Primo Levi: A frustrated stereochemist?—Insight in hindsight

Primo Levi: A frustrated stereochemist? – Insight in hindsight

Giancarlo Cravotto[b] and Pedro Cintas*[a]

Abstract: Primo Levi (1919-1987) has become an iconic figure at the intersection of chemistry and culture. Levi has long been praised for his autobiographical account as survivor in Auschwitz and by his literary masterpiece "The Periodic Table". Little is however known beyond such facts, especially his academic period and early research on stereochemistry at the University of Turin, which were abruptly truncated by the racial laws and WWII. Even if, later on, Primo Levi succeeded as industrial chemist, he had a vivid interest in molecular asymmetry that lasted through his entire life. This concise paper highlights a little known academic period in the midst of social and political upheaval. Levi left us his humanity in an otherwise tortuous life and his literature took inspiration from chemistry; perhaps as a metaphor connecting the physical world and people's life.

Keywords: asymmetry · history of chemistry · Primo Levi · stereochemistry · Walden inversion

INTRODUCTION

"He is not recognized for any contributions to science. He did not receive any scientific accolades, nor was he a university professor. Yet it is likely that Primo Levi will be remembered as a singularly influential chemist of the twentieth century" (Amir H. Hoveyda, 2004).[1]

Hoveyda's forecast above emphasizes Primo Levi's extraordinary impact on both science and art, in an essay that revisits The Periodic Table a quarter of a century after its publication in 1975. One would pair with the Hoveyda's quote, the title of a Levi unpublished text: "I write because I am a chemist", which conveys a simple and notable message.[2]

Levi's first book "Se Questo è un Uomo" (1947, "If This is a Man") traced his most recent memories of the concentration camp and the atrocities and brutality he had witnessed. While there, Levi worked as a slave laborer for an IG Farbenindustrie synthetic rubber factory until the liberation of Auschwitz in 1945. In "The Periodic Table", which appeared much later, Levi often returns to his nightmare, but the perspective moves from description to meditations. The chapters, each named for a chemical element, provide analogies between physico-chemical properties and moral spheres. In doing so, elements are employed as metaphors that admit numerous interpretations. Perhaps, the originality lies ultimately in agonistic views of "reactivity", in both inanimate matter and the way humans behave.

Primo Michele Levi was born and died in Turin. His parents, Cesare and Ester Levi were a Jewish couple whose ancestors settled in Piedmont when the region was ruled by the French House of Savoy. The Levis, like other Jews in northern Italy, claimed to be descendant from the Sephardim (after the Hebrew name for Spain, Sefarad), expatriated from Castile after the 1492 anti-Semitic laws. Primo Levi's biographies are abundant, although in some cases the information may not be completely reliable. There are a few comprehensive treatments to be recommended,[3-5] which compiled hundreds, if not thousands, of original documents and letters, and took advantage of interviews with Primo Levi himself (some years before his untimely death) as well as with close relatives, colleagues, and friends. The dense biographies[6] sometimes obscure the details of Levi's academic career with plenty of anecdotes, peripheral discussion, and fireside episodes. Controversial points are unavoidable, like Levi's role as partisan when he joined friends in 1943 in an attempt to connect with a Resistance movement before being captured and sent to Auschwitz.[7]

It is quite obvious that Primo Levi gained recognition abroad from the early 1980s onwards, when his books and essays, in particular "Il Sistema Periodico", were translated into English and unanimously acclaimed by critics.[8] This period was also coincidental with the progressive appearance of neuroses and mental instability according to his biographers, who however describe a downward path that continued during his last two years. Beyond pluses and minuses along his life, chemistry remained Levi's center of gravity. Like other brilliant scientists-turned-writers, Levi's passion for chemistry occurred in a rather serendipitious manner after childhood as we shall see later. Within a narrow university timeline, Levi was able to conduct and get deeply involved in research projects, from physical chemistry to stereochemistry; the latter a field where he would have likely contributed a great deal, were it not for the wartime most European citizens lived through.

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CHEMICAL MOTIVATION IN ADOLESCENCE

Primo Levi's interest in chemistry could hardly be foreseen when he was admitted to Lyceum in July 1934, then aged 15. As a member of a liberal bourgeois family, yet maintaining some Jewish traditions, Primo Levi benefitted from a cultivated education. Both his father and grandfather were engineers, so that a technical career, rather than in science, would have been an expected choice. The Fascist regime had also encouraged the study of Arts and the Classics as the core curriculum, in an attempt to imbue the past glory and military order of the Roman Empire. Levi could read not only Latin, but also Greek and French. During adolescence he read extensively fictional works by Italian and French authors, and others in translation.

As a shy and physically weak teenager, Levi was soon the victim of bullying. Jews, as minority, were especially vulnerable. Gratifyingly, he met a very small circle of loyal friends, in particular Mario Piacenza. Biographers note a watershed for Levi when Piacenza showed him a chemical (or pharmacy) laboratory on the top floor of the family home belonging to Piacenza's older brother. The two adolescents began to perform simple test-tube experiments with color changes and gas bubbling being part of that magic. Moreover, by that time Cesare Levi bought his son an optical microscope, which enabled him to unveil the intimate forms of insects or red blood cells. Interestingly, slides of evaporated solutions of inorganic salts, placed under the microscope, showed how giant crystals actually grow. Despite such "revelations", biographers and Italian scholars suggest that the inflection point that persuaded Levi to become a chemist was the examination of a well-illustrated monograph, "*Concerning the Nature of Things*",[4,5,9] by British physicist Sir William Bragg, who was awarded the Nobel Prize in 1915 for his research on the determination of crystal structures. The book stimulated Levi to conduct further experiments, like water electrolysis, to construct atomic models and structures with home-based materials, and learning to write chemical equations. The influence of "Concerning the Nature of Things" (a title clearly reminiscent of *De Rerum Natura*, by Lucretius) on Primo Levi and future crystallographers, like Dorothy Hodgkin, was traced in a recent essay by Davide Viterbo, another Turinese chemist.[10]

