

**AAAS Pacific Division
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Symposium Abstracts**

12 Limits to the Second Law of Thermodynamics

Maxwell's Demon: A Brief History, **ANDREW REX** (University of Puget Sound Tacoma, WA, USA rex@pugetsound.edu).

For more than 140 years Maxwell's demon has intrigued, enlightened, mystified, frustrated, and challenged physicists in unique and interesting ways. Maxwell's original conception was brilliant and insightful, but over the years numerous different versions of Maxwell's demon have been presented. Most versions have been answered with reasonable physical arguments, with each of these answers (apparently) keeping the Second Law intact. Though the laws of physics did not change in this process of questioning and answering, we have learned a lot along the way about statistical mechanics and thermodynamics. This lecture will review selected history and discuss some of the interesting historical characters who have participated.

Black Hole Thermodynamics: More Than a Formal Analogy? **CRAIG CALLENDER*** and **JOHN DOUGHERTY** (Department of Philosophy, University of California San Diego, 9500 Gillman Drive, La Jolla, CA 92093-0119; ccallender@ucsd.edu).

Black hole thermodynamics (BHT) understands many relationships amongst black hole variables as manifestations of deep thermodynamic principles operating in the universe. BHT is widely accepted as being more than a formal analogy with thermodynamics; indeed, its identity with thermodynamics is commonly used as justification for many speculations in quantum gravity. Playing the role of philosophical gadfly, we want to pour a little cold water on the claim that BHT is more than a formal analogy. To do so, we show that BHT is often based on a kind of caricature of thermodynamics. Then we point to an important ambiguity in what systems the analogy is supposed to be between. Finally, and perhaps worst, we point out that one of the primary motivations for the theory arises from a terribly controversial understanding of entropy. BHT may be a useful guide to future physics. Only time will tell. But the analogy is not nearly as good as is commonly supposed.

Quantum Oblivion: The Extreme Reversibility Underlying Reversible Classical Physics, **AVSHALOM ELITZUR** (*Iyar*, The Israeli Institute for Advanced Research, POB 651, Zichron Ya'akov 3095303, Israel; avshalom@iyar.org.il).

QM's familiar oddities, namely nonlocality, uncertainty, etc., overshadow the unique role played by quantum nonevents: Suffice it that an event *may* occur that, even if it does *not*, its mere *likelihood* exerts causal effect. Interaction-Free Measurement (IMF) [1] brings this oddity to extreme. Thermodynamics gives it further intrigue: How can a mere "no click" give rise to irreversible results?

Explanations have resorted to extreme Copenhagen or "many worlds." A purely physical explanation is warranted, that may also prove useful for elucidating other oddities.

"Quantum Oblivion" [1] is a simple interaction between two particles, one ending up with momentum changed leaving the other unaffected, disregarding Newton's law. Weak measurement [2] gives a clue: *In every quantum measurement, the particle's uncertainty is balanced by a conjugate uncertainty of the measuring device's pointer.* Oblivion thus gets a straightforward explanation together with several other quantum phenomena: At the quantum level, events not only occur but sometimes "unoccur" as well.

Significantly, even this form of ultimate reversibility takes its thermodynamic toll by the familiar "entropy increase elsewhere." Quantum Oblivion thus has straightforward bearings on both the nature of the quantum realm and the origins of macroscopic reversibility.

[1] A.C. Elitzur, L. Vaidman *Found. Phys.* **23**, 987 (1993).

[2] Y. Aharonov, E. Cohen, A.C. Elitzur. *Phys. Rev. A.* **89**, 052105 (2014).

Loschmidt's Temperature Gradient Paradox – A Quantum Mechanical Resolution, **GEORGE S. LEVY** (Entropic Power Corp., San Diego, CA 92130-2258; glevy@entropicpower.com, glevy@patentsandventures.com).

