addition of  $\text{N}(\text{C}_4\text{H}_9)_4\text{PF}_6$  to the organic solvent and the redox behavior of both the anode and cathode, students were able to set up and carry out the 90 min reaction with relative ease. Full details are provided in the [Supporting Information](#), but, in brief, the procedure was carried out as follows: 50 mg of  $\text{N}(\text{C}_4\text{H}_9)_4\text{PF}_6$  was added to 50 mL of acetylacetone and 15 mL of acetone in a tall 250 mL beaker. Two electrodes of the metal of interest were cleaned using sandpaper then washed with 2 M HCl and 2 M NaOH. The electrodes were attached to the crocodile clips and submerged into the electrolyte, making sure that the crocodile clips were clear of the solution. The electrochemical cell was designed such that there is a plastic sheet between the electrodes, preventing contact and minimizing the chance for short circuiting and fires ([Figure 1](#)). The power pack was



**Figure 1.** Electrochemical synthesis equipment used in this practical.

switched to its maximum voltage, either 120 or 32 V, and the reaction was stirred for 90 min. The choice of voltage was, for us, determined by the availability of power packs. Although the reactions with the 120 V power pack generated significant heat in the cell, it was deemed a hazard to use ice/water baths to cool the solution around the high voltage setup. A potential of 120 V resulted in a greater yield of the metal complexes, but the lower voltage produced sufficient material for analysis. Mass recoveries varied greatly (5–180 mg for  $\text{Fe}(\text{acac})_3$ , 10–750 mg for  $\text{Cu}(\text{acac})_2$ , and 10 mg to 1.16 g for  $\text{Zn}(\text{acac})_2$ ) and

mainly depended on the voltage applied and the surface area of the electrode submerged in the electrolyte. The point of the electrochemical synthesis was to illustrate how to prepare the product rather than focus on the yield, as current was not kept constant. However, a discussion about percentage yield enabled students to understand how an electrochemical yield might be calculated using Faraday's laws. This was not attempted in this practical due to the use of constant voltage power supplies. Students confidently came up with the idea of weighing the anode before and after the reaction, allowing appreciation of the yield in relation to Fe, Zn, or Cu; however, probing the concept of current, and therefore the use of quantity of electrons as the limiting agent, proved more problematic.

Guided questioning such as “if 1 mole of electrons passed through the reaction, how much  $\text{Cu}(\text{acac})_2$  would you expect to form?” and “if 0.4 mol of  $\text{Cu}(\text{acac})_2$  was formed from 1 mole of electrons, what would the yield be?” were useful in pointing students in the right direction.

With  $\text{M}(\text{acac})_x$  complexes in hand, the students were able to prepare samples to analyze by mass spectrometry.

#### Mass Spectrometric Analysis of Transition Metal Acetylacetonate Samples

IR has previously been reported for the analysis of transition metal acetylacetonates;<sup>12</sup> however, the complex theoretical background involved in analyzing these stretching frequencies,  $\nu_{\text{CO}}$  being intricately linked to the spin-state of the metal center and the amount of  $\sigma$  and  $\pi$  character in the metal–ligand bond, precluded unambiguous characterization of  $\nu_{\text{CO}}$  and  $\nu_{\text{CC}}$  ([Figure 2](#)).

Further to this, in our hands, the IR data (recorded on a Shimadzu Spirit IR spectrometer, using a diamond ATR attachment and analyzed using the software supplied with the spectrometer) did not match literature values ([Table 1](#)) nor did it produce an interpretable pattern that linked  $\nu_{\text{CO}}$  to the metal. Therefore, in contrast to previous work where students did not carry out their own mass spectrometry, it was proposed that MS would provide more robust characterization.<sup>12,31</sup> Although MS is less commonly used, it has been employed in teaching laboratories for analytical purposes with a view to its use in a research setting.<sup>32,33</sup>

Despite the fact that the theory of mass spectrometry is covered at pre-university level in the UK, it is an unfamiliar technique to most students in a practical setting. As a way to introduce students to the logical process of analyzing any mass spectrometric data, they were tasked with creating a spreadsheet to calculate the masses of possible species they might observe in their spectra (i.e., molecular ion, solvated molecular ion, fragmented and solvated fragmented ions). This had the added benefit of also improving upon existing skills with *Microsoft Excel*, something which we are keen to promote within a laboratory environment (see [Supporting Information](#)).<sup>34</sup> These skills included the construction of simple formulas and the use of relative and absolute cell references. Despite the mass spectrometric conditions employed (see [Table S1](#) in MS data Supporting Information), fragmentation was observed for certain tris(acetylacetonato)metal complexes, but solvent adducts were only seen in the minority of cases.

