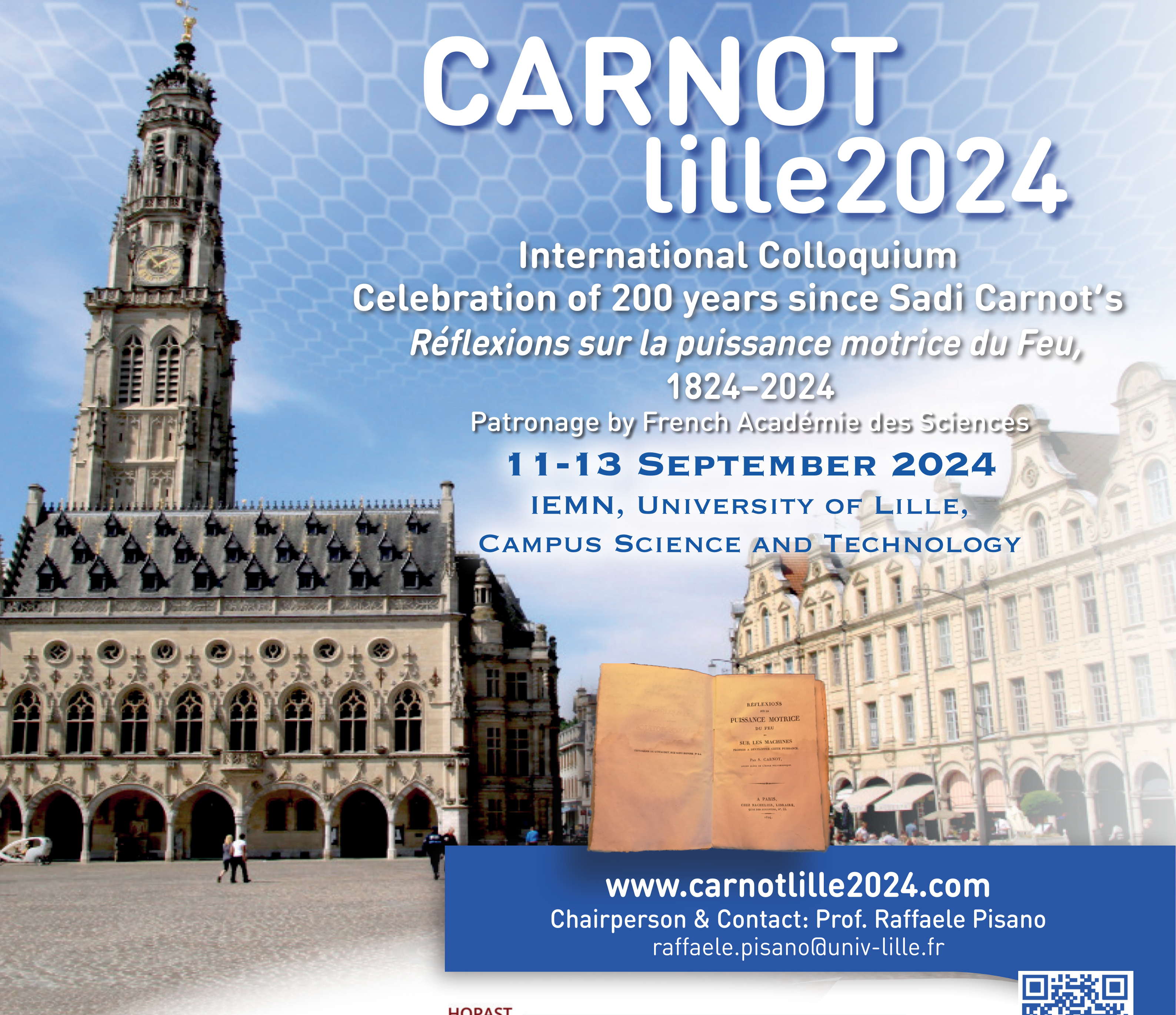

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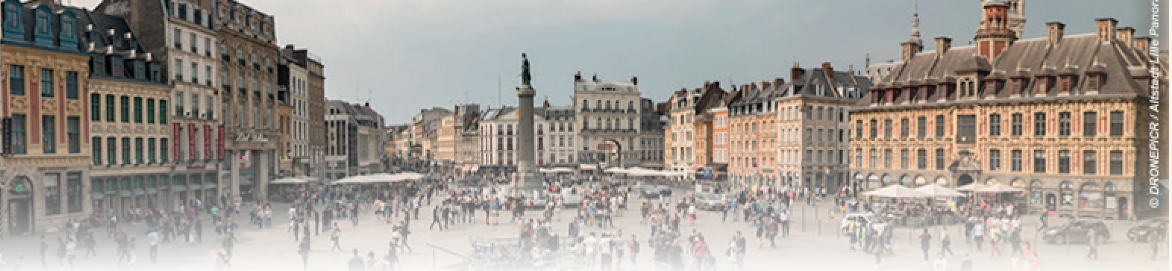

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Using the ”Reflexions” to Teach Thermodynamics

