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Thermodynamic Laws and Measurements

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HIGHLIGHTS

New energy-producing concepts require novel measurement techniques, especially when these new concepts appear to violate accepted scientific principles.

ABSTRACT

This paper outlines issues associated with the verification of claims of thermodynamic law violations, focusing on measurement issues. We do not go into detail about the various interpretations and alternative forms of the thermodynamic "laws," only presenting the reader with a standard interpretation of Laws 1 & 2. The word "laws" is in quotes here as there have been recent experiments appearing to show violations of, or at least subtleties associated with, these laws which necessitate proper measurements and experimental design.

INTRODUCTION

For the purposes of this paper, the lay definition of the First and Second Laws of Thermodynamics can be summarized as:

Law 1: Conservation of Energy: [Internal/Stored energy of closed system] + [Kinetic Energy] + [Potential Energy] = difference between energy (e.g., heat) input to system and work performed (output) on or by the system or on separate system(s). Thus, *No Energy Creation*.

Note the phrase "closed system." In many claimed energy-producing devices, it is the inability to precisely define what the associated closed system is that confounds inventors. Related to this is the notion of "internal energy." Increased understanding of the role of quantum dynamics in energetic systems forces one to consider one aspect of the quantum world, namely Zero Point Energy (ZPE), as a candidate for "internal energy."

Law 2: Universal Entropy Increases: Heat spontaneously flows from higher temperature systems to lower temperature systems and not vice versa, eventually resulting in disordered, higher-entropy states. Cyclic extraction of work cannot take place while a system is embedded in a constant temperature (isothermal) bath. Thus, *No Work Without Temperature Difference*.

Recent experimental discoveries have cast some doubt on the universal application of the second law with regard to energy extraction from systems in isothermal environments. This implies that the system boundaries are known and perforce within the isothermal environment. One might also inquire whether the ZPE or universal sea of quantum fluctuations might be considered as a universal isothermal environment, for instance per the fluctuation-dissipation theorem.

Regarding the second law, the following statements of its inverse are instructive:

Kelvin-Planck "Inverse Steam Engine" statement:

It is impossible to make a cyclic device which receives heat from a single (hot) reservoir and produces work (without transferring some to a cold reservoir).

Clausius "Inverse Refrigerator" statement:

It is impossible to make a cyclic device which spontaneously (i.e., without external work) transfers heat from a cold body to a hot body.

These two statements are equivalent. Note the use of the phrase "cyclic device." Thermodynamic effects take place by transitions to and from a series of states. For instance, in a classical heat engine, where a heat source (e.g., a steam boiler) provides heat energy to a mechanical system (e.g., piston in cylinder), the pressure/volume graph of the working fluid in the cylinder proceeds from state to state and necessarily returns to the original state, or close to the original, given frictional, etc., effects. This constitutes a complete cycle, and the process can repeat ad infinitum with continual energy extraction (conversion). In classical systems, only when such cyclic systems are operating can continuous work be extracted from the heat bath. Therefore, it is important to determine by measurement whether the system returns to the original starting state if a classical heat engine is claimed to be violating a thermodynamic law by, for instance, producing "excess energy" over and above that supplied by the hot thermal bath.

Thus, some knowledge of the basic tenets of these two principal thermodynamic laws can provide guidance for the experimentalist to consider how, where, and why to perform measurements to verify claims of anomalous energy production. In particular, knowledge of system boundaries and unsuspected external influences, the contributions of stored or internal energy, the possible involvement of ZPE, whether there is actually a cold sink when a heat source seems the only option, and whether the system demonstrates a cyclic vs one-shot energy extraction are all important considerations for the verification of claims.

The thermodynamic laws are not solely associated with physical or mechanical systems. Recent work in the field of bioenergetics (Lee, 2022) indicates that certain energy processes in biological systems can apparently assist in, or perhaps be vital to, the formation of chemicals needed for life using energy from a single heat source.

PART A: EXPERIMENTS AND MEASUREMENTS

This section will present aspects of experimental design and associated measurement techniques and issues relevant to thermodynamic situations. However, such considerations can be generally applied to other scientific investigations.

Control Experiments

One important consideration in the experimental verification of potential thermodynamic law violations is the provision of control experiments. Proper experimental design requires that the actual system or device under test ("DUT") be replaced by a device that mimics the actual DUT in all aspects save that it is designed to function in a normal or prosaic manner. For example, in a DUT experiment which apparently indicates the ability to provide an anomalous thrust from on-board electrical storage apparently violating conservation of momentum (i.e., propellentless), the substitution of a control device, e.g., a resistor or capacitor for the actual DUT, should show a null result. If the control shows equivalent thrust, there is of necessity an error in the experimental procedure which allows the actual DUT to show an apparent thrust.