In this work, a dilute sample of the desired transition metal acetylacetonate was prepared in an organic solvent (acetone or MeOH,  $\sim 1$  mg/mL). The sample was introduced to the mass spectrometer via the closed tip of a glass capillary tube which



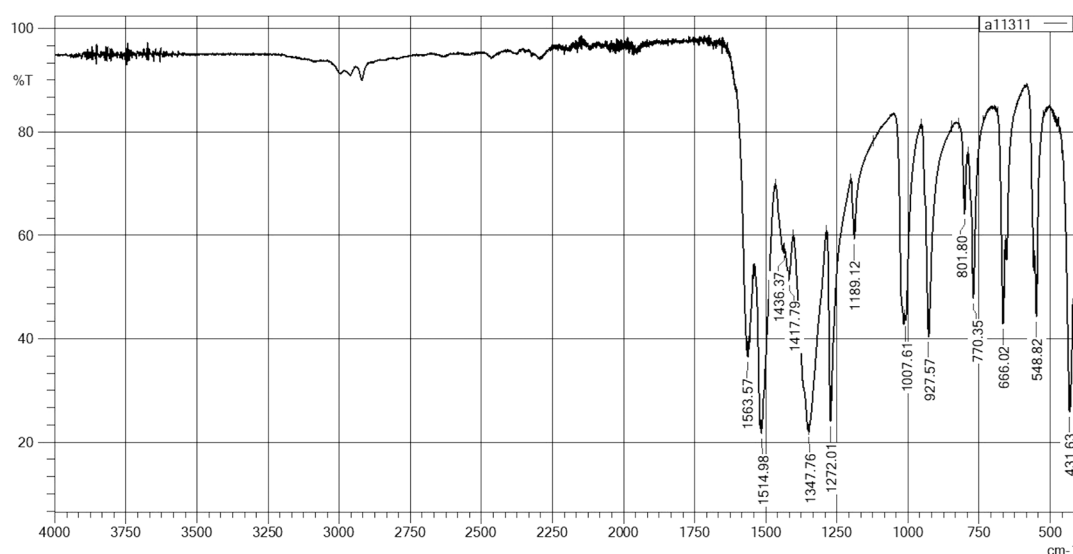


Figure 2. Example IR spectrum of  $\text{Fe}(\text{acac})_3$  displaying the lack of a clear, unambiguous, carbonyl stretch.

Table 1. Mass Spectrometric and IR Data for 10 Pure Samples of Transition Metal Acetylacetonates

entry	complex <sup>c</sup>	mass expected <sup>a</sup>	mass found	ion <sup>b</sup>	$\nu$ found	$\nu_{\text{CO}}$ lit. <sup>12</sup>
1	$\text{Co}(\text{acac})_2$	258.0	257.9	$[\text{}^{59}\text{Co}(\text{acac})_2 + \text{H}]^+$	1575, 1511	1601
2	$\text{Ni}(\text{acac})_2$	257.0	257.0	$[\text{}^{58}\text{Ni}(\text{acac})_2 + \text{H}]^+$	1582, 1511	1598
3	$\text{Cu}(\text{acac})_2$	262.0	261.9	$[\text{}^{63}\text{Cu}(\text{acac})_2 + \text{H}]^+$	1575, 1519	1554
4	$\text{Zn}(\text{acac})_2$	263.0	262.9	$[\text{}^{64}\text{Zn}(\text{acac})_2 + \text{H}]^+$	1589, 1505	1592
5	$\text{V}(\text{acac})_3$	349.1	349.0	$[\text{}^{51}\text{V}(\text{acac})_3 + \text{H}]^+$	1558, 1515	
6	$\text{Cr}(\text{acac})_3$	350.1	350.0	$[\text{}^{52}\text{Cr}(\text{acac})_3 + \text{H}]^+$	1564, 1512	1524
7	$\text{Mn}(\text{acac})_3$	253.0	252.9	$[\text{}^{55}\text{Mn}(\text{acac})_2]^+$	1564, 1505	1590
8	$\text{Fe}(\text{acac})_3$	254.0	254.0	$[\text{}^{56}\text{Fe}(\text{acac})_2]^+$	1564, 1515	1526
9	$\text{Co}(\text{acac})_3$	257.0	256.9	$[\text{}^{59}\text{Co}(\text{acac})_2]^+$	1566, 1512	1580
10	$\text{V}(\text{O})(\text{acac})_2$	266.0	265.9	$[\text{}^{51}\text{V}(\text{O})(\text{acac})_2 + \text{H}]^+$	1515	1541

