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Chapter 14

Lithium

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1. Introduction

Lithium belongs to the short list of elements synthesized during the first three minutes of the universe. According to Big Bang models, the “gradual cooling of matter led to [...] well-known mixture of primordial gas with a mass proportion of hydrogen to helium (H:He) of approximately 0.75:0.25 and a tiny admixture of lithium and an even tinier of heavier elements [beryllium]” [28, p. 172]. One hundred million years later, it was produced by stellar nucleo-syntheses, scattered throughout galaxies, and incorporated into planetary bodies. On Earth, it participated in the evolutionary process of life by bridging gaps between inorganic and organic domains through “multiple physiological manifestations”: ionic transport, modulation of immune systems, stimulation of tissues’ growth, effects on metabolism and defenses against viruses and dermatological disorders [3, pp. vi–viii]. All these skills remained unnoticed until late in human history.

When it entered the chemical stage in the late 1810s, lithium was just a walk-on among dozens of simple bodies identified by analytical

chemists. Indeed, if Antoine-Laurent Lavoisier listed 33 simple bodies in 1789, seven decades later, Dmitri Mendeleev classified around 70 elements in his famous 1869 periodic table. In this chemical race led by Humphry Davy in London and Jacob Berzelius in Stockholm, lithium was found in the private laboratory of the latter by Johan August Arfwedson. This “mineral alkaline” was isolated while analyzing silicate compounds from the iron mine of Utö near Stockholm [7, p. 45]. The name “lithion” (later lithium), which derived from the Ancient Greek word *lithos*, meaning stone, was forged to refer to “its first discovery in mineral kingdom”. This generic etymology echoed the remarkable discretion of lithium until then. Lithium was inscribed in the electro-chemical classification of Berzelius: it was trapped with 30 other bodies in the class of “electro-positive metals” by opposition to (12) “metalloids” and (9) “electro-negative metals”. This soft silvery metal was known to combine with electro-negative bodies (halogens, oxides or sulfurs) to give various solid salts with a high fusibility.

This dull existence lying down in textbooks changed dramatically when lithium met two fields of application in psychiatric treatments and energy storage during the 20th century. The chemical element was thus metamorphosed into two materials: one, a psychotropic drug for medicine and the other, as battery storage for industry. Its material life, which used to be framed by measurement and purification processes, was recomposed to provide broad and deep actions on nervous and electric systems. The lithium-psychotropic drug was extensively used to regulate bipolar disorders of human patients in spite of a number of side effects on brains and bodies while the lithium-ion battery was extensively used to flexibilize the system of electronic devices in spite of undesirable side effects of lithium’s massive extraction on sub-soils and local communities.

This biography intertwines the two social roles taken by lithium in medicine and industry. The following part compares the two historical narratives of lithium, as psychotropic and energy materials, that carry modern myths. The two lithium-based materials are then portrayed at an epistemic level through their ability for crossing the boundaries between nature and culture, between biological, organic, and mineral domains. The third part analyses the global supply chain of lithium for commercial products. This leads to characterize, finally, the two criticality of lithium:

in sociopolitical terms for energy storage; in ethical terms for psychotropic treatments.

1. The Two Lives of Lithium

Historical narratives on psychiatric and energy materials were written and controlled by practitioners rather than historians. This is typical of academic communities, to build their professional identity upon a collective memory [1]. On the psychiatric side, an “official version” of the history of lithium is “familiar to almost everyone who prescribes or carries out research on lithium” [27, p. xvii]. *The History of Lithium Therapy* by Neil Johnson, an English physician, distinguishes three periods: (1) the first uses of chemicals in psychiatry (1850–1900), including the use of lithium bromides to treat mood swings (1870–1900); (2) the “crossing of the desert” for lithium as a psychotropic drug (1900–1950); (3) the successful spread of lithium to treat bipolar troubles (also known as manic-depressive disorders) following the “pioneer” works of the Australian psychiatrist John Cade, in 1949, continued in the 1950s by two Danish psychiatrists, Poul C. Baastrup and Mogens Schou. The historical narratives by practitioners highlight heroic figures (Cade, Schou, Baastrup), moral behaviors (stubbornness) and good practices (interdisciplinary and international approach). A recent book by a former professor of Brown University, Walter Brown, titled *Lithium: A Doctor, a Drug, and a Breakthrough*, tells a “success story” that features John Cade as a hero driven by restless curiosity, working in a shabby room and taking advantage of the economic value of serendipity [11].

