"Analysis of copper alloys as an introduction to data analysis and interpretation for General Chemistry courses",
Adrian Villalta-Cerdas y Corbin McCleary
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Didáctica de la Química

ANALYSIS OF COPPER ALLOYS AS AN INTRODUCTION TO DATA ANALYSIS AND INTERPRETATION FOR GENERAL CHEMISTRY COURSES

Abstract

The work herein presents a laboratory experience designed to foster clear connections between chemistry concepts, experimental measurements, and laboratory techniques. The experience consists of three different experiments to be completed in sequence over several laboratory sessions. First the density of the samples is determined, then the specific heat capacity is measured, and finally the cooling curves are determined for the analytes. The experimental work covers fundamental concepts in chemistry (i.e., density, calorimetry, and first-order kinetics), and guides students to develop an overarching comprehension of the chemical and physical properties of the analytes. The analytes are copper alloys with other metals (i.e., Sn, Zn, and Al) with variable chemical compositions. These alloys are robust (i.e., thermally stable, durable), and allow for the collection of reproducible data under the proposed experimental design, as shown in the work herein. The discussion of student-gathered data and results supports the feasibility of the laboratory experience for its implementation in General Chemistry laboratory programs.

Keywords: density, heat capacity, calorimetry, cooling curve, Newton's law of cooling, convection heat transfer coefficient

ANÁLISIS DE ALEACIONES DE COBRE COMO INTRODUCCIÓN AL ANÁLISIS E INTERPRETACIÓN DE DATOS EN CURSOS DE QUÍMICA GENERAL

Resumen

En este trabajo se presenta una experiencia de laboratorio diseñada para cultivar conexiones claras entre conceptos de química, mediciones experimentales, y técnicas de laboratorio. La experiencia consiste en tres diferentes experimentos completados en secuencia durante varias sesiones de laboratorio. Inicialmente se determina la densidad de las muestras, luego se les mide la capacidad calórica específica, y finalmente se determina la curva de enfriamiento de los analitos. La experiencia cubre conceptos fundamentales de química (i.e., densidad, calorimetría, y cinética de primer orden), y guía a los estudiantes en el desarrollo de la comprensión holística de las propiedades químicas y físicas de los analitos. Los analitos son aleaciones de cobre con otros metales (i.e., Sn, Zn, y Al) con composiciones químicas variables. Estas aleaciones son robustas (i.e., estables térmicamente y duraderas), y permiten colectar datos reproducibles bajo el diseño experimental propuesto, como se muestra en este trabajo. La discusión de los datos y resultados experimentales de estudiantes sustentan la viabilidad de la experiencia de laboratorio para su implementación en programas de Química General.

Palabras clave: densidad, capacidad calórica, calorimetría, curvas de enfriamiento, ley de enfriamiento de Newton, coeficiente de transferencia de calor en convección

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ANALYSIS OF COPPER ALLOYS AS AN INTRODUCTION TO DATA ANALYSIS AND INTERPRETATION FOR GENERAL CHEMISTRY COURSES

Introduction

General chemistry laboratory programs are tasked with developing a better understanding of chemistry content knowledge and practical skills in experimental chemistry for college students. To achieve this task, many laboratory experiments are often compartmentalized by the week, unrelated to other experiments, and require different chemistry concepts studied via different laboratory techniques (Hart et al., 2000; Poletto et al., 2001). Thus students often fail to realize the interconnection between chemistry concepts, laboratory techniques, and the curriculum design of their learning experience (Grove and Lowery-Bretz, 2006; Viera et al., 2017).

The work presented herein presents a laboratory experience that fosters clear connections between laboratory experiments, covering fundamental concepts in chemistry (e.g., density, heat exchange, calorimetry, cooling curves) via multiple laboratory techniques. In the laboratory experience described herein, students handle the same analytes (i.e., metal alloys) over the course of two-to-three laboratory sessions. This approach provides students with time to process the collected data and generate connections amongst measurements, laboratory techniques, and chemistry concepts (Müller et al., 1998). Thus, allowing their experience to be closer to the natural learning progression of a scientist investigating the chemical and physical properties of new materials (Bello, 2000; Poletto et al., 2001). Additional advantages of the laboratory experience are:

(1) Students are introduced to various laboratory techniques.