<sup>a</sup>Mass for most naturally abundant isotope shown. <sup>b</sup>Positive ionization allowed more reliable characterization of the ion peaks than negative ionization. <sup>c</sup>Data for commercially available Co and Ni compounds are included for completeness.

was dipped into the solution and then pushed into the stream of nitrogen through an opening in the probe (see video clip in [Supporting Information](#)). The 0.1 Da resolution spectra produced provide a good qualitative analysis of the contents of a sample. This process requires little experience to carry out and allows first-year undergraduates an opportunity to explore how mass spectrometry works in practice, with sample introduction, vaporization, and ionization processes all clearly recognizable within the experiment.

$\text{M}(\text{acac})_2$  complexes did not significantly fragment, but interestingly,  $\text{M}(\text{acac})_3$  behavior was more complex. Fragmentation of  $\text{M}(\text{acac})_3$  becomes more favorable along the third period, with  $\text{V}(\text{acac})_3$  and  $\text{Cr}(\text{acac})_3$  displaying no fragmentation, whereas Mn, Fe, and Co were all present in the mass spectra as  $\text{M}(\text{acac})_2^+$ . We suggest the effect of increasing effective nuclear charge ( $Z_{\text{eff}}$ ), coupled with steric and electronic interactions between ligands in the octahedral field, gives rise to this phenomenon.

In general, students were able to identify the relevant peaks and the importance of relative isotopic abundance. Use of ChemDraw, further improving the students' use of this important software package, showed the contribution of  $^{13}\text{C}$ , alongside the metal isotopes, to the peaks and allowed prediction of the relative isotopic ratios; comparison to the empirical evidence was discussed with students (Table 2).

Table 2. Example Comparison between Theoretical and Observed % Relative Abundance Showing Good Correlation

ion	theoretical		observed	
	mass	% relative abundance	mass	% relative abundance
$\text{Fe}(\text{acac})_2^+$	252.0	6.4%	252.0	7.1%
	254.0	100.0%	254.0	100.0%
	255.0	10.8%	255.0	12.8%
	256.0	1.9%	256.0	3.3%
$[\text{Cu}(\text{acac})_2 + \text{H}]^+$	262.0	100.0%	261.9	100.0%
	263.0	11.1%	263.0	11.4%
	264.0	46.0%	263.9	50.7%
	265.0	4.8%	265.0	5.5%

After initial instruction, students were both sufficiently confident and competent to carry out analyses unsupervised; the importance of sample dilution was well understood, and in general, undergraduates were able to discuss the mass spectra obtained to a high level with some prompting needed when fragmentation peaks were observed (Figure 3).

All mass spectra were recorded on an Advion Expression<sup>L</sup> compact mass spectrometer (CMS), fitted with an APCI ionization source and an ASAP probe for sample introduction. Spectra were analyzed and processed using the software supplied with the spectrometer (Figure 4).