Loschmidt conjectured that temperature gradients could form spontaneously in a column of gas such as air subjected to a gravitational field. Evidence shows his conjecture to be impossible in a Maxwell-Boltzmann gas. Two competing effects take place resulting in a zero gradient. The first is the well known adiabatic temperature lapse according to which temperature tends to decrease linearly with elevation. The second separates molecules according to their energy in analogy to a mass spectrometer which separates them according to their mass. Because the most energetic molecules are allowed to rise higher, temperature tends to increase with elevation. In Maxwellian gases these two effects cancel exactly leading to a zero gradient. Surprisingly, simulated gases imparted with an impulse distribution through their interaction with the walls of the simulation chamber, can produce a spontaneous temperature gradient. The reason is that the second effect cannot separate molecules when they have the same energy. More generally, any gas deviating from the Maxwell-Boltzmann distribution can produce temperature gradients thereby rehabilitating Loschmidt. Even though gases with impulse distributions are not physically realizable, gases comprised of fermions or bosons do exist and follow non-Maxwellian statistics. Theoretical justification is presented explaining the spontaneous formation of gradients in such gases thereby explaining mysterious experimental data collected by researchers in the measurement of the Seebeck coefficient in thermoelectric materials. Preliminary simulation data confirms the theory. Architectures are proposed for thermoelectric devices that produce a temperature difference output without any electrical input, and electrical output without a temperature difference input.

Epicatalysis and the Inviolability of the Second Law, **D.P. SHEEHAN***, **T.A. ZAWLACKI**, and **W.H. HELMER**. (Department of Physics, University of San Diego, San Diego, CA 92110 USA; dsheehan@sandiego.edu).

In 2000, T.L. Duncan proposed a second law paradox in which differential gas-surface chemical reactions on opposing faces of a blackbody cavity radiometer generate a steady-state pressure differential by which perpetual work is performed at the expense of the surrounding heat bath. In 2014, a series of laboratory experiments involving hydrogen dissociation on transition metals verified a high-temperature version of this paradox, indicating breakdown of the second law. The key phenomenon in these experiments was a low-pressure form of standard heterogeneous catalysis, called epicatalysis. Until recently, all examples of epicatalysis were limited to high temperature systems ($T > 1500$ K). Here we report on the first examples of low-temperature epicatalysis, opening the door for room-temperature embodiments of Duncan's paradox. Prototypes for commercial devices are being pursued. In this talk we report on these recent developments.

Apparatus and Procedures for Detecting Temperature Differentials with Epicatalytic Materials, **DAVID W. MILLER** (2137 Belgrade Rd, Sidney, ME 04330; dmiller@metheus.org).

Recent advances in physical chemistry theory allow for the development of temperature differentials between catalytic surfaces with different equilibrium constants in the presence of a low pressure gas. This process is characterized by non-equilibrium processes and is known as epicatalysis.

Apparatus and procedures are discussed that allow for the testing of multiple surface combinations simultaneously. The equipment is largely commercially sourced, allowing for easy replication.

Harvesting Energy From Thermal Fluctuation Across a Non-Ideal Diode, **GUOAN TAI** (The State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China; taiguoan@nuaa.edu.cn).

Thermal fluctuations in nonequilibrium systems in small systems exhibit remarkable behavior compared to equilibrium systems. Here we report experimental evidence of energy harvested from ambient thermal fluctuations across a non-ideal diode consisting of the tip of a silicon wafer and the surface of planar aluminum. The output depended on the contact force, which modulated the Schottky barrier height and the rectifying ratio of the diodes. The silicon and aluminum interacted in the size regime of the quantum-classical boundary, where thermal fluctuations are appreciable, and the rectification of thermal fluctuations induced the electricity generation. This approach is an innovative way to harvest energy from the environment.

How to build a Maxwell Demon from a 2nd order Phase Change System, **REMI CORNWALL** (University of London Alumni Association/TEC Power Ltd, r.o.cornwall@qmul.ac.uk).

This paper presents a summary of research to utilise the massive amount of low grade heat energy, for instance which exists in the worlds oceans, by a new type of magnetic cycle. Developed herein are methods based on 2nd order phase changes that make it possible to build a Maxwell Demon. Ferrofluids displaying temporary magnetic remanence are an almost perfect embodiment of the working substance for these cycles. Standard kinetic theory, thermodynamic, electrodynamic analysis and experiment validates the new cycle.

Environmentally Heated Engine Concepts, **KENNETH M. RAUEN** (P.O. Box 622, N. San Juan, CA 95960; kmpr27@gmail.com).