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Why do young people neglect physics and particularly thermodynamics? It might well be because the way of teaching thermodynamics has become completely artificial. If you tell a student that the change of energy of a system is the sum of the work and heat it receives, you miss both the question and the answer. In the fresh eyes of Sadi Carnot in 1824, the question is “With 1 kg of coal, how much work can I produce?” Is that a finite quantity or can it be infinite? He answers that question, using tools he could understand and explain: reversibility for adiabatic and isothermal processes. He does not go as far as obtaining the equivalence of heat and work in the ”Reflexions” (1), but will do it shortly after its publication. Temperature is a second example: it is introduced as the “obvious” temperature scale to the students, who then obtain Carnot’s efficiency of heat engines as a exercise. The truth is just the opposite: the cycle devised by Sadi Carnot was used by Thomson to define an absolute scale of temperature. It was also used by Clausius to define entropy. Entropy and temperature must be defined together. When reading the ”Reflexions”, everything is clear and logical. It is possible to follow the path opened by Sadi Carnot to introduce classical thermodynamics to our students. It takes much more time to reach the point when the students can solve simple problems. But the potential gain is huge: the students might understand the subject instead of applying recipes and hoping that they get a correct answer. One could object that it is impossible to use the ”Reflexions” as a teaching textbook because it relies on the concept of the caloric. In reality, Sadi Carnot did not trust the caloric and he uses the caloric as little as possible in his reasonings, so that he does not make mistakes. Another criticism is that the ”Reflexions” do not contain a complete formulation of classical thermodynamics, only achieved in 1850 by Clausius (2). There is a need for further reference and, in my view, the approach by Carathéodory (3) is the best choice. It is very much in the spirit of the ”Reflexions”. The main tool is adiabatic transforms. Like Carnot, Carathéodory does not make assumptions on the nature of heat. This approach has been criticized itself for being too formal and mathematically challenging. It is our duty to make it accessible and some papers already made progress in that direction (4). Hopefully, following the original work of Sadi Carnot, we might change the image of an obscure subject for a clear and straightforward approach to thermodynamics. References

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Keywords: teaching thermodynamics, Carnot, Carathéodory

Symplectic Foliation Model of Sadi Carnot's Thermodynamics: from Carathéodory's seminal idea to Souriau's Lie Groups Thermodynamics

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As observed by Georges Reeb "*Thermodynamics has long accustomed mathematical physics (see DUHEM P.) to the consideration of completely integrable Pfaff forms: the elementary heat dQ (notation of thermodynamicists) representing the elementary heat yielded in an infinitesimal reversible modification is such a completely integrable form. This point does not seem to have been explored since then.*"
Notion of foliation in thermodynamics appears in C. Carathéodory paper where horizontal curves roughly correspond to adiabatic processes, performed in the language of Carnot cycles. The properties of the couple of Poisson manifolds was previously explored by C. Carathéodory in 1935, under the name of "function groups, polar to each other". This seminal work of C. Caratheodory leads to the concept of a Poisson structure which was first defined independently by Lichnerowicz and Kirillov. A symplectic foliation model of Thermodynamics has been defined by Jean-Marie Souriau based on "Lie Groups Thermodynamics" model. This model gives a cohomological characterization of Entropy, as an invariant Casimir function in coadjoint representation. The dual space of the Lie algebra foliates into coadjoint orbits identified with the Entropy level sets. In the framework of Thermodynamics, a symplectic bifoliation structure is associated to describe non-dissipative dynamics on symplectic leaves (on level sets of Entropy as constant Casimir function on each leaf), and transversal dissipative dynamics, given by Poisson transverse structure (Entropy production from leaf to leaf). The symplectic foliation orthogonal to the level sets of moment map is the foliation determined by hamiltonian vector fields generated by functions on dual Lie algebra. The orbits of a Hamiltonian action and the level sets of its moment map are polar to each other. The space of Casimir functions on a neighborhood of a point is isomorphic to the space of Casimirs for the transverse Poisson structure. Souriau's model could be then interpred by Libermann's foliations, clarified as dual to Poisson Gamma-structure of Haefliger, which is the maximum extension of the notion of moment in the sense of J.M. Souriau, as introduced by P. Molino, M. Condevaux and P. Dazord in papers of "Séminaire Sud-Rhodanien de Géométrie ". The symplectic duality to a symplectically complete foliation, in the sense of Libermann, associates an orthogonal foliation. We conclude with link to Cartan foliation and Edmond Fedida works on Cartan's mobile frame-based foliation.
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Keywords: Symplectic Geometry / Entropy as Casimir Function / Foliation

Ilya Prigogine's Non-Equilibrium Thermodynamics as a New Synthesis of Physics?

