Designing Undergraduate Chemistry Experiments to Address Public Concerns: Exploring the Properties of Expired and Expiring Ibuprofen

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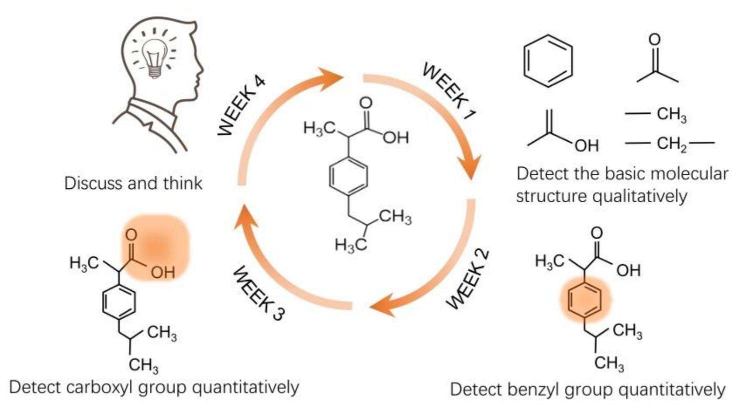
Abstract

The outbreak of the COVID-19 pandemic has led to the irrational hoarding of medicine, resulting in public confusion over the safety of expired medicine in the post-pandemic era. This paper aims to stimulate the interest of chemistry students through an undergraduate teaching experiment and employs the knowledge acquired to address societal concerns. It centers on ibuprofen, a typical antipyretic medication. We employed a range of analytical methods to qualitatively and quantitatively analyze the changes after medicine expires. The experiment is designed to evoke theoretical knowledge such as analytical chemistry, pharmaceutical chemistry, and spectral analysis acquired by undergraduate students with a chemistry major background and demonstrates how to apply these professional skills to solve realistic problems. First, we utilized Infrared Absorption Spectrometry (IR) to detect the fundamental structure of ibuprofen. Based on the obtained Infrared Spectra, we confirmed that the basic structures of ibuprofen remained intact both before and after expiration. However, IR could only facilitate qualitative analysis and did not provide information on content changes. Therefore, we also employed Ultraviolet-Visible Absorption Spectrometry (UV/Vis) and Acid-Base Titration to quantitatively analyze the benzyl and carboxyl groups in ibuprofen molecules. And uncovered the molecular-level changes that occur during medicine expiration. The structure of ibuprofen post-expiration remained, but the content of benzyl and carboxylic groups decreased, with the reduction becoming more pronounced as expiration time increased. This experimental teaching attempt provides an example of exploring the chemical properties of substances related to public health, which fits into analytical chemistry experimental courses.

Graphical Abstract



Explore the structural changes after expiration

Keywords: undergraduate students, medicine expiration, hands-on learning/ experimental teaching, analytical chemistry experiment, qualitative and quantitative analysis

1. Introduction

The continuous introduction of new medicine to the market and advancements in the medical field have led to an increase in medicine usage, inevitably leading to a large amount of medicine waste, including an increase in expired medicines (Faez A, 2020; Martion M, 2022). Additionally, the outbreak of the epidemic has quietly led to irrational hoarding of "medicine." This issue becomes particularly prominent during the COVID-19 epidemic, leaving sick people to have no access to medicine, while unused medicines are piling up in the homes of healthy individuals (Callaway K, 2021). As the COVID-19 epidemic recedes, medicine such as ibuprofen, paracetamol, and COVID-19 test kits, which were once in high demand and purchased at inflated prices have mostly lost their value (Jie H, 2022; Beatriz L. Beatriz L, 2023). After a surge of medicine hoarding, the rational purchase and use of medicine have become issues worthy of consideration and discussion. According to a survey, 81.98% of residents have the habit of storing medicine; 86.49% of residents pay attention to the expiry date when purchasing medicine, and 66.67% of residents dispose of expired medicine by putting it in the garbage (Liang Y.-S, 2019; Milica K P,2016; Bashatah A,2020; Zainabath M, 2022).

The expiry date of a medicine is defined as the period during which the medicine can maintain its quality under specified storage conditions. When the medicine has passed its expiry date, its effectiveness and safety cannot be guaranteed. However, the scientific rationale behind this caution is often overlooked (Sushil S, 2022). Misuse of expired medicine will lead to economic losses for the government, the medical system, and individual patients. It will have a serious impact on everyone's safety, and disposing of expired medicine will also cause irreversible damage to the environment. Furthermore, expired medicine may be repackaged and sold by illegal operators to deceive consumers and disrupt the order of the medicine market (Gehendra M, 2021; Bound Jonathan P, 2005; Sally G, 2016; Dipanshu V, 2022).