To my knowledge, there is no published history of lithium-ion battery. This may be due to its more recent development and the wider number of professional spheres involved: materials research, electrochemistry, energy and car industries, etc. However, the official narrative might spring from the 2019 Nobel Prize in chemistry awarded to John Goodenough, Stanley Whittingham and Akira Yoshino “for the development of lithium-ion batteries”. Their gathering in the same narrative was not obvious. Indeed, each of their Nobel lectures on December 2019 gives an idiosyncratic historical account related to their own techno-scientific interests and professional trajectories. Moreover, a six-page analysis of the history of

lithium-ion battery by one STS specialist of the domain mentioned only Goodenough and Whittingham (without Yoshino) with two other groups: Joseph Kummer and co-workers at Ford Motor Company; and Archie Hickling at University College, Leicester [15]. Yet, the symbolic prestige of the Nobel Prize may change the situation by popularizing the following simple and linear account:

In the early 1970s, Stanley Whittingham used lithium's enormous drive to release its outer electron when he developed the first functional lithium battery. In 1980, John Goodenough doubled the battery's potential, creating the right conditions for a vastly more powerful and useful battery. In 1985, Akira Yoshino succeeded in eliminating pure lithium from the battery, instead basing it wholly on lithium ions, which are safer than pure lithium. This made the battery workable in practice. Lithium-ion batteries have brought the greatest benefit to humankind, as they have enabled the development of laptop computers, mobile phones, electric vehicles and the storage of energy generated by solar and wind power [36].

Another scheme shared by practitioners' narratives on lithium is their linking to systemic mutations, namely "a third revolution" in industry and psychiatry. On the industrial side, the "third industrial revolution" is supposed to follow the steam-engine and coal revolution (1750–1850) and the second one, due to electricity and oil (1870–1930). It refers either to the current era of telecommunication or to the emerging economy based on renewable energy. Lithium-ion battery regulates energy storage for portable devices, electric vehicles and renewable energies as stressed by the 2019 Nobel account. On the psychiatric side, the "third revolution" is supposed to come after a first period when "doctors began to treat the mentally ill as patients rather than criminals" (19th century) and a second one linked to the growing importance of Freud's theory (1880–1950) [19]. It refers to the extensive use of chemical drugs to treat mental illness, including lithium for bipolar disorders after 1950.

These broad periods must be refined in light of historical results. The second part of the 19th century sets the scene for lithium to take on its two social characters. On the medical side, a "system of medical economy" gradually fostered research, development and industrial

production towards new “therapeutic agents” based on biological, chemical and physical processes [9, pp. 11–14]. The biomedical approach was strengthened by the “bacteriological revolution” at the end of the century (1880–1900). It coincided, in psychiatry, with the growing importance of a “neuro-physiological approach” that gradually challenged the domination of the alienists (1850–1930) [29, p. 9]. Brain therapy was first dominated by fever treatments and, from 1935 onward, by electroshock treatments [34, p. 8]. Except for a few anecdotal cases, lithium was not used as a psychotropic drug during the 1850–1950 period, but the infra-structural basis of its existence was set. This is also the case for lithium-ion battery. The three features that made electric storage possible and necessary were settled between 1850 and 1930. First, the concept of energy was formalized by thermodynamics (1840–1850). Then, the 1859 lead-acid battery of Gaston Planté became the model for a new kind of battery, labeled “secondary battery”, which can be charged and discharged alternatively. Secondary batteries were industrially manufactured by electricians and engineers and sold for the market of electric vehicles [35]. Finally, power grids were built and extended all over Europe and the United States by industrial giant corporations (1880–1930) that are still flourishing nowadays [26].