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In 1979, Belgian theoretical physicist and chemist Ilya Prigogine (1977 Nobel Prize in Chemistry) and Belgian philosopher of science Isabelle Stengers published a bestseller in French, *La Nouvelle Alliance*, mainly dedicated to the history, philosophy and popularization of thermodynamics. Translated in English in 1984 as *Order Out of Chaos*, this book has proven to be very influential within scientific and intellectual spheres (with more than 14,000 citations, according to Google Scholar). Based on a rich and historically grounded narrative of European physics, reviewing successively Newtonian dynamics, equilibrium thermodynamics and non-equilibrium thermodynamics, *Order Out of Chaos* can be read as the promotion of the following epistemological thesis: Prigogine's non-equilibrium thermodynamics constitutes the basis for a new synthesis of the whole physics. During the eighteenth century, mainly in England, steam engines were improved in order to use heat to produce mechanical work. In 1824, Carnot's theoretical efforts to increase the yields of these engines gave birth to a new area of physics: thermodynamics. Building on Carnot's work, Clausius formulated the second principle of thermodynamics in 1850, and invented the notion of entropy in 1865. In 1877, Boltzmann proposed a new – probabilistic – definition of entropy: for a macroscopic system, the entropy associated with a given macrostate of this system was thus defined – within a proportionality factor and a logarithm – as the number of microscopic configurations of particles which are compatible with this macrostate. With this new definition of entropy, which, as Boltzmann showed, corresponds to the same quantity as Clausius' entropy, the second principle takes on a probabilistic meaning. The irreversible growth of the entropy of an isolated macroscopic system now corresponds to a temporal evolution of this system towards macroscopic states of increasing probabilities, and this entropy growth must be viewed as a statement about the most probable evolution of this system. Despite Boltzmann's conclusions, Prigogine still wanted to overcome what he considered as Boltzmann's failure to reconcile the microscopic reversibility of dynamics and the macroscopic irreversibility of thermodynamics. In *Order Out of Chaos*, the authors described the recent developments in non-equilibrium thermodynamics, insisting on the work conducted in Prigogine's group. According to them, these developments allowed to propose a new synthesis between dynamics and thermodynamics. *Order Out of Chaos* can thus be seen as an attempt to promote Prigogine's thermodynamics as the foundation on which to build a new synthesis of physics. The posterity of the epistemological thesis that Prigogine's non-equilibrium thermodynamics is the basis for a new synthesis of physics has been hampered in particular by the clash

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of Prigogine's school with another school of statistical physics. However, the singular dialogue between physicist Ilya Prigogine and philosopher Isabelle Stengers highlighted the importance of irreversibility in contemporary physics.
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Keywords: History of Physics, Non equilibrium Thermodynamics, Boltzmann, Prigogine, Irreversibility

Topicality of Carnot's Theorem for the Energy Transition

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Due to Carnot's theorem, any work produced from heat undergoes a poor efficiency. This has helped photovoltaic and wind powers, who immediately appear in the state of work, to become cost-effective with regards to, e.g., power made from coal. But the reverse is also true: for any end-use of energy which is not work and if the starting point is not heat, this advantage will no longer exist, and the fossil fuels will be harder to overcome. Typical examples are: chemical reductions such as steelmaking from coal or hydrogen making from natural gas; and heat production. For low temperature heat production, however, Carnot's theorem allows heat pumps to benefit from sort of an "higher than 100% efficiency", which can make renewable electricity a more interesting primary energy than fossil fuels. Of course, the first principle of the thermodynamics forbids true "higher than 100%" efficiencies, but this question refers to Carnot's notion of "sinks", and seasonal storage can make the combination of heat pumps in winter and air conditioning in summer really very efficient, as energy wastes of both can become valuable resources 6 months later.

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Keywords: Carnot's efficiency, energy transition, fossil fuels, photovoltaics, wind energy, heat sink, cold sink, heat pumps, air conditioning, steelmaking

*Speaker

Lazare Carnot and Michel Chasles: Foundational Programmes for Geometry

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Abstract. In my talk I will analyse the role played by Lazare Carnot within the birth of projective geometry. Poncelet's *Traité des propriétés projectives des figures* (1822) can be considered the work with which the foundation of projective geometry begins. Fifteen years later Michel Chasles published his monumental work *Aperçu historique sur l'origine et le développement des méthodes en géométrie* (1837). This text is enriched by the two memories on duality and homography. It offers a modern foundation to projective geometry. The concept of cross-ratio is introduced in the form which is also used nowadays. Carnot's theory of transversals as well as his ideas on the way in which to use signs in geometry, represent one of the fundamental sources of inspiration for both Poncelet and Chasles. A systematic study on the way in which Carnot influenced these two geometers is still missing. My intention is to full this gap. In the talk, I will expound the basic results of my research on this topic.

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Keywords: Lazare Carnot, Poncelet, Chasles, theory of transversals, projective geometry, cross, ratio

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Quantum Heat Machines and Carnot in the 21st century

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The efficiency of heat-to-work conversion in a cyclic heat engine that operates between cold and hot thermal baths with temperature ratio Tc/Th is independent of the specific design, and limited by the universal Carnot theorem. As opposed to standard heat engines conforming to such a description, diverse models of cyclic engines powered by quantum non-thermal baths have been suggested to function, even at the scale of a single atom, and possibly surpass the Carnot efficiency limit. This brings about several questions for which there is still no clear, rigorously founded answer: Are classical notions still applicable to quantum thermal devices? Are work and heat properly defined at the quantum scale? Is there a common mechanism for the claims of surpassing of Carnot's bounds? And if there is, does it violate the Second Law of thermodynamics?