At present, many researchers use a variety of analytical methods to detect medicine. Wen et al (Zou W, 2018) review an overview of rapid detection technologies, such as Near Infrared Spectroscopy, Near Infrared Chemical Imaging, Raman Spectroscopy, X-Ray Fluorescence, X-Ray Powder Diffraction, Ion Mobility Spectrometry, Ion MobilityMass Spectrometry, Isotope Ratio Mass Spectrometry and visual analytical methods. Liu et al (Guijun Liu, 2021) developed high-performance liquid chromatography method coupled with charged aerosol detection (CAD) for the quantification of related substance of leucomycin (kitasamycin) bulk medicine and tablets. K. Basavaiah et al (K. Basavaiah, 2018) determined anticancer medicine by acid-base titration and spectrophotometry, respectively. However, there are few researches on the qualitative and quantitative detection of expired medicine. With the continuous introduction of new medicine and advances in the medical field leading to an increase in the use of medicine, expired medicine is also increasing, so it is necessary to explore the changes that occur after the expiration of medicine. Therefore, undergraduate chemistry students can apply their expertise in analytical chemistry to explore the scientific basis behind it by consulting a large number of resources, engaging in active discussion, exploration, and designing scientific experimental plans. We collected expired and unexpired medicines around the campus. The amount of expired medicine collected surpassed our expectations. Most of them were fever-reducing medications that people hastily purchased during the COVID-19 pandemic. Consequently, we selected ibuprofen capsules, a representative medicine, as our research subject. We employed fundamental analytical chemistry methods to analyze and compare the chemical structures and contents of the medicine components within the capsules. Under the guidance of teachers, students conducted standardized experiments, analyzed the experimental results, compared the differences between various analytical methods, explained the changes in expired medicine from multiple perspectives, and reinforced their theoretical knowledge. This serves as a suitable practice for undergraduate chemistry students within an analytical chemistry experiment course. Additionally, this experiment can inspire students to identify problems in life and apply their knowledge to solve them. Finally, by disseminating the research findings through lectures, leaflets, and other means, we aim to provide feedback to the public and instill in students the significance of conducting experimental research (Garcia J R, 2023; A. M. R. P. Bopegedera, 2021; Wenzel G A, 2019).

In this study, we utilized a variety of fundamental analytical chemistry methods to investigate the changes in ibuprofen after expiration. Our objectives were to arouse students' interest, reinforce the theoretical knowledge they had acquired, guide them to identify problems in daily life, and solve these problems using their acquired knowledge. We tend to provide new ideas for designing analytical chemistry experimental courses that can generate more interest and promote education outcomes (Homar B, 2016; Sarah L B, 2020). The experimental content not only addresses real-life issues but also complements the undergraduate theoretical courses Analytical Chemistry and Spectral Analysis to ensure its educational impact. This experiment was carried out by undergraduate chemistry students. The experiment was divided into four parts, with each part taking no more than 2 hours. Before the experiment, the students conducted a questionnaire survey on the awareness of expired medicine around the campus to understand the public's doubts. In addition, the students gained a comprehensive understanding of the experimental principle and content through literature searching, reading books, and reviewing handouts. At the start of the experiment, the teacher checked the students' preview outcomes and enhance it through explanation and questions. Then, Infrared Absorption Spectrometer experiments were carried out to qualitatively detect the basic structure of expired ibuprofen medicine, this method could only give structural information and couldn't determine the content. Therefore, Ultraviolet-Visible Absorption Spectrometer were carried out to quantitatively detect the change of benzyl content, and Acid-Base Titration experiments to quantitatively detect the change of carboxyl content. Infrared Absorption Spectrometer and Ultraviolet-Visible Absorption Spectrometer experiments were conducted in groups of two students, and Acid-Base Titration experiments were carried out individually. Throughout the experiment, students will adhere to standardized procedures, wear personal protective equipment, and promptly record experimental results. In the UV-Vis experiment, we will use n-hexane as the solvent. Therefore, the configuration of the solution will be conducted in the fume hood. After the experiment, the students analyzed and summarized the experimental results, elucidating the changes in ibuprofen after expiration using various methods. They consolidated their theoretical knowledge, summarized the differences between different analysis methods, and developed a mindset of approaching the same problems from diverse angles.

2. Method

The experimental methods were derived from the contents of the 2020 edition of the Chinese Pharmacopoeia and other relevant studies, and we combined the methods for the analysis of the active ingredients in ibuprofen medicine (Wang X, 2020; Sunayana M, 2021). Detailed instructions for students and teacher are provided as Student Handouts and Instructor Notes, respectively in the Supporting Information. Students will receive a reading handout one week in advance.

2.1 Materials

Ibuprofen medicine (Fenbid, Company: Zhongmei SmithKline) (the expiration time of ibuprofen is shown in Figure 1, L_{24} means there are 24 months before the expiration date); Sodium hydroxide (analytically pure); Sodium bromide (analytically pure, dry); Anhydrous ethanol (analytically pure); N-hexane (analytically pure); Phenolphthalein (analytically pure).

(Ibuprofen was stored in strict accordance with the instructions, and all of the medicine used in the experiments come from the same manufacturer.)

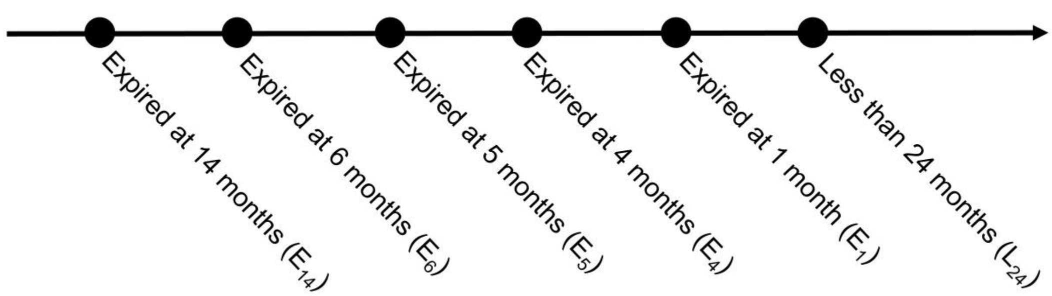


Figure 1. Ibuprofen products with different production dates

Ultraviolet-Visible Absorption Spectrometer (UV-3600 IPLUS,220 C, SHIMADZU, Japan); Infrared Spectrometer (VERTEX 70, Bruck, Germany); vacuum tablet press; acid burette; beaker; conical bottle; mortar; quartz colorimetric dish.

2.2 Learning Outcomes

Proficient in Infrared Absorption Spectroscopy, Ultraviolet-Visible Absorption Spectroscopy, Acid-Base Titration principle and operation.

Learn the structure, principle, and use of Infrared Spectrometer (IR) and Ultraviolet-Visible Absorption Spectrometer (UV/Vis).

Students learn to use OMNIC software to create Infrared Absorption Spectra and use software to create Ultraviolet-Visible Absorption Spectra and external curves, such as Origin and Excel software.

Qualitative and quantitative analysis of expired ibuprofen medicine to explore the changes of expired ibuprofen.

Compare the advantages and disadvantages of different analytical methods and the applicable conditions. Inspire students to observe and find problems in life, use the knowledge they learned to solve problems and disseminate scientific results.

The students' learning outcomes were evaluated through the laboratory report entitled "Qualitative and quantitative detection of ibuprofen by Analytical Chemistry". The laboratory reports provided are graded according to the grading rules in the Instructor Notes (Supporting Information).

Before the Experiment

Before the experiment, the students learned about local people's cognition of expired medicine through questionnaires and interviews and fully understood the background about expired medicine and the significance of the experiment. In addition, students gain a comprehensive understanding of the principles and content of the experiment by reviewing literature, reading books, and Student Handout.

2.3 Week 1: Determining the Molecular Structure of Expired Medicine Qualitatively by IR

In this experiment, transparent pellets were prepared by KBr method, and then IR Absorption Spectra were measured by scanning IR Spectrometer (VERTEX 70, Bruck, Germany) within the 400-4000 cm^{-1} range. The functional groups of each absorption band and their corresponding vibration types were analyzed, and the molecular structures in expired medicine were qualitatively determined. Students were free to work in pairs but were also allowed to work alone if sufficient laboratory equipment was available (Matkovic S R, 2005).

2.4 Week 2: Determining the Change of Benzyl Content in Expired Medicine Quantitatively by UV/Vis

IR experiment could only provide molecular information of expired medicine qualitatively, but couldn't give the changes of structural content quantitative. So, in this experiment, the change of benzyl content after medicine expiration was quantitatively determined by the UV/Vis method. The students worked in pairs to carry out the experimental operation. First, they prepared a 0.6 mg/mL ibuprofen n-hexane solution with different production dates using the samples ground last week (fume hood operation). This solution was then scanned using a UV-Vis Spectrophotometer (UV-3600 IPLUS,220 C, SHIMADZU Company, Japan) in the range of 200-350 nm. The presence of the benzyl group in ibuprofen medicine inside and outside the expiry date was determined based on the band location and Lambert-Beer's law. Finally, the external standard method was used to determine the actual benzyl content in ibuprofen at different production dates and to determine the change of benzyl content after expiration (Ji B Y, 2017; Zhou Z, 2012; Kovarik L M, 2020).

2.5 Week 3: Determining the Change of Carboxyl Content in Expired Medicine Quantitatively by Acid-Base Titration

In this experiment, students used Acid-Base Titration to further quantitatively determine the change of carboxyl group content in ibuprofen medicine after expiration. Using phenolphthalein as an indicator, and titrating ibuprofen solutions in and out of expiry date with NaOH solutions. The reaction equation is shown in Figure 2. This is a simple and easy-to-perform experimental method. In this experiment, students work alone (Hongyang Z, 2012; Lukas G, 2021; Bhukdee D, 2020).

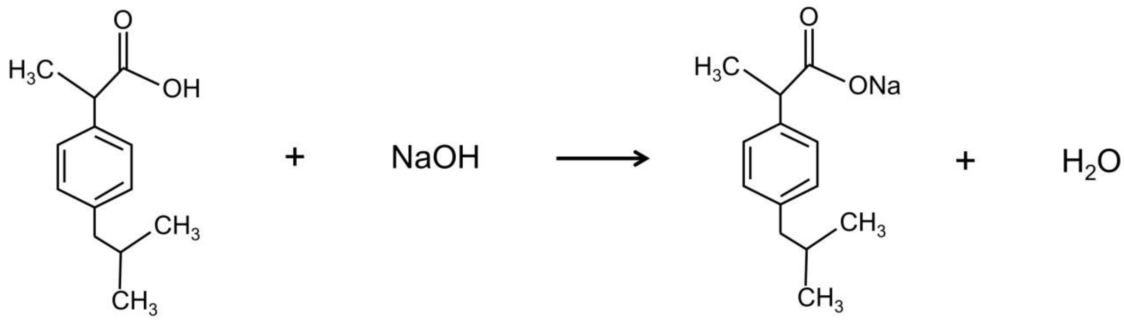


Figure 2. Ibuprofen and sodium hydroxide reaction equation

2.6 Week 4: Discussing and Considering the Experimental Results

During a discussion, students analyzed the difference in medicine between before and after expiration based on data processing results. They concluded that the characteristic absorption bands at 3400-2800 cm^{-1}, 1717 cm^{-1}, and 934 cm^{-1} in the IR Absorption Spectrum, as well as the absorption bands at 263 nm in the UV-Vis Absorption Spectrum. These results indicated that there were benzyl, carboxyl, carbonyl, methyl, and methylene structures in expired ibuprofen. UV-Vis and Acid-Base Titration experiments showed that the content of benzyl and carboxyl groups in ibuprofen decreased gradually with the increase of expiration time.

According to the experimental results, it was observed that the Acid-Base Titration method generally yielded higher values than the UV/Vis experiment. We prompted the students to contemplate the reasons behind this discrepancy and compared the distinctions among various analytical methods, including their adaptability conditions. Additionally, we guided the students to consider alternative analytical methods that could potentially detect structural changes in expired ibuprofen medications. Ultimately, we led the students to select the most suitable analytical method based on the sample being measured, emphasizing that when confronted with a similar problem, different analysis methods can be employed to gather information from diverse perspectives.

2.7 After the Experiment

Gain an understanding of changes in the structure of medicine after expiration.

Compare the advantages and disadvantages of different analytical methods, and flexibly choose analytical methods when facing different detection objects.

Arouse students' interest, find problems from life, use the knowledge to solve problems, and finally let students experience the significance of experiments through activities such as science popularization.

This experiment concludes that the structure of expired medicine will change, but the structure can't be determined, so the safety of expired medicine needs to be further discussed. This experiment provides a way to explore the composition of expired medicine in the future.

3. Hazards

There is almost no risk in the process of the experiment, and most of the chemical reagents used are safe, environmentally friendly, and non-toxic. Sodium hydroxide is highly corrosive and requires the use of gloves and goggles throughout the entire process, but the concentration of the sodium hydroxide solution used during titration is 0.10 mol/L, which is low in concentration and poses little harm. We also used n-hexane during the experiment, and the preparation of the solution was carried out in the fume hood while wearing goggles and gloves.

4. Results

We use the experimental data of a group of students as an example to present the results and discussion. Each group of students follows laboratory safety regulations strictly, which can prevent danger during the experiment. Besides, the students have completed the preview before the experiment, they carry out the operation according to the experiment steps. And the teachers will give appropriate guidance to the students when they need it.

4.1 Qualitative Analysis by IR

According to the experimental results, we found that the positions of absorption bands in the Infrared Absorption Spectra of ibuprofen medicine with different production dates were essentially identical. The Infrared Spectra and Raw IR test data of ibuprofen medicine with different production dates as shown in Supporting Information. Now we take the Infrared Spectra of L_{24} medicine as an example for analysis, as shown in Figure 3. The wide peaks above 3000 cm^{-1} represented carboxyl peaks, 2800-3000 cm^{-1} represented methyl and methylene stretching vibration peaks, and 1700 cm^{-1} indicated carbonyl stretching vibration bands. Additionally, 1600, 1500, and 1450 cm^{-1} were associated with the benzene ring. we could confirm that the basic structures of ibuprofen before and after expiration still existed.

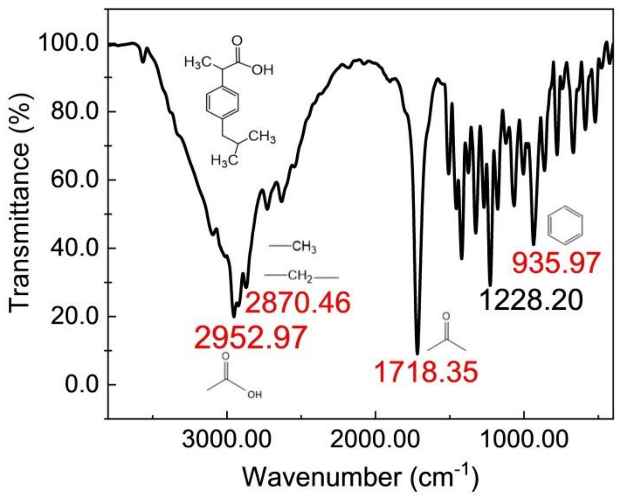


Figure 3. Infrared Absorption Spectra of L_{24} ibuprofen medicine

4.2 Qualitative and Quantitative Analysis by UV-Vis

Figure 4 a showed that UV-Vis Absorption Spectra of ibuprofen medicine with different production dates had similar absorption band positions within the 200-350 nm range, indicating that they all contain benzyl group. (UV-Vis external curve raw data and UV-Vis test raw data are shown in Supporting Information)

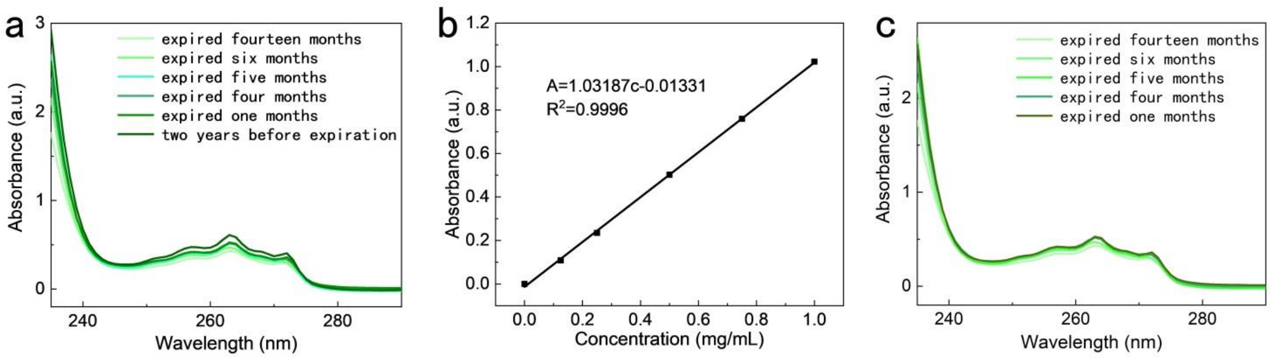


Figure 4 (a). UV-Vis Absorption Spectra of ibuprofen medicine (active ingredient: 0.4 g) (E_{14}, E_5, E_4, E_1, L_{24}); (b). external calibration; (c). UV-Vis Absorption Spectra of ibuprofen medicine (E_{14}, E_5, E_4, E_1) (The absorption curves of each solution were measured in parallel for three times, and finally averaged)

The external calibration formula was A=1.03187c-0.01331, with an R^2 value of 0.9996, indicating a good linear fitting that met the requirements of the external curve method (as shown in Figure 4 b).

By substituting the experimental data (as shown in Figure 4 c and Table 1) into the external calibration equation, the actual ibuprofen concentration of the E_{14} sample can be obtained.

$$0.4327=1.03187c-0.01331$$

$$c_1= (0.4327+0.01331)/1.03187=0.4322 \text{ mg/mL}$$

Actual active component content of E_{14} sample:

$$m_1 =c_1V_1=0.4322\times10=4.322 \text{ mg}$$

Similarly, it could be concluded that the actual ibuprofen mass of E_6, E_5, E_4, E_1, L_{24} medicine. were 4.704 mg, 5.146 mg, 5.107 mg, 5.249 mg, 6.053 mg respectively.

The variance reflects the deviation of a set of data from the mean value. The larger the variance of the feature, the greater the overall fluctuation of a set of data. Conversely, the smaller the variance, the smaller the fluctuation in the data. The standard deviation is a measure of the extent to which a set of values is dispersed from the mean. A large standard deviation represents a large difference between most of the values and their mean.

$$S\char`^2 = \frac{\sum_{i=1}^{n}(xi-x)\char`^2}{n} \quad (1)$$

$$S_1^2= [(4.308-4.327)^2 + (4.329-4.327)^2 + (4.344-4.327)^2]/3=0.000218$$

The same can be obtained: S_2^2=0.0000380; S_3^2=0.0000806; S_4^2=0.0000577; S_5^2=0.000142; S_6^2=0.0000430.

$$\sigma = \sqrt{S\char`^2} \quad (2)$$

$$\sigma_1=\sqrt{S1\char`^2}=\sqrt{0.000218}=0.0148 \quad (3)$$

The same can be obtained: σ_2=0.00616; σ_3=0.00898; σ_4=0.00760; σ_5=0.0119; σ_6=0.00656.

According to the experimental data, the theoretical mass of ibuprofen measured was 0.6 mg, and the actual mass of ibuprofen: E_{14}=4.322 mg, E_6=4.704 mg, E_5=5.146 mg, E_4=5.107 mg, E_1=5.249 mg, L_{24}=6.053 mg.

Through the analysis of the experimental results (as shown in Table 2 and Figure 5), we can observe that compared with the L_{24} medicine, the content of other medicine benzyl groups is reduced, and the longer the expiration time, the more the content of benzyl group is reduced.

Table 1. The absorbance of ibuprofen medicine measured at λ=263 nm (Weighing mass:6.0 mg)

	E_{14} (a.u.)	E_6 (a.u.)	E_5 (a.u.)	E_4 (a.u.)	E_1 (a.u.)	L_{24} (a.u.)
1	0.4308	0.4713	0.5166	0.5145	0.5268	0.6105
2	0.4329	0.4722	0.5177	0.5127	0.5285	0.6112
3	0.4344	0.4728	0.5188	0.5140	0.5297	0.6121
Average	0.4327	0.4721	0.5177	0.5137	0.5283	0.6113

Table 2. The mass of ibuprofen medicine measured at λ=263 nm (Weighing mass:6.0 mg)

	E_{14} (mg)	E_6 (mg)	E_5 (mg)	E_4 (mg)	E_1 (mg)	L_{24} (mg)
1	4.308	4.713	5.166	5.145	5.268	6.105
2	4.329	4.722	5.177	5.127	5.285	6.112
3	4.344	4.728	5.188	5.140	5.297	6.121
Average	4.327	4.721	5.177	5.137	5.283	6.113
S^2	0.000218	0.0000380	0.0000806	0.0000577	0.000142	0.0000430
σ	0.0148	0.00616	0.00898	0.00760	0.0119	0.00656
Percentage mass	72.12%	78.68%	86.28%	85.62%	88.05%	101.9%

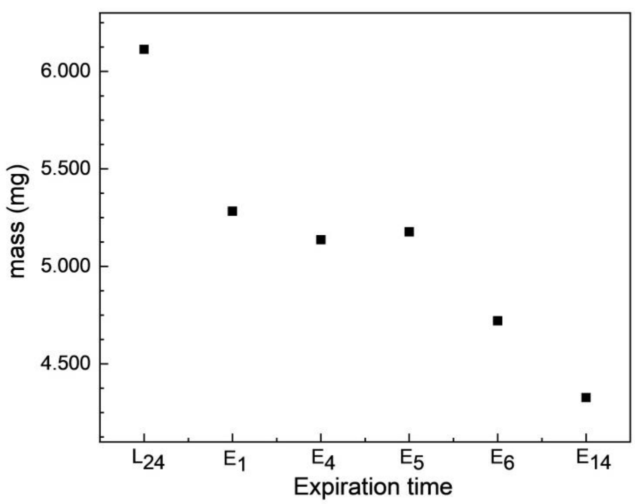


Figure 5. UV/Vis Scatter plot about mass and expiration time

4.3 Quantitative Analysis by Acid-Base Titration

According to the experimental data in Table 3, the actual ibuprofen mass of the E_{14} medicine was calculated (as shown in Table 4 and Figure 6).

$$n_1=C_{NaOH}\cdot V_{NaOH}=0.10\times19.38\times10^{-3}=1.938\times10^{-3}\ mol$$

Actual active component content of E14 sample:

$$m_1=n_1M=1.938\times10^{-3}\times206=0.399\ g$$

Similarly, it could be concluded that the actual ibuprofen mass of E_5, E_4, E_1, L_{24} medicine were 0.403 g, 0.409 g, 0.414 g, 0.415 g, 0.420 g respectively.

Variance calculation: $S_1^2=[(19.30-19.38)^2+(19.45-19.38)^2+(19.40-19.38)^2]/3=0.00390$

The same can be obtained: $S_2^2=0.0217$; $S_3^2=0.0158$; $S_4^2=0.00390$; $S_5^2=0.00890$; $S_6^2=0.00723$.

Standard deviation calculation: $\sigma_1=\sqrt{S1\char`^2}=\sqrt{0.00390}=0.0624$

The same can be obtained: $\sigma_2=0.147$; $\sigma_3=0.126$; $\sigma_4=0.0624$; $\sigma_5=0.0943$; $\sigma_6=0.0850$.

Through the analysis of the experimental results (as shown in Table 3 and Table 4), we can observe that compared with the L_{24} medicine, the effective content of other medicine carboxyl groups is reduced, and the longer the expiration time, the more the content of carboxyl group is reduced.

For the Acid-Base Titration experiment using a pill of ibuprofen, the Pharmacopoeia specifies that a capsule should contain at least 0.4 g of active ingredients. The Acid-Base Titration and UV/Vis experiments demonstrated that the content of carboxyl and benzyl groups in ibuprofen decreases with the increase in expiration time. Furthermore, when comparing the experimental results, we observed that the outcomes of the Acid-Base Titration experiment were generally higher than those of the UV/Vis experiment. Firstly, the UV/Vis experiment aims to determine the change in benzyl content in ibuprofen, whereas the Acid-Base Titration experiment focuses on the change in carboxyl content. Since these two methods target different aspects, it is possible that inverting the methods could yield differing results. Secondly, the disparity may also stem from the inherent characteristics of the methods themselves. In the Acid-Base Titration experiment, the use of phenolphthalein as an indicator and its pH transition interval of 8.2-10.0 could contribute to the higher experimental results.

Lastly, factors such as the titration rate, the judgment of the titration endpoint, and the intensity of shaking may also influence the experimental outcomes, despite our efforts to minimize human interference by ensuring that each group of titration experiments is completed by the same person.

Table 3. The amount of 0.1 mol/L NaOH solution consumed by titrating ibuprofen solution and the actual active ingredient mass ibuprofen medicine (Weighing mass:0.4 g)

	E_{14}/mL	E_6/mL	E_5/mL	E_4/mL	E_1/mL	L_{24}/mL
1	19.30	19.50	19.80	20.10	20.20	20.30
2	19.45	19.40	19.70	20.00	20.00	20.35
3	19.40	19.75	20.00	20.15	20.20	20.50
Average	19.38	19.55	19.85	20.08	20.13	20.38

Table 4. The actual active ingredient mass ibuprofen medicine (Weighing mass:0.4 g)

	E_{14}	E_6	E_5	E_4	E_1	L_{24}
mass	0.399 g	0.403 g	0.409 g	0.414 g	0.415 g	0.420 g
S^2	0.00390	0.0217	0.0158	0.00390	0.00890	0.00723
σ	0.0624	0.147	0.126	0.0624	0.0943	0.0850
Percentage mass	99.75%	100.8%	102.2%	103.5%	103.8%	105%

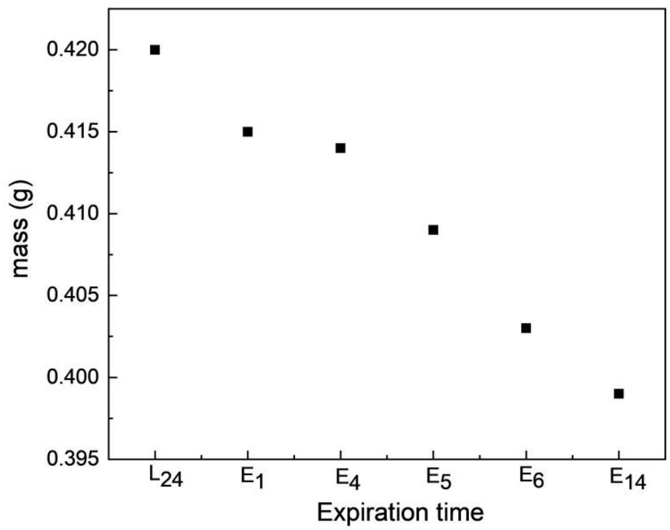


Figure 6. Acid-Base Titration Scatter plot about mass and expiration time

5. Pre-lab Report

Before the experiment, students should read the Student Handouts obtained in advance and refer to relevant literature to gain a comprehensive understanding of the entire experiment. They should cover the background, purpose, analytical principle, experimental process, applicable conditions, and other contents related to the experiment. Students are required to write a pre-lab report based on their preview, which will be used by teachers to assess the results of students' preparation.

6. Laboratory Report

After the experiment, students will compose a laboratory report, which is distinct from the pre-lab report. The laboratory report encompasses the experiment's purpose, principles, procedures, results and discussions, reflective questions, insights, and suggestions. While writing the laboratory report, students will consolidate the theoretical knowledge acquired, consider potential issues in the experimental process, and demonstrate the objective results obtained through the experiment practice, thereby fulfilling the educational objectives. The laboratory report serves as a tool to assess teaching outcomes and to assess students' achievements or deficiencies in the experiment, which will be documented in the Instructor Notes.

7. Teaching Outcomes and Feedback

Students pay attention to events, concern about public doubts, apply the knowledge to solve problems.

Students are proficient in basic analysis methods, such as Infrared Absorption Spectroscopy, UV-Visible Absorption Spectroscopy and Acid-Base Titration for qualitative and quantitative analysis of samples.

Students can compare the advantages and disadvantages of different analytical methods and choose the appropriate analytical method when solving different problems.

Students learn to use OMNIC software to draw Infrared Absorption Spectra and use software to create UV-Visible Absorption Spectra and external curve, such as Origin and Excel software.

Students can think independently. The interference factors in the experiment were analyzed and the experiment contents were optimized.

Teachers will evaluate students comprehensively according to their performance before, during and after the experiment, as well as their laboratory report and discussion presentation. grading rules are shown in Supporting Information.

8. Conclusion

In this teaching experiment design, the students used IR, UV-Vis, and Acid-Base Titration to analysis of ibuprofen medicine qualitatively and quantitatively. Based on their experimental results and analysis, the following conclusion was drawn: The IR Spectral Absorption peaks of ibuprofen were observed at 3400-2800 cm^{-1}, 1717 cm^{-1}, and 934 cm^{-1}, while the UV-Vis Absorption peak was at 263 nm, indicating that the expired ibuprofen medication still retained its basic structures. The UV-Vis experiment and Acid-Base Titration experiment revealed that the content of benzyl groups and carboxyl groups in ibuprofen gradually decreased with the increase in expiration time. However, further exploration of other methods is necessary to fully understand the transformation of ibuprofen into different chemical substances after expiration. This experiment provides a certain theoretical foundation and basis for such future investigations.

To sustain these experiments, the school infirmary and nearby pharmacies would be of great help in regularly providing expired medicine for students to test. In addition to in-class content, students are also encouraged to raise awareness about the risk of consuming expired medicine while collecting expired medicine from the neighborhood. This approach not only integrates fundamental analytical chemistry methods to create a comprehensive teaching experiment but also connects the content of undergraduate learning with public concerns, arousing the interest of the students, thereby demonstrating the significance of experimental teaching.

However, there are still many questions that need answering in the research of expired medicine, such as identifying the molecular structure of the reduced content from expired medicine, the influence of different storage conditions, the reaction mechanism, and the safety and remaining effects of expired medicine. We hope more experiments in these areas can be designed in the future.

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Authors' contributions

Zhijie Li was responsible for methodology, experiment, study design and revising. Guoxing Li was responsible for investigation, experiment, data collection and analysis. Yihan Xu was responsible for investigation and revising. Prof. Zejun Wang was responsible for supervision, guidance and suggestion. All authors read and approved the final manuscript.

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Competing interests

The authors declare no competing financial interest.

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The Publication Ethics Committee of Sciedu Press.

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The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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