ECONOPHYSICS Section

THE HISTORY OF INVENTION OF LITHIUM BATTERIES (1970-1985): AN EXAMPLE OF “ZETA-MANAGEMENT”

Alain Le MÉHAUTÉ*, Frédéric HÉLIODORE**

Abstract. *Seizing the alibi of the 2019 chemistry Nobel prize, and after recalling the formal content of the concept of “Zeta-Management” whose major goal is the innovation, the purpose of this note is to use the history of the early design and pre-development of the Secondary Lithium Batteries to highlight one of applications of this type of management (implicit in the 1970s). “Zeta-Management” must be contrasted with the "h-management" (bureaucratic management), which is practiced when the invention and development of innovation is already acquired, the social structure wants to enhance its "genius" and its "ethos" through uplifting tales.*

Index terms: *History, Lithium Batteries, Zeta function, Spectral Time, Management, Creativity, Invention*

1. Introduction to Zeta-Management: the power of incompleteness

In his Essay titled “Les données immédiates de la conscience” (“On the immediate data of consciousness”, 1889) Bergson wrote “Duration seems to act in the manner of a cause ... under these conditions a presumption in favor of a conscious force or of a free will may be invoked which, subject to the action of time and duration of storage, would thus escape the law of conservation of energy”. We will show that Bergson had an almost accurate intuition about the ambiguous role of energy (versus entropy) in life sciences and more generally in complex systems characterized by certain recursive orders. While the postmodern managerial mind is addicted at “Excel Ethics”, “Power-Point mind” and “Gauss distribution” to justify short term “effectiveness”, far from “Mediocristan” [1], we will prove the relevance

* Materials Design SARL and Co, 42 avenue Verdier 92120 Montrouge France & Department of Physics, Kazan Federal University, Kremlyovskaya St. 480008 Kazan, Russian Federation (alm@materialsdesign.com)

** General Electric Renewable Energy, 204 rond Point du Pont de Sèvres, 92100 Boulogne Billancourt (frederic.heliodore@ge.com)

Bergson's approach. The proof will be provided by a new method of controlling complex systems (usually considered as creative, therefore uncontrolled!) named Zeta-Management. In a non-Euclidean geometry framework, this method will be based on a non-linear dual relationship between space and time. The Zeta-Management will be opposed to Algorithmic Management here called "*h*-Management".

1.1. Time and relativity of the point of view

One of the most radical revolutions about the concept of time in the 20th century was brought about by Einstein's relativity. The idea is simple. Let us first imagine a cavity at rest in which a wave (laser, maser or acoustic wave) enters in resonance. Since the velocity is zero, the resonance provides the beat of a clock whose frequencies measured by a couple of observers inside the box and outside the cavity are similar. Nevertheless if the cavity is brought to a high speed, the inner unit of time is contracted (frequency decreased) relative to the unit of time at rest (observer resting outside). This temporal dichotomy, added to the fact that the velocity of light is constant, gives rise to the Langevintwins paradox. According to Hilbert's analysis, Lorentz's transform, which formalizes this paradox, is associated to a non-Euclidean geometry. The covariance in relativity is well known and even now widely extended [2]. The concept that interests us to illustrate the history of the invention of secondary lithium batteries is also based on a kind of relativity.

Indeed, let us consider the analysis of time in fractal geometry characterized by a dimension $1 < d \leq 2$. Surprisingly, it leads to the same type of hyperbolic duality [3]. The non-integer metric in space leads to the emergence of a space-time dichotomy of the rhythmic – in practice the emergence of two critical frequencies $(\eta, 1/n)$ – implying a distinction between intensive beat (space η) and extensive beats (1/time: n). The two values are related to each other, but instead of the usual relationship expressed by a mean velocity, the fractal dichotomy is unified through a phase angle "φ" when the representation in the complex plane is used. This angle can easily be revealed and evaluated experimentally, e.g. when complex compounds are tested [4, 5]. Figure 1 illustrates the importance of this angle for electrode of standard batteries but the main heuristic content of this observation is the lack completeness behind the presence of this angle.

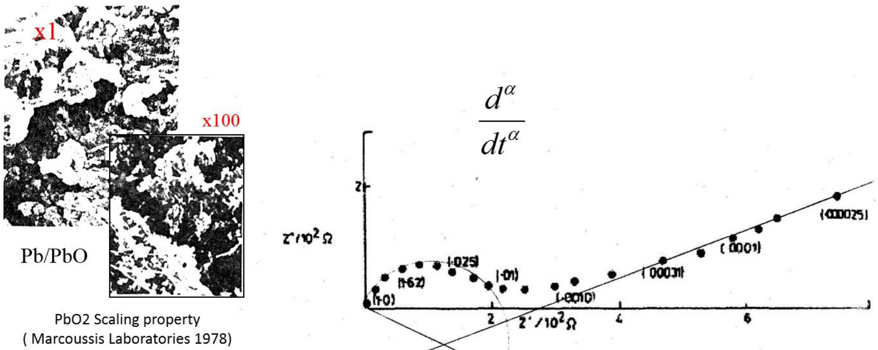
We can show that this lack can be extended to any action in any complex environment. Although this is not obvious when analyzed from a standard point of view [6, 7], the fractal geometric model allows adjusting this lack to the arithmetic (discrete features) of the dynamic characteristics (usually continuous) in non-scalable environment. As in Einstein's relativity, the coupling of space/time rhythms defines a very specific transformation – here using (scalable) power law in a complex plane – which, according to Hilbert's revolutionary point of view, characterizes any given geometry: here the set of the geodesics of any dynamics in fractal environment. The fundamental feature that distinguishes both Einstein and fractal approaches, lies in the fact that in the case of Lorentz transform, the notion of velocity L^2t^{-2} keeps its usual relevance and ensures both a linearization of the space / time and a symmetry of the time signature via a quadratic expression of energy: $E = ML^2t^{-2}$. The Lorentz transform retains the meaning of the concept of energy. In fractal dynamics, as geodesics are not differentiable, it cannot be so; the concept of velocity loses its meaning and with it the concept of energy.

Even if such a situation implies a certain skepticism and some paradoxes in the traditional physical framework, we assert the relevance of this approach because fortunately, the concept of entropy retains its meaning and can be used to move forward even in the analysis of physical issues. Moreover, as the non-linearity of the space/time relation must be taken into account in the framework of a functional space (here Fourier space), a scale covariance naturally emerges (conservation of laws as the scale changes) and the use of mathematical convolution techniques is then well suited to any analytical objective. In practice, the invariance of physical laws uses the Fourier variables as gauges of scales. Consequently, analysis naturally leads to consider the following space / time relationship $\eta \times (in)^{\alpha} \sim 1$, a relation which introduces in the simplest possible way the Cantorian metric α but also (except for the symmetrical situation $\alpha = 1/2$) implicitly $(1 - \alpha)$ the dimension of its co-space. The presence of this co-space is the reason of acertain incompleteness and the involution between the two spaces is placed exactly at a breaking point of symmetry.

This breaking point provides the formal kernel for what we have called Zeta-Management [8]. This new methodology leads to sift our environment through non-linear spatial-temporal sieve, partially controlled by the dynamic action / reaction balance. This duality structures the complexity of the Topos, which determines the logic associated to the active posture when we remove the reference to a rate of efficiency (velocity) in relation to energy (utility) and when the time of marketing is not the time of design or even manufacturing. This analysis virtually integrates the Taleb approach that takes into account the rare events out of Gaussian statistics [1]. By giving a method to control the low-level signal hidden by noise, the symmetry breaking, the creativity of a singular status of a "being", the Zeta-Management, born with secondary lithium batteries and processing scalable Categories, offers a method to address the mechanism of the singular "breakthroughs" whose societies are used to.

1.2. Zeta-Management and "h-Management"

Let's try to explain the originality of Zeta-Management. Every "postmodern scientist" knows what the international significance of his "impact factor" or "*h*-factor". By a strange oxymoron, this factor is used to "quantify" the "quality" of his scientific works. Any "scientist" also knows how this factor is used by research institutions to determine the financial support that can be given to his or her team or even to give them access to academic positions or the media. This digital management (*h*-Management) is based on concepts that seem obvious and unavoidable. This obviousness is only due to the trivial use of basic arithmetic standards and also of continuous functions (locally defined) that are mainly linearized. It is only due to the use of mean values, derivatives, and velocities etc. as paradigmatic notions for thinking. Hiding reality and blinding the mind, these paradigms can be dangerous. At the theoretical level, they lead to the description of processes which, due to Noether's hypotheses, are all based on the existence of an invariant integral form (Energy or Economic utility KL^2t^{-2}), notions based on the invariance of action (optimization) when the time must be shifted: $t \rightarrow t + k$, and even reversed ($t \rightarrow -t$) without consequences as in physical laws; all hypotheses denying the meaning of history, even the intrinsic reason for management. Reducing the human being to a particle and mimicking what any natural geodesic process does, "*h*-Management" only seeks the reduction of all sources of entropy (would the art of dreaming, sleep, contemplation, literature, philosophy etc. be useless then). By a strange inversion of the Cartesian point of view, it is no longer the being that controls the nature but nature that controls the human being. Conversely, if the "physical time" remains a variable without absolute orientation (signature), due to the tacit use of the paradigm of energy/disutility integrals, any econophysical processes can however be a source of entropy (i.e. an irreversibility of duration) because the bases of the concept of macroscopic velocity are mainly stochastic (Einstein's Law, Fokker-Planck equation etc. in physics or free local agent in socio-economics).



Complex-plane plot of a $PbSO_4$/Pb electrode on pure lead in H_2SO_4 (M = 5 mol/l) at –970 mV vs. Hg/Hg_2SO_4, 23°C, surface 7.1 mm², frequencies in kHz in parentheses [KELLY81]

Figure 1. Duality and incompleteness observed in physics: Remarkable physical examples of non-integer dynamics is given in the thesis of E. Karden's (Figure 1[5], figures 20 & 21). These figures emphasize the phase angle locking related to the non-linear relationship that links the discretization of space and time (note the characteristic angle matching the theoretical 45° between transfer and diffusion limitation [3]) and give rise to fractional dynamics of the energy exchange when the battery is working. Although very simple at chemical level (first-order dynamics) due to the fractal geometry of the lead electrode whose fractal metric is given by d = 1.40, the dynamics of the positive electrode of the battery is constrained by long-range correlations associated to scaling characteristics of its geometry (spatial-temporal renormalization). But the mode of existence of this technical object (lead acid batteries) does not meet the Noether conditions (invariance of physical law during the time shift); the energy is thus no longer an invariant of the representation. Nevertheless, it is obvious that any battery is designed to store energy. Where is the error? The solution of the paradox lies in the fact that the above representation is not complete. The experimental data accommodate a single class of internal physical constants, but the same representation can correspond to several set of constants. The role of Cantorian co-dimension is to exchange the role of the space of variables and the space of constants. We see here, from a physical example the difference between a closed project in which the field of responses is reduced to a point (exponential relaxation), the objective to be reached (h-Management) and an open project, here devices capable of storing energy, a question that can be approached in an open way by playing on the incompleteness of the very nature of the system. That is the objective and method of Zeta-Management approaches. The physical basis of Zeta-Management, which is nothing less than a model of creativity, was conceived in parallel with the design of the very first lithium batteries.