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Keywords: quantum theory, quantum thermodynamics

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Fourier's Propagation of Heat Hidden Influence On Sadi Carnot's Réflexions : the Question of Infinitesimals in Physics in the Early 19th Century

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The question of calorique is avoided with particular epistemological care by Fourier in his *Théorie analytique de la chaleur*, while it is maintained in the *Réflexions sur la puissance motrice du feu* in order to guarantee the conservation of heat. Which leads to rechecking the influence of Fourier's book investigating a diffusion phenomenon, while Carnot's aims is for a completely different physical phenomenon with the conservation of energy as a horizon, as Edmund Husserl could say. However, the calorique could, if necessary, be taken as a "mathematical fiction" to which agreed the chemist Lavoisier, undoubtedly influenced by Laplace and their joint work on calorimetry in 1783.This expression, so opposed to Fourier's style who wanted to see physical realities in the proper modes of heat, naturally leads us to the style of Lazare Carnot. In his *Réflexions sur la métaphysique du calcul infinitésimal* he indeed considered infinitesimals as useful fictions which only sign a positive result once they have disappeared from calculation. If the stylistic influence of Lazare Carnot on his eldest son Sadi is now well recognized, we have not sufficiently studied the role of infinitesimal calculation, in the historical context of physics in the early 19th century. Especially since a debate at the Conseil de perfectionnement of the Ecole Polytechnique required, for mechanics, the maintenance of an infinitesimal presentation of differential calculus, at the expense of the theory of limits considered too analytical. This allows us to put into perspective the contrast often made between the good quality of the mathematical training of Sadi Carnot, and his elementary use of mathematics in the *Réflexions.*

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Keywords: Lazare Carnot, Fourier, Sadi Carnot, Infinitesimal, Heat

*Speaker

Lazare Carnot's Mechanics: the Beginning of Group Theory in Science

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Abstract. Present paper summarizes the main characteristic features of Lazare Carnot's formulation of mechanics(1). Of its theoretical development two features are illustrated: 1) its origin – as declared by L. Carnot himself(2) – from the principle of virtual works in the case of the impact of bodies; the theoretical treatment of this case avoids the use of forces, the characteristic main basic notion of Newton's theory of mechanics; 2) its introduction of group theory into theoretical physics; he was proud to have given birth to "an intermediate science between geometry and mechanics"(3). The latter novelty is compared with *i*) René-Just Haüy's introduction of symmetries in crystallography, occurred one year later(4); *ii*) Evariste Galois' introduction of group theory into mathematics, occurred fifty years later(5); *ii*) Pierre Curie's introduction of symmetry breaking in theoretical physics, occurred a century later(6). L. Carnot's formulation is then characterized under the light of the four models of scientific theory(7) and the four prime physical principles(8). Finally, a rational re-construction of this formulation according to the last two features is suggested(9). At the end a proposal to introduce this re-formulation into physics teaching is discussed.

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*Speaker

Keywords: Lazare Carnot, mechanics, principle of virtual works, symmetry, rational re, formulation

Carnot's Principle Applied to Thermoelectrics: Dynamics of Entropy, Charge and Energy

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The Carnot principle is one of the greatest achievements in physics (1). It identifies entropy as the central operational quantity in any kind of heat engine (2). In its generalized form, the principle states that the fall of entropy down its thermodynamic potential, which is the absolute temperature, releases energy that can be transferred to a useful process. An extensive thermodynamic quantity in the energy-receiving process is then raised in its corresponding thermodynamic potential. The Carnot principle provides the framework for a generalized dynamics, often called thermodynamics, covering all kind of energy conversion in the living and non-living world. On the example of thermoelectric materials, transport equations for entropy, charge and energy are easily established, which identify the thermoelectric material by a material tensor instead of a kinetic matrix as in the traditional approach of the so-called thermodynamics of irreversible processes (3, 4). Instead of so-called generalized forces, gradients of the more familiar thermodynamic potentials appear, i.e. temperature and electrical potential. In the reverse mode of operation, these materials can be used as entropy pumps and can transport entropy from a low temperature to a high temperature. The central role of entropy in thermal processes, as clearly described in Sadi Carnot's book of 1824, has been obscured by confusing conceptualizations in the course of the 19th to 21th centuries (5). Key developments and conceptualizations in the period 1824 - 2024 are critically examined and categorized to show that the Carnot principle can be used as a guide with great merit to treat energy conversion, including thermal phenomena, in a more economical and unifying concept compared to traditional approaches.

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Keywords: Carnot principle, charge, electrical potential, energy, entropy, heat, temperature, ther-

*Speaker

modynamics, thermoelectrics

The Intellectual Environment of Sadi Carnot. A Further Look

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An examination of the environment – social and economic, as well as intellectual – in which Sadi Carnot composed the Réflexions sur la puissance motrice du feu does much to explain both the aim and the style of the book. It points to Carnot's analysis as one of numerous responses to the arrival in France, after 1815, of steam engines of the type that Arthur Woolf had patented in England during the Napoleonic Wars. The economy of the new engines took the French by surprise and raised questions. Crucially, how much did the engines' performance owe to the use of pressures above atmospheric and how much to expansive operation, which entailed the cut-off of steam before the end of the power stroke? In fashioning his answers, Carnot encountered major obstacles in the unreliability of key data concerning the thermal properties of gases and vapours. The result was an analysis in which profound insights jostled with loose ends and inconsistencies sufficient to make further progress with the core problem of the Réflexions impossible. Such a conclusion is consistent with Carnot's turn, in his last years, from power technology to political economy, to which (according to his brother Hippolyte) he devoted himself with as much insight and commitment as he had shown in his engagement with the theory of the heat engine.