In both cases, World War II was a transition landmark. For medicine, it boosted the expansion of a medical–industrial complex in Europe and the United States, while health became a central political issue and an economic heavyweight of the mass market [21, pp. 11–15]. Psychiatry was characterized after 1945 by “the closure of mental hospitals and the rise of community care” as well as the increasing use of chemically synthesized psychotropic drugs from the 1950s onward. Two major drugs were tested clinically in 1954: lithium, by Mogens Schou, in the treatment of mania; chlorprozamine, by Jean Delay and Henri Deniker, for its anti-psychotic potential. Psycho-pharmacology increased in the 1950s side by side with the increasing regulatory role of the states and the growing size of the pharmaceutical–industrial complex. The 1970s were marked by the authorization of lithium treatments for bipolar disorders by Food and Drug Administration in the United States. The social regulation gradually shifted “from the cane to the pill” over the 1945–1975 period [10].

State investments and regulations for strategic materials also increased during the Cold War. This framed “a military–industrial–academic complex” for research and development of new advanced materials [31] Solid-state batteries emerged in the late 1960s at the crossroad of academic and industrial stakes: sodium-sulfur battery in 1967 at Ford Motor Company; lithium-ion battery in 1972 at Exxon. These two petroleum-based companies were exploring the possibility of high energy density battery for electric vehicles. In the 1970s, lithium-based batteries were fostered by the oil crises and environmental critics against petroleum. Later advancements led to the commercialization of the “lithium–cobalt–oxide battery” by Sony in 1991 and AT&T in 1992. This technology prevailed for energy storage on the mass-market of electronic portable devices such as mobile phones and laptop computers. Strikingly, the 1970s radical political groups had opposite opinions on lithium: while they pushed up lithium-ion batteries through electric vehicles and renewable energy for environmental purposes, the anti-psychiatry movement opposed the extensive use of chemicals, including lithium, in psychiatry.

2. Models and Performances

The development of lithium materials for psychiatry and energy relied on epistemic models and experimental tools. The process was nurtured in the “triple helix of university–industry–government relations” that characterizes “the global knowledge economy” of the second half of the 20th century [16].

Psychiatrists perceive the injection of lithium drugs as a means to regulate the nervous system of their patients and to reduce their pains. Their development and production were driven by the medical–industrial complex worth US\$ billions for psychotropic drugs in the 1970s. Chlorpromazine, synthesized by Rhône-Poulenc in the early 1950s and known as Thorazine, was the first anti-psychotic medication: it was used by European and North American psychiatrists to “calm many schizophrenic patients without sedating them [...] Increasingly during the 1960s and 1970s, hospital psychiatrists were using a number of phenothiazine derivatives to treat schizophrenia, lithium carbonate to stabilize manic patients and imipramine to relieve psychotic depression” [33, pp.

334–335]. In the 1980s, in Europe and North America, around “one person in about two thousand” regularly took lithium for bipolar disorders [27, p. xiii]. After decades of intensive pharmaceutical R&D to find other “classes of drugs as anticonvulsants and atypical antipsychotics,” lithium is still used to regulate “abnormal mood swings” of bipolar patients in the 21st century [5, p. 267].

The simplicity of lithium drugs made the positive ion Li^+ an epistemic model to understand the psychotropic effects of neurotransmitters. Many practitioners assumed that the interactions of lithium-ion with the nervous system would be simpler to characterize than the large organic molecules of other psychotropic medicines: chlorpromazine, reserpine, amphetamine. They tried to substitute lithium for other alkali ions like sodium (Na^+) or potassium (K^+) [27, p. xv]. The assumption of simplicity proved to be empirically wrong.

It is also in its ionic form that lithium works in batteries. Small electropositive ions (H^+ , Li^+ or Na^+) were known to move quickly in bi-dimensional structures such as graphite, tungsten bronzes and beta-alumina. This property increased the conduction of electricity in solid-state matter. The idea of using bi-dimensional crystals as cathode materials for advanced batteries was driven by car makers seeking power sources for electric vehicles and by the US Army for light portable electronic devices [2, 43]. It was hoped that solid-state electrolytes would carry more electricity than traditional liquid ones. A NATO conference held in 1972 in Belgirate (Italy) spurred academic and industrial interactions [22]. Cathode and anode materials, which alternatively store ions, posed technological problems. The Stanford Materials Research Laboratory directed by Robert Huggins oriented Michel Armand and Stanley Whittingham toward the use of titanium disulfide for cathode. When he left for Exxon in 1972, Whittingham reused this material to design a workable solid-state battery in the mid-1970s. When Goodenough substituted titanium disulfide for cobalt oxide, the performance of the battery was doubled. Yoshino designed the other side of the battery, the anode, with graphite. During discharge, the lithium-ion left graphite (anode) to intercalate into the welcoming layers of the cobalt oxide, while, during the charge, the electric power forced the lithium-ion to go back and intercalate into the atomic layers of graphite. The reversibility of the discharge–charge cycle