In the low-energy nuclear reactions (LENR) realm, say for example that someone measures a heat output from flowing gas over a specially prepared palladium substrate in apparent agreement with a theoretical prediction about some physical aspect of the metal's surface. A typical control experiment may be to alter the metals' surface characteristics to guarantee a null heat result. If a similar heat signature results, it is highly likely that the test procedure is flawed.

The proper design of control experiments requires much thought and planning and is usually foregone in many experimental programs. However, it is essential to have at least one solid control experiment to demonstrate that the experimental apparatus is performing as expected and that artifacts and prosaic explanations are either nonexistent or their influence has been calibrated and can be removed from the data representing the actual DUT's performance.

Calibration

Typically, the notion of calibration applies to the measuring instruments used to confirm the validity of claims. However, calibration necessarily also applies to the use of the correct instruments for the measurement job. For instance, when a claim is made that a device produces nanowatts of "excess energy," the correct instruments must be chosen prior to their calibration for the sensitivity, etc., of the measurements at hand. This seems an obvious point, but this association is sometimes overlooked. In many situations, a typical commercial multimeter is used in place of an oscilloscope when a non-sinusoidal AC waveform is being measured. This can lead to serious measurement errors. It is always necessary to have at least some reasonable and reliable standards of frequency, voltage, current, resistance, temperature, etc., against which to calibrate the measuring instrument at the amplitudes, frequencies, etc., of the expected signals. Generally, the highest standards are derived from the National Institute of Standards and Technology (NIST) and include reference codes related to NIST. In the absence of NIST or NIST-derived standards (called "secondary reference standards"), having two or more similar instruments giving the same readings is at least better than nothing.

The two important considerations noted above can be summed up as "No Calibration, No Control: No Claim."

Prosaic Explanations

In addition to the above issues, it is important to consider how likely it is that the anomalous measurements are the result of prosaic explanations which were not immediately obvious at the start of the experimental program. In most cases, prosaic or artefactual explanations are those which are obvious in hindsight and are the result of normally understandable processes without the need to invoke unusual or exotic explanations. Some of these artefacts are summarized in Part B of this paper. It is typical that as the experiments proceed within a program or campaign, some of these prosaic explanations start to become obvious, necessitating additional experimentation.

Thermodynamic Laws and Energy Inventions and Concepts

Energy inventions and novel concepts appear at all scales. There are a few experiments apparently demonstrating anomalous energy effects at the quantum scale (Moddel et al., 2021), the scale of biological proteins (Lee, 2022), materials and surface interactions (Thibado et al., 2020) and at larger scales (LENR, no date). At larger scales, examinations of thermodynamic laws are more relevant to the first law. This is because system boundaries are more easily defined and artefacts more easily accounted for. For instance, in a system of permanent magnets and wires, a large-scale system, the identification of prosaic explanations for the claimed violation(s) is a relatively easy task.

At the micro scale of energetic interactions, examination of the second law issues is more relevant, although it is more difficult to define system boundaries and design true control experiments.

Laws, Claims, and Measurements

Typically, claims of thermodynamic law violations result from:

— faulty or incomplete measurements (by far the most prevalent)

— incorrect system boundary definitions

— spurious and unaccounted for energy inputs, including stored energy

— under-accounting for the energy inputs

— reliance on earlier (and disproven) results.

Later in this paper, some of the usual energy measurement issues and pitfalls will be addressed. The definition of boundaries relevant to the system under examination is associated with accounting for all energy inputs and outputs. For instance, some highly sensitive force measurements on Earth may not have accounted for Coriolis effects. Often, the experimenter overlooks or ignores the fact that the laboratory in which the investigation is being undertaken is itself immersed in a sea of mechanical vibrations, tidal forces, spurious EM radiation, ZPE, etc.

Confirmation bias can also blind the experimenter to other explanations for their alleged thermodynamic law violations.

In some situations, there is a difference in approach between demonstrating thermodynamic law violations, particularly the second law, and proving anomalous energy input/output ratios. This is the case, for example, in systems claiming to produce work from a single heat bath.

Many inventors of lab-scale energy systems involving components such as magnets, coils, switches, etc., fail to realize that there have been more than 150 years of experimentation with such attempts at providing "over-unity" devices, all of which have failed. That does not seem to deter them as they point to examples on the internet claiming to have successfully replicated previous "over-unity" devices, without realizing the poor quality of these measurements and other features.

Questions to Ask Prior to Undertaking a Test Campaign to Verify Existing Claims

— *Who is the test for*: An inventor trying to convince him/herself or an investor that their idea has merit; an investor looking for confirmation of an inventor's claims; publication, fame? The distinction may be important as the level of detail required of the test campaign may vary depending on the target audience.

— *Design of suitable test bed for each project*: Is the experiment going to be conducted under circumstances related to the expectation of the inventor or the investor, i.e., "real world" situation or under a controlled laboratory situation?

— *Replication vs reproduction*: Regarding the development of a test protocol, will the experiment be an exact replica of the original invention or a reasonable reproduction of essential elements but allowing for better measurements?

— *Costs of new equipment vs re-use of existing equipment:* In many cases, the costs to verify claims can be prohibitive in terms of specialized measurement equipment, environment factors (screen rooms, temperature and humidity rooms), and other issues. A reasonable assessment of existing equipment can usually reduce costs if suitable adaptations and re-calibrations are performed.

— *Cost/benefit of simple "look–see" experiments without or prior to full testing*: Sometimes a less intense test series is warranted rather than a full-up test campaign. This depends on the urgency and whether a yes/no answer is required. This type of test should be performed with the understanding that a full test will be undertaken eventually.

— *Hypothesis generation vs hypothesis testing:* Hypothesis generation is the elucidation of alternative explanations for an observed system. It is based on observed physical phenomena without prior theory. Hypothesis testing represents the confirmation or denial of prior theory of the system's operation. Each of these requires a different approach to the design of the experimental program. Typically, hypothesis generation is more time-consuming as the extent of the experimental parameter space is unknown.

— *Enumeration of likely prosaic/artefactual explanations*: As has been alluded to, careful thought regarding prosaic explanations for the expected results prior to the experimental campaign will save a lot of headache and time during and after the experiment.

— *Design of proper and appropriate control experiments*: This requirement cannot be stressed enough. It is through proper control experiments that prosaic explanations can be accepted or rejected as explanatory to the experimental outcome.

— *Degree and sophistication of statistical and error analysis required*: Rigorous scientific experiments require that error bars, standard deviation, P values, or other statistical measures be associated with the principal outcome(s) of the experiment. In some experiments these are used to rule out the result as being obtained simply by chance. In most energy-related experiments, however, these measures tell the experimenter how "loose" the experimental procedure has been, and point out the areas that, if performed with more precision, would result in increased confidence in the outcome.

— *Instrument appropriateness and calibration*: Is the instrumentation proposed to measure the various parts of the experiment fit for purpose? A simple RMS-responding meter may not be appropriate for the measurement of spiky waveforms.

— *What minimum resolvable measurements are required to prove the claims*: This aspect is associated with instrument appropriateness as well as whether the proposed experiment is a simple "look–see" or more rigorous. The minimum resolvable measurements usually are decided by critics or reviewers of the experiment but should be elucidated prior to the experimental program if possible. This feature is typically invoked when an experiment is proposed which is designed to validate a similar but previous experiment, that is, how much more resolution will be necessary to prove or disprove the results of a prior experiment?

Measurement, Uncertainty, and Decision-Making

We enter into an experimental program to answer questions about nature, to make decisions about how and whether to proceed with an experimental program, as well as to decide the next stages of development after the experimental phase. Fortunately, most of the properties relevant to the thermodynamic analysis of forces, thrusts, electrical power, and energy and heat are amenable to quantitative measurement. Measurements can be seen as vital to minimizing experimental uncertainty. If there was no uncertainty in nature, there would be little need for experimentation. Thus it is imperative to highlight measurement issues such as those enumerated above, which factor into the evaluation of uncertainty. Also vital is the ability to transfer the experimental protocols and measurements from the experimenter to interested parties such as investors, reviewers, and other scientists.

Additional Factors for a Successful Experimental Campaign

— *Consider all relevant explanations:* Just because an explanation for the observations seems far-fetched, if the observation appears to violate thermodynamic laws the explanation should be taken seriously.

— *Design the simplest measurements that will validate (or not) the claims*: Layering on extra measurements not designed to answer the fundamental question being asked (e.g., what is the uncertainty in this measurement of potential thermodynamic violation?) leads to a dilution of attention.

— *Ensure sufficient information is available before embarking on a test campaign*: Often an inventor will either wittingly or unwittingly fail to mention certain vital aspects of the system under investigation. Sorting this out is hard to do at the beginning of a program but usually becomes obvious as the program proceeds.

— *Beware of confirmation bias*: Confirmation bias plagues many experimental programs involved in novel or exotic physics, especially in systems that may violate one or another thermodynamic law. One's own views about why an observation appears to conform to one's prior belief should be absent from an unbiased experimental program.

— *Concentrate on claims backed up with a reasonable theory*: Although there are many instances where a proposed experiment is not preceded or accompanied by some sort of theory, it is always preferable if even a rudimentary theory is available. The experiment is not only for the benefit of proving, disproving, or amplifying a theory, but also a theory can guide the experimental program to seek out alternative explanations in a more structured manner.

— *How to handle the influence of quantum effects*: Recently there has been a raft of experimental work claiming to involve zero point energy (ZPE), zero point fluctuations, quantum field energy, or whatever moniker is appropriate. This is largely due to increased sensitivity and decreasing scale of experimental apparatus over the past couple of decades. The actual influence of ZPE on quantum and microscopic systems has been well-documented and understood. However, these systems have, until recently, not allowed investigation of energy generation or energy throughput questions. Many have considered trying to drive a quantum system below the ground state. Even with today's sophisticated experimental apparatus, it is difficult to experimentally prove that a particular quantum system has been so driven. Therefore, experimentally addressing the claim that a certain energy-producing system derives its anomalous energy output by sub-ground state quantum effects can be a huge experimental challenge. Experimental tools to address this challenge are still in their nascent stage.

PART B: PITFALLS

Nightmares in the Art of Measuring: Power and Energy or "What Could Possibly Go Wrong?"

What follows is a continually growing list of pitfalls into which the experimenter can stumble regarding the measurement of electrical and mechanical power, energy, and heat. Most of them will be obvious but a more-or-less comprehensive list is at least useful as a reference. The major themes can be summarized according to the following. Due to the size of the list, only the main topics will be enumerated. The diligent researcher can find more detailed explications in the literature.

I. Electrical Power and Energy
II. Mechanical Power and Energy
III. Heat
IV. Electric/Magnetic Screening
V. Electromagnetic Effects: Electromagnetic Coupling
VI. Electromagnetic Effects: Grounding/Earthing
VII. Electrostatic and Related Effects: Charge Pooling and Induced Charges
VIII. Electrostatic Effects: Charge Leakage
IX. Instrumentation Issues
X. Signal Analysis

I. *Electrical Power and Energy*
  1. DC
    DC as heat equivalent
    "Pulsed DC" and ringing waveforms
    High voltage effects: circuit effects, environmental effects
    Sources and loads—resistance matching
    Power measurement using passive components (e.g., resistors)
  2. Low Frequency (DC—few KiloHertz)
    Active and reactive power
    Power factor
    Nature loves sinusoids—so do electron-pushing meters
    RMS as equivalent heating value and power measurement
    Non-sinusoidal waveforms & importance of visualizing (e.g., oscilloscope)
    Sources and loads, including absorption vs transmission power measurements
    Concept of impedance and matching
    Instrumentation, including shielding and grounding
  3. High Frequency (few KiloHertz—few GigaHertz)
    Skin depth and effects
    Spikes and noise
    2-way power flow
    Transmission lines
    Linear passive devices act strangely (e.g., resistors look like caps, etc.)
    Power measurement
    Sources and loads
  4. Microwaves
    Where is the power?—coax and waveguides
    Reflections and impedance mismatch
    Sources and loads
    Power measurement e.g., bolometric calorimeter

II. *Mechanical Power and Energy*
  1. Types of mechanical power—rotation, reciprocation, thrust, pressure

2. Torque and RPM
3. Sources (e.g., motors, pneumatics, springs) and loads (e.g., friction, weights, inertia)
4. Instrumentation: load cells, torque sensors, dynamometer, scales and balances
5. Conversion between electrical power and mechanical power
6. Devices, e.g., motors, generators, magnetic systems, capacitive systems, piezo systems
7. Instrumentation and comparable units (e.g., mechanical hp vs electrical kwhr)

III. *Heat*

1. Contact vs remote thermal sensing
2. Remote IR thermography, emissivity, diffusivity
3. Calorimetry and heat localization
4. Types, uses, and limits of thermocouples, RTDs, thermistors
5. Optical pyrometry
6. Optical spectrometry

IV. *Electric/Magnetic Screening*

1. Leaking/improperly sealed "Faraday Cage" / electrostatic screens
2. Improper reliance on Faraday Cage for complete exclusion of DC or quasi-static electric fields
3. Inability of screen-type Faraday Cage to screen magnetic fields therefore "muMetal" screens
4. Frequency dependence of Faraday Cage—need for calibration over wide frequency range
5. Improper feedthroughs into and out of Faraday Cage

V. *Electromagnetic Effects: Electromagnetic Coupling*

1. Avoidance of switching transients especially in high-power circuits, especially sudden stopping of current though inductive loads or conductors producing EMP inducing large spurious signals even through shielded coax or aluminum instrument boxes/cases
2. High-frequency RF radiation from nearby transmission lines or conductors especially those powering or recording the experiment interfering with electronics and electronic-based measuring instruments
3. Lack of RF suppression on power and instrument lines, e.g., ferrites, shunting caps, proper RF connectors and cables, unless disallowed for frequency response reasons
4. Avoidance of capacitive coupling between signal cables and grounds/ground leads carrying transient/fault currents
5. When a source is incorrectly matched to a load, a greatly increased level of EMI across a broad frequency range may be generated as the reflected power interferes with the correct operation of the source (usually an amplifier). This in turn may induce spurious currents in electronic measuring instruments.

VI. *Electromagnetic Effects: Grounding/Earthing*

1. Avoidance of contact potentials developing across multiple connections. In some cases, contact potentials must be compensated by a deliberately applied counter potential.
2. Strive for single-point RF ground system for all instruments and experiments.
3. Correction of ground loops and ground faults both internal to the experiment and between experiment and measuring system
4. Understand the difference between independent earth ground (e.g., copper stake in virgin earth) vs mains "ground" vs mains neutral, and potentials between these.
5. Poor/loose ground connections: preventing complete charge draining; allowing transient voltage artifacts on recording & display devices; allowing small signals to be amplified by amplifiers along with the signal of interest, etc.
6. Use of large cross-section circular wire or flat ribbon strip from experiment and/or instrumentation to earth, especially for pulsed high-power experiments

VII. *Electrostatic and Related Effects: Charge Pooling and Induced Charges*

1. Accumulation of invisible pools of surface charges on insulators on conductors. Especially problematic for metal enclosures/surfaces which have unavoidable insulating metal oxide layer formed on surface, e.g., aluminum
2. Accumulation of surface charges on water patches on inner surfaces of vacuum chambers and components even when evacuated to apparently high vacuum
3. Accumulation of charge on insulating or non-conductive surfaces, e.g., wire insulation, after exposure to electrostatic and sometimes time-varying electric fields
4. Reaction against image charges created on conductors

VIII. *Electrostatic Effects: Charge Leakage*

1. Unaccounted-for corona or other uncontrolled charge leakage usually in bursts ("Tricel Pulses") in

high-voltage experiments which can create time-varying charge on nearby conductors. Especially problematic at sharp corners

2. Avoidance of triple points—spurious conduction paths at junctions of 2 or more states of matter, e.g., corners, junctions of differing materials and gas
3. High voltage creation of weak conduction paths between device under test and ground even across or through insulators. Depends on humidity, vacuum

IX. *Instrumentation Issues*

1. Modern vs "antique" instrumentation, digital vs analog true signal bandwidth
2. Match the instrument to the job.
3. Proper connection of instrument to the job
4. Probes and accessories
5. Controlling and recording the results e.g., LabView
6. Overload and saturation
7. Frequency response
8. Matching to other instruments
9. Sampling rate, aliasing, and related errors
10. Internal math functions accuracy
11. Measurement outside specifications of instruments including sensing/measuring instruments, signal processors/amplifiers/ conditioners, and recording/display/acquisition devices. Usually applies to measurement of fast transients, e.g., pulsed waveforms
12. Lock-in amplifier response to high-amplitude transients riding on input lines causing artifacts even when not phase locked to the reference signal
13. Voltage sags/surges resulting in poor mains power quality, e.g., startup of nearby large rotating equipment

X. *Signal Analysis*

1. Correct use of averaging to tease out buried signals and suppress noise
2. Statistical Analysis: use of Chi^2, calculation of correlation coefficients, sigmas, etc.
3. Noise SNR: Is noise floor burying signals of interest?
4. Error analysis and error propagation: How confident that signal is inside measuring instrument range and that it is real—requires full specs of instrumentation or independent calibration.
5. Exploiting adjustable parameters:
    1) Adjusting phase of various parameters to detect artifacts
    2) Suppression of common-mode noise
    3) Alternate mechanical orientation of experiment with respect to possible local forces or sources

IMPLICATIONS AND APPLICATIONS

The ability to detect and measure smaller and smaller forces, currents, charges, wavelengths, etc., has allowed increasing experimental sophistication resulting in new insights into nature in general and thermodynamics in particular. Without these new understandings based on proper measurement and application of the above-noted principles allowing re-examination of the applicability of thermodynamic laws, humanity's energy future looks increasingly uncertain.

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