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Keywords: Sadi Carnot, power technology, team engine, political economy, Arthur Woolf, thermodynamics

*Speaker

The Rediscovery of Sadi Carnot by Henry Le Chatelier (1850-1936), a Forgotten Contribution to Energetics ?

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"Henry Le Chatelier was the first, I believe, to indicate the true and profound meaning of Carnot's doctrine". Georges Mouret made this statement in 1892 in an article where he underlined the fundamental notion of Carnot's work which had not been preserved in the theory of Clausius, the dynamic notion of the restoration of equilibrium. This is why Emile Picard in a speech given in honor of Henry Le Chatelier could recall that he "was one of the first to take up Carnot's points of view, starting from the notion of motive power". In this presentation we would like to return to the rather little-known energetics Le Chatelier developed based on this return to Carnot's ideas which occured in 1891. That year, in a short note addressed to the Chemical Society of Paris, Le Chatelier explained how Carnot's principle, based on a generalization of motive power, allowed him to find chemical laws more easily than he had done previously based on Clausius' theory. This is what we would understand by analyzing his Recherches expérimentales et théoriques sur les équilibres chimiques published in 1888. On this new basis, Le Chatelier gradually developed a certain energetics until giving it a completed form which he published in 1894. A first stage of this development could be observed through an article written at the beginning of 1891 in collaboration with Georges Mouret. The notion of availbale energy is introduced while still remaining associated with the principles of Clausius. A few months later, in his short note, Le Chatelier will declare the equivalence of this notion with the motive power of Carnot by linking it directly to the principle of the latter. Mouret's article of 1892 finally provided Le Chatelier with new conceptual elements which enabled him to formulate in three laws a general theory of transformations of motive power. The conservation of entropy for reversible evolutions becomes a special case of his first law. Likewise, the notion of internal energy no longer comes into play directly. The principle of equivalence as established by Joule thus founds his third law.

Le Chatelier's energetics ultimately reveals itself as an attempt to base the entire theory of energy transformations on the notion of motive power. In this respect it will be interesting to question the influence that the article Sur l'énergie utilisable by the French physicist Georges Gouy could have exerted. Published in 1889, this article constitutes according to its author a development of the point of view indicated by "the English physicists" Sir W. Thomson, Tait and Maxwell who introduced the equivalent notions of motivity and available energy and whose "ideas would have doubtless received more extension if the introduction of entropy by Clausius had not taken Thermodynamics into a slightly different path".

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Keywords: Henry Le Chatelier, Energetics, Available energy, Exergy

Reconsidering the use of Carnot's heat engine in thermodynamics education

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By transforming the caloric theory of heat to the concept of energy and its conservation in 1850, Rudolf Clausius corrected the fatal flaw in Sadi Carnot's heat engine and subsequently established the 1st Law of Thermodynamics and a new version on the 2nd Law of Thermodynamics. In 1865, after much additional theoretical work, Clausius further identified entropy as a property of matter, thereby opening a path to a breakthrough interpretation of the 2nd Law based on the probabilistic theory of nature. While today's educators understandably employ Carnot's heat engine to teach these foundational concepts, students remain confronted. Trying to understand these concepts is difficult enough as it is, but using Carnot's heat engine as the teaching vehicle makes the challenge even more difficult. Carnot's heat engine is important to understand, but perhaps not as an early step in the educational process. A more effective method for teaching thermodynamics could be to ground the instruction in the atomic theory of matter, emphasizing the movement and interactions of atoms. By linking the micro-level of atomic behavior to the macro-level concepts of classical thermodynamics, students can gain a deeper understanding of the subject. This contrasts with the prevalent Carnot-based approach, which often leaves learners perceiving thermodynamics as an impenetrable black box, leading to a reluctance to harness the full potential of this influential science. In this paper I propose how employing an "atoms first" approach will enable students to better learn, better understand, and more confidently employ thermodynamics in a proactive and creative way. I also propose how we as educators can develop this curriculum. Most of the material is already available in the pages of books and journals and in the minds of many. We need to assimilate this material, naturally including an atoms-first explanation of Carnot's heat engine and its implications, into one single place, while acknowledging that some remains to be discovered if not created. Time to start.