was increased by reducing chemical side effects. The 1991 Sony battery, which incorporated a cobalt oxide cathode, a graphite anode and a lithium-based salt as liquid electrolyte, had a specific power of 100 watts per kilogram [38, p. 19]. Its performance has been tripled for three decades but stays at a quarter of its theoretical maximum. Its nominal tension of around 3.6 volts is also the triple of its closer technological competitor, nickel-metal hydride battery. By increasing the quantity of stored energy, lithium-ion batteries increase the autonomy of electronic devices and loosen the meshes of power grids.

The two lithium-based materials share similar traits. Both perform ahead of their commercial competitors but exhibit serious drawbacks. In psychiatry, lithium is used to control symptoms without curing illnesses. In energy, lithium-ion battery is highly inflammable due to the ether-based liquid electrolyte used by Sony. A safer technology based on solid-state electrolytes was developed by Armand with a reduced power [4]. Both materials also required interdisciplinary research. In psychiatry, “pharmacologists, biochemists, physiologists, psychiatrists, psychologists, and many others, joined forces in the search of the century — the search for the key to mental illness” [27, p. xv]. In energy, lithium-ion battery gathered researchers from materials science and engineering, solid-state chemistry, electrochemistry and physics. This might be linked to the fact that both domains required the convergence of instrumental tools (statistics, devices) and theoretical knowledge (models, theories) to stabilize results and provide efficient products [15]. Lithium bridged gaps: between psychiatric phenomena, suggesting “that mania and depression are closely linked conditions and, in all probability, share a common underlying mechanism” [27, p. xvi]; between research fields like “intercalation chemistry” and “solid state ionics”. The role of model-material in both domains hides a strong difference in the comprehension of the action of lithium: clear in electrical systems; fuzzy in nervous systems.

3. Global Division of Work

From an economic perspective, lithium supports two global mass-markets. The market of lithium-ion battery is bigger and increases faster with the expansion of portable electronic devices and of electric vehicle markets:

around \$35 billion worldwide in 2019 with a 14% annual increase. By contrast, the US market of lithium psychotropic drugs would be worth around 1 billion dollars nowadays. The quantitative difference lies in the fact that, even if the pharmaceutical industry has a high added value, there are much more laptop computers and cellular phones than bipolar treatments so far in society — in the United States, around 300 million phones and 3 million prescriptions of lithium — and that each electronic device contains more lithium than an annual drug prescription: 1 gram for a cellular phone; 10 grams for a laptop computer; more than 3 kilograms for an electric vehicle; less than 1 micro-gram in one pharmaceutical dose. In its medical life, lithium is so cheap compared to other psychotropic drugs that it is no longer of interest for industry [5, p. 268]. According to Anna Fels, an American psychiatrist, the “grim and undeserved reputation” of lithium as a drug is partly due to the industrial disinterest [18]. She uses the fairy tale of *Cinderella* to balance symbols: “lithium is the Cinderella of psychotropic medications, neglected and ill used” like this poor girl despised by her step-family (i.e. corporations?).

The mass production of lithium-ion batteries is characterized by a harsh economic and political competition to control the international supply chain, from the extraction of raw materials to the refinement of advanced materials and their integration to commercial batteries. Two countries, Australia and Chili, are by far the two first for the extraction of lithium ores [41, p. 178]. Three transnational companies — “the Big Three” — hold more than 50% of the global market of extraction and refinement of lithium materials: Albemarle and FMC Corporation of US origin and SQM of Chilean origin [24, pp. 24–27]. However, the increasing demand of lithium-ion batteries for the energy transition may change the balance of power in a near future. Chile and two of its neighbors, Bolivia, and Argentina, form the “lithium triangle” since they would hold 60% of the globe’ known lithium deposits [41, p. 17]. Thanks to the salt flat of Uyuni, a 10,000km² area at 3,600 meters above sea level, Bolivia detains two-thirds of the known world reserves of lithium. At the other side of the chain, China buys around two-thirds of the lithium bulk materials for the production of around half the lithium-ion batteries in the world, the second half being shared by Japan and South Korea. Some business analysts draw a parallel between South America for the extraction of