CHEMISTRY IN THE FOREFRONT AND THE RISE OF EVIL

In October 1937 Primo Levi embarked on chemistry studies at the University of Turin (Figure 1). For the next three years, Levi digested not only chemistry courses, but also a lot of physics, mathematics, and mineralogy, among others. The first academic year (1937-38) reinforced Levi's decision to love chemistry despite an exhausting program, as morning lectures were followed by five hours in the laboratory. During the first year, Levi attended the inorganic chemistry course delivered by Professor Giacomo Ponzio (1870-1945), then close to retirement, but still a dominant figure at the Chemistry Institute. Through interviews, Levi ranked Ponzio as his best teacher, someone who exerted later a major influence on Levi's pursuits.[11]


CITTÀ DI TORINO

DIVISIONE XII

SERVIZI DEMOGRAFICI - RIPARTO CERTIFICATI

Si certifica che la presente fotografia è il ritratto del Sig. Levi Primo

Torino, addì 20 OTT. 1937 XV

Il Podestà

FIGURE 1. Primo Levi's identity card by the time he registered for a Chemistry degree.

Like most boys of his generation, Primo Levi was enrolled in Fascist youth movements and, as a result he also joined the University Fascist Group, which served as a social club on campus. During the early 1930s, Italy's anti-Semitic laws were not particularly problematic for Jews, despite the alliance with the Nazi regime and a similar racial legislation that fueled the Aryan supremacy. Initially, the latter proved to be a quite confusing idea. Most Italians ignored what the term Aryan actually meant. Like other Mediterranean countries and European territories sympathetic to the Nazi propaganda, inhabitants were heterogeneous and clearly most people lacked Caucasian origin. Moreover, the Turinese Jews divided into pro-Fascists and anti-Fascists. Levi's father, Cesare, a liberal man, was politically far from Fascism and opposed to the sympathizers who also urged a call to arms. Things changed dramatically when in the mid-summer of 1938, Mussolini's government announced a Manifesto ("*The Manifesto of Racial Scientists*"), signed by *racial experts*, who had discovered the existence of an Italian race, dating back to pre-Roman times, of Aryan origin. The argument ended up in a diabolic syllogism; since the Italians had been Aryans and Jews are not descendant of Aryans, Jews cannot be (first-class) Italian citizens. Even worse, by 1939 all non-Aryans were officially registered as Jews. As a consequence, Jews were forbidden to teach at or attend schools and universities. Nor could they be admitted to public institutions. The Levis and the Jewish community in Turin realized that exile would soon be the only solution to escape from the official persecution.

Paradoxically, Primo Levi was able to complete the 3rd year of chemistry studies and even register for his final 4th year in November 1940. He knew, however, that the racial laws will not allow him to continue a career at the University or elsewhere in his own country. Also, his teachers (some having venerable loyalty to the regime) could impede a Jewish student to pass exams or to obtain a degree. In spite of such hurdles, Primo Levi had the highest score in *viva voce* exams on his three doctoral dissertations and was awarded the *Laurea* degree *summa cum laude*.[12]

L'INVERSIONE DI WALDEN AND THE PUZZLE OF THESIS SUPERVISIONS

By the end of 1940 Levi faced both academic and personal challenges. He was working on some projects to earn his graduation while wishing to get a position as university assistant

(*interno*), a goal that seemed extremely difficult to achieve in view of the Fascist laws. Two subjects had a physical or physico-chemical orientation and were registered as *sotottesi* (or sub-thesis),[13]: "*I Raggi Elettronici*" ("*Electronic Rays*"), supervised by professor Mario Milone who had studied X-ray crystallography with William Bragg in Cambridge. Certainly, the topic echoed Levi's early contact with chemistry. Apparently, he developed an interest in radiation chemistry after reading Thomas Mann's "The Magic Mountain" describing the use of X-rays for clinical treatment.[14] The other *sottotesi* was performed in experimental physics entitled "*Comportamento Dielettrico del Sistema Ternario* C_6H_6-C_6H_5Cl-$CHCl_3$" ("*Dielectric Behavior of the Ternary System* C_6H_6-C_6H_5Cl-$CHCl_3$") with professor Alfredo Pochettino as supervisor (Figure 2). Levi had showed interest in physics during his second-year studies in the search for in-depth explanations about the transformation of matter, rather than the phenomenological observations chemistry usually provides.[15]

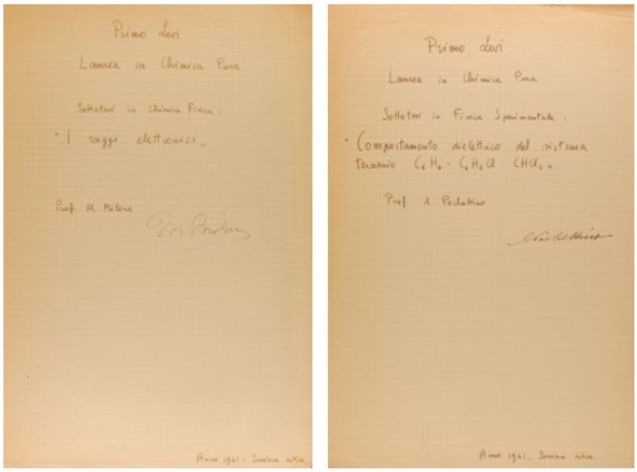

FIGURE 2. Primo Levi's hand-written registrations of sub-theses in Physical Chemistry and Experimental Physics. Source: Archivio Storico-Università degli Studi di Torino.