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Keywords: Sadi Carnot, Rudolf Clausius, heat engine, 1st Law of Thermodynamics, 2nd Law of Thermodynamics, energy, entropy, education

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From Carnot to Clausius

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Currently, three thermodynamic theories underpin the global energy system. This paper presents proof that there are actually just two: the First Law of Thermodynamics and the Carnot theorem. The presented Carnot-to-Clausius derivation provides analytical, mathematical, and phenomenological proof that Clausius entropy does not explain thermodynamic principles beyond the First Law of Thermodynamics and the Carnot formula. The Clausius entropy formula incorporates a variable known as the Clausius entropy (ΔS), which has the unit J/K and is not accounted for in the First Law of Thermodynamics. The thermodynamic model from which the Carnot-to-Clausius formula is derived clearly explains that the variable Clausius entropy (ΔS) can be expressed as a certain amount of thermal energy (J) and a corresponding temperature (K). Furthermore, the Carnot-to-Clausius derivation reveals the remarkably sophisticated underlying working principle of how the Clausius entropy formula can quantify the magnitude of any thermodynamic irreversible process in any process taking place in industry, nature, and the universe. Among other improved insights, this paper highlights the completion of the thermodynamic definition of ΔS=0, which, according to the authors, has a broad impact on industrial heat engines and heat pumps.

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Keywords: Carnot theorem, Carnot formula, Clausius Entropy, First Law of Thermodynamics, Irreversable process, Heat engines, Heat pumps

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The Role of Experimental Practice in the Rise of Technical Thermodynamics at the University of Liège from 1868 to 1914

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This paper describes how experimental practice around a steam engine at the University of Liège at the end of the long 19th century facilitated the rise of technical thermodynamics as both a topic of education and a topic of research in that Belgian university. This experimental practice has been carried out in a Laboratory of industrial physics and mechanics that has been established in 1887 after a long process initiated in the 1870 by Professor Victor Dwelshauvers-Dery. The investigated corpus mainly comprises educational material of Applied Mechanics and Industrial Physics from 1868 to 1913. While a course named Technical thermodynamics still didn't exist, the two latter courses paved the way to a modern technical thermodynamics course. The corpus is completed by laboratory books and scientific publications. The first part of the paper briefly explains the process of creation of the laboratory, in the socio-economic context of the time, and highlights oppositions faced (but also support) by his new director, Victor Dwelshauvers-Dery. The second part of the paper describes the experimental facility of the laboratory: a steam engine equipped with all measurement devices (pressure, temperature, indicator, Prony brake) to perform energy balance and assess its performance. Original measurement practices are described, including water flow measurements and early use of thermocouples (to better observe the state of the steam inside the cylinder). The paper then describes the evolution of the content of Applied Mechanics and Industrial Physics courses from 1868 to 1913, illustrating the progressive diffusion of knowledge about classical and technical thermodynamics in a Belgian University: mechanical equivalent of heat (probably around 1868), the Second Law (use of the Rankine Theorem in 1868-1869 and reference to Carnot from around 1888), concepts of energy and entropy (only introduced in 1888-1889), properties of working fluids, thermodynamic diagrams, conception and representation of machines. The work also illustrates the still vivid analogy, at the end of the 19th century, between hydraulic and thermal engines when illustrating the maximal engine efficiency or heat losses at the steam expander walls. The notions of thermal weight and thermal height proposed by the thermodynamicists of Liège are presented and discussed.

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Keywords: steam engine, machine, experimental, thermodynamics, applied mechanics, industrial physics, indicator, Prony brake, thermocouple, thermal weight

Thermodynamic Time Asymmetries

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One of the oldest and greatest disputes of philosophy concerns the nature of continua and the natural investigation of them. We experience natural phenomena as continuous, yet we investigate them using discrete, elemental, and mechanical theoretical structures that seem not to be in keeping with the original objects of study. The topic of this paper is the debate over the order of natural, physical processes. A classic version of the second law of thermodynamics states that heat flows between adjacent bodies from the hotter to the colder. Entropy is a gauge of that flow. A great tradition holds that entropy itself explains the asymmetry of thermodynamic processes in time. But does it? The thermodynamic time asymmetry seems not to mesh nicely with the atomistic mechanistic world view, even though we appeal to statistics to study it, making the debate seem intractable. Certain aspects of the debate are intractable but not all. I argue that the ontological debate is derivative on the nature of analysis and follow up on a philosophical proposal by Boltzmann.

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Keywords: Determinism, Mechanism, Reduction, Continua, Entropy, the Second Law of Thermodynamics, Symmetry, the Labyrinth of the Continuum

Carnot and the Conservation of Energy

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The historiography of thermodynamics has focused on concepts, energy and entropy. Entropy appears linked to Carnot's *Reflections*, which, in turn, appears in opposition to energy, due to the concept of heat as a substance. In the present article, the focus is on the experimental basis of energy, which is the mechanical equivalent of heat. The value of the equivalent is mentioned in Carnot's posthumous manuscripts. This value is in line with the one calculated by Mayer, who created the concept of energy, the one calculated by Holtzmann, who admitted that heat was a substance, and with that deduced from the Carnot-Clapeyron theory by Clausius. Therefore, the equivalent does not depend on the theory of energy, as will also be shown through the Joule case. On the other hand, if we reflect on the phases of Carnot's machine, we can justify passages from the manuscripts, for which Carnot has been listed among the discoverers of energy. The position of Carnot's *Reflections* in the history of physics can also be improved regarding the first principle of thermodynamics if the historiographical focus is not on the energy concept but on its experimental basis.