Physics solves this paradox with a superb sleight of hand: a closure! The propensity to think of the optimization of complex systems as a suppression of everything that cannot be determined a priori appears as a truism. Project Management is an expression of such point of view. Likewise, the "quality strategy" is merged with the "quantity strategy", now widely developed in the majority of companies. Nevertheless, this “h-truism” is misleading when action has to deal with rare events or a non-Euclidean world; indeed history teaches us that life has no optima, complexity has no additivity for its subsets... even if they can be defined [9, 10]. The choices needed to design the future are always strategic and not local, much more than local and optimal in the short term. Statistics are the current backbone of the training of the minds of the "best students" from the “Ivy League” to the first class business schools around the world. Starting from purely local and short-term linear models, or even from allegedly "sophisticated" models, but always ignoring the "black swans" that these elites are pushing for "optimization", wether in private or public action. Like viruses that kill including their host, their models force the reduction of costs and the maximization of the profitability of financial assets, while the ontological status of money (trust, consideration, liquidity, holding etc.) as a source of creativity (the basis of the capitalism) and an incentive for innovation is radically ignored. While many economists currently reject methods based on a childish thinking or on casino gambling addiction, no scientific group is supported to develop an alternative model of research thinking for a fonctorial creativity: toposic and / or dualistic approaches capable to take into account "multivocal" geodesics [11, 12, 13, 14, 15], models capable of giving meaning to political choices, to the irreversible thermodynamics of open systems; what Taleb termed “extremistan” far from the "h-standard" of the “mediocristan” its closed counter part, favoring the “h-Management”. The main current main risks come from decision-making processes when they are based on the fundamental assumptions of the natural sciences (h-Management): simple additivity of cause and effect, subject / object distinction, observer/experimentation etc. all paradigms that ultimately involve very elementary stochastic assumptions and the reduction of the human being to an elementary particle.

Far from the use of chance or pure determinism, the toposic logics are at work in creative and inventive processes, in arts, techniques and living or social organizations. The distinctions required in the natural sciences between subject and object, inner and outer, true and false etc. are then revoked. Using power laws ruling the log-linearity and also the difference between concepts of quantity and quality, we have called Zeta-Management a set of methodologies that open up possibilities of differentiation with “h-methodologies”. Among the main features of Zeta-Management, the main one is the openness to self-referencing, namely a recursive formalization [16, 17], a possibility of “soft control”, fractional dynamics control [3, 18, 19, 20]. In the new framework defined by the Zeta-Management, the local cause / effect relationship becomes partly fuzzy, variables and environment constants can no more be absolutely disjoint (due to non-additivity) and systems come under the non-integer control of "dual sets", i.e. factual but also virtual data, a situation which can be mathematically formalized using sheaves (integration of local Pre-sheaves PSh), algebraic manifolds, graphs etc. [22, 23, 24]. In this context, the principles of "digital" management are obviously revoked; nevertheless the scientific approach is not by the way ignored. The well known "Mean Action Principle" of physics must only be considered for special kind of actions: the geodesical ones. Faced with numerous choices, the only significant epistemological question therefore concerns the geometrical structure of all possible geodesics, and first of all their metric invariants, their nexus. In a categorical context the subject (outside vector of rules and morphisms: "arrows") and the associated objects (internal variables), are joined by the means of a "living interface", a fuzzy set of interactions (double layer). Mathematically, this interface is multiple and characterized by an implicit or explicit role of boundary constants (Euler's constant, of homotopy and cohomology characteristics [25, 26, 27]). The global stability of these systems (unifying subject and object within a monade) results from their self poiesis [Spinosa's conatus; power of life (Bergson); self-organization under flow (Prigogine)]. Self-organization presumes the existence of certain dissipation factors (production of entropy). These factors ensure, within the external flow, the heterogeneity of a partly closed structure (see the Prigogine's proposals [28]) which fades during any optimization. The equations that control such systems are no longer classical differential equations but recursive equations, expressed by means of finite differences along the scales, which opens herein on an infinity of details even if the structure is bounded (this situation is well known in fractal geometry). The frequency of recursivity (the rhythm of the internal clock) can no longer subsume its link with the geometrical content of the overall structure (expressed by the frequencies of the external space). Very complex and ambiguous behaviors are then hidden in particular behind fractional differential forms [19] which formalize the dynamics of recursivity. Paradoxical logics emerge that are nevertheless coherent and at work in the organization and stability of living systems of organs or social realms. Although such complex systems are open, the fact that they are, among other things, closed on the adjunction experimenting scientifically his relations to the world, implies that it is not important to know what are the input / output relationships seen by an outside observer, but what is the ontological status of the space in which the observer sketches the representation of his living topos [30]. As one can see, the Zeta-posture is based on epistemological choices leaving aside certain major roots that underlie the usual models of natural sciences. Grounded upon an intrisic incompleteness, and on a subject/object adjunction, the Zeta-Management is, far from the distinguo between subject / object, nothing else than the use of a generalized duality, taken in its internal complex relationships, as a monad. More precisely, it is an Isbell's like duality which formalizes in fine the adjunction between time and space required to build a space of sheaves representation (Ring versus spectrum):$((\mathcal{O} \dashv Spec): CoPSh \underset{\mathcal{O}}{\overset{Spec}{\rightleftarrows}} PSh$ [30]). Figured versus Creative experience leads the authors to think that this ultimate duality is none other than that which gives an ontological status to the space / time itself, a primitive space of life, whose scale covariance (conservation of rules of transformations along the scales) can be unveiled through some order (to be found) associated to the dynamic processes in complex "scalable" fields. Though strange at first sight, the natural metric associated to them, introduces efficient and coherent logics very different from the ones of child (linear causality) or of the gambler (stochasticity). Virtually, the Zeta-Management asserts in its principles the central role of the incompleteness and the requirement for involution for finding again some roots of a rationality adapted at complexity when, due to the subject, any object of thinking becomes multiple.

1.3. Role of a Phase: Holography of Zeta-Management

For pedagogical reasons, let us illustrate our reasoning from an analogy whose validity is based on category theory. It summarizes previous works of the authors' in theoretical physics. These works use the universal models of sets of geodesics associated to any type of exchanges of extensities in fractal geometry. These models have otherwise some relations with the set of geodesics featured in the Beltrami Poincaré Disc, to which the authors added some additional singularities. This set allows to illustrate the role of the hyperbolicity, curvature and metric, and beyond of the incompleteness of the universal representation, through a clear physical experimentation. The way in which an hyperbolic rationality solves the incompleteness– and ultimately establishes the origin of the universality – is proved to be hidden in the distingue between intensive variables (which is measured namely which need a gauge) and intensive variables (which must be counted in the frame of modular approach). The principle here applied considers that an intelligent management of complexity must be based on taking into account a nonlinear space-time structure in which the action (and the resistance which naturally corresponds to it) takes place.

Being instructed by the physical experience of dynamics in a d-fractal environment (see figure 1), non-linearity is here expressed by the means of a the phase angle related to a non-integer metric $\varphi = (\pi/2)(1-\alpha)$ with $\alpha = 1/d$. It can be attributed to two origins. The first one uses directly the nonlinear space-time relationship: $\eta \times (in)^{\alpha} \sim 1$ where the phase is related to the factor i^{α}. The velocity associated with the dynamics is thus replaced by the usual Cantorian Hausdorff content in accordance with [31][1]. In other words, the distance between any object η must be though hyperbolic and the time must be thought only like a dual variable partly associated with these formal distances η but also partly associated with external clock n. The simplest image is a stack of two discs having two different radius $(\eta, 1/n)$ whose perimeter is raced, for example by two ants, with the same linear velocity. How the set of the possible encounters between the two ants can be characterized? This question can be analyzed from the point of view of ants. To synchronize their watches at the start, ants can use a formulation of the time under a complex form, namely: $s = \alpha \pm i\theta$. Later, on running, both ants may understand the lack of synchronization of their positions, like a difference of spatial gauge: space-time emerges through a difference of scale underpinned by a scaling differential form (scaling over a double layer). Moreover, let's observe the ant running on the small perimeter can use a reversible time $\pm\theta$ for example by changing the sense of rotation, but the ant running with its watch adjusts on time s cannot change the sign of α and thus cannot change so easily the sign of its time. Both variables have not the same status with respect to the reversibility, except if $\alpha = 1/2$ because $s = 1 - s$ in his case. Due to the 2D representation of many there are two "times" namely two kinds of beats (frequencies): "s" and "θ". At this step, the introduction of modular arithmetic (ring, ideals, set of octaves, phase deviation etc.) leads a formal miracle by bringing out a ideal basis on which it become possible to project a new representation of the dynamical complexity. The ideal basis of representation, far from any intuition without formalization, can provide the means to find of a suitable coherence adjusted to the consequences of the natural irreversibility found out here: physical incompleteness, social creativity and innovation and, in fine, in management, "soft holistic control" of complexity, can be based on this dissymmetry. The power of fractal approach is based on the fact that the external clock time, the time of experimenter (space), does not agree with the proper internal time of the system under tests (irreversible time). This last gives the gauge of the physical process that, unfolded in the form of a universal geodesic, conveys something like a least action principle which thus

[1] This distinction is equivalent to the fundamental distinguo between extensive variable and intensive variable, a major distinguo in category theory.

is not one for the experimenter but the one of the system and vice versa. Both principles oppose themselves. The standard techniques of optimization therein lose any relevance. The long range dynamics correlations (namely new symmetries) then express the conjugation of the couple of beats itself controlled, through the phase angle. Virtually, the unit of space is not only distinguished but also splitted from the unit of time (hence not only the disappearance of the concept of velocity but also the emergence of incompleteness). The unity of space becoming a Cantorian content leads, in 2D, to an incompleteness of the representation attributed to the hidden role of co-dimension in the determination of the geodesics. Virtually, we are unable to define such a dual space / time structure as soon as we note that the universally observed geodesics are compact arcs of circles (therefore hyperbolic geodesics here in Fourier space) and that furthermore $\eta = u / \upsilon$ represents the integral hyperbolic distance measured at boundaries of these geodesics. As a simple inversion of straight line with respect to a singularity, these kinds of geodesics can be used to rebuild a causality based on a new rationality (a new toposic logic). This logic uses the concept of impedance (as resistance to any density of action) and the concept of Riemann Zeta arithmetic integral function, which justifies the naming of the method, indeed the same alpha in the impedance $Z_\alpha(\omega\tau)$ defines through a Hausdorff content the properties of respective time-space scales in Fourier space, s extends the same class of properties of scales this time extended by the means of the Zeta Riemann function [32, 33, 34, 35, 36, 37, 38, 39, 40][2].

1.4. Universal Duality and Riemann Zeta Function

The above analysis introduces the duality of space-time as an assumed expression of Isbell's universal duality [30], not only for physics but also for econophysics. Otherwise, just as the derivative of an exponential function is always an exponential function, it is well know that Fourier Transform (FT) of

[2] Zeta function $\zeta(s)$ is defined using both additive and multiplicative forms: $\zeta(s) = \sum_{n\in\mathbb{N}} (2/n)^s$ and $\zeta(s) = \prod_{p\in\Im} (1/1+(1/p)^s)$ with p prime number. The additive form allows to assert that Zeta Riemann function is the trace of exponential operator in therepresentation of the set of natural numbers in Riot space (Hilbert vectorial type of space with $\log(p_i)$ as axes if p_i is a primenumber). In this space α or s become scaling factors. This representation unveils the fractal characteristics of this Riemann function. The question opens by the duality of this form concerns the location of non trivial zeros when the analytic expansionof the field of definition of Zeta is considered with $0 < \alpha < 1$. Riemman's hypothesis asserts that $\zeta(s) = 0$ if and only if $\alpha = 1/2$. This condition corresponds to a breaking of symmetries in the fractal model [39].

a power law is also a power law, but now, if and only if some conditions are duly fulfilled, namely $t^{v}/\Gamma(v+1).\xrightarrow{FT}.(1/n)^{v+1}$ if $\Re(v)>0$ and except if $v=-1/2$; thus, generally $s\neq v$. Nevertheless, we will show that, because of the duality between Riemann's Zeta function and Möbius function, we can create some notions analogically close to a Fourier transform to preserve, despite the transformation, a kind of homology between a dynamic object $Z_{\alpha}(\omega\tau)$ and its transformations. Let us consider here the bounded universal arc, smaller than a semi-circle, which expresses a fractal dynamics $Z_{\alpha}(n)\sim\frac{1}{1+(in)^{\alpha}}$ in the complex plane. Its spectrum is called "Universal Cole and Cole's arc". It is often observed in the spectroscopy of complex compounds [3, 4]. This transfer function leads to consider two transformations:

