Primo Levi and *The Periodic Table*: Teaching Chemistry Using a Literary Text

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The Periodic Table (1) is one of the autobiographical books written by Primo Levi (1919–1987), an Italian chemist and writer. Levi was born in Turin, Italy, into a middle-class family of assimilated, nonreligious Jews. In 1941, he graduated in chemistry as the first in his class at the University of Turin—in spite of Fascist Italy's racial law of 1938 that forbade Jews access to higher education. He worked in a pharmaceutical laboratory until 1943, when—after Mussolini's fall and the invasion of Italy by German troops—he joined a partisan group. Arrested by the German army, Levi was eventually identified as a Jew and deported to the concentration camp at Auschwitz. He survived because he was sent to work in an I. G. Farben laboratory, which produced synthetic rubber at the labor section of the camp. Levi died in 1987, after falling down the stairwell from the third floor of the house where he was born, and where he lived since his return at the end of the war. The episode has been described as a suicide; however, there are strong arguments in favor of the hypothesis of an accident *(2)*.

In most of *The Periodic Table*, Levi narrates his memories from a period ranging from a little before to a little after World War II. Each one of the twenty-one chapters of the book is named after a chemical element, and Levi poetically associates properties of the elements to facts of his own life. The reading is especially interesting for chemists, who will be able to better appreciate the beautiful analogies and reflections proposed by Levi. While the book is not a didactic text, this paper describes how we have used excerpts from *The Periodic Table* to discuss many chemical concepts with first-year students, engaging them in this unusual context.

Design of the Exercises

A slightly edited excerpt of the chapter "Potassium" was handed out to the students (see the Supplemental Material[W]). In this text, Levi describes an accident in a laboratory in which he was involved as an undergraduate student. Levi had to distill benzene in the presence of sodium; however, since he was unable to find this metal in his laboratory, he decided to replace the sodium with potassium. After the distillation, Levi took the flask to the sink to wash it. As the water entered the flask, an explosion occurred, and a fire started in the laboratory. Levi was able to extinguish the fire without any serious consequences. He then tried to find an explanation for the incident.

Course Application: Chemistry of the Elements

The text was used by the students of two courses, with different goals. In Chemistry of the Elements, a course that aims to give chemistry majors a general view of the periodic table from the standpoint of inorganic chemistry, it was used as an "advance organizer" *(3)*. In the first class of this course, the students read Levi's text and answered the following three questions:

1. Why did the author suppose that he could use potassium instead of sodium? How do you think he got that idea?
2. Do you think it is part of a chemist's work to make "innovations" like that, namely, to introduce changes in established procedures, like changing potassium for sodium?
3. Write your opinion on the following comment made by the author: *"[T]he chemist's trade consists in good part in being aware of these differences* [between almost-the-same substances], *knowing them close up, and foreseeing their effects."*

The goal of these questions was to help the students recall their previous knowledge about the periodic table, about similarities and differences between the elements, and about how the elements may be categorized. Afterwards, faculty presented a general view of the course, which focuses on the study of the groups of the periodic table.

Course Application: Integrated Chemistry I

The second use of Levi's text occurred in Integrated Chemistry I, a course with the goal of integrating general and inorganic chemistry taught in various courses during the first year of study in the program for chemistry majors. The course is offered to students enrolled in the traditional (daytime) program—which leads to a bachelor's degree in chemistry—and to students enrolled in the nontraditional (evening) program, which leads to a bachelor's degree with an emphasis in environmental chemistry.[1] We have found that using this excerpt from a chapter of Levi's *The Periodic Table* is an excellent starting place, providing material for discussions on several fundamental chemical concepts.

The students received a copy of the text and instructions for the assignment, and were asked to work individually or in groups of two. They had fifteen days to respond fully to these two questions:

1. Make a list of the substances and materials that are mentioned in the text. If possible, write the formula or give the constitution of the items you listed.
2. Analyze each chemical fact mentioned in the text, trying to explain it in the light of the chemical concepts you learned in the courses you have already taken. Also consult the literature. Avoid superficial or incomplete explanations. For instance, if you explain something by saying that "substance X has a low boiling point", you shall add *why* it is low. Whenever you consider that a chemical transformation has occurred, write the chemical equation, properly balanced.

Results

A total of 55 sets of written answers were presented to faculty: 32 were from students attending the daytime classes and 23 from those of the evening classes. Table 1 presents a list of text excerpts that could serve as starting points for discussions of chemical concepts. Students were expected to address most of these topics, although not all of them did.

Class Discussion

Faculty graded the assignments, wrote short comments when necessary and discussed the assignments with the students in the classroom. Students received a handout with a list of the topics they could have discussed, similar to Table 1. Some of the students were amazed at the amount of chemical information that they had missed in the text, and some of them recognized that they should have analyzed the text more carefully. Most students were able to list the main chemicals cited in the text, and the main reactions—such as the reaction between sodium and water, and between sodium and atmospheric oxygen.