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Keywords: Carnot's Reflections, Carnot's manuscripts, historiography of thermodynamics, energy, mechanical equivalent of heat.

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Carnot theorem for Constrained Hybrid Mechanical Systems

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Hybrid systems are dynamical systems with continuous-time and discrete-time components in their dynamics. This class of dynamical systems are capable of modeling several physical and engineering systems. In this paper, we propose a geometrical approach that extends Carnot's theorem to the hybrid systems subject to constraints, which characterize the changes of energy due to contact-type impulsive forces. We also review several previous results in the case of non-holonomic impulsive constraints and to time-dependent holonomic and non-holonomic instantaneous constraints. In the simplest case of holonomic boundaries this result is indeed known as Carnot's theorem. We also consider the situation when we are in presence of symmetries and obtain the corresponding reduction process.

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Keywords: Carnot theorem, hybrid systems, nonholonomic constraints

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Sadi Carnot Paradigm Changes in Physics and Economics

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Sadi Carnot entered the Paris Polytechnic School at a very young age. Having been born in 1796, in 1812 he entered that renowned educational institution. As a military engineer, he followed some actions of the French army, but it was the period of peace after Waterloo that provided the development of his talent for engineering disciplines. He studied mainly physics and economics, spending much of his time visiting industries and studying industrial organization and economics, having become an expert on trade and industry issues in several European countries. In 1824, he published his Réflexions sur la puissance motrice du feu. The aforementioned work by Carnot, inaugurating the science of thermodynamics, lays the foundations and philosophical foundations for changing several paradigms already established in the sciences of the 19th century. Thermodynamics immediately presents itself as a new theory of machines, providing a solution and extending the limits imposed by Newtonian theory to explain machines, because energy degradation. We examine in more depth the application of the concept of entropy to economics, and the creation of a new discipline called ecological economics. These developments, more modernly, have taken over the debates and launched many issues related to energy, the environment and sustainability into the field of economic discussions, all of them having as their origin the work of Carnot in 1824. We will study the work of the Romanian economist Georgescu Roengen (1906-1994) and his difficulties in breaking with the paradigm established in classical economics or even in neoclassical economics, of considering economic processes disconnected from the environment, as if they were selfsustaining itself, for an indefinite period of time. New economic visions that break this paradigm introduce the environment in this context, through the concept of entropy. One of the main consequences of the Romanian economist's studies was the degrowth thesis. But condemning economic growth – seen as a solution to all social and even environmental ills – sounded like a real delusion. It was a thesis considered very radical not only by conservative economists, but even by some environmentalists. Georgescu said that one day humanity will have to think about stabilizing economic activities, as there will be no way to avoid the dissipation of materials used in industrial processes. These studies and the new perspectives presented have their origins in Sadi Carnot, even as a reflection and an echo that continues to reverberate more than a century later.

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Keywords: Thermodynamics, Entropy, Environment, Sustainability, Ecological Economics

A Continued Fraction Expression for Carnot Efficiency

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A new and interesting continued fraction expression is derived for Carnot efficiency. The derivation is based on a series combination of a set of Carnot heat engines, wherein heat rejected by a member of the series is absorbed by the following member of the series. Our analysis of this combination of Carnot heat engines shows that mathematical consistency is maintained only if the efficiency of Carnot heat engine is zero. This calls the attention of researchers to look back at the puzzling definition of Carnot efficiency that says the efficiency of an ideal heat engine (Carnot heat engine) is less than one, in spite of the fact that each of the steps involved in the cycle of operation is hundred percent efficient.

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Keywords: Carnot efficiency, Thermal efficiency, Continued fraction expression

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On Lazare & Sadi, Cycle & Machines: A filial and Scientific Project

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Lazare Nicolas Marguérite Carnot (1753–1823) stated the chimerical dream of an unlimited production of work by means of a general working substance (Carnot L 1786; 1778; 1780, §§ 149–160). How? The source of an unlimited power, evidently correlated with theoretical studies on the conversion of heat–in–work, was analytically formulated by the first law of thermodynamics and its general energy conservation (Joule 1965, pp. 277–281; 1847, pp. 173–176; Clausius 1850, 1865ab; Thomson 1848, 1851ab). Finally, Thomson also analytically discussed the second principle of thermodynamics and the necessity of a second thermostat with the aim of executing a passage of heat between a difference of temperature (Thomson 1848–1849, pp. 541–574; 1882–1911, pp. 113–155; 1852, pp. 248–255). In 1789, Antoine–Laurent Lavoisier ((1793–1794); 1789; 1862–1893)) as well as other chemists of his time, searched for the basic principles of this new theory in a revolutionary fashion. Nevertheless, these new principles were different from Newtonian Mechanics (Cfr. Pisano and Bussotti's works on Pisano's homepage). General speaking, scientific knowledge on the matter took two main paths, one based on the properties of gases (Newtonian kinetic model of gases) and another based on the efficiency of heat machines, which naturally included the gas theory. The latter would later become thermodynamics. In 1824, the Thermodynamics (2nd principle only) was born by means of Sadi Carnot's *Réflexions* sur la puissance motrice du feu (hereafter *Réflexions*). Sadi Carnot (1796–1832) was one of the most important and ingenious scientists of the 19th century. He dealt with heat machines and gas theory by: a) the *caloric hypothesis* mixed with a *weak heat concept*, b) the *cycle* and c) *ad absurdum proof theorem* (atypical at that time). The impossibility of a perpetual motion linked to state of a system, (novelties of) reversible processes & cycle (four phases). In his unpublished *Notes sur les mathématiques, la physique et autres sujets* (Carnot S. s.d.) slightly made indirect use of the hypothesis on puissance mortice/conversation/heat–work (Carnot S. 1878, pp. 134–135). Sadi's book, and considerations on theory on gases, appeared in quite a short period, ca. three years. It was an early scientific and filial project of father, Lazare and his son, Sadi. It was a total overturning of the Newtonian paradigm and related physics–mathematics relationship, which was a new the*ory, which had its origins in physical–engineering practices. In my talk I will scientifically present the two Carnot and focusing on: how describe the scientific relationship between the two Carnots, with respect to Newtonian paradigm within mathematics and physics relationship*? After Lavoisier's chemistry, *is thermodynamics another outlaw theory*? *Where did the idea of a cycle come from*?