Several theoretical engine concepts are presented that can run on the heat of the environment as their energy inputs. They are based upon the preceding work of Wayne Proell, Jacob Wainwright, Chris Hunter, and Boris Kondrashov. The author presents the Proell-based engine concept and experimental evidence in depth. The Wainwright-based engine concept is introduced from Wainwright's early 1900's publications. The Hunter and Kondrashov concepts will be introduced, as time permits. The mechanisms by which the interpretation of universality of the second law is circumvented are clearly identified in each case. Mathematical proofs of engine cycles have been developed for the Proell and Wainwright concepts. The Hunter concept does not have a math proof, but Hunter has recently demonstrated two different engines. The Kondrashov concept is of historical record in the USSR during the Cold War years.

A Fundamental Collision Between Thermodynamics and Statistical Physics, **ALEXEY NIKULOV** (Institute of Microelectronics Technology, Russian Academy of Sciences, 142432 Chernogolovka, Moscow District, Russia; nikulov@iptm.ru).

Most scientists of the 19th century, including such eminent scientists as Jules Henri Poincare and Max Planck, rejected the atomic-kinetic theory of the heat proposed by James Clerk Maxwell and Ludwig Boltzmann because of the collision between the reversibility of the dynamics and the irreversibility postulated by the second law of thermodynamics. Most scientists in the 20th century believed that the Boltzmann 'H-theorem' has eliminated this collision. But Max Planck called the 'H-theorem' into question because "*Boltzmann omitted in his deduction every mention of the indispensable presupposition of the validity of his theorem – namely, the assumption of molecular disorder*". Indeed, the assumption of molecular disorder, i.e. of the randomness of any thermal equilibrium motion of atoms, molecules, Brownian particles etc. is the indispensable presupposition for the validity of the second law of thermodynamics. Marian Smoluchowski proved as far back as 1914 that of perpetual mobile is not possible in spite of perpetual thermal motion of atoms etc. because of the impossibility of regulating this motion with the help of a mechanical device. R.P. Feynman repeated this proof in the Section "Ratchet and Pawl" of his Lectures on Physics. This proof is reasonable because of the susceptibility of all elements of any mechanical device to random thermal motion. But this proof is not universal. The ordered equilibrium motion is not only possible but even observed in some well-known phenomena. These phenomena testifying to the scientific conscientiousness and genius of Max Planck will be considered in this work.

Challenges to the Second Law Challengers, **M. KOSTIC** (Professor Emeritus, Mechanical Engineering Department, Northern Illinois University; kostic@niu.edu).

A growing but small group of creative physicists and inventors, the "*Second Law Challengers*," are 'bravely' challenging the Second Law universal validity, often based on a fact that they have been successful in achieving a non-equilibrium, using innovative and creative methods and processes, and hoping to utilize it to produce energy from the environment, as a single thermodynamic reservoir. However, nobody has been successful achieving sustained conversion of environmental (thermal) energy to work (stationary or cyclic) or providing reliable evidence (comprehensive energy and entropy 'accounting') of achieving a sustainable overall process efficiency higher than Carnot's (which is zero-impossible from only a single thermal reservoir). After all, the Second Law is related to a working process direction (towards equilibrium) and its limitation, degradation up to conservation, but not spontaneous creation of nonequilibrium, the latter quantified by its work potential. Related issues will be reasoned and analyzed here. Just achieving a sustainable non-equilibrium state is not a violation of the Second Law. As the fundamental laws of nature and thermodynamics are extended from simple systems in physics and chemistry, to different space and time scales and to much more complex systems in biology, life and intelligent processes, there are more challenges to be comprehended and understood. There is a need to better discern the fundamental concepts at different scales and complex systems, like "complex

equilibrium,” a self-sustained, steady-state without net-fluxes at scale of interest, but with non-uniform concentration-potentials under coupled force fields; e.g., hydrostatic pressure and adiabatic temperature distributions in gravity field, charge and concentration distributions in electromagnetic-chemical fields, as well as, to differentiate between transient and stationary processes under influence of known and stealth boundary and field conditions. The 'challengers' need to demonstrate and quantify destruction of entropy to challenge universal validity of the Second Law. After all, the 'wishful'_Maxwell's Demon could not be realized since 1867.