In the meantime, Primo Levi was also engaged in organic chemistry and chose Walden's inversion as the subject of his main dissertation for the *Tesi di Laurea* in Pure Chemistry, a work ultimately supervised by Giacomo Ponzio (Figure 3). But Levi failed to be taken on as assistant by Ponzio, which disappointed him to look for an opportunity at the Experimental Physics Institute. There, he found Dr. Nicolò Dallaporta who, based on Levi's credentials, took him on as his assistant. As an astrophysicist, Dallaporta was scientifically light years far from Levi's abilities, although Levi later became fascinated by Dallaporta's cosmological investigations. Dallaporta suggested to Levi to revisit recent work by Lars Onsager (1903-1976 and 1968 Nobel Prize winner), whose studies on electrolyte solutions were already noticeable. Levi's studies concluded that Onsager's prediction does not agree with the experiment when the molar concentrations of the polar components are different, while the formula is verified if the concentrations are equal.[12]

The potential interaction of Levi with other chemistry or physics professors while seeking a position as research assistant is still a debatable point. A figure of choice could be Eligio Perucca (1890-1965), Physics professor at the University of Turin and expert in light polarization. As documented in an outstanding re-investigation by Kahr *et al*., Perucca showed for the first time the enantioselective adsorption of an organic dye to sodium chlorate ($NaClO_3$), which like quartz exists as a racemic conglomerate of enantiomorphous crystals.[16] Whether or not Levi approached Perucca remains unnoticed by his biographers, with the exception of Anissimov, who indicated that Levi attended Perucca's courses.[17] The investigation by Kahr *et al*., based on interviews with Levi's relatives, clearly suggests that Perucca did not refuse to accept Levi and other Jewish students due to anti-Semitism. A declared anti-Fascist, Perucca was also a *tough guy*, someone capable of intimidating any aspiring student looking for tutelage, and he should reasonably be exonerated from racial discrimination.[16,18]

FIGURE 3. Front cover of Levi's main dissertation on Walden's inversion at the University of Turin (1941).

Unlike Perucca, Ponzio pretended to be a liberal man, but he took a convenient pro-Fascist and distant attitude against Jewish students. There is little doubt that Ponzio was highly qualified to evaluate a dissertation on organic (stereo)chemistry. He had extensively studied organonitrogen compounds and in 1897 disclosed a new oxidation of aldoximes with N_2O_4 affording *gem*-substituted dinitro compounds,[19] which is now named after him.[20] Ponzio disagreed with the "static" views of Hantzsch and Werner on the stereochemistry of nitrogen compounds, especially oximes, for which isomeric differences were poorly interpreted.[21] Levi's primary thesis on Walden inversion is remarkable for recognizing dissymmetry as a key ingredient for life to occur. He returned to such ideas much later in the *Periodic Table* and his essay on *Asymmetry and Life*. Latvian chemist Paul Walden (1863-1957) was still alive in 1940 and his method of interconverting asymmetric compounds[22] had revolutionized the static arrangement of molecules as spatial entities, by showing that stereochemistry could provide enough evidence about their dynamics in solution.[23] Working on apparently two similar reactions of (+)-malic acid with achiral reagents, one gave rise to the (–)-enantiomer of chlorosuccinic acid, the other leading to (+)-

chlorosuccinic acid, thereby verifying that the mechanisms should be different. There must be either inversion or retention of the configuration, but the question of which is which could not be solved by Walden as the optical rotation alone is not necessarily related to configuration. By 1911, Emil Fischer concluded on the basis of his own study of the Walden inversion that van't Hoff's model of tetrahedral carbon is incorrect for dynamic processes, yet maintaining its value for static structural arrangements.[24] Only in the 1920s did synthetic cycles shed light into the steps proceeding with retention or inversion depending on the bonds broken around the asymmetric carbon.[25,26]

On the other hand, and quite unusual for an undergraduate student, Levi addressed a contemporary problem of organic chemistry, as Hughes and Ingold were investigating by that time the mechanisms of nucleophilic substitutions, whose details took long to be elucidated.[27] Surely, the topic chosen by Levi could not completely displease Ponzio, who opposed the Hantzsch/Werner theory on the structure of glyoximates based on a geometrically rigid interpretation for the addition to the C-N double bond. However, he was still distant from the then bizarre ideas of dynamic stereochemistry.[12] Levi's thesis did not include any experimental work (otherwise prohibited by the racial law), but he was aware of the current background and showed the working hypothesis through different reaction schemes (Figure 4).

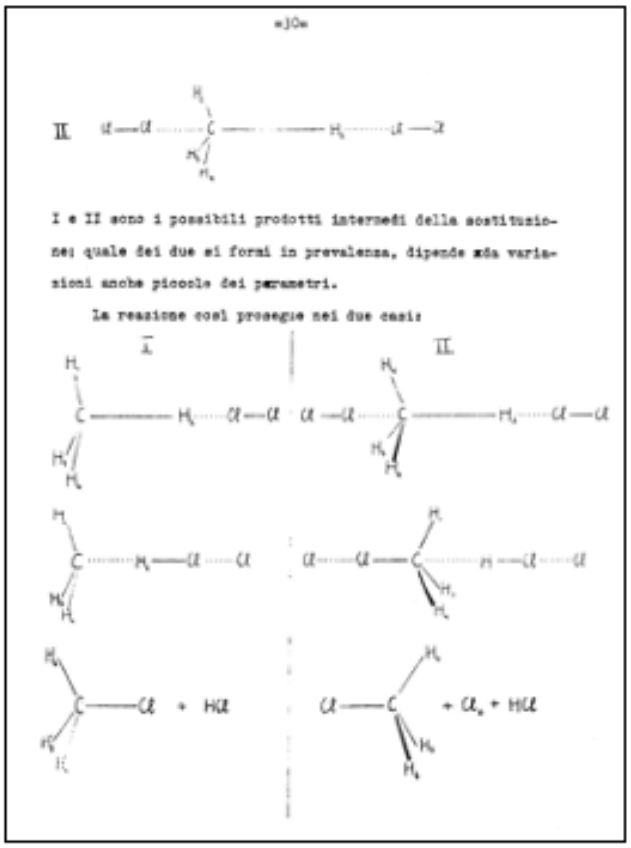

FIGURE 4. Excerpts from Primo Levi's hand-written schemes for his dissertation on Walden's inversion Source: Archivio Storico-Università degli Studi di Torino.