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Keywords: Lazare and Sadi Carnot, Cycle, Mechanics, Thermodynamics, Filial Project, A Book Without Mathematics

The Importance of Conceptual Teaching in Early Technical Education: The Case of Carnot Engine

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The pursuit of quality education demands a focus on factors that elevate teaching standards. Central to this is the recognition that excellent teachers are the cornerstone of quality education. Teachers must understand not only the theoretical and historical foundations of science but also how science progresses. This understanding enables them to choose appropriate didactic approaches, enhancing their ability to convey complex concepts effectively. In teacher education, particularly for those preparing to teach science and technology, it is crucial to develop an epistemic repertoire that allows pre-service teachers to create cognitive artifacts. A shift in teaching paradigms, influenced by constructivist theories, moves the focus from what teachers do to what and how students think. This change requires teachers to make didactic decisions that are reflected in their teaching methods. A conceptual understanding approach is vital in teacher education, necessitating that students think critically, understand, and make sense of the learning material. Teachers must use various methods and forms of teaching to ensure that students achieve lasting and meaningful knowledge. Conceptual teaching must be adapted to the students' developmental stages. In early technical education (ages 12-15), concepts are simplified to facilitate understanding of abstract ideas. As students progress to secondary technical education (ages 16-19), these basic concepts are expanded upon.This gradual build-up ensures that students can effectively grasp more complex ideas as their cognitive abilities develop. Effective teaching strategies must include a variety of scientific research methods to develop both conceptual and procedural knowledge. However, when experiments are impractical due to ethical or logistical constraints, models and simulations become valuable teaching tools.These tools help students visualize abstract concepts and interrelate scientific ideas, leading to a deeper understanding of the material. The integration of historical artifacts in teaching provides a simplified version of complex devices, aiding in the conceptual understanding of technical concepts.For example, the study of Sadi Carnot's work on heat engines in the 19th century serves as an excellent case of how historical developments can inform modern teaching. Carnot's insights into the efficiency of heat engines laid the groundwork for the second law of thermodynamics and the concept of entropy, which are fundamental to understanding modern engines.

In Slovenian schools, the current curriculum's scattered approach to teaching about engines makes conceptual teaching challenging. However, efforts are underway to reform the curriculum, grouping related topics together and introducing conceptual teaching at an earlier stage. By aligning the curriculum with research findings, students will be better equipped to build on their knowledge as they progress in their technical education. Overall, the effective introduction of conceptual teaching in technical education, adapted to the students' developmental stages,

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lays a strong foundation for deeper understanding and further learning.This approach ensures that students not only grasp the theoretical constructs but also understand their practical applications, preparing them for advanced studies and real-world challenges in science and technology.

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Keywords: Carnot Heat Engine, Conceptual Teaching, Historical Foundations of Science, Teacher Education

Carnot-Batteries for Large-Scale Electricity Storage

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The storage of renewable electricity on the scale of gigawatthours is one of the central challenges of energy research. Carnot-Batteries could be a potential solution to the storage problem. A Carnot-Battery transforms fluctuating electricity into heat, stores the heat in high-temperature media like molten salt or ceramics and transforms the heat back to electricity using steam turbines, gas turbines or combined cycles. The storage efficiency of a Carnot-Battery depends both on the efficiency of the heat pump and of the heat cycle. It thereby encompasses the seminal contributions of Sadi Carnot to the foundations of thermodynamics. The presentation will give a elementary introduction into the technology of Carnot-Batteries and will explain how the work of Carnot is embodied in these storage systems. The presentation will also provide a glimpse at the fourth International Workshop on Carnot Batteries, to be held in Stuttgart from 23 to 25 September 2024, including a special Carnot session.
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Keywords: Carnot efficiency, Carnot heat pumps, energy storage

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- Maddaluno Paola
- Mallick Kirone
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- Marcacci Flavia
- Oliveira Agamenon
- Prof. Dr. Missinne Stefaan
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