(I) *Approach for a completion*: the first one is expressed by the geometrical extension of the arc $Z_{\alpha}(n)$ aiming the associated full semi-circle; a kind of completion is here at play by means of exponential relaxation (see figure 1 for the illustration). When the semi-complex plane is used as a model of non-Euclidean geometry, this extension gives rise a standard Poincaré geodesics. In this context the overall usual exponential arc is splitinto a couple of "dynamics": Factual $Z_{\alpha}(n)$ / Potential $Z_{1-\alpha}(\tau)$. Two questions then arise. What is the formal form of the additional part? What is its spectral content? The answers to these questions appear as unexpected gems. Indeed, provided that a mirror representation (parity) is adapted, the additional part can be written $Z_{1-\alpha}(\tau)$ and appears like a pseudo-dynamic inverted in time. In accordance to the fundamental theorem of arithmetic leading $n=\omega\tau=\coprod_{p_i\in\Im}p_i^{ri}$ the content of $Z_{1-\alpha}(\tau)$ fits the set derivation of n (the set of all possible dichotomies into ω and τ) and in terms of τ, we get that the measure is a hyperbolic distance, identical to that given by n in $Z_{\alpha}(n)$: it is clearly something like a hyperbolic dynamic but one *where the entropy would be replace by a negative entropy* (Parity: mirror effect). In Spite of a disordered construction process due to the partial order of the set of prime, the final parity seems to give a $Z_{1-\alpha}(\tau)$ a natural self-organization (self-poises) created by the dissipation induced by $Z_{\alpha}(n)$. In the framework of Categories, the content of the extension ties in the set of sheaves associated with n. These sheaves link experimental data associated with $Z_{\alpha}(n)$ and the set of possible consistent data $\{\tau_i\}_n$, whose integral form is expressed through $Z_{1-\alpha}(\tau)$. Virtually this pseudo-impedance (anti-dissipative) adds up all the arithmetic morphisms that is possible to attach to each point of the non-integer dissipative dynamics n. The existence of these hidden arithmetic symmetries, namely, Galoisian ambiguities due to hidden degrees of freedom, involves that experimental "truth" does not give a unique representation but corresponds to a multi-universe (co-multiverse) which constitutes its unity within its multiplicity [41, 42, 43]. Correlations associated to this co-multiverse explain the anti-entropic behavior. The adjunction $Z_\alpha(n) \rightleftharpoons Z_{1-\alpha}(\tau)$ is the expression of the resolution of the incompleteness. Because of the dynamics, Factual (action) / Potential (virtual) duality has nothing to do with the Athenian static duality, Morphé / Logos. Far from being the only chance (associated with $\alpha = 1/2$), the basic principle of Zeta-Management is to take into account the incompleteness of any experiment or model and therefore to take the adjunction between the two factual and virtual components as a scientific object per se, as well any decision of action within the framework of a single point of view involving multiplicity. It will be observed that this dual object is basically associated with the set of proper time-constants associated with an arithmetical horizon at each point of the geodesic of action, locally but in a framework of a multiplicity of perspectives (sheaves). The open practical question is that of the duality of time. How can the manager build a rationality upon a posture of schizophrenia and an uncertainty guidance? Precisely by expanding the categorical adjunction, by "declining" the conjugated dualities. The pre-sheaves are virtually attached to the openness of any system of representation. In this context, how can we take into account not the own time of the system but the external time, i.e. the “time” attached to $\eta = u/\upsilon$?

(II) *Answer lies in the use of Kan extension upon adjunction*: This is where we use the existence of the constant $1 = e^{im\theta} \times e^{-im\theta}$ according to the second transformation previously introduced $\mathcal{I}:\eta^{\pm ik\theta}$. This operation fonctorizes the set derivation operator $\partial: Z_\alpha(n) \rightarrow Z_{1-\alpha}(\tau)$ (fibering of transfer function) and thus opens the way to a Kan’s extension analysis, namely the status of the commutator $[\jmath * \partial - \partial * \jmath]$. This leads to distinguish the natural transformation at right $Ran_{i\theta}(\partial)$ and at left $Lan_{i\theta}(\partial)$. The denomination Zeta-Management comes from the fact that the mathematical fibering of transfer functions naturally gives rise to the emergence of a Riemann Zeta function $Z_\alpha(n) \xrightarrow{J} Z_s(n)$. straightly generalized to the adjunction $Z_\alpha(n) \rightleftharpoons Z_{1-\alpha}(\tau)$. Traditional management, or "h-Management", implicitly leads us to think that right and left Kan natural transforms are equivalent, which amounts to assert that “possibilities” are only a matter of will (project: $\alpha = 1$) or chance (serendipity: $\alpha = 1/2$), a point of view contrary to all creative process. Conversely, the distinction between Ran and Lan not only asserts that chance is subsumed by a prospective thought, but that more deeply, far from any optimum, and in accordance with Prigogine’s thought, the possible emerges from entropic dissipation itself, namely from action, even if it is without appearing purpose. Because of the mathematical status of the Kan's extension and its contribution to the forcing process toward new universes, failing experiences, bias historical tales forgetting of the true actors, marketing without content, predation, can never stop the creative processes; dissipation is intrinsically a factor of creation. As we observe, this approach is exactly the opposite of a research for primitive optimization, approach which, forgetting the subtle organization of things and the associated information with it, looks only for any minimal entropy production (like natural systems). Like in Boromean rings, it is the conjunction of three dualities (the third related to underlying exponential) which restores No ether principles with a re-emergence of an energy-like invariant, now based on the existence of a singular point ($0_\alpha \sim \infty_{1-\alpha}$) – as anti-entropy source – located on the track of overall virtual exponential dynamics. Going further, one can imagine that there probably exists an optimal fractal metric which results from the link between the triadic Cantor set and the distribution of prime numbers, which optimum would determine a good balance between energy balance (volume) / power (Flux) with $\alpha = log2/log3$ namely $\varphi = 33°21$ for the critical angle (fractal aspect of the three section of angles).

How is the status of the "time" crucial for thinking about Zeta-Management [44, 45, 46, 47]?

In standard theory, paradigmatic physical time is a simple parameter associated with any semi-infinite geodesic. In a self-similar hierarchical structure characterized by$1 < \alpha \leq 1/2$ the standard "time" has no meaning (except in the strict case of pure chance α=1/2), only the frequencies, as arithmetic data "n" (duration) can acquire physical meaning, but in the fractal context one has to considered the fundamental laws of decomposition of any integer, and therefore take into account, at least, the set of all possible bi-partitions. In other words, the "now" has reality only as multiplicity, then as well the "here". There is no "present" but a spectrum of the future and therefore of "possible" that we will call local spectrum of duration with reference to Bergsonian thought. Does this mean that this spectrum is dissociated from the past? Precisely not, because there are arithmetic morphisms between spectra of duration localized differently on the compact geodesic. The past, present and future are then entangled in the framework of possibles controlled by the capability of will projection. The high frequency (voluntarist) spectra are thus much more fertile in opportunities than the low frequency spectra (instituted). At short "time constant", all opportunities are scattered infinitely in a space based on ideal sets (with partial order) capable to ensure the simplest representation of complexity. In other words, any localized duration spectrum is a vector of future capabilities imbued with past data. This internal tension of the duration harbors a temporal potential of action just like any couple of distinct materials hides an electrochemical potential. The important point is that we are not led to these ideas only through philosophical intuitions (nevertheless paradoxically relevant after reading Leibniz, Bergson or Hursell approaches) but by physical analogies after a strict use of theories of categories, sheaves, topos, dynamic sites and in accordance to an approach which subsumes the static theory of sets, mostly tacitly manipulate in pedagogy. The specificity of Zeta-Management toolbox, thus consists in distinguishing "quality" and "quantity" by ramifying "time" in the framework of hyperbolic metrics. Their curvatures determine in fine both the non-linear space-time relationships and their modes of completeness capable of assuring suitable contextual representations of complex scalable environment. It is the deep understanding and required control of the non-linearity that explains both the recurrence of creative processes, the social and linguistic hierarchies produced by history, the universal structures of these hierarchies, and, by the way, the opposition they arouse from "Euclidean managers" (who use the ”h-Management”). Then remains the important category of the "in-between", these “short sale” experts who will be able to socially pull the chestnuts out of the fire by placing themselves as “The Manager” at the junction between the two approaches: an opportunist position also very justly referred as “time-table servers”!

To summarize, the Zeta approach requires to substitute the notion of Topos at the notion of set, that is to say a "good" category with no pathological characteristics and of which one recalls (i) that all the limits are finite, therefore that the Yoneda’s lemma makes sense, (ii) that the notion of exponential is at the heart of the definition of the subsystems (here including its dynamic and opportunistic implications) namely if there are objects A and B there is an object B^A which acts like the set of functions $f{:}A\rightarrow B$, finally (iii) that it is possible to design a sub-object classifier. This classifier acts as a set $\{0,1\}$. Any function of a set X to 0,1 is interpreted as the subsets of X. These characteristics deal with the properties of the sheaves. We see here that the structure of the set of choices required to defined any future becomes complex, nevertheless the frame of representation then allows a straightforward self-consistent tree of choices. Far from the a priori definition of "a project" the efficiency of the approach is then precisely linked to the multiplicity of the aims. As one will show the Zeta-Management techniques were implicitly applied during the design and development of early lithium batteries, during the 1972-1984 creative period.

2. Introduction on the post-modern context of the invention

Disturbed by the emergence of complexity, confidence in post-modern science now relies on the h-factors, which are well known to be "highly impartial". These factors measure the consensus within a "scientific community". They determine where the truth lies in a given area of expertise. In the associated bureaucratic context, social recognition and thus research funds can easily be granted to "stage jokers" [1, 48, 49, 50] or “scientific Pythies” converted retrospectively into Advisors of Projects Managers. So, we can find "h-experts" whose expertise is based on a density of "scientific publications" higher than one publication per month over more than 40 years of activism! This type of "experts" is a candidate for some of the most profitable scientific awards and generally win some of them, awards that are immediately reinvested in the career and give rise to new publications. Far from the modular thinking required for true creative management, “h-Management”, which linearizes and figures any complex thinking, can profitably excel in "Excel spreadsheet handling" and social striving. These “experts” can easily convince political partners that scientific ethos is proportional to the number of publications and to financial profit forecast. The "set theory" then ensures the legitimacy of "elitist coteries" perverting, with the help of institution, the scientific spirit. Let us note that "h-methodology" can be used in perfect good faith, the cognitive dissonance playing then its usual role of "scientific morality". The awarding of scientific awards now fits very naturally into this post-modern framework of *h*-ranking technosciences. But the disruptive technologies thought and developed at the end of the 20th century, the laser, the PC, optical telecommunications, socialization software, man-machine interfaces, CAD, 3D reprography etc. were never invented in a bureaucratic “*h*-Management” framework. We assert that major inventions were most often in the framework of Zeta-Management and were made by a few scientists or their teams hiking in uncertainty and in unknown environment, only capitalizing on a "black swan" and the beneficial of serendipity. Most of the time, these inventions were, as usual, later used to glamorize the scientific tales addressed to kids, candid students and ambitious politicians. We will show that the invention and the realization of the first lithium batteries should be seen as a paradigmatic example of Zeta-Management as opposed to "*h*-Management"[3].

The lithium battery device, whose current economic impact is now well known, was designed in the 1970s in a pure and informal scientific partnership between the United Kingdom, the United States and France. The 2019 Nobel Prize in Chemistry was awarded to *John B. Goodenough* (USA, Yale Skull and Bones Fraternity, Bachelor in Maths (1944), PhD in Physics (1948)), *Stanley Whitthingham* (UK, Oxford PhD in chemistry 1968) and *Akira Yoshino* (Japan, MS Engineering 1972), for the "invention" of Lithium batteries. Science needs tales! But no Tales can perfectly be granted upon a real story, which is why it is necessary to enlighten and explain here the choices of the Nobel Committee through a detailed historical and social analysis of the invention. As we shall see, the creation of the first lithium batteries was not thought of in the context of scientism, post-modernity and the "Society of the Spectacle" by G. Debord but in a frame of an almost fair competition between different scientific teams of which the Nobel Prize winners were only a part. The content of the "Bulletin of the French Chemical Society" [50] offers an opportunity to look back at the history of these batteries. In particular, the history of the manufacture of early lithium batteries in French Laboratories provides an opportunity to illustrate the Zeta-Management methodologies (Dual Management for Creativity) previously introduced to anticipate what the management of innovation should be in the future. This management should be rightly opposed to "*h*-Management", whose epistemological bases are for instance analyzed by M. Mazzucato [51] and here extended to the field of sciences such as the search for empirical truth.

The design and pre-development of the first lithium batteries will allow us to illustrate how the invention used the principles of a Zeta-Management for Research (see first paragraph) implementing the spirit of exchange, donation, open scientific collaboration between partners and the belief in an universal scientific spirit, far from any individual promotion. Without disputing the choice of the Nobel committee, this article returns in a factual manner to the history of lithium batteries. The authors congratulate in particular

[3] Giving a remarkable but unintentional illustration of the current way of what modern technosciences is, a noteworthy notein the Bulletin de la Société Chimique de France [50] endorsed by the French Academy of Sciences makes the panegyric ofthe winners, forgetting paradoxycally a great part of the real role of the exchanges between France, the United States and theUnited Kingdom in the design of the first Lithium batteries. Let us notice that the qualifier „paradoxical" would not be therelevant word. Indeed the transition from Science to Technosciences throughout the 20th century, an evolution which basedevery "scientific career_ on the *h*-factor, matches very well with Guy Debord's _spectacle society_ [49].

S. Whitthingam and J. Goodenough, whom they knew very well in the 1970s and whom they never challenged, at least for having been deprived of the beautiful Oxfordian accent of their interlocutor. This article is dedicated to two scientists now deliberately forgotten by their French colleagues: Jean Rouxel died young in 1998 and Michel Armand, still active in the field of electrochemistry (figure 2).

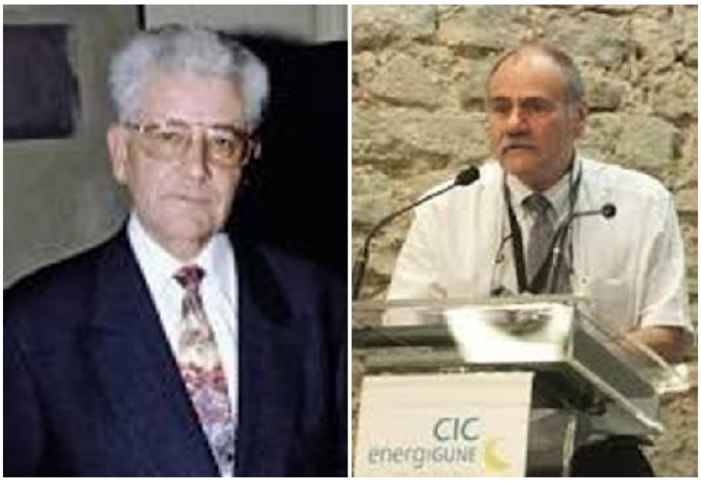


Figure 2. On the left, Jean Rouxel (1935-1998) in the 90s.On the right, Michel Armand (1946-) at the end of 20th century. At the scientific height of a J. B. Goodenough, and given their role in the birth of lithium batteries, these scientists would have deserved to be on the list of the Nobel prize in Chemistry 2019. This note explains why it did not so.

Whereas the history of lithium batteries is still underway today, the historical analysis of the creation of this kind of battery gives the opportunity to put into perspective the contribution of French teams to this disruptive technology while illustrating through a concrete example what an adequate Management of Creativity must be. It should be pointed out that the main author of this note, cited as one of the players in the design of early lithium batteries, left the first efficient batteries in the mid-1980s in the hands of new managers commissioned to advice the CEO of the Marcoussis Laboratories.

These new "experts" uphold at once (i) that there is no European market for lithium batteries; (ii) they suggest shifting research commitments towards super-capacitors with virtually no chemical complexity; (iii) to sell the patent portfolio already provisioned in France to Japanese groups, accompanied by trade agreements. Indeed, at that time, the Japan was investing a lot of money in research aimed at taking leadership in energy storage devices. These purely tactical and opportunistic choices then correspond to a scuttling of the subject when, for nearly 15 years, multidisciplinary scientific teams working on the development of materials and technologies that had already led to the pre-manufacturing of efficient batteries.

Since the mid-1970s, this team has been structured around three groups:

- The Solid State Chemistry Laboratory of the University of Nantes, then managed by Pr. J. Rouxel since 1966, assisted by his collaborators (see bibliographic note), was dedicated to the design and synthesis of new materials.
- The Laboratory of Ionics of Solids (and Electrochemistry) of the University of Grenoble where M. Armand's team has been working on the optimization of the ionic transport in solid either for electrodes and batteries electrolytes.
- The "Laboratoires de Marcoussis", Corporate Research Center of the "Compagnie Généraled'Electricité" (1898), later named "Alcatel-Alsthom" (1991). Recruited at the end of 1973 by the the Department of Electrochemistry (DEC), A. le Méhauté took charge, from 1975, of the pre-development of industrial lithium batteries, as well as the thermodynamic and kinetic optimization of new materials.

J. Rouxel was the backbone of this group. Doctoral student of Professor Paul Hagenmuller*, Director of the Solid State Chemistry Laboratory of the University of Bordeaux, J. Rouxel was appointed Professor at the University of Nantes in 1963, and immediately set up a Solid State Chemistry Laboratory in this young University. In the fall of 1966, he limited his research field to the two-dimensional structures (for example, MoS2 has long been used as an additive for lubricants, precisely because of its two-dimensionality), focusing his team's research in particular on lamellar dichalcogenides of the type CdI_2: SnS_2 as well as TiS_2. Historically, it is following the work of von Rüdorff's [52] on the intercalation of chemical species in graphite, that the new group analyses the A_xMS_2 structural types obtained by intercalation of any alkaline $A(Li, Na, K, Rb, Cs)$ in the chalcogenides where M is a metal. These new phases disclose several structural classes depending on the value of x and the nature of the inserted alkali, this last occupying different types of possible crystallographic sites. For example Li_xTiS_2 forms a very singular prismatic phase[53, 54] but is partly amorphous. This material was patented in Belgium (!) six years later in 1975 [56] by the English scientist using French language,

S. Whittingham, as the positive electrode of a lithium battery demonstrator. Nevertheless, at this date, this idea is already known to the scientific community (the referees of the patent seem to ignore this information). Indeed, eight years younger than S. Whittingham, the chemist M. Armand began his doctorate in 1971[4]. His studies were to focus on electrochemical intercalation of compounds characterized by lamellar structures capable of hosting a reducing or oxidizing species between stacked layers. Using the example of the compound $M_x/Graphite/CrO_3$, M. Armand argued at the 1972 NATO conference in Belgirate – three years before the Belgian patent – that a solid lithium or sodium battery could be designed using appropriate two-dimensional graphite-like compounds. This position was confirmed by B. Steele who explicitly chose Li_xTiS_2. The theoretical capacities of such batteries should be close to the kWh /kg [57, 58], thus offering foremost characteristics than standard energy storage materials known in the early 1970s.

In addition, M. Armand will soon qualify as "Rocking Chair" batteries consisting of a pair of electrodes based on the insertion or intercalation of ions and atoms [55]. To be reversible, materials must to be capable of inserting active species, but also restoring their chemical structures, under several milliamps per square centimeter without excessive dissipation and without aging along the cycling. These anticipations then suggest the existence of a subclass of weak bonds between the layers of the 2D compounds suggesting first the use of the intercalated chalcogenides, for instance synthesized at the Nantes laboratory since 1969. In this conference, B. Steele explicitly states the great interest of TiS_2 [59]. S. Whittingham, who attended the same meeting, merely announced for his part…his departure from Stanford's Huggins Laboratories and his commitment at the Exxon Research Labs. Four years later, in early 1975, and on the advice of M. Armand and J. Rouxel, DEC-Marcoussis Labs. entrusted A. Le Méhauté [60], the responsibility of launching the design of lithium batteries in partnership with the Universities of Nantes and Grenoble. He then decided to develop both engineering actions and fundamental research on the strange crystallography of inserted chalcogenides [3, 61, 62]. While M. Armand defended his doctoral thesis in 1978 in

[4] on his return from a stay in Robert Huggins' laboratory at Stanford** where he was a post-doctoral colleague of S. Whittingham.

Grenoble, A. Le Méhauté[5] defended his own thesis at the Solid State Chemistry Laboratory in Nantes in September 1979. This thesis will be completed by that of Guy Ouvrard in 1980 for the physico-chemical characteristics of 2D materials considered. These PhDs must be considered as a single whole. The purpose of this set was to base the design and pre-development of lithium batteries on a fine science of two-dimensional positive electrode materials.

The analysis of the organization described highlights that the Topos from which research is built is very different from a standard project because if all the actors, working in parallel, have the same goal, this goal is only considered by each of them as the co-limit of a multitude of addresses of many issues, corresponding to the multitude of problems opened since 1970. In particular, no sequence is proposed and no deadline is set. We find here one of the main characteristics of Zeta-Management. The project is built on the basis of increasing of knowledge and not of a device at aim. With the stage set, let's get back to the details of this instructive story.

3. Context: French industrial battery research in the mid-1970s

Since the takeover and merger within the group of small companies which created the electrochemical energy storage industry at the end of the 19th century (1898), increasing battery capacity has been a recurring objective for the Compagnie Généraled'Electricité (one of the leading companies in Europe). Seventy years after this merger, the companies Fulmen, Tudor (Lead acid batteries) and SaftLeclanché (Zn / MnO2 and NiOOH / Cd, Ni (OH) / H2, among others batteries) dominate the civil and military domestic market and, despite stiff foreign competition (Varta, Yuaza, Duracell etc.) their export

[5] Younger than M. Armand, A. le Méhauté worked as a research engineer in the Electrochemistry Department (DEC) of theMarcoussis Research Center (Compagnie Générale d'Electricité) from 1974 to 1984. He will move to the Materials Departmentand then leave, the company which had become in 1991 Alcatel Alsthom, when the financialization of the group will becomeobvious (1994). A. le Méhauté held up by his team made up of G. Crépy and G. Marcellin led the design and the pre-developmentof lithium batteries during a ten years. Although conceived in the SAFT environment, the industrial research action was mainlysupported by the Direction of Research and Technical Study (DRET). It led among others to the construction and cycling ofthe first batteries as well as to the defense in September 1979 of a State Doctorate based on the first interesting electrochemicalresults. This work will be followed by some twenty publications about the fractal structures of composite compounds and aswell as a series of patents. Although still in close contact with universities, A. Le Méhauté has always worked in a strictlyprivate context.

position is excellent. This industrial context will be strongly consolidated from 1973 onwards. The oil shocks of the 1970s would indeed help the politicals leaders to highlight the fragility of industrial countries in terms of energy availability and storage needs. Electricity being strategic for a country whose energy choices are based on nuclear energy, storage studies were accelerated and diversified, notably with the help of Marcoussis Research Center, research aimed in particular at developing Metal / air and Sodium / sulfur batteries, but also that of Fuel Cells. In Europe fairly similar studies have also been carried out, for example at the autonomous Battelle Institute in Geneva. Obviously, forecasts, such as those reported by M. Armand and B. Steele since 1972 [57, 58, 59] in the university context, have helped to stimulate a great deal of research on materials already set up in other laboratories. Nevertheless, in the early 1970s, the way to design a reliable commercial battery only appeared to be a challenging horizon for the mind[6]. Thanks to the knowledge of Na/S batteries [60], the dangerous handling of alkalis, required to start research on lithium batteries, is fortunately well mastered at the Marcoussis Research Center. This skill will be particularly useful when electrochemical work requires the handling of metallic lithium. Research on Na/S introduces the Department (DEC) of Electrochemistry to the technical problems associated with the use of alkalis facing the sulfur positive compounds. During these years, the industrial development of a lithium negative battery operating at room temperature still seems to be an industrial "Holy Grail", and it is only in France that M. Armand really believes in the future of such research [57, 58]. It is at this stage that, like Monsieur Jourdain (Molière, "Le Bourgeois Gentilhomme") confusing prose and versification, the principles of Zeta-Management began to be implemented in total innocence but with the efficient ingenuity of a naive young man. If the idea of using non-stoichiometric compounds of low dimensionality compounds other than graphite emerges, research on lithium batteries operating at room

[6] In the mid-1970s, the Materials Department of the Marcoussis Laboratories made very slowl progress on the pre-developmentof the Sodium / b-alumina / Sulfur battery, encountering in particular technical problems related to Metal / Alumina sealing, a sealing that must be reliable at 350 °C. The conductivity of the Na^+ ion only sufficient for power applications at this hightemperature. Sulfur and sulphides from the positive electrode are then liquid, but in terms of electrochemical yield, the lowefficiency also remains an obstacle to be overcome. This last problem is addressed to the Department of Electrochemisitry (DEC) to be solved [60].

temperature must be carried out in a tense and commercially unstable industrial context[7].

The French solid-state chemistry teams, and in particular the Nantes team around J. Rouxel, and the chalcogenides studies are among the very first world's leading specialists in intercalation materials. in the early 1970s, the performance of intercalation processes indeed improved radically, with liquid ammonia being substituted by the *n*-Butyl lithium as a vector of intercalation of the alkaline ion (an idea introduced by Professor Di Salvo's team), and then by the emerging electrochemical techniques [57, 58, 59]. The Nantes laboratory is particularly interested in the crystallochemistry of the phases obtained. Unfortunately in this academic field, lithium metal sulfur compounds, partly amorphous, are not among the easiest to master (see in this subject, the outstanding ionicity-structure diagrams published by J. Rouxel). The DEC of the Marcoussis laboratories having the skills required to design a new battery and being able to study, by new electrochemical methods, behaviors that may seem confusing for crystallographers used to studying stoichiometric compounds with perfectly defined chemical bonds and sites, a parnership was signed in 1975 between the two laboratories. This partnership was based on preliminary results disclosed in a series of publications in 1969 [53, 54] and after (1971-1973), which proved the reversibility of the intercalation process [63, 64, 65, 66, 67]. It appears to be related to a binary instability of the crystallographic order in the chalcogenides sheets. It will be shown during the 80's that the dynamic order is based on a fractal order (self-similarity leading a pseudo-crystallography) which controls the intercalation dynamics in the layers through a biphase structures [6, 7]. Nevertheless, at the beginning of the 1970s, knowledge is not yet at this stage and many data remain puzzling even for update experts.

For safety reasons, all battery tests during the period 1976-1983 were carried out with the lithium / aluminum alloy as negative electrode. The salt

[7] At the end of the 1970s, Dr. Jean-Paul Gabano, engineer at SAFT-Poitiers, worked on the optimization of high power $Li=SOCl_2$ batteries for military applications. Nickel-Hydrogen batteries are also developed for space applications which allowcomplex and expensive technologies. Thus, if applications very naturally orient research towards the use of the first columnof Mendeleev's table, in particular lithium for negative electrode, then the metal-oxides represent the most promising positiveelectrodes for industrialists. However, the oxides have chemical bonds too strong not to seriously harm the reversibility of thereaction, which is not even considered with alkalis. For example, only a few tens of microamps would then be available persquare centimeter for $Li=Ag_2CrO_4$ pacemaker batteries, if they did not operate on impulse. At the time, although the stakeswere high, a commercial lithium / metal oxide battery was still a mirage for companies, a chimera to be left to academics. J. B. Goodenough succeeded in this last field, especially with $LixCoO_2$ and $LixFePO_4$.

solvated in ether-electrolyte is the lithium perchlorate. Beyond the use of intercalation compounds as a positive electrode, the design of a reliable a battery requires extensive scientific studies on electrolytes and salts. Among other researches, these last are entrusted to M. Armand who completes in Grenoble the research team formed by the Nantes and Marcoussis laboratories. M. Armand will attach his name, among other things, to the fundamental study of electrolytes (complex salts, solid polymer electrolytes etc.).

Unlike a project organization, the goal to be achieved is not clearly defined and must emerge as knowledge advances. In particular, it is impossible to partition the project into active tasks. The most important aspect of Zeta-Management is to take into account different time scales and use the morphisms between these scales to progressively build classes of subsets of topics, i.e. an exponential tree structure of material classes and issues. It is within this framework that the categorical classifier is defined (immediately efficient / to be improved). So, although working from chalcogenides and initial failing with oxydes, the study of oxides has never been abandoned, especially since most of the standard battery materials were precisely based on oxides with a better potential than chalcogenides. The same applies to the use of carbon as negative in place of Lithium alloys. The hypothesis of their use was merely postponed to a later date justified by an increase in the budget, and then imagined has being associated to progresses made every day on cycling due to a better understanding of the mechanisms involved by the insertion/intercalation processes. However, this favorable hypothesis subsequently proved to be illusory. It should be noted that the use of Zeta-Management only concerns active researchers. It is not the same for an external expert who can accumulate the knowledge acquired to place this research within the framework of "h-Management" by synthesizing knowledge and positioning this synthesis as a managerial act. Given the structure of the techno-scientific research institution, the success of such a posture is perfectly guaranteed [48].

4. The central role of the Nantes Solid State Chemical Laboratory

In its overview of the history of intercalation procedures, the Nobel committee explicitly recognizes the intellectual priority of J. Rouxel, citing only the publication dating from 1973 [63]. Then the committee joins to the argumentation two 1974 publications signed by S. Whittingham, one of which “would institute” the electrochemical intercalation of lamellar dichalcogenides [68, 69][8]. At this stage the Committee overlooks the crucial publications of 1969 [53, 54] mentioning TiS_2 intercalation compounds… although no mention of electrochemical intercalation was ever specified at this very early stage of research. A detailed analysis of 1969-1975 time sequence would fall under academic quibbles if the lamellar materials as energy storage materials had not also been the subject of the dual presentation of M. Armand and B.C.H. Steele at the 1972 *NATO*-sponsored conference on Lake Maggiore [57, 58], while S. Whittingham attended these operational lectures without any comment. It can then be observed that if the priority of patents is easy to establish and justifies the choice of S. Whittingham as a Nobel laureate, not only does the academic argument vanish, but it is probably vain to look for a scientific reason to the final choice: the Committee is sovereign. Concretely, this choice illustrates the theory defended by J. Rancière in his pedagogical book, "Le maitre ignorant" [70]: the duality between teaching and the emancipation of the students. Conversely, as regards the Committee's position, the only truth that can be affirmed in academic matters is that the chemistry and electrochemistry laboratories in Nantes and Grenoble invested, at the end of the 1960s and the beginning of the 1970s, in the research that founded the chemistry of intercalation (insertion) during the following decades, which would soon give rise to the secondary lithium battery industry.

Seniority plays a very important role in academic matters. In particular, the American J. B. Goodenough, who belongs to the same generation as P. Hagenmuller, J. Rouxel's mentor, celebrated his 54th birthday at Oxford in 1976, and has thus had an undeniable scientific leadership position over J. Rouxel for the past 15 years. In addition, close links exist between the Solids Chemistry Laboratory of the University of Bordeaux and the Inorganic Chemistry Laboratory of the University of Oxford, where J. B. Goodenough, physicist, exercises his talents (1976-1986), already widely recognized in the field of bonds in transition metal oxides [71]. It should be noted that in this field, computer-aided quantum chemistry is barely in development with

[8] It is at this stage that the anthropological approach of a scientific institution becomes really interesting, because the NobelCommittee is placed on the academic field and, while the French have been disseminating their results without any industrialprecautions [3,4,9 -13] since 1969, Exxon Research takes a „commercial" leadership by filing a generic patent for batteries usingprecisely the materials studied in Nantes. Using the facilities, S. Whittingham signs the belgian patent (!) in 1975. It is isbased, among other, on TiS2 positive electrodes [4]. It should be noted that Exxon has all the rights to patent because thiscompany patents a battery with these materials and not a material. However, by dating J. Rouxel's intellectual priority a yearbefore a communication from S. Whittingham in 1974, the Committee seems to disregard a serie of publications written overprevious 5 years, publications which traced the path followed to initiate the design of the new batteries.

personalities such as Jurgen Hafner in Vienna and Mike Payne at MIT. J.B. Goodenough therefore does not yet use techniques that will make structural chemistry computational [72]. If his books [71], J. B. Goodenough owes it to his pedagogical qualities and his superb classical culture in physics for inorganic chemistry. Although his skills are focused on bonds in metallic oxides, J. B. Goodenough (applying Zeta-Management [73]) is building an efficient partnership with S. Whittingham (applying h-Management) in the field of chalcogenides[74]. At the same time, we very often meet J.B. Goodenough both at the Solid State Chemistry Laboratories of Nantes and Bordeaux and, more surprisingly, at the Marcoussis Laboratories where John Apelby, one of his colleagues at Oxford, was then in charge of Energy Prospective [75][9].

At the end of the 1970s, computer simulation resources did not yet model the characteristics of crystallography and spectroscopy NMR, RPE, Mössbauer, Band-Gap etc., were obtained experimentally by chemists and physicists who, mainly in Nantes with Raymond Brec and friends (see acknowledgments) and in Bordeaux around Claude Delmas and his colleagues, designed respectively new Chacogenides and new Oxides that could be intercalated or inserted, among other methods via electro chemical reductions. At the same time, new salts and electrolytes are designed in Grenoble by M. Armand and his teams. In the academic context, it is undeniable that the advance and the influence of J. B. Goodenough on these players in solid state chemistry and theories of chemical bonds ─ including in France ─ explain that this eminent scientist had been selected as a possible Nobel Prize winner in Chemistry since the 1980s. Conversely, it should be noted that in technical matters, the situation appears much more clear-cut because from 1976 the Laboratory of Exxon Research & Engineering Company, where S. Whittingham worked for a decade (1972-1984), was challenged by Marcoussis / Nantes / Grenoble consortium, formally backed by an industrial group, SAFT, exclusively dedicated, unlike Exxon, to electrochemical storage

[9] Let us observe that it is in the work of J. B. Goodenough, very obscure for an engineer trained in chemical engineering, that A. Le Méhauté built his culture in „quantum chemistry”. The dificulties encountered in reading J. B. Goodenough's cited worksand in informal discussions with him, will have an unexpected industrial consequence, since after having introduced thanksto Erich Wimmer Scientific Manager of Biosim Inc. the Quantum Material Design Software at the Marcoussis Laboratories (1992), A. Le Méhauté, in memory of the complexity of J. B. Goodenough's books and exchanges, will later contribute on theone hand to the creation of Materials Design SARL (1999) then Inc. (2002) [72] and on the other hand, in the spirit of thepedagogical analysis of J. Rancière [70], to the design of educational programs for engineers using Computer Aided MaterialDesign at Quantum level, an engineering pedagogy implemented since 1995 at Master level.

of energy. The asymmetry between Zeta-management (action) and h-Management (reaction) will push the tip the scales in the direction we know today.

We have seen that the main property of Zeta-Management is incompleteness. This last can nevertheless be made up by adding a creative anti-entropic part characterized by the adjustment of the time constants in adequacy with the issues. This adjustment obviously intervenes in the creative technical process; the scope remains limited because the creative process is also exercised with much longer time constants if it no longer concerns only the technical aspect but also the sociological aspect. This is how the GAFAM has imposed their own algorithmic rules to the planet. At this stage the categorical existence of limit and colimit for the extension of incompleteness, leads to overlap between "h-Management" and Zeta-Management. By situating the strategy at this limit and ensuring that the final category is also an initial category, for instance by playing with ambiguous position between academics (knowledge) and industrialists (profit and "sound efficiency"), it is possible to win on both sides: academic and social. Since the mid-1980s, this has been a winning strategy except for the commons.

5. The competition of the seventies

In order not to subject the pre-developments of the battery to the patent filed in 1975 on the positive Li_xTiS_2 [56] and to increase the stored energy, the French Lithium Team decided, in early 1976, to work on new positive phosphosulfides, in particular $NiPS_3$ and $FePS_3$. These efficient materials were first synthesized in small quantities in Nantes, then in larger quantities in the Marcoussis Laboratories. The synthesis of this class of compounds dates back to the end of the 19th century with a first synthesis of $FePS_3$ carried out by the French chemist Charles Friedel (1832-1899). Structural studies were carried out much later by the German W. Klingen in the context of a doctoral thesis defended in 1969. At the same time, Professor Wold's team, from Brown University in Providence (RI, USA), worked on the physical properties of these materials (magnetism, electrical conductivity). Raymond Brec, who will be the co-author of numerous patents on lithium batteries, became aware of the potential of these materials during his post-doctoral stay in Providence (1975-1976). He reported on the characteristics of these materials in Nantes in 1976 in the presence electrochemical teams at Marcoussis, giving rise to the idea of using these materials as batteries electrodes.

We see herein how ideas spread according to circumstances that are often fortuitous and / or providential... Nevertheless it is not by chance that on September 20, 1977 a patent of Exxon was disclosed inter alia under the name of S. M. Wittingham ─ claiming with priority on April 19, 1976 – the use of positives, $NiPS_3$, $FePS_3$ [76]. Independently, the same materials are patented by the French team with a priority date dated February 19, 1977; at this date, these electrodes are obviously already tested in cycling at Marcoussis laboratories [77]. The diffusion of ideas is clearly a historical issue which must be analyzed in detail here! Bad and strange surprise for the French Team ! However, considering the cost / energy / power potential of the MPS_3 electrodes (M: Ni, Fe), but also the work already done, the team decided to continue the studies and keep up with the Exxon team by diversifying the electrolytes and positive materials and among others with syntheses of initially reduced materials such as Li_xFeS_2, followed later by now discrete studies on sulfur-polymer complexes, in the perspective of the design of a Lithium / Sulfur battery without transition metals, operating at room temperature. Despite unbalanced competition in terms of seniority and institutional support, the cohesion of the French Team is not only maintained but strengthened in this critical period.

Examination of the patent filing dates shows that the priority given to phosphochalcogenides batteries is probably due to the expeditious intelligence of S. Whittingham [74, 76, 79]. It appears that seniority, the embodiment (as opposed to team strategy), the "mining" of scientific knowledge in the environment [80, 81], the appropriation of knowledge, industrial “shielding”, adequate financial support and finally the use of imperial idiom, play a crucial role in this type of competition. At the end of the 1970s, S. Whittingham, J. B. Goodenough, J. Rouxel, M. Armand, R. Brec and A. le Méhauté met and communicated in all the major meetings where the future of lithium negative batteries was discussed (Lake Geneva, Tokyo, Saint Andrews, Rome, Varna among others). We will thus consider with all due attention the formal priority granted by the Nobel Committee to J. Rouxel if we analyse historically how S. Whittingham while still in the laboratories of Exxon Research, very opportunely published from 1979 onwards, Text Books summarizing the results obtained in various laboratories, in particular concerning the solid state chemistry of the solid of low-dimensional intercalation materials [80, 81] devoted to energy storage. Witihn the frame of “h-Management” the elitist leagues are most often formed by archivists termed *Bildungphilisters* by Nicolas N. Taleb [1]. At the time of publication dates, it has not yet migrated to the academic world, which shows once again the decisive role of "text books" not only in pedagogy but also in the field of scientific marketing and the strengthening of a social position. As Paul Valery says: "Glory does not depend (only) on the effort, which is usually invisible: it depends on staging". Here we are !

At the junction between the experimental and the theoretical fields of expertise, the first electrochemical spectroscopic studies carried out in Marcoussis by means of primitive methods[10] show, against all expectations, that the intercalation kinetics and thus the dissipation and the hysteresis in cycling the batteries do not fall under diffusion law (Brownian motion), but to incomplete non-linear dynamics due to aggregation and clustering effects, in accordance with entropic power laws, in the sheets of the two-dimensional materials. Experimental understanding of these complex phenomena, so different from traditional symmetries [6, 7, 82], may allow the optimization of the Energy (volume) / Power (aero) balance of the batteries, thereof adapting the electrode materials to applications and cycling requirements. It is on these bases that at the end of seventies and the beginning of eighties, several hundred increasingly deep and deeper cycles were performed, in particular with nearly 300 cycles obtained at 50% DOD under currents close to 5mA / cm^2 for the best of the pre-industrial tests conducted first with experimental batteries (Figure 3) and then with the "button" geometries that are now well known.

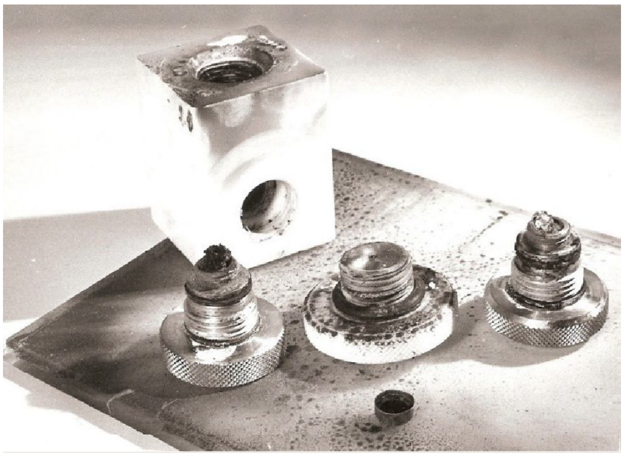


Figure 3. Opening of an experimental battery used in the late 1970s for kinetic spectroscopy, thermodynamic studies and cycling, just before developing batteries under button geometry. The tripartite structure provides a lithium reference electrode. The first deep cycling and the first aging studies of the phosphochacogenides LixMPS3 (M = Ni, Fe) and LixFeS2 were carried out on this type of cell. The negative electrode used was then an AL / Li alloy. The carrier salt is a lithium perchlorate. LiClO4 (Photo A. Le Méhauté, Laboratoires de Marcoussis).

[10] The Lissajous methods, a spectroscopic technique that preceded the development of the Solartron by the team of the of Professor J. Epelboin, head of „Interface and Electrochemical Systems Laboratory", University Paris-Jussieu.

Here we begin to guess that outstanding social recognition in the field of science cannot be based on Zeta-Management alone. This type of management is essentially devoted to the creative and innovative process, i.e. the dynamics of breakthrough. Rupture positions were never cozy ones. To be not so tear away, these ones must be in a clever conjunction with a subtle use of "h-Management" paradigms, giving to see a pushy distant with the gratification factors associated with the only building knowledge. This explains why J. Goodenough had to reach the age of 97 to have his scientific work recognized, him which deserved a Nobel Prize since 50 years. This also explains why the Nobel committee needed the alibi of the commercial success of lithium batteries to award J. Goodenough's outstanding scientific career, when it was certain, as early as the 1970s, that betting on lithium batteries, would ensure a long-term victory for any intelligent player at the time. We confirm herein that, as in economics, Zeta-Management's understanding of "h-Management" can be used as a remarkable, and probably, the only lever of social promotion[11].

6. Western Industrial strategy in the 1980s

By the early 1980s, the efficiency of these batteries over many cycles had been proven. The mass capacities were already three time those of the best known standard batteries and the energy fading in storage was close to zero. Both the CNRS and the Marcoussis laboratories had a large portfolio of patents, signed by authors from the Universities of Nantes, Bordeaux and Grenoble. All patents were for efficient electrode materials for secondary lithium batteries. But such a portfolio is above all a commercial instrument, which is why the question arises as to whether or not an private European group wants to develop the techniques which are claimed by these patents. If the CGE Group is wealthy, the SAFT subsidiary alone does not have the financial basis to invest in a technological line that is still at the problematic pre-development stage; moreover, this company has mainly invested in other sectors, such as the Ni / Cd battery, whose commercial success, at least in the short term, is then assured. Orthodox, the management is not only skeptical

[11] The technical progress achieved is measured when one remembers that at the beginning of the studies and with the oxidesas positive electrode, only a few microamps / cm^2 could be applied without any cycling. While engineering is improving itstechnical approach of chalcogenides, the Bordeaux Solid Chemistry Laboratory with C. Delmas and J. Goodenough continuesto focus its research on oxides which have the advantage of having a higher electrochemical potential though yet low propertieson cycling. It was only in the end of eighties that the non-stoichiometric properties of the oxides began to show real operationalqualities by playing with multicomponent structures.

about breakthrough technologies, but even some of the technical staff is hostile to Marcoussis's autonomous strategy. SAFT also takes into account the fact that there are no industrial partners in Europe in the field of mobile electronics devices that would require batteries with greatly improved mass and volume energy storage. Conversely, Japanese manufacturers are investing heavily in these new technologies. Driven in fact by the innovative spirit of Konosuke Matsuchita which radiated out over Japan after the war, the need of such consumer developments became obvious for Panasonic, Sony etc., all companies supported by MITI and the local battery manufacturer Yuaza, which detected very early on a market that would soon prove to be very profitable. SAFT's office in Japan, in the mid-1980s, finally convinced the general management, to sell the patents portfolio to major Japanese electrical storage companies in exchange for future industrial partnerships. From then on, the mass is said and its servants must put away their personal convictions[12]. In this industrial context, it then becomes obvious that if a Nobel Prize should be awarded for the development of lithium batteries, a Japanese scientist should be present on the list. Thus Achira Yoshino, working at Asahi Kasei Corporation, has established himself as the recognized promoter of Lithium-Ion battery safety [83, 84, 85]. In the mid-eighties, he promoted the use of specific carbon structures for reversible intercalation of the lithium "atom" as a negative electrode. In 1985, he therefore gave a final touch to the "Rocking-Chair" drums concept initially proposed by M. Armand. Within the framework of "h-Management", Achira Yoshino will soon, like others, but more success, rewrite the history of Lithium-Ion batteries [86]. These batteries containing operational stored energy close to 200 Wh/kg now make it possible to carry out portable uses that previously required a physical link to the electrical network. The M. Armand and B. Steele's 1972-forecasts are now confirmed [57, 58, 59]... with awards!

But is this really the end of the story? Are there any doors that remain open?

7. Conclusion in memory of Jean Rouxel

We have seen that the Zeta-manager institutes a fractional action whose global correlations must be parameterized by $1/2 < \alpha < 1$ located very exactly

[12] The Japanese will then take charge of the industrial development of lithium batteries, an action which will later be relayedby Korean and then Chinese manufacturers. 90 years after the feat of the first electric competition car equipped with Fulmenbatteries (in 1999 the aptly named „Jamais Contente" reached 105km / h on Acheres Agricultural Park), this last country setsup a large battery industry for applications in mobility field (cycle, automobile, electronics etc.).

between Laplacian determinism $\alpha = 1$ and Gaussian chance $\alpha = 1/2$ (law of large numbers, Gaussian bell curve, Poisson law etc.). As there is an intrinsic differential link between determinism and Gaussian chance, uncertainty does not really exist in the latter case because the probability that an event deviates too much of the mean is infinitely low and the law of large numbers makes this mean the sole attractor of any action in the framework of "Mediocristan". Bureaucratic societies are based on these principles and creation can then only result from serendipity, i.e. the capture of a small fluctuation and the illusory belief of increasing this fluctuation to make it a new overall attractor. It is easy to understand that an invention such as lithium batteries can be a part of such a strategy. "h-Management" is a bureaucratic strategy, and it easy to understand that the more it wants to take advantage of creativity, the more its mechanisms escape it. In some of its aspects and in the absence of oligopolies, capitalist societies "gantlet" the Zeta-Management. The history of the invention and development of lithium batteries illustrates quite well how these societies combines a dynamic of innovation under Zeta-Management (gantlet) and then promote a dynamic of development and recognition controlled under "h-Management". This last type of management appears clearly as the expression of standards set within the framework of a balance of power based on social investment and obviously the mastering of monetary flows, i.e. the control of space-time, as we have already had the opportunity to show [87, 88, 89].

Would Jean Rouxel have been with J. B. Goodenough in the list of laureates if he had had at disposal 20 more years of scientific research [73]? No one can bet on that. Indeed, nothing guarantees it if one takes into account the educational shadow [80, 81] which could have veiled the precedence of the work of the Rouxel team [53, 54, 63, 77, 78] at the end of sixties and the early of seventies. By using the efficiency of "short selling techniques", the "h-action" is always able to take over any forecast and action even if it is already closed! In any case, hisuntimely death in 1998 avoided asking the question and the reference to his 1973 publication was considered sufficient recognition for the Nobel Committee. Furthermore, neither the American manufacturers nor the French Industries considered, in the mid-1980s, developing a secondary lithium battery. This is why S. Whittingham migrated (1984) from Exxon to an academic environment. At the same time, faced with a lack of contracts, the Battelle Institute contributed to application of many of its scientists, in different Universities. In France, much to M. Armand's dismay, the CNRS patent portfolio for Lithium batteries was sold to the oil company, Elf-Aquitaine, with the patents quickly being resold to Japanese manufacturers[13]. It is clear that considering his scientific expertise and the historical priority of his thinking on secondary lithium batteries [80, 81], M. Armand, still young should have been in the list of Chemitry Nobel awarded in 2019. Indeed with J. Rouxel and his team, its status as "Prima in Primum" in the design of lithium batteries is indisputable. But how could it have been so without an impresario and stage manager, when academic theater has been, since the end of the 1970s, worthy of a "société du spectacle"[49], including in the field of science. Let us consider, however, a deeper reason to M. Armand's absence from the final prize list: he is eager to move on the stage[14]. It is clear that the use of lithium batteries poses safety problems both during use [83] and in the absence of industrial recycling (see the question of the scooter vandalism in large cities). M. Armand has concentrated all his efforts on the design and development of solid electrolytes (new salts and

---

[13] Change is also socio-political. In France, after the success of the socialist party in the 1981 presidential elections, Universities-Industries links were promoted to the rank of "Academic Sesame". In the framework of "h-Management", the management ofresearch laboratories is entrusted to self-proclaimed "experts of public-private con-fusion". In 1983 the promoters of an industrialdevelopment of lithium batteries, M. Armand and A. Le Méhauté were replaced by "marketeers" with even more specialisedpolitical skills. Aware of economic and strategic choices that go beyond any scientist issue and, moreover, completely imbuedwith a sociological and literary culture that has its roots in his personal history, A. Le Méhauté, redirected his professionalinterests towards other scientific sectors (see Wikipedia site), refusing to take up a research position at the Bell Labs Laboratory (Murray Hill, New Jersey), a position offered by D. Murphy (member of the jury for his thesis) but a position that would havebrought him back to electrochemistry. Conversely, M. Armand, pugnacious in his research efforts (several hundred publicationsand dozens of international awards and positions for his work on Lithium batteries), headed to Quebec to try to motivateHydro-Quebec, the local electricy provider, to the economical interest of the lithium Rocking-Chair batteries.

[14] Brief history of oxides: The French players who developed oxides and polyanionic compounds (Li_xFePO_4 produced in China> 120 000 tons in 2019 for batteries) are Claude Delmas who has worked extensively with J. B. Goodenough on lamellar oxides of the $L_{ix}CoO_2$ type, such as $Li(Co–Ni–Mn–Al)O_2$, i.e. *Co-Ni*, or *Co-Ni-Al* etc. but also on $Li_{1+x}(Co\text{-}Ni–Mn–Al)_{1–x}O_2$. He was one of the first to work on Na_xCoO_2 in 1983 and resumed the study of $Na(Co–Ni–Mn–Al)O_2$ for sodium batteries. C. Delmas is an international leader in these compounds. We will also note the international status of Christian Masquelier (LRCS, Amiens) who worked with J. B. Goodenough in post-doc in 96-97-98 on Nasicons, then continued in France in Orsayon $LiFePO_4$ then Amiens, on multi polyanionic compounds-substituted. Dominique Guyomard has also worked extensively atthe Institut of Materials Sciences, Nantes (Nantes-Tournoux oxides team) on LiV_3O_8 as a cathode for LMP Bolloré batteries (1998-2007), resulting in 7 patents and some twenty publications. LiV_3O_8 was used in the first prototype of LMP batteriespowering "experimental Bluecars. LiV_3O_8 was then replaced by $LiFePO_4$, storing less energy but characterized by the absenceof capacity loss in cycling; $LiFePO_4$ is now the material of positive LMP batteries sold.

polymers adapted to the reversibility of interfacial transfers) to improve safety. But just as with academics, manufacturers do not consider such a subject to be “sexy”. Moreover, raising this issue is risky for the manufacturers who would like to occupy some critical markets. M. Armand’s image is not marketable either in Paris or Oslo and the "*h*-managers" do not like the assertion of freedom. The tale of Science must be uplifting. Nevertheless we can bet that the structures of the devices designed by M. Armand will in the long run guarantee the optimal safety of devices whose performances are already too low for the new high-energy, high-power applications. This is where the patent on electronically conductive sulfur complexes [90, 91] could bring a new technological breakthrough. It was demonstrated experimentally in 1984 that the capacity of a battery with a conductive sulfur electrode can reach, at room temperature, 1000 Wh/kg in operation, provided that a suitable sulfur complex is used as a positive electrode. It will be observed that the cycling constraints then become critical for the negative electrode because such a storage capacity can only be designed in thin layers due to the DOD which must then be applied to the negative electrode. The polymer electrolyte is then required. It is certain that the ecological crisis and the need to move quickly away from fossil fuels now will soon revive research, aiming at the next step to increase electrochemical storage capacity. The French protagonists who set the scientific bar high will then have confirmed the role played by their premonitory scientific work in the development of one of the most important reliable industrial devices designed in the 20th century. The inventors of the first stage just have to wait, one again, for the implementation of their idea !

Finally, let us note that the practical problems posed by secondary Lithium batteries at the beginning of the 21st century are aging problems and that it should be noted that recent publications still refer to work carried out by French group in particular M. Broussely, former engineer at SAFT Poitiers [92, 93, 94, 95] finally embedded on an industrial adventure initially denied by “h-managers” [96][Q].

Acknowledgments

We would like to thank the Rouxel-Tournoux team for 45 years of wonderful scientific exchanges and especially Dominique Guyomard and Annie Le Blanc-Soreau for their contribution to the historical details of this document. Among the multiple patents filed during the crucial first ten years of the early infancy of lithium batteries (1972-1984), we note the names of the following co-authors, who are not necessarily mentioned in the above text: Claude Berthier*, Raymond Brec, Luc Brohan, Yves Chabre*, Alain Dugast, Michel Danot, Michel Evain, Annie Le Blanc-Soreau, René Marchand, Guy

Ouvard,YvesPifard, Pierre Ségransan*, Michel Spiesser, Michel Tournoux, Luc Trichet, among others. This set of names is included in numerous patents of MarcoussisLaboratoris portfolio. (*) *Laboratoire de Physique de l'Université de Grenoble, in collaboration with the Nantes team.*

We would like to thanks Materials Design Inc& SARL (Dr. E. Wimmer) for the support of these studies and the team of the Federal University of Kazan (Pr. D. Tayurskii and his group), P. Riot (Zeta Innovation), L. Nivaven (ISMANS), A. El Kaabouchi ((ESTACA) and Alexandre Wang (Complex System and Quantic information Lab. ESIEA) for scientific discussions.

REFERENCES

[1] N. N. Taleb, *The Black Swan: the Impact of Highly Improbable*, Random House publishing group N.Y., 2007;

[2] L. Nottale, *Fractal Space-Time and Micro-physics*, Editions World Scientific, Singapore, 1993;

[3] A. Le Mehaute, *Les geometries fractales,* Hermes Paris, 1990 & *Fractals geometry and applications* Penton Press, Londres, 1991;

[4] A. K. Jonscher *Universal relaxation law,* Chelsea Dielectric Press, London, 1996;

[5] E. Karden, *Using low frequency impedance spectroscopy for characterization monitoring and modeling of industrial batteries*, PhD dissertation Electrical and Information Department Aachen Technical University 06/02/2001 (see Figure 20: capacitive electrical Pb interface: $d \sim 1.60$; Figure 21: proof of Hyperfractality on $Pb0_2$ interface $d' \sim 1.40$ values already obtained at the end of the seventies);

[6] A. Le Méhauté, A. de Guibert, M. Delaye, M. Fillipi, *Modèle de transfertd'énergiesur interfaces fractales*, C. R. Acad. Sci. Paris, 294(II), 865-872, 1982;

[7] A. Le Méhauté, A. *Transfer Process in fractal media*, J. Stat. Phys., 36(5&6), 665-671, 1984;

[8] A. Le Méhauté, P. Riot, D. Tayurskii, *From Algorithm to imagination: Introduction to Zet- Management*, Hyperion International Journal of Econophysics and Modern Economy 12, 29-43, 2019;

[9] G. Choquet, *Theory of Capacities*, Ann. Inst. Fourier 5, 131-295, 1953;

[10] I. Kojadinovic, *Contribution à l'interpretation des mesures non additives de Choquet*, HDR Laboratoired'Informatique, Université de Nantes, 11/21/2006;

[11] T. Leinster, *A general theory of self-similarity*, Advances in Mathematics 226, 2935-3017, 2001;

[12] T. Leinster, *Basic category theory*, Cambridge Studies in Advanced Mathematics, Cambridge, 2014;

[13] S. Mac Lane, *Categories for working mathematicians*, Springer-Verlag, New York, 1971;

[14] F. W. Lawvere, S. Schanuel, *First introduction to categories*, Cambridge University Press, Cambridge, 1997 (2nd Ed. 2009);

[15] E. Ghys, P. de la Harpe, *"Sur les groups hyperboliques d'apres Mikhael Gromov*", 83, 1-25, Progr. Math., Birkhauser Boston, 1993 (web: perso.univ-rennes1.fr/serge. cantat/Documents/ disque-poincare.pdf);

[16] M. B. Smyth, G. Lotkin, *The category-theoretic solution of recursive domain equations*, SIAM Journ. Comp., 11/4, 761-783, 1982;

[17] G. L. Cattani., M. Fiore, G. Plotkin, G. Winstel, *A theory of recursive domains with applications to concurrency*, 13th conf., 214-225, 1998; completed by G. L. Cattani, M. Fiore and G. Winstel, dedicated to G. Plotkin, *The bicategory-theoretic solution of recursive domains equations*, GDP Festschrift ENTCS, 172, 2007;

[18] K. B. Oldham and J. S. Spanier*, The fractional calculus*, Academic Press, New York, 1974;

[19] Y. Podlubny, *Fractional differential equations*, Academic Press, London, 1999;

[20] P.M.H. May, *The algebra of self-similarity and its applications,* PhD Thesis, Bangor, 1997;

[21] A. Oustaloup, *Diversity and non-integer differentiation for system dynamics*, ESTE Wiley, London, 2016

[22] A. J. Lindenhovius, *Grothendieck topology on posets*, [arxiv14054408 [math CT]], 2014;

[23] M. Gromov, *"Hyperbolic groups*", in Essays in "Group Theory", Mathematical Sciences Research Institute Springer-Verlag Publications 8, 75-263, 1998;

[24] M. Gromov, *"Spaces and questions*", GAFA 2000, Tel Aviv, 1999 (a); Geom. Funct. Anal., Special Volume, Part I, 118-161, 2000;

[25] G. Chatelet, *L'enchantement du virtuel*, Eds C. Alunni& C. Paoletti, Edition Rue d'Ulm, Paris, 2016;

[26] F. Jedrzejewski, *Ontologie des catégories*, L'Harmattan, Paris, 2011;

[27] A. Badiou, *Mathematics of the transcendental*, Bloombury, London, 2014;

[28] I. Prigogine, I. Stengers, *La nouvelle alliance*, Gallimard, Paris, 1979;

[29] https://www.alainconnes.org/docs/scalingsite.pdf

[30] A. Valence, *Montrer et démontrer*, Edition de la Sorbonne, Paris, 2019

[31] F. W. Lawvere, *Taking Categories Seriously, Reprints in Theory and Applications of Categories* **8**, 1-24, 2005;

[32] A. Ivic, *The Riemann Zeta function. Theory and applications*, Dover, New York, 2003

[33] H. M. Edwards, *Riemann Zeta function*, Academic Press, London, 1974;

[34] A. Connes, *An essay on the Riemann hypothesis*, [ArXiv 1509.05576v1, Sept], 2015;

[35] M. Wolf, *Will a physicist prove the Riemann Hypothesis?*, [arxiv:1410-1214 [math Ph]], 2015;

[36] J. P. Keating, N.C. Snaith, *Ramdom matrix theory,* Comm. Math. Phys. 57-89, 2000

[37] J. Steunding, *On the universality of Riemann Zeta function*, PhD Thesis, J.W. Goethe Universitat, 2002;

[38] A. Le Mehaute, A. El Kaabouchi, L. Nivanen, *Riemann Conjecture and Fractional derivative, Computer and Mathematics with Applications*, 59(5),1610-1620, 2010;

[39] P. Riot, A. Le Méhauté, *Autosimilarité, fonctionzêta et conjecture de Riemann*, Revue d'Electricité et d'Electronique REE 01/ Fevrier 17, 118-125, 2017;

[40] A. Le Méhauté, P. Riot, *Arrows of Times, Non Integer Dynamics, Self Similarity, Riemann Zeta Function and hypothesis: A Synthetic Categorical Approach*, J. Nonlinear Dynamics 6(2) 261-299, 2017;

[41] A. Connes, *Advanced Lectures in Algebraic Geometry for Quantum Mechanics*, Collège de France, Paris, 2017;

[42] A. Gavrilut, I. Merches, M. Agop, *Atomicity through fractal measure theory*, Springer, Zurich 2019;

[43] C. Tricot, *Géométrie et mesure fractale*, Ed. Ellipses, Paris 2008;

[44] L. Smolin, *Time Reborn: From the Crisis in Physics to the Future of the Universe*, Houghton Mifflin Harcourt 2013;

[45] C. Rovelli, *L'ordre du temps*, Flammarion, Paris 2018, and *Et si le temps n'existaitpas* ? [« *Checos'èil tempo? Checos'è lo spazio?* »], Dunod 2014;

[46] A. Connes, C. Rovelli, *Von Neumann Algebra Automorphisms and Time-Thermodynamics Relation in General Covariant Quantum Theories*, Class. Quantum Grav. 11, 2899-2918, 2014;

[47] P. Riot, A. Le Méhauté, D. Tayurskii, *Fractional Dynamics, Riemann Zeta Function and Self Similarity through Category Theory*, in Advances in Special Functions and Analysis of Differential Equations (Chapter 14) Agarwal Praveen, Agarwal Ravi P., Ruzhansky M. Editors. CRC Press Deleware 2019;

[48] A Storck, A. Le Méhauté, J. Forrest, « *La recherché dans les Grandes Ecoles* », Numéro Special Revue des Sciences de gestion 235, Jan. Fev. 2009;

[49] G. Debord, *La société du Spectacle*, Buchet-Chastel, 1967;

[50] P. Simon, « Prix Nobel de Chimie 2019: *Des batteries qui ont modifié notre quotidien*", Bulletin de la société Chimique de France 446,, 7-8 dec 2019

[51] M. Mazzucato, *The Value of Everything: Making and Taking in the Global Economy*, IIPP-UCL London UK, 2017;

[52] W. von Rüdorff, E. Schulze, *Compounds of Graphite and Alkali metals*, Z. Anorg.Allg.Chem 277 156-171, 1954;

[53] A. le Blanc, M. Danot, J. Rouxel, *Sur l'insertion de métaux alcalins dans les structures de CdI2 du disulfured'étain*. Bulletin de la Société chimique de Franc, tome 1, 1969;

[54] M. Danot, A. Le Blanc, J. Rouxel, *Les composes intercalaires KxTiS2* Bulletin de la société chimique de France, tome 8, 1969;

[55] A. Mauger, C. M. Julien, J. B. Goodenough, K. Zaghib, *Tribute to Michel Armand: From rocking chair-Lithium Ion to solid state lithium batteries*, J. Elect. Chem. Soc. 167 070507, 2020;

[56] S. Whittingham, *Batteries à base de chalcogénures* Brevet Belge (1975) 815672. In French (!);

[57] M. Armand, *New Electrode,* Proceeding of the NATO sponsored, for Advanced Study Institute on Fast Ion transport in solid and Solid state Batteries and Devices, Belgirate, Italie 5-15 Sept 1972 (see also Brian C.H. Steele lecture on Li_xTIS_2 as electrode of batteries material);

[58] M. Armand, *New Electrode materials in Fast ion Transport in Solids*, ed. W. van Gool, North-Holland, 1973 (see also: M. Armand, J. M. Chabagno, M. J. Duclot, *Fast Ion Transport in Solids: Electrodes and Electrolytes*, Lake Geneva Meeting, WI, USA, 21-25, May 1979;

[59] B. C. H. Steele, *Chemical Diffusion,* Fast ion Transport in Solids, ed. W. van Gool, Noth-Holland, 1973;

[60] A. Le Méhauté, P. Bordet, *Générateur électrochimique Sodium/Soufre*, Demande de brevet français BF 35 35469, Priority 20/09/1975;

[61] R. Brec, A. Le Méhauté, *Générateur électrochimique à électrode de Chalcogénure*, Demande Brevet Français, 77 04 518, Priority 17/02/1977;

[62] M. Armand, R. Brec, A. Le Méhauté, *Generateur au lithium*, Demande Brevet Français 78 08 662, Priority 26/03/1978;

[63] L. Bichon, M. Danot, J. Rouxel, *Systématique Structurale pour les series d'intercalaires A_xTiS_2 avec A(Li, Na, K, Rb, Cs)* C.R. Acad. Sci. (C) 1283-1286, 1973;

[64] J. Rouxel, J. Cousseau, L. Trichet, *Les composes intercalaires K_xZrS_2*, C.R. Acad. Sc. t 273 (1971);
[65] J. Rouxel, M. Danot, J. Bichon: *Les composes intercalaires NaxTiS2. Etudes Générale des phases Na_xTiS_2 et K_xTiS_2* Bulletin de la Société Chimique de France, 1971;
[66] A. le Blanc, J. Rouxel, *Sur les types structuraux des composes intercalaires $MSnS_2$ avec M (Li, Na, K, Rb,),* C.R. Acad. Sc., t274, 1972;
[67] M. Dano, A. Le Blanc, M. Danot, L. Trichet, J. Rouxel, *Les composes intercalaires A_xTiS_2 avec A (Na, Li, K, Rb, Cs),* Material Research Bulletin, 9, 191-198, 1974
[68] M. S. Whittingham, F. R. Gamble, *The Lithium Intercalates of the Transition Metal Dichalcogenides*, Mater. Res. Bull., 10 (5), 363-371, 1975;
[69] M. S. Whittingham, *Electro-intercalation in Transition-Metal Disulphides*, J. Chem. Soc., Chem. Commun, 328-329, 1974;
[70] J. Rancière, *Public Education and the Taming of Democracy,* Eds Maarten Simons (Sous la direction de), Jan Masschelein, Ed. Wiley Blackwell, 2011;
[71] J. B. Goodenough, *Les oxydes des métaux de transitions*, Gauthier Villard, 1973 & *Magnetism and chemical bond,* Interscience Wiley, 1963;
[72] Materials Design Creation SARL, *Computeur Aid Materials Design*, https://www. materialsdesign.com/, 1999;
[73] S. Le vine, *The man who brought us the lithium batteries at the age of 57 has an idea for the new one in 92*, Quart, 05/92/2015;
[74] J. B. Goodenough, M. S. Whittingham*, Solid State Chemistry of Energy Conversion and Storage*, American Chemical Society Symposium, Series #163, ISBN 978-0-8412-0358-7, 1977;
[75] A. Le Méhauté, J. Appelby*, Parametric analysis of the structure of the international energy consumption,* Oxford, 2-2, 105-114, 1977;
[76] A. H. Thomson, M. S. Wittingham, *Intercalated transition metal phophorus disulfides*, Brevet US 4 049 879, 20 Sept. 1977 Priority 1976
[77] R. Brec, A. Le Méhauté, *Générateur électrochimique à électrode positive comportant une chacogénure*, Demande de Brevets 77 04 911, 17 Fev. 1977;
[78] M. Armand, R. Brec, A. Le Méhauté, *Insertion du Li+ dans les structures lamellaires de $NiPS_3$*, Mat. Res. Bull., 12, 1191-1197, 1977;
[79] M. S. Whittingham, *Chemistry of Intercalation Compounds: Metal Guests in Chalcogenide Hosts*, Prog. Solid State Chem, 12 (1), 41-99, 1978;
[80] G. G. Libowitz, M. S. Whittingham, *Materials Science in Energy Technology*, Academic Press, ISBN 978-0-12-447550-2, 1979;
[81] M. S. Whittingham, A. J. Jacobson, *Intercalation Chemistry*, Academic Press, ISBN 978-0-12-747380-2, 1984;
[82] L. Fruchter, G. Crépy, A. Le Méhauté, *Batteries Identified Fractal Object*, Journal of Power sources, 18, 51-62, 1986;
[83] https://fr.theepochtimes.com/batteries-au-lithium-lautre-frayeur-des-compagnies-aeriennes-3865.html;
[84] A. Yoshino, K. Sanechika, T. Nakajima, *Secondary Battery,* Japanese patent no. 1989293, 1985;
[85] A. Yoshino, K. Sanechika, T. Nakajima, *Secondary Battery*, US patent no. 4,668,595, May 26, 1987;
[86] A. Yoshino, *The Birth of the Lithium-Ion Battery*. Angew. Chem. Int. Ed., 51, 5798–5800, 2012;

[87] A. Le Méhauté, D. Tayurskii, *From Algorithm to Imagination. Introduction to Zeta-Management*, Hyperion International Journal in Econophysics and Modern Economy, Issue 12(2), 29-44, 2019;
[88] P. Riot, A. Le Méhauté, D. Tayurskii, L. Nivanen, S. Raynal, *Zeta-Management from Category Theory and Fractional Differential Approach,* Hyperion International Journal in Econophysics and Modern Economy, Issue 11(1), 7-48, 2018;
[89] A. Le Méhauté, D. Tayurskii, P. Riot, S. Raynal, *Grothendieck Topos. Zeta Complexity and Arrow of Time*, Hyperion International Journal in Econophysics and Modern Economy, Issue 10(2), 7-47, 2017;
[90] A. Périchaud, A. Le Méhauté, *Composition based on a electron conductive polymer and its applications to a positive active materials for electrochemical generator*, US Patent 4.664.991 (1987), priority French Patent sept 1984
[91] A. Le Méhauté, F. Héliodore, S. Galag, *Charge transfer complex between sulfure and poly acetylène like*, Mat. Synt. Metal, 11, 373-375, 1985;
[92] H. Plaehn, P. Ramdass, R. White, *Solvent diffusion model for ageing of Li-Ion Battery*, Journal Elect. Chem Soc., 151 (3), 456-467, 2004;
[93] K. Smith, M. Earleywine, E. Wood, S. Pereran, *Battery wear from disparate duty cycles: opportunity for electric drive vehicule batteries health management*. American Control Conference. June 27-29, Montreal Canada, 2012;
[94] M. Broussely, S. Herzcyne, P. Biensan, P. Kasztejna, K. Naslow, R. J. Stanicwicz, *State of art on aging,* Journal of Power Source, 97-98, 13-21, 2001;
[95] M. Broussely, S. Herzcyne, P. Biensan, P. Kasztejna, K. Naslow, R. J. Stanicwicz, *Main aging mechanisms in Li ion batteries*, Journal of Power Source, 146, 90-96, 2005;
[96] S. Fletcher, *Bottled Lightning: Super batteries, Electric Cars, and the New Lithium Economy,* Hill and Wang New York, 2011;