Before going further, it is fair to mention that Levi's stereochemical studies have been detailed by Naso in an Italian magazine.[28] Much of the territory covered here was therefore discussed by Naso, but it is now made available for an international audience. Part of Levi's originality lies in the search for a mechanistic interpretation, which can be summarized in the *"teoria dell'oscillatore doppio"* or *"dell'oscillazione doppia"* ("double oscillation"),[28] a concept formulated by Danish chemist Rørdam in the late 1920s.[29] In short, an optically active molecule after splitting off one of the substituents linked to the asymmetric carbon would oscillate between two configurations, each of which, by the attack of a new group will produce only one of the two possible enantiomers.[30] Rørdam formulated a simplified mathematical treatment, known and mentioned by Levi, accounting for either retention or inversion depending on the distance between the entering group and the vacant place as well as the time of oscillation.[29c] Although the hypothesis is no longer valid, modern computation-aided analysis of Walden's inversion points to geometrical considerations of competitive transition structures.[31] Levi sought out a physical argument for explanation, quoting Giovanni Battista Bonino (1899-1985), in fact the father of quantum chemistry in Italy, who had previously suggested a link between Walden's inversion and configurational stability.[32] Both Bonino and Ingold were pioneers of physical organic chemistry, but the former focused on importance of structure and symmetry,[33] the other on reactivity. Introduction of quantum wording in Levi's dissertation is noticeable if one bears in mind he was 21 only. Bonino's conjecture is reminiscent of Hund's paradox, which tackled the apparent stability of optical enantiomers at the dawn of quantum mechanics.[34,35] As noted above, the oscillation hypothesis deviates from our modern interpretation of the inversion pathway in nucleophilic substitutions, i.e. concerted (not necessarily synchronous) backside attack of the nucleophilic partner and ejection of the leaving group.[25-27] This idea was not generally accepted by chemists until the late 1930s. However, visionaries like Gilbert Lewis had argued, in 1923, that a backside attack was the most (if not the only) reasonable explanation by which an inversion could occur.[36]

ASYMMETRY AT THE END

After WWII and some vicissitudes, Primo Levi got a job in 1948 at a local paint company, SIVA (*Società Industriale Vernici e Affiniti*), an association that lasted nearly three decades until his retirement, which enabled him a familial life (Figure 5). Recognized as industrial chemist and writer,[9,37] with scholarly activity largely vanished, Levi's pursuits in stereochemistry flourished with an acclaimed article *"L'Asimmetria e la Vita"* (*The Asymmetry and Life*), which appeared in September 1984 in a magazine, *Prometeo*, devoted to science, philosophy, and history with a lay audience. The article was subsequently reprinted in different collections (Figure 6),[38] and ultimately in an Italian journal of mathematics, which boosted further scientific interest.[39,40]

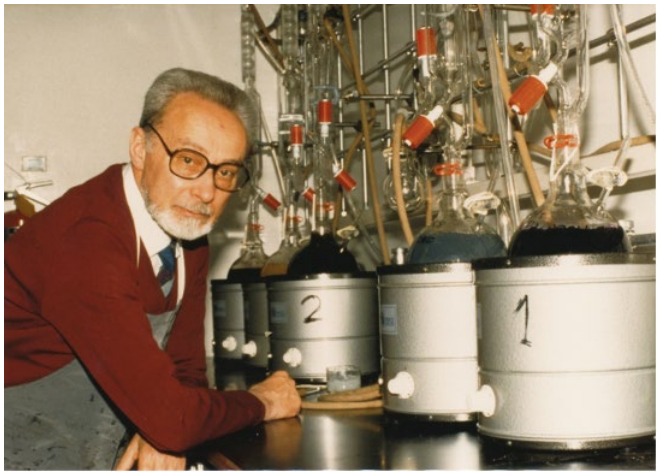

FIGURE 5. Levi's portrait at a chemical factory. Reprinted with permission from Ref. 8. Copyright *Società Chimica Italiana*.

Levi's essay on asymmetry is a fine piece of work. It not only provides a concise overview of molecular handedness (Pasteur's breakthrough and classical resolutions) and its biomolecular implications (left-handed amino acids and proteins), but also discusses the riddle of homochirality in nature. No main mechanism is left untouched: effect of circularly polarizing light; the potential role of chiral inorganic minerals (like quartz); meteoritic sources, or external physical fields (Levi alludes to strong magnetic fields in the early Earth, although clearly a magnetic field alone cannot induce any enantioselectivity under thermodynamic equilibrium). He wonders whether sequences of oligomers with opposite handedness coexisted in primeval times and whether there was a competitive mechanism triggering one enantiomeric bias. Levi suggests that re-investigation of fossil records could be worthwhile to that end:

"E veramente un peccato che nei fossili (salvo quelli recentissimi, come accennato prima) non si conservi traccia dei tessuti organici: altrimenti, sussisterebbe la speranza di rinvenirvi i segni di quell'antica contesa…... O che forse esistano in forme chirali gli scheletri di radiolario di diatomee? Sarebbe un bel tema per una tesi di laurea"