Does Reduction in Entropy Associated with the Magneto-Caloric Phase Transition of Type I Superconductive Particles Violate the Second Law? **PETER D. KEEFE** (University of Detroit Mercy, 24405 Gratiot Avenue, Eastpointe, Michigan 48021 USA; PDK@Keefengine.com).

A priori, the most fundamental aspect of reality, and upon which the entire enterprise of science is rooted, is historicity. In this regard, all mathematical and epistemological descriptions of the physics underlying reality only have meaning if, and only if, historicity is universally operative. The First Law of Thermodynamics may be stated in terms of heat engines as follows: No heat engine can produce an energy output which exceeds its energy input. The ontological proof for this statement of the First Law is straightforward. All processes require historicity. If an engine could produce more energy than it consumed then the created energy would have no historical origin, and further any interaction of this energy with the environment would also have no historical basis. Therefore, the universality of historicity requires an absolute status of the First Law. The Second Law of Thermodynamics may, or may not, have absolute status because a device converting exiting energy into work neither creates nor destroys. The talk will provide a real world example of an energy conversion process that exemplifies why the Second Law may not have absolute status.

Physical Ergodicity: Another Faith-Based Myth (Which We Were Not the First to Debunk), **L.S. SCHULMAN and B. GAVEAU** (Physics Department, Clarkson University, Potsdam, NY 13699-5820, USA; lschulma@clarkson.edu).

The concept of ergodicity was invoked to justify (or was defined as) the equating of phase space and time averages. The idea was that in short times a system would wander through a sufficient sample of phase space. But it has long been realized that the notion of visiting all states is absolutely untenable, even if mathematicians have created a subject called ergodic theory and glorified it with proofs for artificial single particle evolution in the infinite time limit. In this presentation we explicitly show that "visiting all states" is a physical impossibility for moderate size systems. The interesting question then is why, despite its lack of justification, ergodicity and related notions (such as use of the thermal state) have been so successful in the description of physical and chemical phenomena.

Quantum Heat Engine Enhanced by Coherence: Revisiting Chambadal-Novikov Efficiency, **KONSTANTIN E. DORFMAN** (Precision Measurement Group, Singapore Institute of Manufacturing Technology, 71 Nanyang Dr 638075, Singapore; dorfman@simtech.a-star.edu.sg).

Various quantum effects have been observed in the thermodynamics of small systems. For instance understanding the microscopic origin of the quantum coherence and its role in the energy and charge transfer processes along with thermodynamics characteristics of the small systems is a key problem in both thermodynamics and quantum mechanics.

Previously we had investigated the possible role of quantum coherence and interference on steady state and transient behavior of the quantum heat engines (QHE), e.g lasers, photovoltaic cells, photosynthetic reaction centers, and nanoplasmonic devices. We showed that the maximum power of a QHE that converts incoherent thermal energy into coherent cavity photons could be enhanced by manipulating quantum coherences. We demonstrated that in both artificial (solar cells) and natural (photosynthesis) light harvesting coherence affects the same population-coherence coupling term which is induced by bath (e.g. phonons), does not require coherent light, and will therefore work for incoherent excitation under natural conditions of solar excitation. Despite the power enhancement the efficiency at maximum power of the QHE was not improved beyond standard Chambadal-Novikov limit.

We investigate a novel model of the three-level laser QHE where lasing occurs between two closely spaced metastable states and the ground state. Engine operates by transferring energy from hot bath to cold bath via nonequilibrium coherence assisted process. Coherence has two sources: first is due to

quantum interference generated via hot bath and second is due to the lasing field. The resulting efficiency is beyond the Chabada-Novikov limit due to interplay between these two coherence contributions.

Entropy Decrease in Isolated Systems, **JEAN-SELVA RATTINACANNOU** (180 rue du centre aere, 40990 Saint Paul les Dax, France; jsrtnn@free.fr).

Let us consider a system containing just one resonator, its Brownian motion being stopped by any means. At time t_1 the resonator is released, free to vibrate, and the system is isolated: no energy nor heat flows into or out of it. At time t_2 the resonator has recovered its usual Brownian motion, which is a vibration at its resonant frequency. Now, between the first state of the system at time t_1 and the second state at time t_2 , energy is brought to the resonator. Since the system is isolated, the law of energy conservation involves this energy comes from a lowering of the thermal energy of the system, that is, from a fall in its temperature. Since the resonator vibration has a constant frequency, its energy can be taken as mechanical. This fall in temperature entails a decrease of the entropy of this isolated system. However this decrease is very small, because the amount of thermal energy used to directly produce work is almost negligible. By a similar reasoning in a second system containing a very large number n of resonators, it is shown that if n is high enough there will be a large decrease of entropy in this system.

An experimental device based on this reasoning is proposed. A mechanical resonance is established between the nanoresonators and a macroscopic structure, which allows energy to be extracted from it, and not from the nanoresonators. Designs that could work are examined.

Testing: The Gravitational Potentials of Equilibrium Solute-Concentration Fluctuations — Finding: The Gravitational Potentials Exist and The Second Law of Thermodynamics Is Not Universal, **NORMAN K. BORSUK** (Alameda, CA, USA; normborsuk@gmail.com).

Equilibrium solute-concentration fluctuations are a variety of spontaneous particle fluctuation—ubiquitous, random vacillations in the distribution of solute particles within fluid solutions—that were first quantitatively characterized by Marian Smoluchowski early in the 20th century. In the studies presented here, I have posited that solute-concentration fluctuations can become exotic solute species that develop gravitational potential energy within simple liquid solutions that are at rest within earth's gravity. In this presentation I report on two sets of investigations into the core hypothesis, each set using test results from analytical electrochemistry ('electrochemical cells') and comparing those results to modeling using statistical mechanics and classical thermodynamics. The salient findings are these: The gravitational potentials of solute-concentration fluctuations empirically exhibit in accord with theoretical modeling and calculations; they (1) add to the chemical potential of a solute in solution, (2) participate in an electrolyte column's equilibrium equation and, (3) preclude the electrochemical cells from a steady state of thermodynamic equilibrium. It is this third finding which contradicts the Second Law of Thermodynamics. Recent and on-going tests, expanding on the original work, indicate compatible results but that are at least three orders of magnitude more powerful—perhaps enough to eventually demonstrate a spontaneous temperature decrease within a column of electrolyte at thermodynamic equilibrium commensurate with electrical work done on an external load by the electrochemical cell, which is precluded from thermodynamic equilibrium, in which the electrolyte column resides.

The Generation of Heat Through Insulated Assemblies of Molecules, **RODERICH W. GRAEFF** (Professor Domagkweg 7, D 78125 Koenigsfeld, Germany; rwgraeff@yahoo.com).

Experiments have shown that assemblies of molecules, placed in a container, have a higher temperature, than that of the outside of the container, provided the container is thermally insulated from its environment. This implies that heat is generated among the molecules. This can be demonstrated by filling a thermos bottle with molecules and measuring the temperature difference between the inside and the outside. Typically, temperature differences from 0.5 to 1.5 C are being measured, warm at the inside and cold at the outside. The amount varies with the size of the thermos bottles and the type of molecules used. One finds the highest temperature differences with high density solids and lower ones when using liquids or gases. These experimental results negate many of the presently accepted formulations of the Second Law.

Implementing Brownian Ratchets in Solid State, **PETER M OREM^{1*} and FRANK M OREM²** (¹12107 SE 174 Ln, II 203, Renton, WA, 98058; ²41 Condolea Court, Lake Oswego, OR 97035; peter@thermawatts.com).

Ratchets seem to offer an opportunity to organize random behavior. Ratchets have been proposed to convert Brownian motion into rotational motion. Simple mechanical ratchets don't work because of detailed balance (Feynman Lectures I 46). Any break of detailed balance opens the door to constructing ratchets. Semiconductors present such breaks in carrier recombinations in connecting materials of differing carrier densities of states. One observable effect of recombination - and the corresponding break in detailed balance - is the escape of a photon from an LED. A second observable effect is the voltage across semiconductors of different carrier densities of state. Descriptions and measurements of semiconductor ratchet operations are presented.