lithium and the Middle-East for that of petroleum, where China would play a similar leading role for lithium as the United States for oil. This is not so obvious for at least three reasons. First, there is no common policy between the three South American countries of the “lithium triangle” and the transnational companies can be stronger than the national states to negotiate the financial conditions of extraction [41, p. 234]. Then, the production costs are relatively low throughout the entire supply chain, the global market of lithium-ion battery being 20 to 30 times larger than that of lithium bulk materials. Last but not least, lithium, although strategical and rare in the short term, is not the most critical element, in the long term, to produce a lithium-ion battery. When considering the ratio reserve/production in the late 2010s, lithium is 2–3 times most critical than rare earths but 10 times less critical than nickel and cobalt [24, p.7].

Thus, the problem is not a geological constraint of ore reserves, but the regulation of the supply chain to get good quality materials in sufficient quantity and at acceptable prices [30, pp. 43–44]. Therefore, Goodenough is still rather “keen on a sodium anode because [...] it is available to anyone with access to an ocean, whereas lithium may one day, like oil, require what he calls ‘gunboat diplomacy’ to secure supplies” [23]. Even if the “gunboat diplomacy” of the early 20th century has not yet returned, the mining competition tends to favor the development of military conflicts, especially in Africa. Working on empiric data covering 92% of African countries and including 14 minerals (but no lithium), geographers established a statistical correlation between mining business and the increase of average violence and spatial extension of military conflicts during the 1997–2010 period, when international prices of raw materials rose due to Chinese and Indian growing economies [6].

4. The Sociopolitical Criticality of Lithium for Energy

Besides economic values, mining generates ecological wastes and social disorders that are all the more dramatic than the states are weaker to negotiate the local conditions of extraction with the transnational companies. The history of Latin America is gashed by many environmental and social problems induced by large-scale mining, as sharply pictured by the iconic

essay of Eduardo Galeano: *Open Veins of Latin America: Five Centuries of the Pillage of a Continent* [20]. It tackles the political problem about how lands, works, damages and benefits are distributed between local groups and international powers. Interestingly, Bolivia is “one of the poorest countries” of South America while it has “one of the longest histories of mining” [40]. After the 1985 tin market crash, it turned its “tin-based economy” toward alternative mining businesses (gold, zinc, silver, lead, lithium, potassium) to avoid mine workers joining illegal activities of smuggling and cocaine traffic [14, pp. 84–85]. This national “extractivism” induced strong environmental and social problems in Bolivia, which forced indigenous communities to enforce their territorial rights [39, pp. 102–109].

The left-wing administration of President Evo Morales (2006–2019) used the rise of the international prices of raw materials, especially natural gas, to increase the public investment for the development of mining and industry. Its 2008 creation of a state company, Yacimientos de Litio Bolivianos (YLB), aimed at building the entire supply chain of production in Bolivia since the profit increases through the chain of value, from raw materials to advanced devices. Economic agreements were concluded with transnational corporations based in Asia (China, Japan, South Korea), Europe (France, Germany) and North America [12, p. 93]. If the foreign know-how and investments were needed, the private–public conglomerates were put under public control with 51% shares belonging to the Bolivian state [32]. Such a strategy was intended to increase the state control and collective benefits at the expense of private interests.

The lithium supply chain exhibits the sharp constraints due to the unbalance of power between the ubiquitous transnational corporations, the industrial states that control the production of advanced materials generating high added-value (Asia), and the extractive states where the extraction of bulk materials generate industrial wastes and social conflicts (South America, Africa). A fourth powerful set of actors, Northern America along with Europe, takes advantage of this global division of work by a mass consumption of storage batteries hidden in electronic devices and electrical systems. Indeed, lithium-ion batteries and fuel cells are useful to store energy in electrical systems powered by intermittent renewable energy such as solar and wind powers. They regulate the electrical systems from off-peak to peak hours of consumption and the unpredictable

meteorological fluctuations through time and space. This partnership over-sells the image of an ecological transition toward a carbon-free economy where “green” (for renewable) and “blue” (for hydrogen) are valued in contrast to “black” pictures (for oil) [42, p. 71]. The tone is even more epic in the 2019 Nobel Prize narrative where the expansion of smart-grids powered by renewable energies is said to work for the “greatest benefit of humankind” [36]. No room is left for the *far-from-Stockholm* environmental and social side effects of the mass extraction of lithium in South America and the mass production of lithium-ion batteries in China. Instead, this politically correct discourse weaves an harmonious symbiosis between fundamental research and industrial profits.

5. Ethical Criticality of Psychotropic Lithium

If lithium-ion batteries contribute to regulate electrical systems, lithium pills did the same for psycho-social systems. Three aspects of lithium regulation will be considered: side effects of medication, the ethics of therapy and the anthropological question of brain regulation. The first issue does not mention social and environmental damages for communities like in the case of lithium mining but biological and psychological effects on individuals. Several effects of lithium have induced “crises” among therapists and patients since the 1950s: thyroid disturbances; renal damages; accentuation of cardiac deficiency; cardiac malformations of fetuses in pregnant patients [27, pp. 123–129]. Psychotropic drugs can also generate nauseous states and sickness in patients. The side-effect issue is related to the antique question of *pharmakon*, in which a drug can have poisonous or therapeutic actions. A good therapy encompasses standards of medication (frequencies, quantities, forms), users’ practices (including misuses and over-medication) and patients’ idiosyncrasies (individuality, history). As the negative side effects are usually recorded to produce improved drugs [37], it could be expected that the epistemic gap between the statistical results and the patients’ individual experience would be overcome [13, p. 648]. However, the lithium effects on sample populations during 50 years of clinical trials [25, pp. 534–536] hardly converged with the trial-and-error adjustment for a “long-term or even life-time medication” to get a suitable therapeutic performance.

This epistemic discrepancy questions the ethical values of pharmaceutical treatments to regulate and control the social behaviors of individuals. Lithium may contribute to “the intensified standardization of human beings”: a century after the industrial standardization of products such as batteries, the individual is threatened to become an *homo artefact* through mass-market series [8, pp. 142–144].

Besides personal and ethical impacts, the chemical normalization of psychiatry led to a third set of issues at the anthropological level. What becomes of the individual when he is deeply regulated by psychotropes? “In such a medicalized culture, diagnoses make sure that individuality is left in the dark — and along disappears the individual’s struggle for freedom and autonomy” [8, p. 142]. The individual is also the one who acts, thinks or feels, remembering, refusing or hoping for his evanescent self. To what extent would it be possible to break out of the regulated box under lithium?

*Lithium, don't want to lock me up inside.
Lithium, don't want to forget how it feels without...
Lithium, I want to stay in love with my sorrow.
Oh, but God, I want to let it go [17].*

6. Conclusion

A ubiquitous element, lithium reached an academic status in 19th century chemistry labs and textbooks before embarking on two parallel careers in 20th century consumer societies: energy and psychiatry. In both domains, it climbed the social ladder to advanced materials thanks to the joint efforts of industrial complexes, research laboratories and state policies. It became strategic for psychiatric treatments in the 1970s and for energy storage in the 1990s. In spite of defects and risks, its small, interactive, boundary-crossing ionic form makes it a world leader to treat bipolar patients and to energize electronic devices and electric vehicles in the early 2020s. This was due to its great ability to regulate nervous and electrical systems according to managerial and economic standards. On the social side, lithium was criticized for ethical reasons. It was enrolled under the green banner of the energy transition toward a carbon-free utopia, whereas its large-scale mining provoked environmental damages and serious social disorders. Its psychotropic use provided relief to some

human sufferings by making individuals less energetic and its therapeutic extension hardly hid the growing psycho-social pressures of capitalist competitions. Finally, lithium-based materials collaborated toward the normalization of individuals on the psychiatry side and the flexibilization of electric systems on the energy side.

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