[*It is truly a pity that in the fossils (except the very recent ones, as mentioned above) no trace of organic tissues is preserved: otherwise, there would be the hope of finding the signs of that ancient dispute…... Or that perhaps the skeletons of diatom radiolaria exist in chiral forms? It would be a good theme for a thesis*]

Unlike his 1941 thesis, Levi's *Asymmetry* employs the modern concept of chirality throughout the text, although *optical antipodes* still replaces the notion of enantiomers. Without explicitly mentioning parity violation, Levi indicates that there is a subtle asymmetry at the subatomic level, which breaks the degeneracy of optical isomers, thereby recognizing that no true enantiomers exist in our visible world:

"Se così stanno le cose (si tratta di questioni recentissime,ancora calde), l'universo intero sarebbe pervaso da una tenue chiralità, e le compensazioni sarebbero solo apparenti: l'antipodo «vero» dell'acido lattico destro, o della mia mano destra, non sarebbero l'acido e la mano sinistra terrestri, ma quelli sinistri nel reame lontano dell'antimateria"

[If this is the case (these are very recent, yet hot, questions), the entire universe would be pervaded by a tenuous chirality, and the compensations could be only apparent: the "true" antipode of dextrorotatory lactic acid, or of my right hand, would not be the (levorotatory) acid and left hand of Earth, but the left hand in the far realm of antimatter]

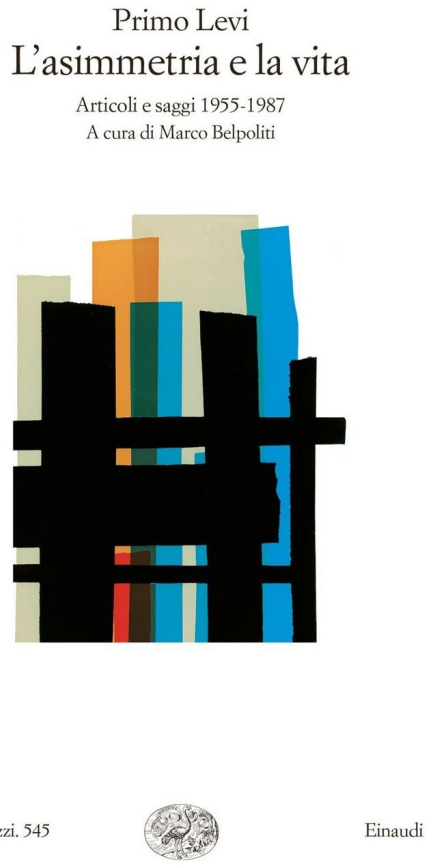

FIGURE 6. Frontispiece of *"L'Asimmetria e la Vita"* in a collection of Levi's articles and essays published posthumously.

Levi also highlights the "fragility" of asymmetry in living organisms, as racemization can easily take place affording the symmetric state composed of both antipodes. Levi invokes Miller's "prebiotic soup" experiments from 1953 as a plausible mechanism to generate key building blocks of life, such as amino acids; however, no asymmetry could be detected at all. According to Levi, Miller explains the origin of life, not asymmetry. The essay also unveils the (now well-established) thalidomide tragedy stemming from the wrong antipode of a therapeutic substance.

CONCLUSION

Primo Levi had a troublesome existence, he experienced racial discrimination and the impact of WWII. Trained as chemist, he graduated with honors in 1941, and working as industrial chemist from the late 1940s, Levi became the scholar and teacher never to be. Ranging from an early interest in Walden's inversion to the origin of asymmetry in the universe, stereochemistry and chirality would have doubtless been dominant elements in Levi's chemical research. He proved to be a diligent student; someone capable of starting an independent career in academia, a potential success frustrated dramatically in a conflicted Europe. Best known by his

"Periodic Table" and other writings expressing personal views on morality and humanity, chemistry is the hidden spectator of Levi's works. The science of matter is the recurring metaphor behind every attitude and situation he witnessed. Primo Levi has become an influential chemist in ways he could never have imagined.

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CONFLICT OF INTEREST

The authors declares no conflict of interest.

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7. (a) Luzzatto S. *Partigia. Una Storia della Resistenza*. Milano: Mondadori; **2017**. 415 p. (b) The obscure point, as documented by Thomson (Ref. [4], p xv), is how far could Levi be involved in the execution of two young partisans during German occupation.

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10. Viterbo D. Primo Levi, William Henry Bragg and the atomic theory of matter. *Acta Cryst* **2013**;A69:452-456.

11. Biographers (Ref. [5]. p 71) indicate that Levi was fully prepared in all subjects by February 1938 and knew Ponzio's inorganic chemistry by heart. Giacomo Ponzio had edited two treatises on inorganic and organic chemistry, respectively, which served as primers for student's instruction: (a) Ponzio G. *Chimica Inorganica*. Torino: Unione Tipografico; **1937**. (b) Ponzio G. *Chimica Organica*. Torino: Unione Tipografico; **1938**.

12. Borello E. Primo Levi, studente di chimica. *L'Ateneo. Notiziario dell'Università degli Studi di Torino* **1997**;XIII(3):6-10 (an excellent overview of Primo Levi as chemistry student, including his thesis works).

13. Although in agreement with the Italian aphorism "*Traduttore, traditore*" ("*Translator, traitor*"), the equivalence among the different types of undergraduate/graduate dissertations in Latin and Anglo-Saxon countries may be inaccurate, if not erroneous, a "*sottotesi*" involves a concise dissertation to earn a Bachelor or related degree, prior to Master or postgraduate studies.

14. Mann T. *The Magic Mountain*. New York: Vintage; **1996**. There are numerous paragraphs mentioning and invoking X-rays in this novel. In fact, *X-ray plates* can be regarded as recurring protagonists. One reads, for instance (p 183, the above-mentioned edition): "And I haven't even had my picture taken with X-rays yet, and only that will give us an objective view of the facts"].