Table 2 shows the percentage of students who listed and correctly explained the main items of chemical interest in the text. Results are shown separately for students attending daytime classes and students attending evening classes. The outcomes are similar for the two groups; this was a rewarding result for us as educators because there were concerns when introducing the evening study program that students in it would accomplish less than their daytime peers.

These results were not compared to results obtained after conventional teaching approaches, since the questions were based on Levi's text and would make little sense if not attached to his narrative. However, by means of informal conversations with the students, faculty observed the increase in the students' interest in the lectures: they recognized the value of the discussion of the text for their learning. Their motivation could also be seen in the classes in which the assignments were discussed, for many students took active part in the debates.

During the discussion, the students had the opportunity to have their questions answered and to modify previous alternative conceptions. For the sake of example, we present and comment on a few of the answers given by the students in

Table 1. Topics for Class Discussion Based on Text Excerpts

Text Excerpts from Primo Levi's *The Periodic Table* (1)	Related Topics for Class Discussion
Now I had to distill [benzene] *a second time in the presence of sodium.*	Why was benzene distilled twice? Why is sodium or potassium used in the second distillation? What is the residue in the flask after the second distillation? Can benzene contain much water? Are water and benzene miscible?
It [sodium] *is neither rigid nor elastic; rather it is soft like wax.*	Why is sodium different from the usual metals? Why is sodium not rigid, but soft?
It [sodium] *is not shiny or, better, it is shiny only if preserved with maniacal care, since otherwise it reacts in a few instants with air, covering itself with an ugly rough rind.*	What reaction takes place? What are the products? How must sodium be stored?
[Sodium] *reacts with water, in which it floats (a metal that floats!).*	Why does sodium float on water? What reaction takes place?
[Potassium] *is sodium's twin, but it reacts with air and water with even greater energy.*	Why does the author consider potassium and sodium as "twins"? Why does potassium react with more energy than sodium? (Consider thermodynamics and kinetics.)
In contact with water it [potassium] *not only develops hydrogen but also ignites.*	Is it correct to say that potassium ignites?
I placed it [the residue of potassium] *on a piece of dry filter paper, wrapped it up in it, went down into the Institute's courtyard, dug out a tiny grave, and buried the little bedeviled corpse.*	What is the proper way to dispose of an excess of potassium?
Adhering to the glass of the flask there must have remained a minuscule particle of potassium, all that was needed to react with the water I had poured in and set fire to the benzene vapors.	Why did a fire begin in the flask? What was the immediate cause of this fire?
By looking closely, one could see, barely visible, a tiny white fleck. I tested it with phenolphthalein: it was basic, it was potassium hydroxide. The guilty party had been found…	What is the nature of potassium hydroxide? How does phenolphthalein react with potassium hydroxide? In the episode described, was the potassium hydroxide formed only during the cleaning of the flask?
Sodium is almost the same as potassium, but with sodium nothing would have happened.	Is it correct to say that with sodium nothing would have happened?

their written assignments. (Responses were translated into English by the authors.)

Some students did not know why sodium (or potassium) was needed in the final distillation of benzene. Others, although knowing the reason, held an incorrect idea about the presence of water in technical benzene. The following quotation exemplifies this point:

> If you do not make the first distillation [without sodium], the concentration of water is too high, and the reaction with sodium may be explosive.

Discussion of molecular polarity in the classroom led students to conclude that there would never be much water in benzene, since the former is only sparingly soluble in the latter.

Another issue that was discussed was the origin of the fire. One student wrote:

> The statement that required the most research for me to understand was that "in contact with water, potassium ignites". It has been difficult for me to understand, for in fact what ignites is the hydrogen gas formed in the reaction.

At first, some students took too literally the statement "potassium ignites", and ascribed the beginning of the fire to the combustion of potassium. The above quotation is interesting, for it shows that the student was able to correct his misconception for himself as a part of this exercise, prior to the class discussion. Correct answers from students helped to deal with questions of others. Here is an example of a sound explanation about the origin of the fire, given by one of the students:

> The flask contained a small piece of solid potassium (which was not noted by the chemist), and also benzene vapors, which are flammable. When water was poured into the flask, it reacted with the piece of potassium, yielding hydrogen gas, hydroxyl ions, potassium ions, and heat. The heat ignited both the hydrogen and the benzene vapors. The flame thus formed set the curtains on fire.

Another matter that required some research by the students was the statement that potassium "reacts with air and water with even greater energy" than sodium. Fewer than one-half of the students (combined day and evening programs, see Table 2) were able to give an appropriate answer, such as the following one:

> The ignition of the hydrogen is mainly due to the rate of the reaction and not so much to the energy released (per mole). Lithium is an example of this: it releases more energy than potassium in the reaction with water; however, it does not ignite, for the reaction rate is lower.

Because of the difficulty students had in explaining this topic, they were reminded of the reaction between sodium and water, an experiment they had already performed in the inorganic chemistry laboratory. (If students have not done this experiment, instructors can do a safe classroom demonstration of sodium reacting with water; see ref *4*.)

Through experimentation students had observed that whenever hydrogen ignites, a yellow flame is produced; we connect this with a discussion of the atomic emission of sodium. With potassium the flame is violet, as we had illustrated for students with photographs of the reaction of this metal with water *(5)*. Other elements produce other colors and, in fact, the explosion of hydrogen balloons containing small amounts of salts has already been proposed to add interest to lectures when discussing emission spectra and electronic energy levels *(6)*, a topic for which few classroom demonstrations have been described.

At this point, we discuss heterogeneous reaction rate dependence on surface area. Refluxing benzene melts the potassium (melting point 64 °C) and can generate finely divided metal. The rates of potassium reactions with water or oxygen are then increased. When exposed to air, potassium can form a dangerous crust containing the superoxide, KO_2, a powerful oxidizing agent. It undergoes very hazardous reactions, especially in the presence of water and combustible materials. The KO_2 crust may even be responsible for explosions when one tries to cut old pieces of potassium metal with a knife *(7)*.

Table 2. Comparative Results of Student Recall of Chemistry Facts Introduced by a Literary Text

Chemical Facts	Day Students, Correct Responses (%)[a]	Evening Students, Correct Responses (%)[b]
List all the chemicals cited in the text[c]	66	65
Chemical properties of sodium:		
"soft like wax"	41	44
"not shiny"	66	83
"reacts with water"	94	100
"floats on water"	47	39
Chemical equation for the reaction of Na + H_2O	88	74
Differences between Na and K[d]	34	52

[a]*N* = 32; [b]*N* = 23; [c]Benzene (C_6H_6), Na, K, H_2O, H_2, KOH, phenolphthalein ($C_{20}H_{14}O_4$ as a solute); [d]That is, reasons why potassium reacts with air and water with even greater energy than sodium does.

Table 3. Safety-Related Physical Properties of Selected Substances

Substance	Boiling Point, °C	Flash Point, °C	Auto-Ignition Temperature, °C	Flammability Limit in Air (% by Volume)
Hydrogen	-252.8	— —	580	4.0–74.2
Methane	-161.5	— —	537	5.0–15.0
Acetylene	-84.7	— —	335	2.5–80.0
Diethyl ether	34.5	-45	180	1.9–36.0
Carbon disulfide	46.0	-30	90	1.3–50.0
Benzene	80.0	-11	498	1.2–7.8

The reactions of alkali metals with water has led to discussions of flammable materials and fire hazards, some of which were unfamiliar to students. We showed students the data in Table 3 and explained the concepts of flammability limits, flash point, and autoignition temperature *(8, 10, 11)*.

Flames or explosions can only occur when the gas or vapor concentration in air is between the flammability limits. The very broad ranges for hydrogen and acetylene make them very flammable gases. An ignitable hydrogen/air mixture can burst into flames spontaneously when the temperature is raised to 580 °C. This temperature can be achieved in a vigorous exothermic reaction, such as that between metallic sodium or potassium and water.

Benzene is a flammable liquid because at –11 °C it gives off sufficient vapor to reach the lower flammability limit of 1.2 % of benzene in air. This concentration is easily attained, meaning that an "empty" flask of benzene (full of vapor) can be very dangerous at temperatures above 498 °C.

As a final remark, it must be emphasized that flammability is not the only hazard associated with benzene. Although in the past Primo Levi and other students distilled benzene and used it in laboratory experiments, many years ago severe restrictions were established for its use because of the health hazards of this carcinogenic agent *(12)*. It should only be used when absolutely necessary and under the strictest control.

Conclusion

The use of a literary text as a starting point of discussions of chemical concepts allowed integration of several topics covered in separate courses of the undergraduate program in chemistry. Some students stated their satisfaction in working on a "problem-solving" basis and in dealing with chemical concepts in a new context. Some of them remarked that they were able to learn more about combustion, structure, and other topics. For faculty, the experience was useful in detecting misconceptions and difficulties in specific topics. These findings will be taken into account in the planning of first-year courses in the future.

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[W]Supplemental Material

The adapted excerpt (as it was given to the students) of the chapter "Potassium" from Primo Levi's book, *The Periodic Table*, is available in this issue of *JCE Online*.

Note

1. An evening study program was started in 2003 at the Institute of Chemistry of the University of São Paulo, leading to a bachelor's degree with emphasis in environmental chemistry or with teaching credentials. It improves access to higher education for many students who have to work to support themselves and family, even though the University of São Paulo is tuition-free. Fellowships for undergraduate students are essentially not available.

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