(2) Technical skills are built and reinforced over the course of the experience.

(3) The experimental setup is simple and requires standard glassware and equipment.

(4) Analytes are reusable after the experience is completed.

(5) Data is reproducible and reliable if the experiments are performed skillfully.

In these laboratories, the data collected during one experiment is fundamental to support future analyses. Thus, the design implicitly guides students into developing an overarching comprehension of the chemical and physical properties being studied.

Background

In this work, we focused on metal alloy samples of different chemical composition. Specifically, the samples were studied via density, specific heat capacity and cooling curve. These experimental variables were analysed in reference to the chemical composition of the alloys. The expected relationships amongst the experimental variables and the chemical composition can be derived using General Chemistry content knowledge. The theoretical relationships (eq. 8, 14, and 15) were tested, by students, via experimental data collection on three binary alloy systems to support their feasibility, and consequently, to show the potential of the designed laboratory experience for its implementation in general chemistry laboratory programs.

Relationship between the density and the chemical composition of binary alloys

The expected relationship between the density of a metal alloy and its chemical composition can be postulated based on two assumptions: (1) the volume of the alloy is equal to the linear addition between the volumes of the pure metals before mixing; and (2) the alloys are made of two pure metals. Considering these assumptions then it follows:

$$d_{metal\#1} = \frac{m_{metal\#1}}{V_{metal\#1}} \qquad \text{(eq. 1)}$$

$$d_{metal\#2} = \frac{m_{metal\#2}}{V_{metal\#2}} \qquad \text{(eq. 2)}$$

$$d_{alloy} = \frac{m_{alloy}}{V_{alloy}} \qquad \text{(eq. 3)}$$

where d is density, m is mass, and V is the volume of the samples.

Based on the first assumption stated above, it follows:

$$V_{alloy} = V_{metal\#1} + V_{metal\#2} \qquad \text{(eq. 4)}$$

Combining equations 1 and 4:

$$d_{alloy} = \frac{m_{alloy}}{V_{alloy}} = \frac{m_{alloy}}{V_{metal\#1} + V_{metal\#2}} = \frac{m_{alloy}}{\left[\frac{m_{metal\#1}}{d_{metal\#1}}\right] + \left[\frac{m_{metal\#2}}{d_{metal\#2}}\right]} \qquad \text{(eq. 5)}$$

Inverting equation 5:

$$\frac{1}{d_{alloy}} = \frac{\left[\frac{m_{metal\#1}}{d_{metal\#1}}\right] + \left[\frac{m_{metal\#2}}{d_{metal\#2}}\right]}{m_{alloy}} = \left[\frac{1}{d_{metal\#1}}\right]\left[\frac{m_{metal\#1}}{m_{alloy}}\right] + \left[\frac{1}{d_{metal\#2}}\right]\left[\frac{m_{metal\#2}}{m_{alloy}}\right]$$

If %M is the percent composition of the alloy regarding metal M, then:

$$\frac{1}{d_{alloy}} = \left[\frac{1}{d_{metal\#1}}\right]\left[\frac{\%M_{metal\#1}}{100}\right] + \left[\frac{1}{d_{metal\#2}}\right]\left[\frac{\%M_{metal\#2}}{100}\right] \qquad \text{(eq. 6)}$$

Based on the second assumption stated above, it follows:

$$\%M_{metal\#1} + \%M_{metal\#2} = 100 \qquad \text{(eq. 7)}$$

Combining equations 6 and 7:

$$\frac{1}{d_{alloy}} = \left[\frac{1}{d_{metal\#1}}\right]\left[\frac{\%M_{metal\#1}}{100}\right] + \left[\frac{1}{d_{metal\#2}}\right]\left[\frac{100-\%M_{metal\#1}}{100}\right]$$

$$\frac{1}{d_{alloy}} = \left[\frac{1}{d_{metal\#1}} - \frac{1}{d_{metal\#2}}\right]\left[\frac{\%M_{metal\#1}}{100}\right] + \left[\frac{1}{d_{metal\#2}}\right] \qquad \text{(eq. 8)}$$

Equation (8) relates the density of the metal alloy to its chemical composition. The relationship is linear where the slope is equal to the difference of the inverse densities for each metal in the alloy, and the intercept equates to the inverse of the density of the second metal in the alloy.