15. In interviews with Levi's classmates, Thomson indicates that Levi had repeatedly spoken of switching to physics, as "chemistry is superficial" (Ref. [5]. p 96, 562).

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22. The term "chirality", coined by Lord Kelvin, was completely absent in the chemical literature for more than six decades. Nor does Levi mention it through his essays. *Chiral/chirality* was re-introduced by Kurt Mislow in the 1960s: (a) K. Mislow, *Introduction to Stereochemistry*. Reading, MA: Benjamin; **1965**. p 51-52; (b) Cintas P. Tracing the origins and evolution of chirality and handedness in chemical language. *Angew Chem Int Ed* **2007**;46:4016-4024.

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24. See Ref. [21a]. p 305, 337.

25. Smith MB, March J. *Advanced Organic Chemistry-Reactions, Mechanisms, and Structure, 5th Ed*. New York: John Wiley & Sons; **2001**. p 391-392.

26. The terms "retention" and "inversion" of configuration may be misleading in the absence of an eye-catching synthetic scheme. In modern stereochemical language, both terms should be denoted correctly as *homofacial* and *heterofacial* replacements, respectively, of ligands attached to the chiral carbon or other chiral center: Eliel EL, Wilen SH. *Stereochemistry of Organic Compounds*. New York: John Wiley & Sons; **1994**. p 134.

27. (a) Eliel EL, Wilen SH. *Stereochemistry of Organic Compounds*. New York: John Wiley & Sons; **1994**, pp. 135-137; (b) Hughes ED, Ingold CK, Martin RJL, Meigh DF. Walden inversion and reaction mechanism: Walden inversion in unimolecular reactions of secondary and tertiary alkyl halides. *Nature* **1950**;166:679-680.

28. For a good overview (in Italian) of Levi's thesis and some linguistic problems linked to English translations by his biographers: Naso F. Chimica, stereochimica e fantachimica negli scritti di Primo Levi: Oltre il Sistema Periodico. Parte 2: Stereochimica. *Chim Ind* **2015**;97:56-60.

29. (a) Rørdam HNK. CCCXXIV-The Walden inversion. Part I. *J Chem Soc (Resumed)* **1928**:2447-2453. (b) Rördam HNK. CLXV-The Walden inversion. Part II. *J Chem Soc* **1929**:1282-1290. (c) Rördam HNK. CCLXI-The Walden inversion. Part III. *J Chem Soc* **1930**:2017-2026.

30. The stereochemical language employed by organic chemists during those years was obsolete and often confusing; i.e. "optical antipodes" to denote enantiomers, or "radical" instead of group/substituent.

31. Buchanan JG, Diggle RA, Ruggiero GD, Williams IH. The Walden cycle revisited: a computational study of competitive ring closure to α- and β-lactones. *Chem Commun* **2006**:1106-1108.

32. Bonino GB. A possible mechanism of racemization and of the Walden inversión. *Gazz Chim Ital* **1933**;63:448-452.

33. Karachalios A. *I Chimici di Fronte al Fascismo. Il Caso di Giovanni Battista Bonino (1899-1985)*. Palermo: Istituto Gramsci Siciliano; **2001**. p 94-95.

34. Hund F. Zur Deutung der Molekelspektren. III. *Z Phys* **1927**;43:805-826.

35. Hund's resolution of the paradox assumes that typical chiral molecules have such high barriers to inversion that the lifetime of a given enantiomer is virtually infinite. Hund's approach is brought to date by injecting a tiny parity-violating term into the Hamiltonian, which results in the two enantiomeric states becoming the true stationary states. For an excellent discussion: L. D. Barron, *Molecular Light Scattering and Optical Activity, 2nd Ed.* Cambridge: Cambridge University Press; **2004**. p 207-213.

36. Ramsay OB. *Stereochemistry*. London: Heyden; **1981**. P 112-113.

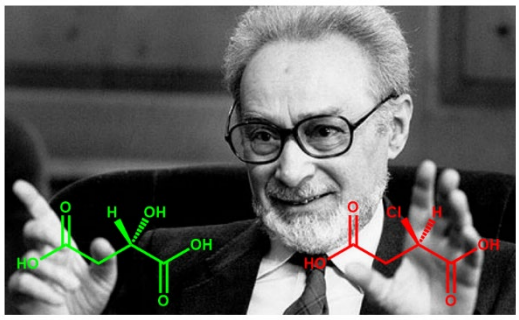
37. Cerruti L. Primo Levi, chimico industriale. *Minerva* **2008**;*2*(*Allegato*):12-20 (An overview of Levi's activities as industrial chemist, in Italian).

38. Levi P. *L'Asimmetria e la Vita. Articoli e Saggi 1955-1987*. Torino: Einaudi; **2002**.

39. Levi P. L'Asimmetria e la vita. *Bolletino dell'Unione Matematica Italiana* **1998**;2A(8):131-141.

40. Levi's article reprinted in the *Bolletino* was followed by a commentary on the profound problem of the origin of asymmetry in the universe. The introductory editorial noted that Levi's arguments could be difficult to understand by a forum of mathematicians, even being people educated in science.