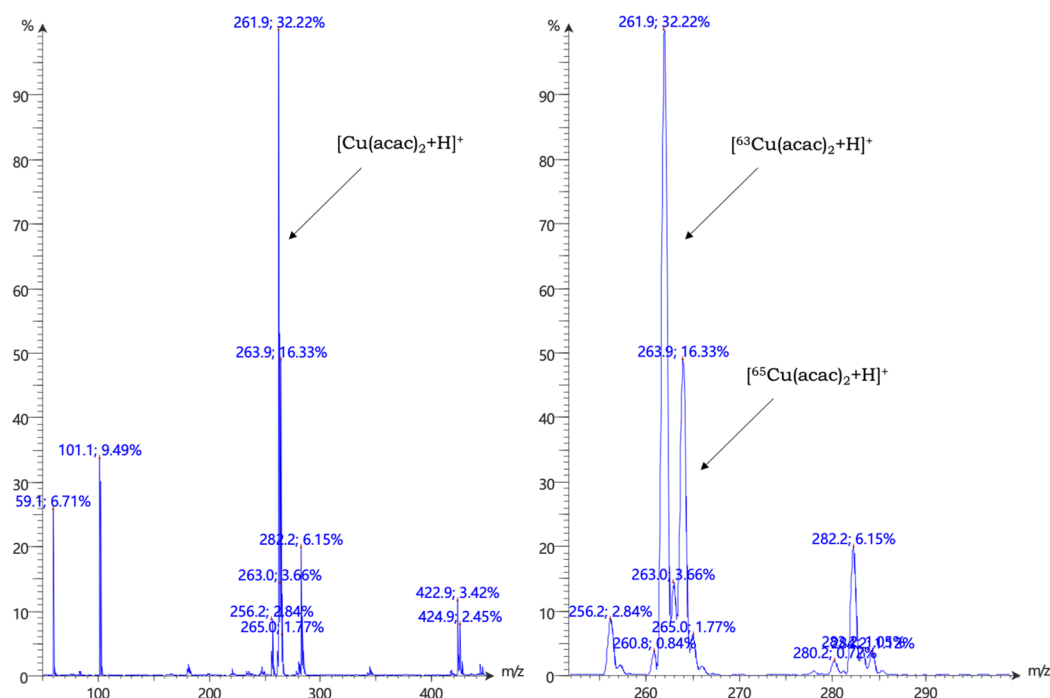


Figure 3. Example mass spectrum of  $\text{Cu}(\text{acac})_2$  from conventional salt metathesis displaying two major isotope peaks.

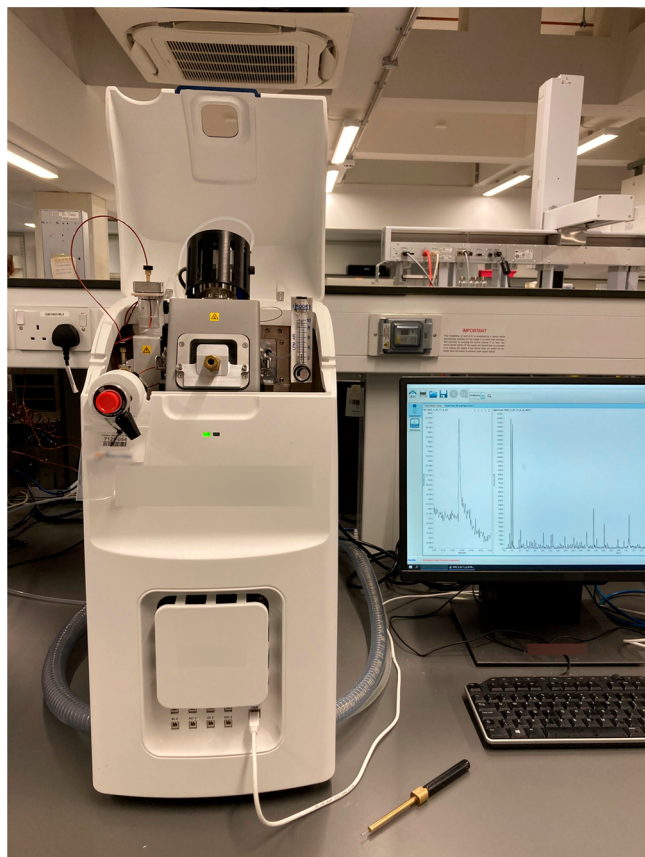


Figure 4. Image of the APCI-MS system with solids probe attachment.

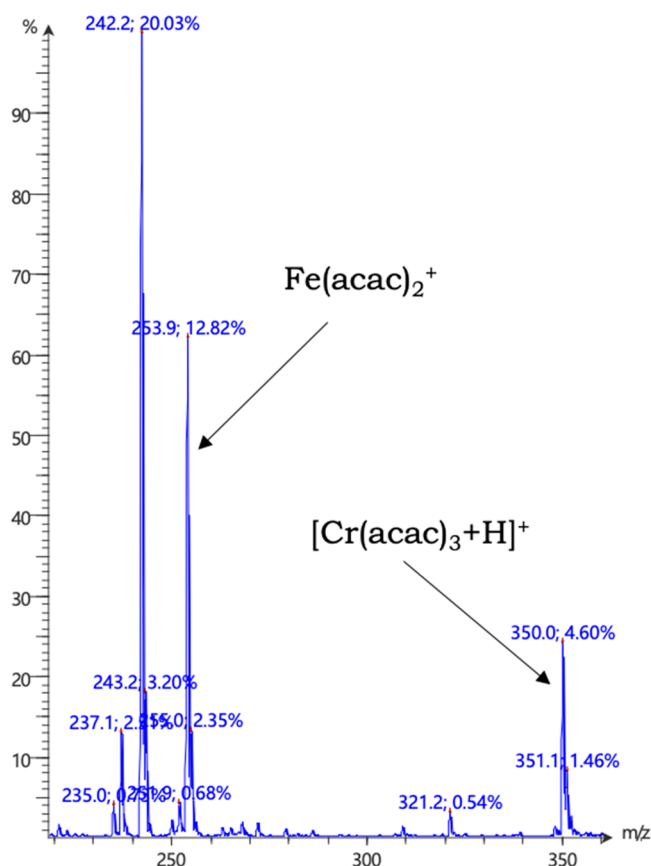
### Mass Spectrometric Analysis of Coins

With a thorough understanding of the formation of metal acetylacetonate complexes under conventional and electrochemical conditions, groups of up to 12 students, working in

pairs, were set the task of identifying the metal constitution/composition of a coin. A collection of  $\sim 100$  assorted coins from around the world was provided (previously purchased *via* ebay.co.uk). Once pairs had designed their experiment and analysis, they presented their ideas to an experienced graduate teaching assistant (GTA). If at any time a GTA was unsure about a student-generated plan, experienced staff members were always present for consultation. All students rapidly realized that conventional synthesis would be unsuitable, due to the metallic nature (rather than the salt-form) of the materials in the coins. By comparison to the previous day's work, they also realized that submission of the coins to electrosynthetic conditions would ultimately allow observation of any  $\text{M}(\text{acac})_x$  complexes formed by MS.

A common misunderstanding was the assertion that each electrode had to be the same type of coin (e.g., two 50 lira coins, both made in 1959, should form both the anode and cathode). Reference back to the expository electrochemical synthesis section, and discussions about current flow and anodic oxidation with a GTA, overcame this misconception and certainly aided in the students' overall understanding of electrolytic/electrosynthetic cells. Students were then free to choose the nature of the cathode—a coin, a strip of metal, or a graphite rod.

After successfully running the reaction, the samples were submitted to mass spectrometric analysis using the same conditions as before. As with the  $\text{M}(\text{acac})_x$  samples prepared from the pure metal electrodes, comparison with a spreadsheet of possible masses allowed identification of the metal species found within the coins. Commonly observed were  $\text{Fe}(\text{acac})_3$  and  $\text{Cu}(\text{acac})_2$ , while  $\text{Cr}(\text{acac})_3$  and  $\text{Zn}(\text{acac})_2$  were also found. In general, students were competent at analysis of the mass spectra at this stage (Figure 5); however, answers also included complexes such as "lithium acetylacetonate," which arose from incorrectly assigning the peaks to masses from the spreadsheet instead of appreciating the possibility of impurities or fragmentation. Students were encouraged to perform an



**Figure 5.** Example mass spectrum of a coin (50 lire, 1959) showing the presence of Fe and Cr.

Internet search in order to compare their experimental results to known compositions. In the case of a 1959 Italian 50 lire coin, the experimental data showed the presence of iron and chromium, indicative of its known composition (acmonital—a type of stainless steel containing mostly iron, up to 19% chromium, and other trace elements).<sup>35</sup>

A noteworthy comment on the conditions employed in the practical is that  $\text{Ni}(\text{acac})_2$  is generally not obtained under these conditions, an observation that has previously been reported.<sup>12</sup> Given the safety concerns surrounding  $\text{Ni}(\text{acac})_2$ , this was considered a significant benefit for our purposes. Although this limits the elucidation of Ni within coins, it presents an opportunity for discussion about experimental limitations in research in general, an invaluable concept for students who wish to pursue a career in research chemistry. Despite not being in the scope of this work, it is possible to isolate the “missing”  $\text{Ni}(\text{acac})_2$  complex through electrochemical synthesis in neat acetylacetone with a 300 V potential difference<sup>19</sup> or in an EtOH/acetylacetone mixture at a constant 0.2 A current.<sup>35</sup>

### Hazards

All chemicals used in this exercise are suitable for use in an undergraduate laboratory as long as a full risk assessment is carried out under local rules (e.g., Control of Substances Hazardous to Health (COSHH) in the U.K.). The use of relatively high voltages (up to 120 V) can be dangerous, and students should be made aware of this before undertaking the practical (see Notes for Instructors in the [Supporting Information](#)).

## CONCLUSION

Transition metal acetylacetonate compounds have proved to be a useful tool for the teaching of inorganic complex synthesis via conventional salt metathesis and electrosynthetic techniques allowing comparison of the two methods in terms of practicality, reaction outcome, and sustainability.

Anecdotally, students carried out salt metathesis with relative ease due to prior practicals focusing on conventional synthetic techniques; however, recrystallization was often completed with limited success leading to low yields. Electrochemical synthesis of  $\text{Fe}(\text{acac})_3$ ,  $\text{Cu}(\text{acac})_2$ , and  $\text{Zn}(\text{acac})_2$  proved easily accessible for first-year undergraduate students, and guided discussion about current flow and yield furthered understanding of Faraday's laws.

Introduction to mass spectrometry as an important and accessible analytical technique was successful through the use of the ASAP-MS system, allowing students to gain hands-on experience in this area. In general, first-year undergraduates became competent in the analysis of mass spectra through the use of a previously generated spreadsheet although fragmentation patterns and impurities commonly led to misassigned peaks; repeated use of MS for characterization should further improve students' analytical skills.

Through utilizing hands-on MS as the analytical tool, this enabled experimental design to be introduced readily at the earlier stage of students' university education, allowing students to experience “real-world” chemistry through a small research project and further extending their knowledge of analytical techniques. Students were quickly able to discern the link between probing the metal composition of coins and the electrochemical synthesis investigated earlier in the practical, successfully comprehending that salt metathesis would be unsuitable for this application. Mass spectrometric skills were further improved, and undergraduates were able to identify possible metals in the coins that were tested.

## ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available at <https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00266>.

Notes for instructors edited ([PDF](#), [DOCX](#))

Scaffolded spreadsheet—APCI Mass Spectrometry ([XLSX](#))

MS data edited ([PDF](#), [DOCX](#))

$\text{Cu}(\text{acac})_2$  MS analysis ([MOV](#))

Metal chelates—Intro Talk edited ([PDF](#))

## AUTHOR INFORMATION

### Corresponding Author

Andrew F. Worrall — Chemistry Teaching Laboratory, Oxford, United Kingdom OX1 3PS; [orcid.org/0000-0002-2875-6905](https://orcid.org/0000-0002-2875-6905); Email: [andrew.worrall@chem.ox.ac.uk](mailto:andrew.worrall@chem.ox.ac.uk)

### Authors

Jonathan G. Moloney — Chemistry Teaching Laboratory, Oxford, United Kingdom OX1 3PS; [orcid.org/0000-0001-9843-5827](https://orcid.org/0000-0001-9843-5827)

Craig D. Campbell — Chemistry Teaching Laboratory, Oxford, United Kingdom OX1 3PS; [orcid.org/0000-0002-1082-3508](https://orcid.org/0000-0002-1082-3508)



Malcolm I. Stewart – Chemistry Teaching Laboratory,  
Oxford, United Kingdom OX1 3PS; [orcid.org/0000-0002-5724-9160](https://orcid.org/0000-0002-5724-9160)

Complete contact information is available at:

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## Notes

The authors declare no competing financial interest.

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