Relationship between the specific heat capacity and the chemical composition of binary alloys

The expected relationship between heat capacity and the chemical composition of the alloy samples is derived based on two assumptions: (1) the total heat required heat up or cool down the alloy (Q_{Alloy}) is equal to the linear addition of the heat requirement for each of the pure metals within the alloy; and (2) the alloys are made of two metals.

Considering these assumptions, it follows:

$$C_{p,alloy} = \frac{Q_{alloy}}{m_{alloy} \times \Delta T} \quad \text{(eq. 9)}$$

$$C_{p,metal\#1} = \frac{Q_{metal\#1}}{m_{metal\#1} \times \Delta T} \quad \text{(eq. 10)}$$

$$C_{p,metal\#2} = \frac{Q_{metal\#2}}{m_{metal\#2} \times \Delta T} \quad \text{(eq. 11)}$$

where C_p is the specific heat capacity, Q is heat, m is the mass of the sample, and ΔT is the change in temperature of the sample (Perry and Chilton, 1973; Cengel, and Boles, 2016).

Based on the first assumption stated above, it follows:

$$Q_{alloy} = Q_{metal\#1} + Q_{metal\#2} \quad \text{(eq. 12)}$$

Combining equations 9 and 12:

$$C_{p,alloy} = \frac{Q_{alloy}}{m_{alloy} \times \Delta T} = \frac{Q_{metal\#1} + Q_{metal\#2}}{m_{alloy} \times \Delta T}$$

$$C_{p,alloy} = \frac{C_{p,metal\#1} \times m_{metal\#1} \times \Delta T + C_{p,metal\#2} \times m_{metal\#2} \times \Delta T}{m_{alloy} \times \Delta T} = \frac{C_{p,metal\#1} \times m_{metal\#1} + C_{p,metal\#2} \times m_{metal\#2}}{m_{alloy}}$$

$$C_{p,alloy} = C_{p,metal\#1} \times \frac{\%M_{metal\#1}}{100} + C_{p,metal\#2} \times \frac{\%M_{metal\#2}}{100} \quad \text{(eq. 13)}$$

The second assumption states that $\%M_{metal\#1} + \%M_{metal\#2} = 100$ (eq. 7).

Combining equations 7 and 13, it follows:

$$C_{p,alloy} = C_{p,metal\#1} \times \frac{\%M_{metal\#1}}{100} + C_{p,metal\#2} \times \frac{100 - \%M_{metal\#1}}{100}$$

$$C_{p,alloy} = (C_{p,metal\#1} - C_{p,metal\#2}) \times \frac{\%M_{metal\#1}}{100} + C_{p,metal\#2} \quad \text{(eq. 14)}$$

Equation 14 relates the specific heat capacity of the metal alloy to its chemical composition. The relationship is linear were the slope equates to the difference of the specific heat capacities of the pure metals in the alloy, and the intercept equates to the specific heat capacity of the second metal in the alloy.

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Cooling curve equation for alloy samples

Under the experimental design proposed in this work, the alloy samples are allowed to cool down to room temperature in free convection air flow. Thus, Newton's law of cooling can be utilized to explain the relationship between the sample temperature and cooling time (Birk, 1976; Bartholow, 2007; Piergiovanni, 2014; Cengel and Boles, 2016). The relationship is expressed as follows:

$$T(t) = (T_0 - T_{env})\, e^{-kt} + T_{env} \qquad \text{(eq. 15)}$$

where T(t) is the temperature of the object at time t, T_0 is the initial temperature of the object, T_{env} is the temperature of the environment, and k is the cooling constant. Under Newton's law of cooling, the heat exchange for the cooling process follows first-order kinetics where the temperature of the hot object depends on the total temperature difference between the object and the environmental temperature (i.e., room temperature; Cortes-Figueroa and Moore-Russo, 2004; Cengel and Boles, 2016).

The value of k depends on four experimental variables: the surface area (A) for the heat exchange, the mass (m) and specific heat capacity (C_p) of the object, and the convection heat transfer coefficient (h) of the system. The expected value for h is between 2-25 W/m^2K for systems under gasses in free convection (i.e., cooling under air without forced currents; Perry and Chilton, 1973; Cengel and Boles, 2016). The value of h is to be determined experimentally for every system under study. The cooling constant, k, is expressed as follows:

$$k = \frac{h \times A}{C_p \times m} \qquad \text{(eq. 16)}$$

Based on equation 16, the value of h can be determined using a standard sample of known mass m, specific heat capacity C_p, and surface area A, once the value of k is known from the relationship in equation 15.

Equation 15 can be used to predict the cooling time of the alloy samples, and if the value of h is determined. Also, based on equation 15, the specific heat capacity of an unknown alloy can be estimated from the value of k, and the relationship between k and C_p in equation 16.

Experiment description

Alloy production

Copper alloys of varying composition were produced for three systems: Cu-Al, Cu-Sn, and Cu-Zn. To make the alloys, a total mass of 100 g of a mixture of the pure metals was added into a one litter graphite crucible. The crucible was then placed in a preheated furnace at 500 °C. The temperature was then increased to 1100 °C over 10 minutes. After twenty minutes, the hot molten mixture was taken from the furnace and poured into a preheated small graphite crucible. The small graphite crucible functioned as the mold for the molten metal, thus giving the alloy its shape and final volume (no larger than 15 mL). The leftover mixture that did not fit the mold was allowed to cool down within the one litter graphite crucible. Once the newly made alloy had cooled down between 700-800 °C it was placed in room temperature water to quench it. After quenching the sample was ready for experimental analysis. The percent composition of the alloy samples was calculated based on the weighted amounts of the pure metals. The samples were studied via density determination, calorimetry, and the cooling process under air. All of the analyses were non-destructive and had no detectable impact on the integrity or composition of the materials.

Density of alloys

To find the densities of the alloys, the mass of each sample was measured to 0.01 g using a balance. The volume was determined indirectly by measuring the mass of water displaced in a calibrated beaker. To this end, a pre-weighed beaker was filled with water to a carefully set mark on the beaker, and the total mass of water and beaker was measured. Then an alloy sample was added to the beaker, and the water level was set to the initial mark by removing the excess water. The total mass of the water, alloy sample and beaker was recorded. The mass measurements allowed for the calculation of the mass of displaced water by the alloy sample. Using the density of water at the temperature of the experiment, the volume of the displaced water was determined, and this volume value was equal to the volume of the alloy sample. Following this method, the volume measurement for the alloy samples had a precision of ± 0.09 cm^3. The results of the mass, volume, and density determination for all alloy samples are shown in table 1.

Type of Alloy	%Cu ± 0.1	Mass ± 0.01 (g)	Volume ± 0.09 (cm^3)	Density ± 0.07 (g/cm^3)
Brass Cu + Zn	100.0%	70.22	8.23	8.53
	80.0%	105.51	12.43	8.49
	50.0%	88.72	11.24	7.90
	20.0%	44.71	6.02	7.43
	0.0%	35.52	4.82	7.36
Bronze Cu + Sn	100.0%	70.22	8.23	8.53
	90.0%	92.86	10.78	8.62
	63.0%	88.80	10.01	8.87
	50.0%	84.00	10.22	8.22
	40.0%	83.25	10.37	8.03
	10.0%	81.77	11.19	7.31
	0.0%	79.69	11.61	6.86
Aluminum Bronze Cu + Al	100.0%	70.22	8.23	8.53
	90.0%	26.68	3.26	7.23
	80.0%	58.82	9.94	5.92
	50.0%	53.29	13.21	4.03
	10.0%	24.26	8.38	2.90
	0.0%	32.67	12.19	2.68

Table 1: Density values for binary alloy systems.

Specific heat capacity of alloys

Specific heat capacity, C_p, was determined using a coffee-cup calorimeter. The alloy sample was heated between 80-95 °C in a hot-water bath and placed into the coffee-cup calorimeter containing 90 g of deionized water at room temperature. The calorimeter was stirred until the equilibrium temperature was reached. Results of the specific heat capacity for each alloy sample are shown in table 2.

Type of Alloy	%Cu ± 0.1	Heat Capacity C_p ± 0.02 (J/g ºC)
Brass	100.0%	0.39
	80.0%	0.38
	50.0%	0.39
Cu + Zn	20.0%	0.40
	0.0%	0.40
Bronze	100.0%	0.39
	90.0%	0.37
	63.0%	0.33
	50.0%	0.31
Cu + Sn	40.0%	0.29
	10.0%	0.25
	0.0%	0.24
Aluminum Bronze	100.0%	0.39
	90.0%	0.46
	80.0%	0.47
	50.0%	0.61
Cu + Al	10.0%	0.81
	0.0%	0.89

Table 2: Specific heat capacity for binary alloy systems.

Cooling curves of alloys

The cooling curves for the alloy samples were measured using the equipment shown in figure 1. The alloy samples were suspended with a thin metal wire above a Bunsen burner. Each sample was then heated over 200 °C and then allowed to cool to room temperature. While the sample was cooling, a thermocouple was set to measure the sample temperature every second for 15 minutes. The samples were

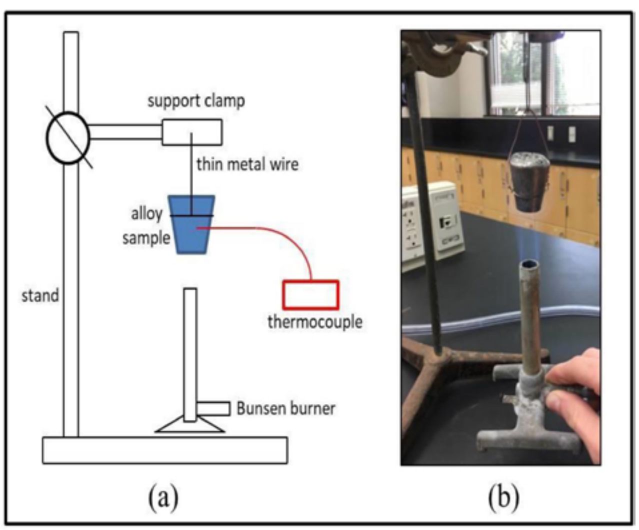

Figure 1. (a) Equipment diagram and (b) experimental setup.

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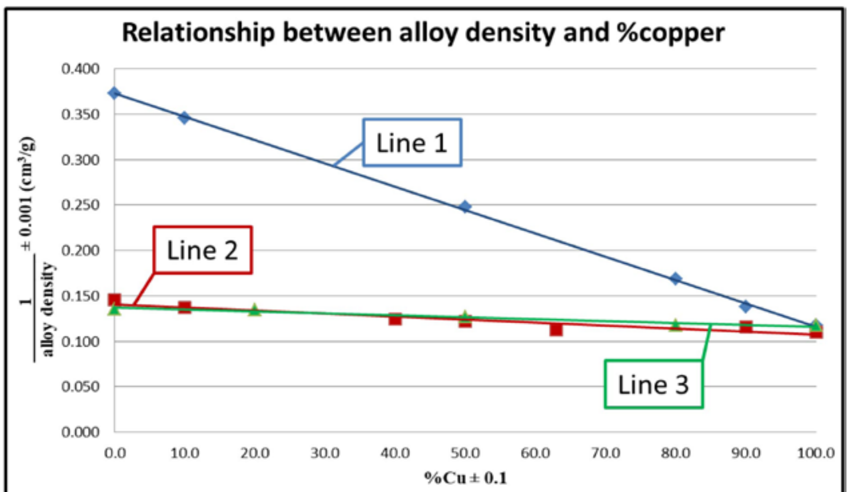
allowed to cool under free-convection flow, avoiding any air currents that might speed up the cooling process. The process was repeated three times for each sample. The thermocouple and the data collection interphase were purchased from Vernier Software & Technology. Alternatively, other temperature equipment (e.g., infrared thermometers) could be used for data collection over longer time intervals (e.g., every 30 seconds). The cooling data (i.e., temperature against time) were fitted to an exponential relationship, as it is the expected relationship based on equation 15. The best fit exponential equations were determined using the Vernier's Logger Pro (version 3.12) statistical program.

Results and discussion

Relationship between density and the chemical composition of alloy samples

The density and the chemical composition of the three binary systems under study were plotted based on the expected relationship shown in equation 8. That is, the x-axis is the %Cu and the y-axis is the inverse of the sample density. The results of the curves of best fit show a linear relationship between the experimental variables (Figure 2).



Line on graph	Alloy system	Slope	Intercept	R^2
Line 1	Cu – Al	$(-257 \pm 6) \times 10^{-5}$	0.373 ± 0.004	0.999 ± 0.006
Line 2	Cu – Sn	$(-33 \pm 11) \times 10^{-4}$	0.140 ± 0.007	0.88 ± 0.01
Line 3	Cu – Zn	$(-21 \pm 5) \times 10^{-5}$	0.137 ± 0.003	0.963 ± 0.004

Figure 2: Relationship between alloy density and percent composition of copper, and parameters of linear regression model.

From the results in Figure 2, the Cu-Al system shows the best fit between the expected relationship and the obtained data, thus suggesting that the assumption of the linear addition of volumes is not rejected. In the alloy systems of Cu-Sn and Cu-Zn, there seems to be a misfit between the expected relationship and the data. Sources of measurement error were considered along all experimental determinations and incorporated in the results presented above. Thus, the results suggest a potential deviation from the assumption of the linear addition of volumes for these binary systems, in particular, the Cu-Sn system with an R^2=0.88. However, the observed deviations from linearity do not significantly affect the overall trend in the data and considering the experimental sources of error; the experiment can provide a good experience for students to learn about the uncertainty of scientific measurements.

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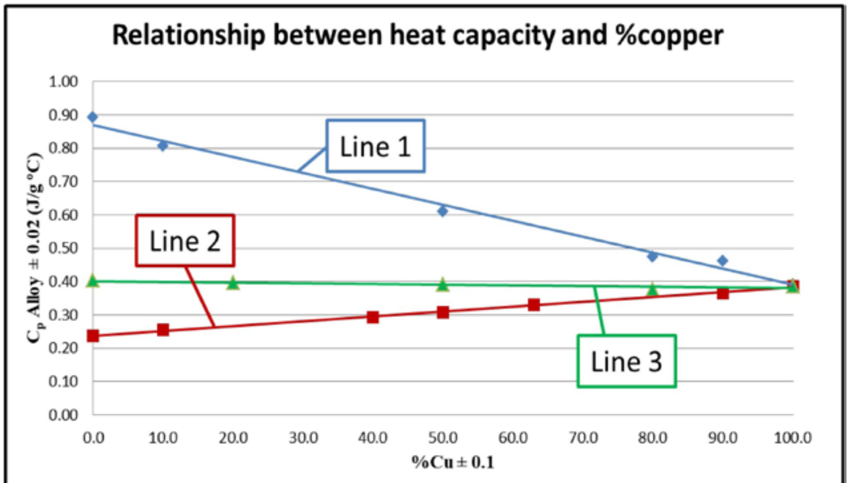
Relationship between specific heat capacity and chemical composition of alloy samples

Experimental results for specific heat capacity and percent composition of copper matched the expected relationship shown in equation 14 (Figure 3).



Line on graph	Alloy system	Slope	Intercept	R^2
Line 1	Cu – Al	$(-48 \pm 5) \times 10^{-4}$	0.87 ± 0.03	0.99 ± 0.04
Line 2	Cu – Sn	$(147 \pm 7) \times 10^{-5}$	0.236 ± 0.004	0.997 ± 0.006
Line 3	Cu – Zn	$(-20 \pm 16) \times 10^{-4}$	0.40 ± 0.01	0.68 ± 0.01

Figure 3: Relationship between specific heat capacity and percent composition of alloy samples, and parameters of linear regression model.

The obtained data for the binary systems fit a linear relationship for the Cu-Al and Cu-Sn systems. Thus, the data support the expected relationship stated in equation 14 where the heat capacity of an alloy can be calculated from its percent composition and the heat capacity of the pure metals.

In the case of Cu-Zn, there is a significant misfit, as the R^2=0.68. The misfit can be associated with how close the values of the specific heat capacities of the zinc and copper metals are. Thus, causing the alloy samples to have no significant change in their specific heat capacity in comparison to their pure metal constituents. Therefore, the expected value of the slope in equation 14, for the Cu-Zn system, approaches zero making the expected change of heat capacity against percent composition constant, as observed in the obtained experimental results (Figure 3).

Cooling curves for alloy samples

As an example, three runs of the cooling data for the alloy composed of 90%Cu and 10%Al are presented in figure 4. The obtained data fits an exponential relationship, as the R^2 values are 0.997 and higher. The results of the analysis of all alloy samples for the binary systems under study showed similar results to those seen in figure 4. Thus, the experimental methodology provided reproducible data that fit the expected behavior based on Newton's law of cooling (equation 15).

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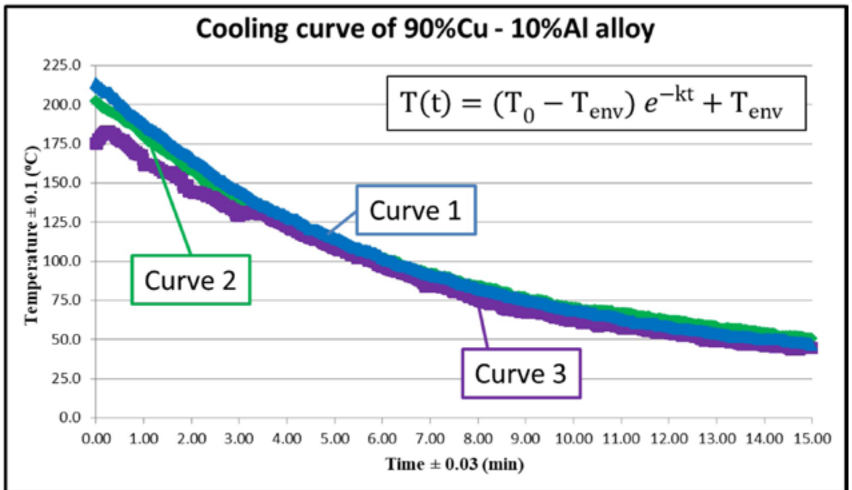

Curve on graph	$T_0 - T_{env}$	k	T_{env}	R^2
Curve 1	194.8	0.138	19.0	0.999
Curve 2	183.2	0.128	19.0	0.997
Curve 3	163.1	0.127	19.0	0.998

Figure 4: Exemplar cooling curves for the three runs of the 90%Cu - 10%Al alloy, and parameters of exponential regression model.

As the cooling process follows first-order kinetics, an estimate of half-life for cooling can be calculated based on the obtained exponential equation. In the experimental work herein, the half-life time, $t_{1/2}$, is the time it takes for the temperature of the hot alloy sample to drop to half of its initial temperature in comparison to the environmental temperature (i.e., room temperature). The calculated half-life times for the alloy samples are shown in table 3. The obtained values for $t_{1/2}$ are unique to the alloy samples used, as it depends on the shape and mass of the alloy (equation 16). As the alloy samples did not have the same mass, comparisons between the $t_{1/2}$ values are not possible even within the same alloy system. The next steps in the data analysis present a way to extract more information from the cooling curve results.

Type of Alloy	%Cu ± 0.1	Surface area ± 0.1 (cm^2)	Cooling Constant ± 0.002 (min^{-1})	$t_{1/2}$ ± 0.1 (min)
Brass Cu + Zn	100.0%	22.7	0.108	6.4
	80.0%	30.1	0.094	7.3
	50.0%	27.6	0.073	9.5
	20.0%	19.2	0.149	4.7
	0.0%	16.9	0.164	4.2
Bronze Cu + Sn	100.0%	22.7	0.108	6.4
	90.0%	27.7	0.107	6.5
	63.0%	26.3	0.128	5.4
	50.0%	26.9	0.120	5.8
	40.0%	27.2	0.088	7.9
	10.0%	28.2	0.102	6.8
	0.0%	28.6	0.103	6.7

Table 3: Cooling constants and half-life times for cooling for alloy samples.

Aluminum Bronze **Cu + Al**	100.0%	22.7	0.108	6.4
	90.0%	12.9	0.131	5.3
	80.0%	24.7	0.095	7.3
	50.0%	31.3	0.122	5.7
	10.0%	23.4	0.127	5.5
	0.0%	29.5	0.111	6.3

Determining the convection heat transfer coefficient, h

Based on the cooling curve results, it is possible to determine the convection heat transfer coefficient, h, for the experimental setup. The design of the experiment determines the value of h, as it depends on the heat exchange surface geometry, the gas used during the cooling process, and how the gas moved around the sample during the cooling (equation 16). In the experiment, air was the gas used and it moved in free convection around the sample. To determine the value of h, the alloy samples of Cu-Zn and Cu-Sn were used as standards, as their mass, surface area, and specific heat capacity were previously measured (Table 3). The average value for h was 19 ± 4 W/m^2K with a 95% confidence level. The reported value for h with gases in free convection is between 2-25 W/m^2K (Perry and Chilton, 1973; Cengel and Boles, 2016). Thus, the obtained value for h is within the expected range.

Predicting the heat capacity of alloys using the cooling curve results

Based on the cooling curve results and equation 16, the specific heat capacity of Cu-Al alloys was calculated to determine the accuracy of the results (Table 4). The average percent error in the specific heat capacity values derive from the cooling curve analysis was 4%, with estimated values being under and above the expected values (determined via calorimetry; Table 2). Thus, the cooling curve data can provide a rough approximation of the heat capacity for an alloy sample, despite the associated error in the measurements.

Type of Alloy	%Cu ± 0.1	C_p ± 0.02 (J/g ºC) (Determined via calorimetry)	C_p ± 0.09 (J/g ºC) (Derived from cooling curve results)	Percent error (%)
Aluminum Bronze **Cu + Al**	100.0%	0.39	0.34	-14
	90.0%	0.46	0.42	-10
	80.0%	0.47	0.50	5
	50.0%	0.61	0.54	-11
	10.0%	0.81	0.86	6
	0.0%	0.89	0.91	2

Table 4: Specific heat capacity derived from cooling curve data for aluminum bronze samples.

Conclusion

The experimental data and results showed that the designed laboratory experience could yield valuable data for the students to analyze and interpret in light of chemical concepts and theories. As designed, the experience consists of three laboratory sessions

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linked together by the analytes (i.e., alloy samples) that are studied under three main processes: density determination, calorimetry, and the cooling process. Each of the three processes can be used as independent experiments, but together they craft an overarching experience that can guide students to a better understanding of the interconnection among different chemistry concepts and laboratory techniques.

The density determination, calorimetry, and cooling process of the alloy samples were done via simple experimental designs, and with standard laboratory equipment. The samples were not destroyed during the processes, and their composition was kept intact. Thus, the use of metal alloys is a robust and reproducible approach to experimentation for General Chemistry programs. These materials also have the potential of reducing the costs, since after the initial production they may be reused multiple times.

Although, the work herein presents the study of three binary alloy systems, students could be asked to complete the analysis of a single binary system (e.g., Cu-Al alloys of varying composition) by distributing the alloy samples amongst sub-groups of students, to later share the collected data with the whole group prior to data analysis and interpretation. Alternatively, groups of students could be asked to focus on one family of alloy samples (e.g., Cu-Zn) while other groups analyze other family of alloys (e.g., Cu-Al, Cu-Sn).

Furthermore, students could analyze metal samples provided by the instructors as "unknown" composition samples to determine the density and specific heat capacity and calculate the percent composition using the plots presented in this work as calibration curves. Then students can collect cooling curve data for the unknown sample to determine the $t_{1/2}$ of cooling.

The use of metal alloys allows for a cohesive study of the chemistry of such materials, which are widely available in everyday products, like hardware tools, coins, and cooking supplies. Thus, the laboratory experience herein can lead to the cultivation of the interest in material science, and how chemical manipulation can be used to adjust the properties of the materials depending on the end-product applications (Bello, 2000). In summary, the laboratory experiences herein have the potential to be an effective teaching experience for General Chemistry laboratory programs.

Conflict of interests

Authors declare no conflict of interest.

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