Graphical Abstract



ARTWORK (Separate Figures)

FIGURE 1 Primo Levi's identity card by the time he registered for a Chemistry degree

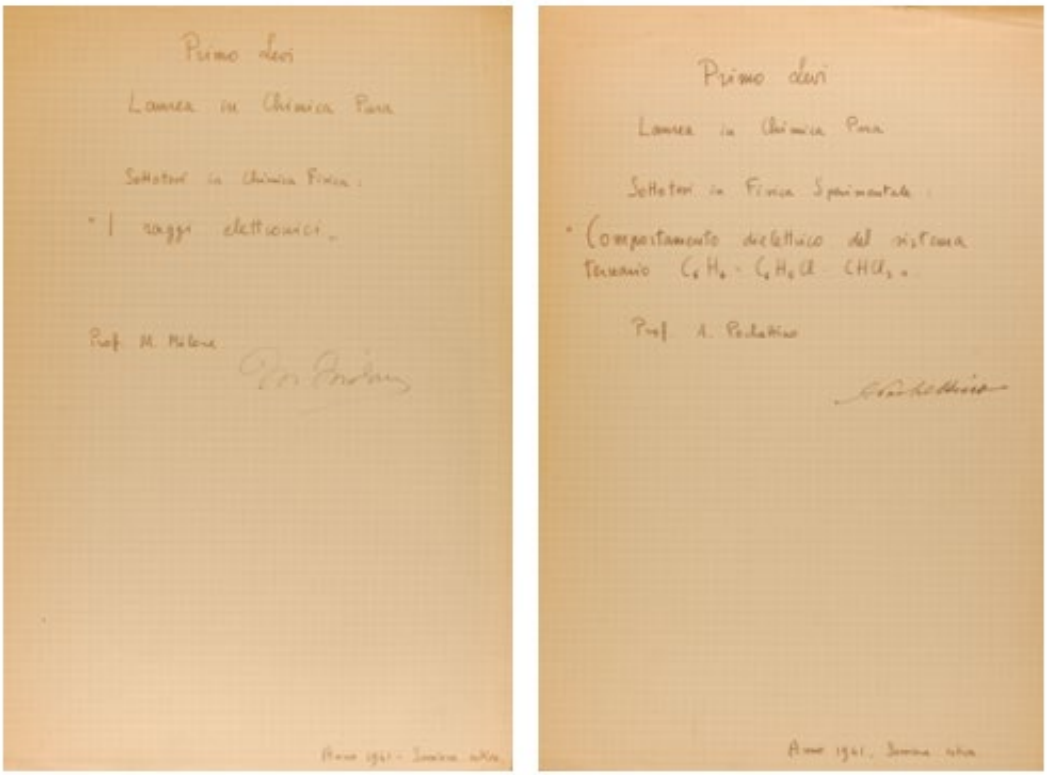


FIGURE 2 Primo Levi's hand-written registrations of sub-theses in Physical Chemistry and Experimental Physics. Source: Archivio Storico-Università degli Studi di Torino

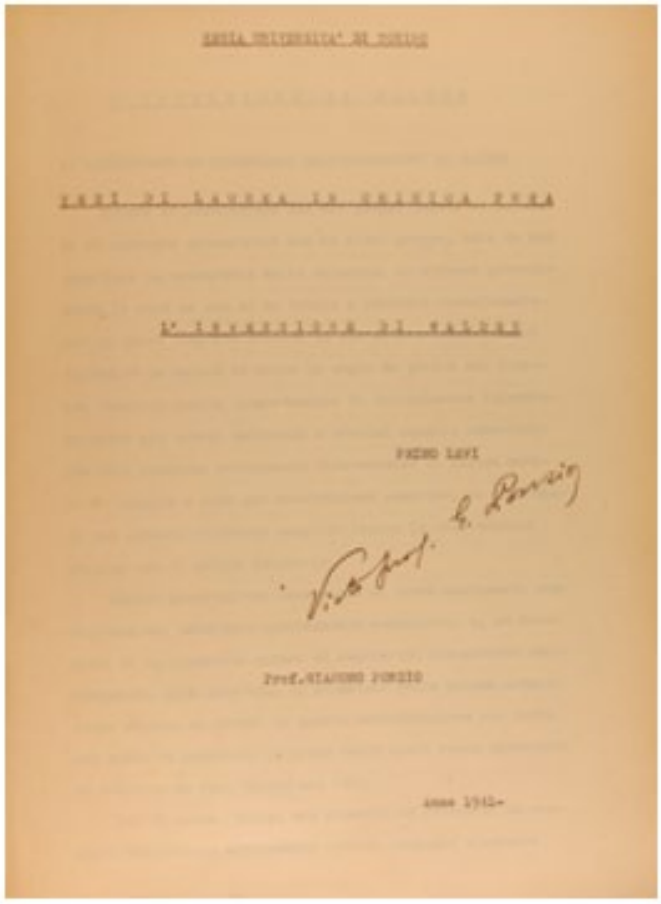


FIGURE 3 Front cover of Levi's main dissertation on Walden's inversion at the University of Turin (1941)

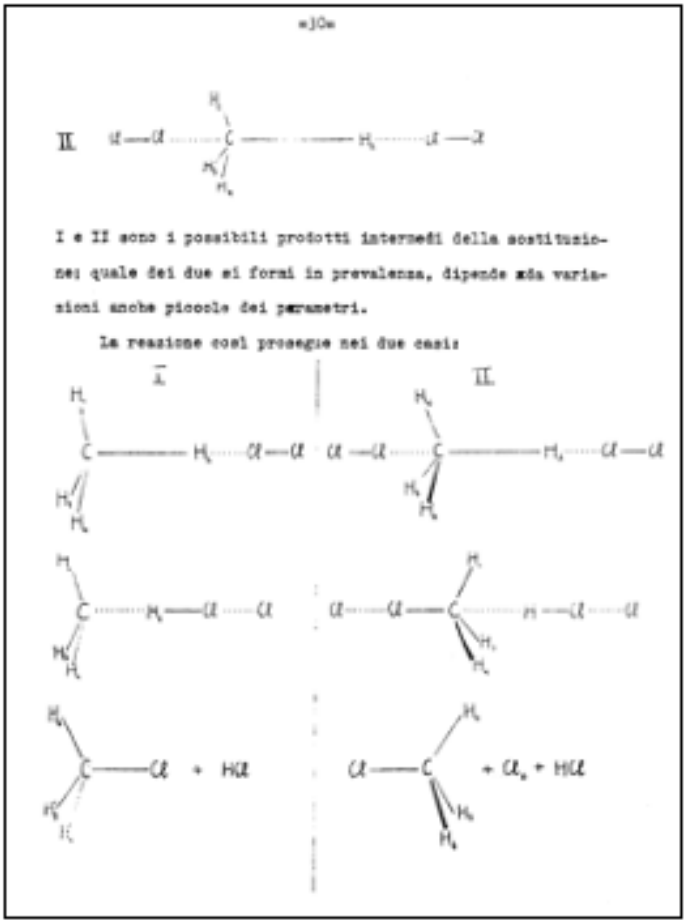


FIGURE 4 Excerpts from Primo Levi's hand-written schemes for his dissertation on Walden's inversion Source: Archivio Storico-Università degli Studi di Torino

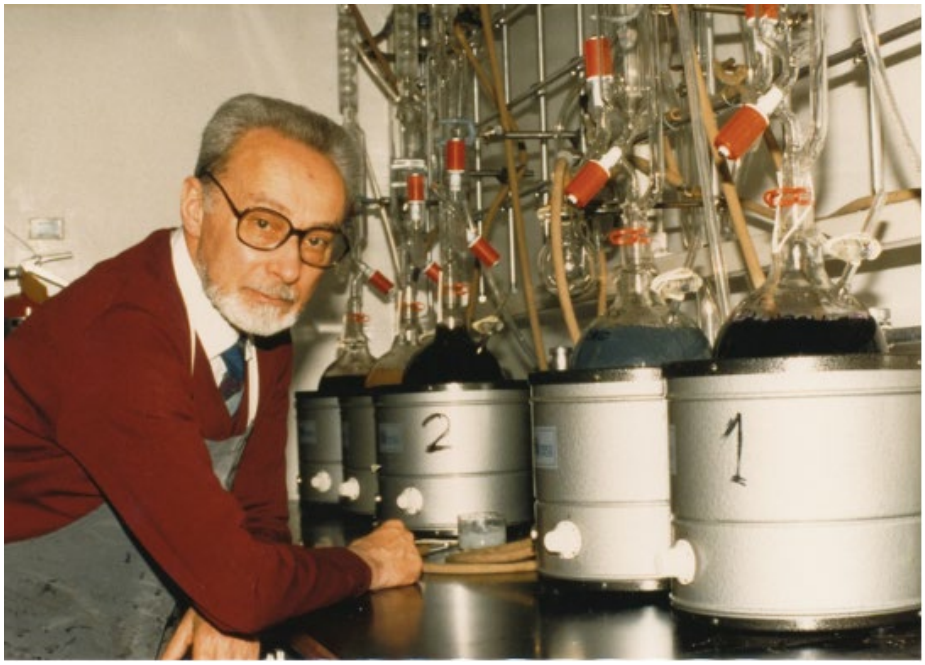


FIGURE 5 Levi's portrait at a chemical factory. Reprinted with permission from Ref. [8]. Copyright *Società Chimica Italiana*

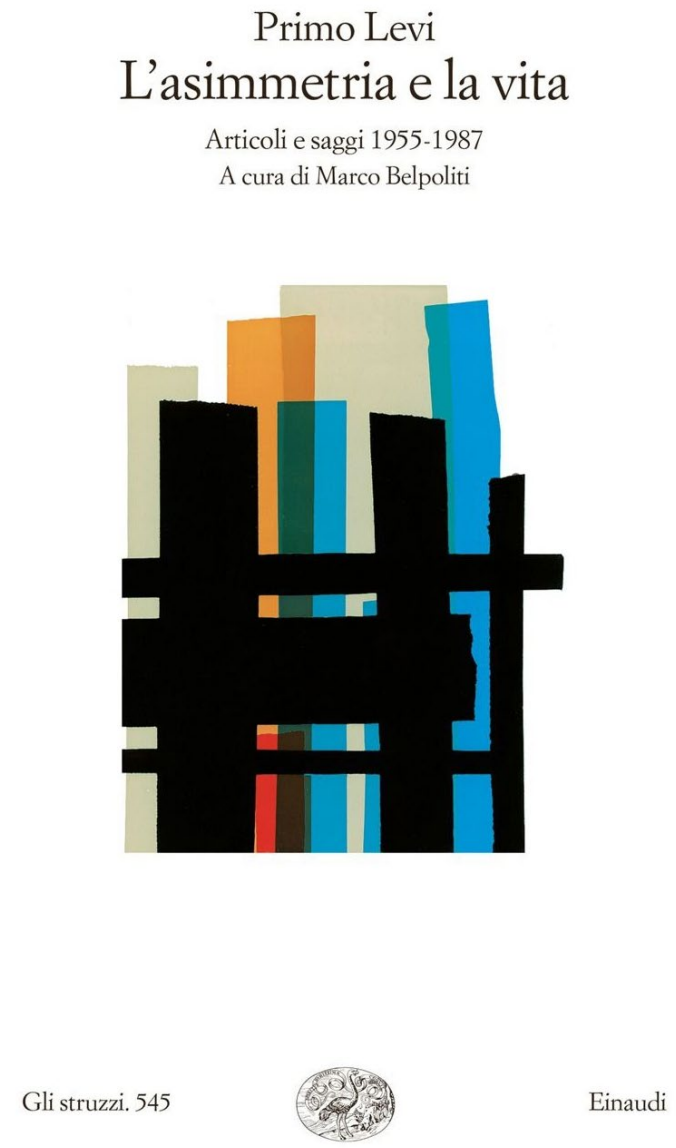


FIGURE 6 Frontispiece of *"L'Asimetria e la Vita"* in a collection of Levi's articles and essays published posthumously

GRAPHICAL ABSTRACT: