Heat engines of extraordinary efficiency
And the general principle of their operation

Remi Cornwall
University of London Alumni Society
Malet Street, London WC1E 7HU
http://webspace.qmul.ac.uk/rocornwall

Abstract

The need for better heat engines for our civilisation is obvious. The intention of this paper is to elucidate new types of heat engines with extraordinary efficiency, more specifically to eventually focus on the author's research into a temporary magnetic remanence device. First we extend the definition of heat engines through a diagrammatic classification scheme and note a paradoxical non-coincidence between the Carnot, Kelvin-Planck and other forms of the 2nd Law, between sectors of the diagram. It is then seen, between the diagram sectors, how super-efficient heat engines are able to reduce the degrees of freedom resulting from change in chemical potential, over mere generation of heat; until in the right sector of the diagram, the conventional wisdom for the need of two reservoirs is refuted. A brief survey of the Maxwell Demon problem finds no problem with information theoretic constructs. Our ongoing experimental enquiry into a temporary magnetic remanence cycle using standard kinetic theory, thermodynamics and electrodynamics is presented – yet a contradiction results with the 2nd law placing it in the right sector of the classification diagram. Finally a discussion shows that there isn't a problem with microscopically time symmetric laws and macroscopic irreversibility and that "Time's Arrow" is really to be found in loss of information in the system state vector.

1. Introduction

It isn't often that natural high-grade energy sources present themselves to us, to transform into other forms of energy for our civilisation efficiently; for instance hydro-electric power (neglecting turbulence) conceptually allows the conversion of the potential energy of a mass of water at height to mechanical energy very well. We are usually presented with sources of potential energy (nuclear, chemical) that are released into the random motion of heat energy. A type of energy conversion device known as an "heat engine" is then able to convert this into other forms of energy with the well-known ideal reversible Carnot limitation[1, 2]:

Figure 1 – Carnot heat engine and refrigerator

The 1st law balance for both the heat engine and refrigerator is:

$$Q_H = W + Q_L \qquad \text{eqn. 1}$$

The Carnot engine is ideal and generates no entropy; we can say that the entropy change of the reservoirs in both cases is equal, thus:

$$\frac{|Q_H|}{T_H} = \frac{|Q_L|}{T_L} \qquad \text{eqn. 2}$$

If we define the efficiency of the engine as Q_H/W then immediately using eqn. 2, the ideal efficiency would be:

$$\eta \to \frac{T_H - T_L}{T_H} \qquad \text{eqn. 3}$$

For refrigeration we define the coefficient of performance (C.O.P.) as Q_L/W and for a heat pump, the C.O.P. is defined as Q_H/W. Once again using the ideal constraint of eqn. 2, we can relate these figures to the absolute temperature scale:

$$C.O.P_{\text{Refrigeration}} \to \frac{T_L}{T_H - T_L} \qquad \text{eqn. 4}$$

$$C.O.P_{\text{Heat Pump}} \to \frac{T_H}{T_H - T_L} \qquad \text{eqn. 5}$$

The transformations of heat engines can be viewed diagrammatically (fig. 2) by the 1st law / Thermodynamic identity:

$$\begin{aligned} dU &= \delta Q - \delta W, \\ dU &= TdS - PdV \end{aligned} \qquad \text{eqn. 6}$$

The working substance of the heat engine is cycled back to its original thermodynamic co-ordinates, so that the exact differential representing the internal energy is zero. We can see immediately that around a cycle, changes in the work are equal to changes in the heat. The familiar adiabatic expansions and contractions, (isentropic processes, 2-3, 1-4 in fig. 2), alternated with isothermal expansion and contraction processes, (1-2, 3-4 in fig. 2) of the Carnot engine results. We shall return to this argument, with its assumption of the exactness of the form of the internal energy and the necessary result of the need to alternate adiabatics with isotherms later in the paper, to show that this argument is not closed and the Carnot result does not limit heat engines. First, however, it is enough to whet the appetite by showing a non-coincidence of definitions of the 2nd law by asking in the next section, just what is an heat engine?

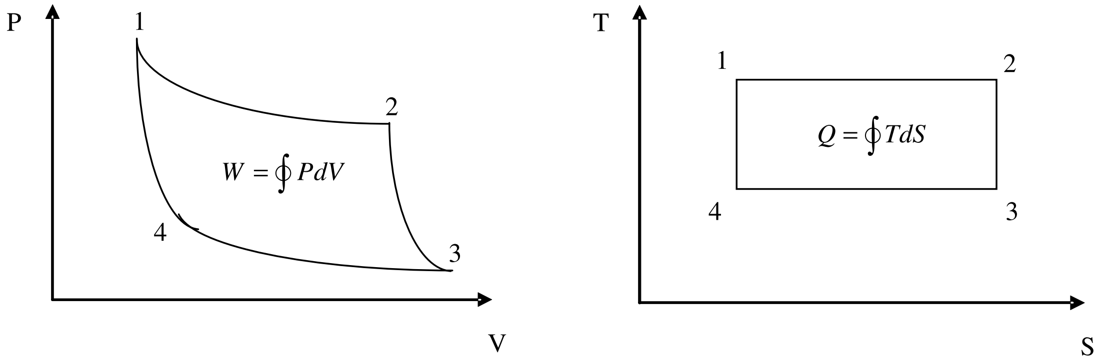


Figure 2 – P-V and T-S diagram of Carnot heat engine or refrigerator

2. What is an heat engine?

An engine or machine is understood to be a device that transforms one form of energy into another, usually mechanical energy. An heat engine is then one which a substantial change in its entropy that is intrinsic to its operation. Thus a charged capacitor discharging into an electric motor is an engine but not an heat engine; although there is a change in chemical potential of the electrons constituting the current, it operates at high efficiency and little of the electrical energy is converted to heat, the device can operate, in the limit (using superconductors, etc.) of turning all the electrical energy into mechanical energy. Let us see how this is so with a more complete rendition of the thermodynamic identity:

$$dU = TdS - PdV + Fdx + \sum_{i=1}^{n} \mu_i dN_i$$

Where we have included a generalised force term and generalised displacement Fdx. It is noted that entropy is a property of the system and an exact differential:

$$\Delta S=\int_{T_0}^{T}\left(\frac{\partial S}{\partial T}\right)_{V,x,N_i}dT+\int_{V_0}^{V}\left(\frac{\partial S}{\partial V}\right)_{T,x,N_i}dV+\int_{x_0}^{x}\left(\frac{\partial S}{\partial x}\right)_{T,V,N_i}dx+\sum_{i=0}^{n}\int_{N_{0,i}}^{N_i}\left(\frac{\partial S}{\partial N_i}\right)_{T,V,x}dN_i \qquad \text{eqn. 7}$$

It is possible for some types of engine to proceed from a starting, to an end state, with little variation in T, V and also $\left(\frac{\partial S}{\partial x}\right)_{T,V,N_i}$ or $\left(\frac{\partial S}{\partial N_i}\right)_{T,V,x}$ such that the generalised work term responds to the changes in the chemical potential. In other words, the energy conversion is very efficient. This is the case with our capacitor-motor analogy. The chemical potential of electrons in a charged capacitor will have a potential term from the electric field QV but this doesn't affect the entropy before or after the process.

However for the type of cycle or process where it is part-and-parcel of the operation that working substance undergoes a change in temperature, pressure, volume, particle number, chemical association or disassociation, then that cycle or process has an entropy change intrinsic to its operation – heat is unavoidably generated. This of course includes Carnot cycle limited engines but it must include batteries, fuel cells and biochemical processes too. These latter categories are not thought of as heat engines but they must be: one has only to look at the change in standard entropies of the reactants and products and note that this change is intrinsic to their operation. We make the assertion that amongst heat engines, that there is a continuum from pure heat conduction, to Carnot limit engines, to fuel cells and biological systems to Maxwell Demon processes[3, 4] (fig. 3).

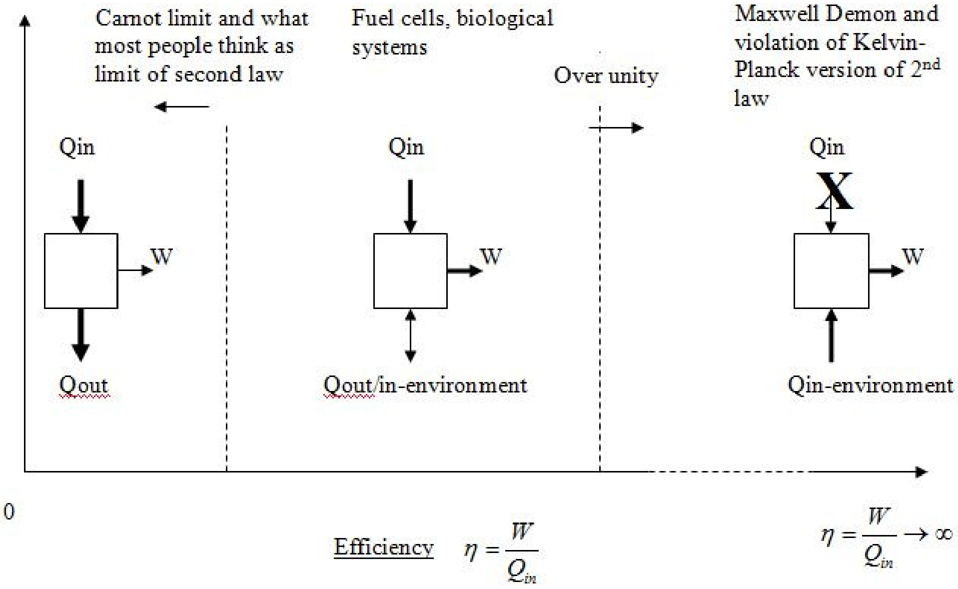


Figure 3 – The continuum of heat engines

The chart shows from the point of view of efficiency, how particular types of engine fit into the continuum scheme. Logically to the left at zero efficiency, is where heat conduction is placed. Next come the Carnot cycle limited engines, where some useful work is delivered up to their efficiency limit.

In the middle sector of figure 3, we insist (for the argument given previously about the change in entropy) must be the position of batteries, fuel cells and biological systems as heat engines. We have the conundrum that a battery or muscle can still function when the environment (the supposed cold sink) is at an higher temperature than the "engine". It is known that biological systems exceed Carnot efficiency and indeed, E. T. Jaynes[5] in a contentious unpublished work, took the Carnot reasoning applied to a muscle to an illogical conclusion: that living muscles must be operating at some 6000K to achieve their work output! Correctly Jaynes points out that the degrees of freedom for the release of chemical energy are very curtailed, unlike the random motion of linear motion being cohered from a piston in a Carnot cycle, muscles fibres extend and contract in one very specific direction under the control of ATP. Try as one might to deny that fuel cells and biological systems aren’t heat engines, one cannot deny the change in entropy of the reactants.

We think our diagram (fig. 3) makes clear that one can utilise heat energy much more subtly than a Carnot cycle. The continuum from the middle ground and especially biological systems to Maxwell Demon type processes becomes apparent. Moving to the limit of the middle sector of figure 3, Mae-Wang-Ho[6] has argued that some biochemical processes (especially membrane processes) utilise random thermal motion to achieve more than can be explained by conventional thermodynamics. Thus in the right sector of figure 3, we include the possibility where there is no input heat and the work is achieved wholly by the conversion of environmental heat energy input – a Maxwell Demon. Furthermore we can see that several definitions of the 2nd law[7] do not coincide by this diagram:

- Carnot theorem: All Carnot engines operating between the same two temperatures have the same efficiency and this is always less that unity.
- Kelvin-Planck: No device, operating in a cycle, can produce the sole effect of extraction a quantity of heat from a heat reservoir and the performance of an equal quantity of work.
- Clausius: No process is possible for which the sole effect is that heat flows from a reservoir at a given temperature to a reservoir at higher temperature.

These considerations of non-coincidence in the definitions, alone, should make us question or find a flaw in the Carnot theorem. The next section shall do just that.

3. The general principle of heat engines of extraordinary efficiency

We wish to show that heat engines constructed from materials undergoing a phase transition permit the development of extraordinarily efficient heat engines. To begin, let us consider microscopic heat flows. Microscopic fluxes at equilibrium have an exceedingly large amount of *microscopic work* occurring at *constant temperature,* as this clearly is how individual particles can rise and fall in a potential field at equilibrium. There is no conflict with the Carnot result if one takes this viewpoint, that as $T_H - T_C \rightarrow 0$ the efficiency tends to zero (eqn. 3): we argue that the microscopic work-flows at constant temperature become essentially limitless, based on the microscopic heat-flows, which are essentially limitless too, $(Q^+ - Q^-)/(W^+ - W^-) \rightarrow 0$, where the positive superscripts represent large, finite heat or work into the system and the negative superscripts represent large, finite flows out. This is guaranteed by the statistical fluctuation of temperature at equilibrium[8, 9], as depicted in figure 4.

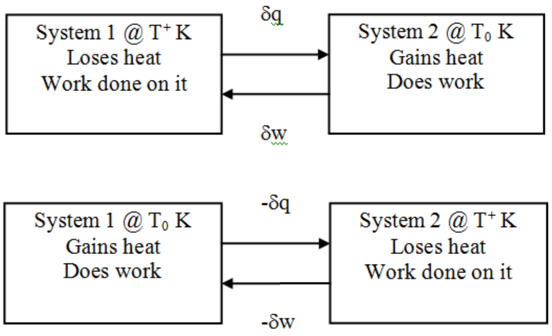


Figure 4 – Statistical fluctuation in temperature with micro-heat and micro-work flows

We are now in a position to see why phase change is the key to making a Maxwell Demon. At equilibrium between two phases, microscopic fluctuations in temperature effectively form microscopic heat engines that are able to do work against the phase boundary.

Lemma: Constant temperature microscopic work theorem

At constant temperature microscopic heat and work are available and can partition energy across a phase boundary.

So if a *microscopic* demon is possible how is a *macroscopic* demon made?

> Lemma: Phase Transition Sorting
>
> Macroscopic work is potentially obtainable from microscopic work processes at constant temperature by the working substance undergoing a phase transition.

By definition, a phase is a macroscopic representation of underlying microscopic properties. In a sense, the phase change has "magnified" the microscopic demon. We say "sorting", as the energetic molecules have partitioned across the phase boundary, as distinct from the less energetic. This can be understood from the thermodynamic identity:

$$dU = TdS - PdV + \mu(P,T,\varphi)dn$$

Where ϕ is a potential function (of position, particle number etc.)

Since dU is an exact integral, any means of cycling the working substance by any of the variables of the system, will not produce excess energy from the lowering of the internal energy of the working substance. Let us understand this more by reviewing a conventional Carnot engine: The working substance being only one material is constrained to traverse fixed trajectories in P-V or T-S space (fig. 2). The familiar alternating of isothermals with adiabatics is required to map out an area, as moving reversibly along 1-2: isothermal-adiabatic or 1-2-3: isothermal-adiabatic-isothermal, will not return to the starting co-ordinates. The last process, 4, maps out an area so that changes in heat are equal to changes in work: $dU = 0 \Rightarrow \Delta Q = \Delta W$. This cannot be done with just one reservoir and the last step 3-4 must come into contact with the lower reservoir.

Is there a way around this two reservoir argument? Consider now the meaning of the chemical potential, it is the thermodynamic potential per particle:

$$du = Tds - pdV + \mu dn \qquad \text{eqn. 8}$$

The lower case indicates that this is per particle. The chemical potential has two parts, the internal and external[1]; the sum is often called the total chemical potential. If at some point in a thermodynamic cycle an external potential μ_{ext} is added or changed then the thermodynamic identity can be made inexact, relative to the old expression for the identity,

$$\delta u' = Tds - pdV + \mu_{\text{int}}dn + \mu_{ext}dn \qquad \text{eqn. 9}$$

The condition for exactness for du would require $\mu = \left(\frac{\partial u}{\partial n}\right)_{s,V}$ or if the Gibbs free energy is used, $\mu = \left(\frac{\partial g}{\partial n}\right)_{T,P}$ or still, the Helmholtz free energy $\mu = \left(\frac{\partial f}{\partial n}\right)_{T,V}$. Thus if any external potential is added and results at some point in the cycle in a change in the total chemical potential, such that the independent variables cannot be factored out of the expression as a constant, the resulting thermodynamic potential du' will be rendered inexact compared to du. It is as though we have a different working substance not constrained to the trajectories of one substance in P-V or T-S space (fig. 5), that at some part of the cycle, reverts to the original substance (without doing the trajectory 2-3 in reverse) to complete the cycle, so we can achieve net work from only one reservoir. Considering the ideal heat engine argument and the extremal trajectories (from the point of being adiabatic and only doing work or isothermal and only transferring heat), at step 2-3 there is a process performing work and absorbing heat that isn't polytropic (and so in contact with a reservoir).

A change of μ can only correspond to a phase change as this will introduce potential energy terms, such as that pertaining to latent heat (1st order) or new magnetisation energy terms (2nd order), for instance, i.e. dipole-work (section 5).

Appendix 1 contains a probably impractical setup of 1st order phase transition Maxwell Demon thought of by the author in his early endeavours. Later (section 5) we shall present a 2nd order phase transition demon which will possibly lead to practical power generation on a large scale. This demon is a “reverse demon”: rather than the randomness of heat being sorted directly (as by a 1st order phase transition demon), a volume of working substance is ordered and then randomised. The step of randomisation is made to couple to some other system, such that the randomisation is forced to perform macroscopic work; figure 6b illustrates this concept. Other bold claims of extraordinarily efficient heat engines are beginning to be cited in the literature base [7, 10-13] and if these are cyclical thermodynamic processes (as opposed to kinetic – say in rarefied gases), then they must be operating by a change in chemical potential to render the thermodynamic potential inexact around a cycle.

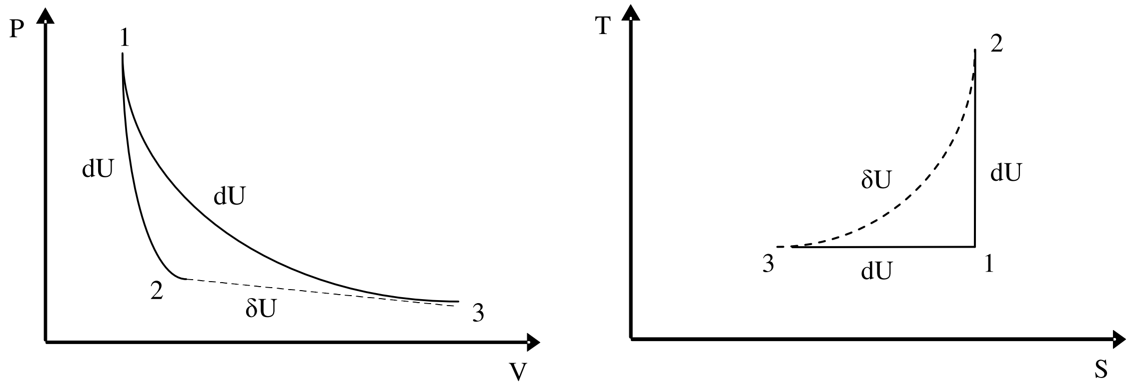
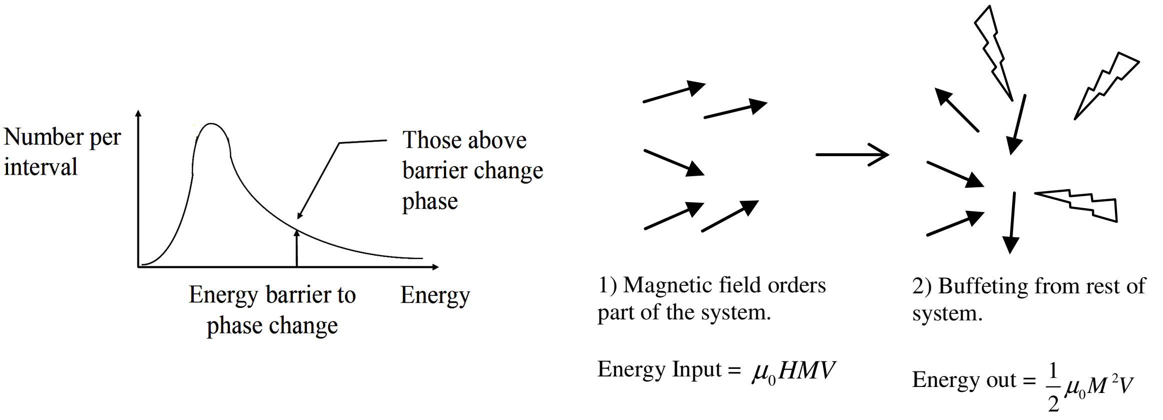


Figure 5 – Illustrative P-V and T-S diagrams for an one reservoir engine

Having challenged the Carnot formulation of the 2nd law, we should now seriously look at the status of it and just how demons could work, given the literature against it.


1st order: (See appendix 1 and “phase changing catalyst”)

2nd order: (See section 5)

Figure 6a,b – 1st order and 2nd order phase transition “reversed sorting” demon

4. Real Maxwell Demons from phase transitions

The introduction of Clausius’ integrating factor (1/T) into the thermodynamic identity lead to the discovery of an exact property of systems, the entropy[1-3] and this was soon realised by Boltzmann to be related to the microstates of the system[1, 3]. Contemporaneous developments in statistical mechanics and kinetic theory elucidated notions of molecular chaos and the approach to equilibrium, in the thermodynamic limit, by Boltzmann’s H-Theorem[9]. It would seem perverse to question the 2nd law for the principle of ergodicity; in the long run, things randomise, how can they un-randomise? A sorting process is needed and this invokes notions of the celebrated Maxwell Demon[3, 14].

In the intervening years of debate started by Maxwell, the counter-arguments condensed into three areas:

- The Demon would be blind in black-body radiation to see anything. Kirchhoff[15];
- A mechanical sorting element of size commensurate to the molecules to effect the sorting, gets randomised too, until ineffective. Smoluchowski[14], Feynman[16] ‘Ratchet and Pawl’;
- Or, to perform sorting would require measurement and expenditure of energy for storage of information. Szilard[4], Brillouin[15], Landauer/Bennett[17].

The last consideration defined Information Theory, as the first half of the 20th century saw the development of the digital computer – this Demon wouldn’t have to be supernatural but a finite state machine, with the concomitant use of energy and dissipation to heat. Ironically the very thing it was trying to do, lower entropy, would cause more production of it.

It can be seen that the problem with the Demon is the need to construct something that measures, keeps the processing state of the machinery and then acts effectively. It is pointless to try and build anything mechanical to affect sorting; however by the analysis of the previous section, the energy barrier due to material phase acts at a microscopic level between molecules, it intrinsically measures and “keeps the state of the machinery” and then partitions/sorts molecules by kinetic energy.

The theory developed shall now be applied, with a description of the author’s research into a 2nd order phase change demon, made with a magnetic fluid as the working substance.

5. A temporary magnetic remanence cycle with extraordinary efficiency projections

It has been discussed previously in this paper how heat energy will partition across a phase boundary. The Zeroth law would have two adjacent phases at thermodynamic equilibrium, yet the chemical potential would show one phase as having an higher potential than the other. One might consider a phase as an “halfway demon” (fig. 10), having “harvested” the heat energy (microscopic randomised energy), what remains is to liberate macroscopic work from the higher energy phase. In the case of a discontinuous 1st order transition, the latent heat, in the form of a temperature rise of the working substance and potential energy from the change in density was considered (appendix 1). In the latter consideration regarding potential energy, it can be argued that the external chemical potential (eqn. 9) forms a continuously changing phase in the rising vapour phase part of figure 11 (appendix 1), so this is a gravity sorting demon.

The continuous order-disorder the transitions of 2nd order phase changes afford another means of making a sorting demon. It was decided to pursue a more practical 2nd order device that would allow the direct conversion of heat energy to electricity[18]. The starting point for analysis is the thermodynamic identity of a magnetic system:

$$dU = TdS + PdV + \mu_0 H d\mathrm{M} \qquad \text{eqn. 10}$$

The magnetic work term is composed of the intensive magnetising field variable, H and the extensive magnetisation variable, *M*. The research studied a magnetisation-demagnetisation cycle of a super-paramagnetic material[18, 19] called ferrofluid, which had the aim of (slowly) magnetising the ferrofluid and then abruptly removing the magnetising field to leave a temporary remnant flux. The last aspect of this cycle distinguishes it from other magnetic heat engines: usually the field is continuously applied at one value, then another, whilst the working substance is placed in contact with the upper and then lower reservoirs; variation in magnetic entropy absorbs or rejects heat energy. The magnetic work is cyclical, such that the absorbed heat is usually then expressed as pressure volume work, for instance, the magneto-calorific ferrofluid pump[19] (or figure 10 ref. [18]). In our temporary remanence, magnetisation-demagnetisation cycle, we aren’t concerned with pressure-volume work and use the following identity:

$$dU = TdS + \mu_0 H d\mathrm{M} + \mu_0 K_e M d\mathrm{M} \qquad \text{eqn. 11}$$

Where a new work term, called the dipole-work (appedix 4, ref. [18]), reflects the work done by the temporary remnant flux into an electrical load, on removal of the magnetising field by the working substance. The figures below illustrate the basic concept and a plant diagram.

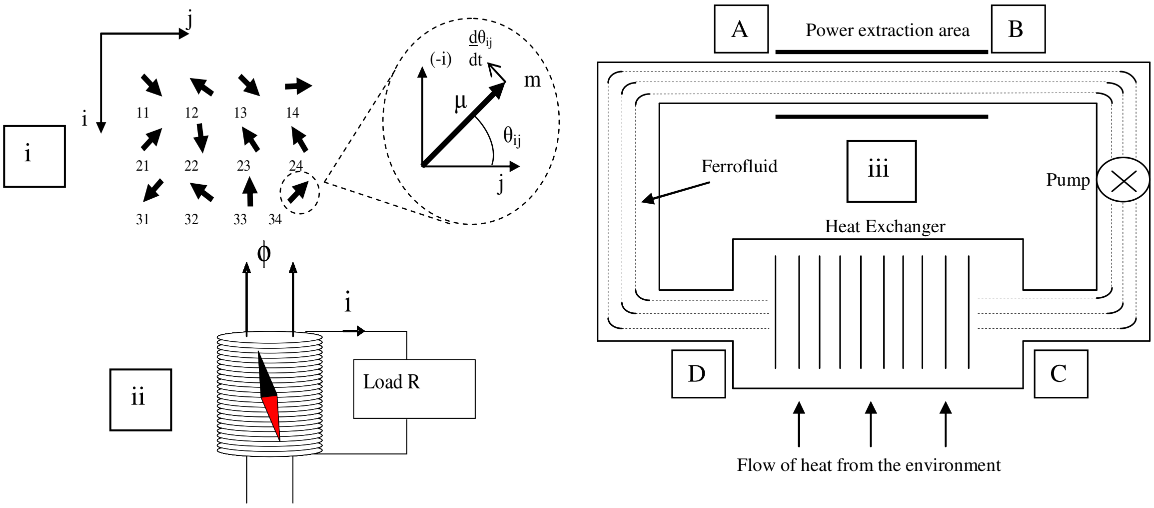


Figure 7i,ii,iii – The basic flux collapse power generation method and plant diagram

Figure 7i shows an ensemble of magnetic dipoles, representing the ferrofluid working substance in a matrix for kinetic computer simulation and this will be discussed shortly. Figure 7ii conceptually shows how the decaying flux, from the multitude of nanoscopic ferrofluid working substance dipoles, looks just like a rotating bar magnet (section 2.1.1 ref. [18]), whereupon it directly generates an electric current into an electrical load.

Figure 7iii shows the plant diagram for the process: in the power extraction area A-B, many magnetisation-demagnetisation cycles occur per second, such that the collapsing flux in the region A-B delivers electrical work by induction into a coil around the region. It is of note too that if the magnetisation is bipolar, no net magnetising moment is expressed in the region, such that pressure-volume work becomes negligible. The working substance cools in the region A-B as it performs electrical work into the load and so it is pumped around to the heat exchanger in region C-D, to go around the circuit once again.

The thermodynamic analysis is closely based upon the magneto-calorific effect (section 2.2 and appendices 6, 7 ref. [18]) in close proximity to a reservoir (in this case the suspending fluid of the magnetic particles in the ferrofluid). The magnetic work term in eqn. 11 also reflects the chemical potential of the working substance, as the magnetisation M, indicates the quantity of species in a phase, as does the dipole work term as an external work term (eqn. 9). In a nutshell for a symmetric case with no dipole work (eqn. 11), we find that upon applying a magnetic field, heat is rejected from the magnetic particles in the ferrofluid to the suspending liquid and upon turning the field off, the same heat is returned from the fluid.

However for the asymmetric case on the demagnetisation step, if the magnetic system is coupled by induction to the output coil (fig 7ii) and if the magnetising field is switched off abruptly (appendix 8 ref. [18]), not only is the magnetising energy returned but additional dipole-work results from a lowering in temperature and entropy of the working substance by the conversion of heat energy (section 2.2.2 ref. [18]).

Kinetic theory model

The conversion of heat energy comes from the thermal buffeting of Brownian motion (fig. 6b). A kinetic theory model can both analytically and numerically prove the lowering of temperature. Regarding figure 7i, a model of dipole-dipole interactions leads to the angular acceleration of each dipole, with I the moment of inertial, k_{dip} a coupling constant, m_{ij} the dipole moment at array position ij:

$$\ddot{\theta}_{ij} = \frac{1}{I}\left(-k_{dip} \sum_{\substack{ii=i-1,\\ jj=j-1\\ ii\neq i \wedge jj\neq j}}^{\substack{ii=i+1\\ jj=j+1}} \tau\left(\theta_{i,j},\theta_{ii,jj},\mathbf{m},\mathbf{r}\right) - \mathbf{m}_{ij}\times\mathbf{B}_{ext} \right) \qquad \text{eqn. 12}$$

The torque experienced by each dipole is from the external field of the solenoid (B_{ext}) and the dipole-dipole interactions resulting from the local fields of its neighbours:

$$\tau\left(\theta_{ij},\theta_{ii,jj},\mathbf{m},\mathbf{r}\right) = -\mathbf{m}_{ij}\times\overline{\mathbf{B}_{local.neighbour}} \qquad \text{eqn. 13}$$

This equation (eqn. 13) taken as a bulk effect over the whole lattice, is of the form const x MdM or the dipole-work, where $B_{local.neighbour} = \mu_0 M$. The model can be run as a molecular dynamics simulation and the author attempted this to good success, apart from the lack of convergence or *energy drift* in these type of simulations from use of non-sympletic algorithms[20]. It wasn't thought worthwhile to pursue this further when, as we shall see, analytical solution exists. Furthermore, energy drift *adds* energy to the system and yet the simulations show temperature and entropy reducing, *despite this*. The entropies of position and velocity and the temperature can be calculated from the simulation data:

$$\begin{aligned} S_{pos} &= const\times\ln\left(\text{standard deviation } \theta_{ij}\right) \ \text{(positional)} \\ S_{vel} &= const\times\ln\left(\text{standard deviation } \dot{\theta}_{ij}\right) \ \text{(velocity)} \\ T &= const\times\text{average}\left(\ \dot{\theta}_{ij}^2\right) \ \text{(from kinetic energy)} \end{aligned} \qquad \text{eqn. 14}$$

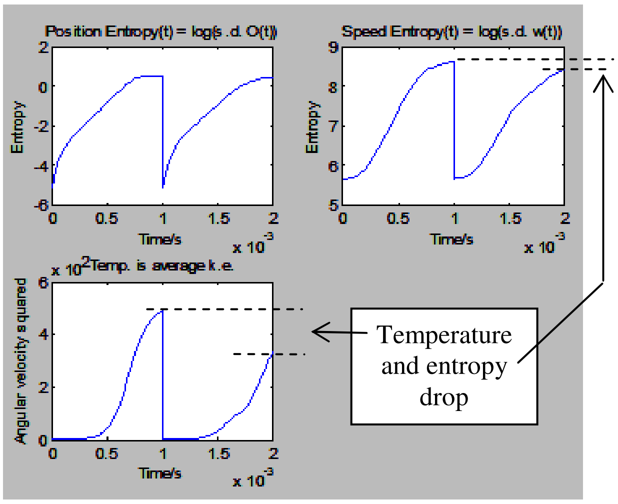


Figure 8 – Two back-to-back simulations: Relaxing to equilibrium and then relaxation to equilibrium with dipole work

Two simulations were performed, one after the other: In the first simulation the dipoles were all aligned at the start with zero kinetic energy. The simulation shows this "relaxing" to a random orientation (the position entropy increases). The potential energy at the start is converted into random kinetic energy (hence the temperature rises, as does the velocity entropy). It is interesting to note that the model randomises itself without any random input. This is just the chaotic dynamics of the three (or more) body problem – the reason why ordered energy degrades to heat energy.

The second simulation follows right after the 1st for comparison, models relaxation with dipole-work, that is, the assembly generates electrical work which leaves the system and gets dumped into the resistive load. An analytical solution can be obtained (section 2.1.2 ref. [18]) by the statistical averaging of the ensemble eqn. 12:

$$\overline{I\ddot{\theta}_{ij} = -k_v m_{ij}\sum_{ii,jj}\frac{\partial}{\partial t}\left(m_{ii,jj}\cos\theta_{ii,jj}\right)\sin\theta_{ij}} \rightarrow I\ddot{\theta}_{ij} = -k_v\left(m_{ij}\sin\theta_{ij}\right)^2\dot{\theta}_{ij} \qquad \text{eqn. 15}$$

Thus each dipole experiences a drag force (hence proportional to the angular velocity $\dot{\theta}_{ij}$) and slows (hence both temperature and velocity entropy decrease) and this is directly related to the dipole-work (eqn. 11). This shows the mechanism for the transduction of heat energy from the working substance to the electrical load.

Sundry considerations

There are a few subtle but non-fundamental electrodynamic considerations (section 4, appendices 8 and 9, ref. [18]), which would properly be called technical electrical engineering type matters, related to cancelling the re-magnetising field from the induced current. The so-called "H-field cancellation circuit" is required to ensure that the dipole-work can exceed the magnetising energy input.

Power losses are also modelled with the most notable being the working substance's (ferrofluid) dissipation on applying a field (appendix 5, ref. [18]). The physical aspect of ferrofluid relaxation and heating effects is closely related to the fluctuation-dissipation theorem[8, 9] but it is sufficient to say that, if the magnetising field is turned on more slowly than the relaxation rate of the ferrofluid, these losses become vanishingly small. Other losses such as pumping losses can be minimised by design and it was already mentioned that, if the magnetising field is bipolar, there will be no net ferrofluid pump effect[19] into the region A-B (fig. 7iii) for which work would have to be expended. Hysteresis or "anomalous" magnetic losses are quantifiable and minimal, as too are electrical I^2R losses by design.

Plant T-S diagram and expected power levels

The device consists of two conceptual cycles: the multitude of magnetisation-demagnetisation cycles on the working substance that occur in region A-B of figure 7iii, called the "micro-cycle" and the overall flow of the working substance in the circuit A-B-C-D, called the "macro-cycle" (sections 2.2.2 – 2.2.4 ref. [18]). The micro-cycle T-S diagrams are complicated but it is essentially enough to say that in region A-B, temperature and entropy decrease, as shown in the kinetic simulation too.

In the region A-B, all the temperature and entropy lowering of the micro-cycles act to traverse path A-B on the diagram below. Compared to the path C-D, which represents the working substance heating up as it passes through the heat exchanger (fig. 7iii), the path A-D behaves as though the working substance has an higher, or "virtual" heat capacity, $C_{virt} > C_H$; it looks like a different working substance. The reasoning is this: if instead the path B-A was traversed on the T-S diagram, warming it up with be more difficult and this is not surprising, the substance has been coupled to an external system to which it loses energy. Around the cycle to A-D, we come back to the initial thermodynamic co-ordinates and thus the changes in entropy can be related to the work extracted. Expected power levels are large, in the region of mega-Watts per m^3/s flow rate of the working substance (section 2.2.3. ref. [18]).

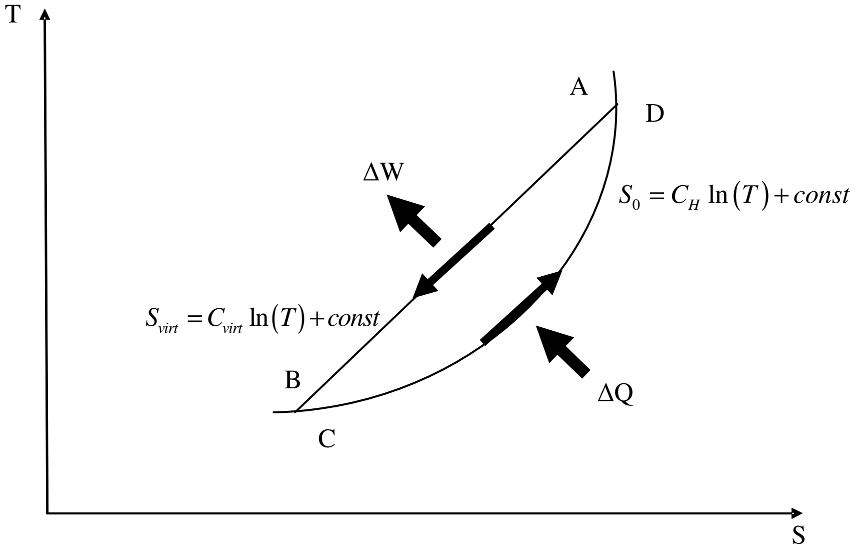


Figure 9 – Macro-cycle T-S diagram related to points on plant diagram

6. Conclusion and discussion: The 2^{nd} Law is universally valid but what is Time's Arrow when $\Delta S = 0$?

The universe is a big place and the 2^{nd} law is ultimately global and true. Despite claims that it is not valid[7], this needs to be qualified with the notion that for relatively small regions (compared to the universe) and for relatively small time timescales, it can go into reverse by Maxwell Demon processes. A demon device in a closed, isolated environment (section 5 and fig. 11, appendix 1) presents a paradox: processes that generate entropy are balanced by those which reduce it. Presumably the demon device could generate enough excess power to operate a maintenance automaton, thus allowing this state of affairs to persist indefinitely. The only constraint would be whether the automaton could have enough time to refine and reconstitute materials in the device, as they denude from it into the environment (reversing the 2^{nd} law tendency for erosion and dispersal) and that the computer code operating the automaton doesn't become corrupted by thermal motion. The total entropy change for the macroscopic system comprising the device, repair automaton and the closed isolated system could be kept at zero, indicating no time evolution of the system – much as the microscopic equilibrium state, so whither the 2^{nd} Law and Time's Arrow?

Should we be so scared by the concept of type 2 perpetual motion? The demon device in the setting discussed is not really perpetual but probablistic – its code could fail by Boltzmann thermal disruption. Furthermore, as it repairs itself, the modifications will not be precisely the same as tp what went before but wholly acceptable and functional to the specification of the device: If the control unit of the demon device had a transistor to be replaced by the repair automaton, it matters not that an impurity dopant in a p-n region of the transistor is in one crystal plane than another, rather, that the bulk properties are consistent with the functioning of the device (not to mention simply printing the serial number of the device in a different font, to be flippant). To be "perpetual" must mean to be perennially the same, by definition. To the point, looking at cosmological time-scales, how can thermodynamic abstractions on the states of matter be generally true? There is no "perpetual" in physics, the term should be banished.

In search of a law to describe the time evolution of the condition $\Delta S = 0$, we already know that heat energy is microscopic "perpetual" motion with the continual exchange of kinetic to potential energy. Two-body simple harmonic oscillation does this and generalised three-body and n-body motion introduces a chaotic element[9, 21, 22]; we might extend the notion and call it "n-body complicated oscillation". Clearly a demon is part of the n-body complicated oscillatory dynamics of the system and we should find the law to describe macroscopic time evolution when $\Delta S = 0$. Such a law already exists and covers all cases when $\Delta S = 0$, $\Delta S > 0$ or even if $\Delta S < 0$. Moving beyond two bodies, one can characterise the evolution of the separation of two initially close trajectories in phase space by the Lyapunov Exponent[21, 22], λ:

$$\left| \delta s(p,x)\big|_t \right| \approx e^{\lambda t} \left| \delta s(p,x)\big|_{t=0} \right| \qquad \text{eqn. 16}$$

As such, it represents the loss in information from the state vector. Given the precision we can specify the state vector, once the system evolves the error bounds to which we can specify a trajectory will soon take up a volume as great as the phase space. Even for a god, in a clockwork universe too, such a calculation would be impossible to perform with infinite precision. Although the universe can be described by mathematics, it is not merely a machine; a similar viewpoint was raised in section 4 about real demons, as compared to the information theory construct of one. So at equilibrium with $\Delta S = 0$, if it were possible to know a system state vector at some instant to some precision, its predictability will soon be gone. Loss of information is truly the arrow of time.

This leads onto the interesting disparity between microscopic, time reversible processes and macroscopic irreversibility. We believe that there is a category error in relating the real world to a computer simulation: The *results* of a computer simulation maybe run back and forth as a movie, supposedly reflecting the microscopic reversibility of laws but the computer has given the luxury and false misconception that the state vector is stored, as if on a reel of film. The truth is, physical laws predict differential sequential processes: we move from a time t_1 to $t_{2,}$, specifically +t+dt *or* -t-dt. It matters not if we use a positive or negative direction of time in the microscopic laws, as long as we use it consistently. The evolution of the state vector will always suffer loss of information, run forward or backward. The universe isn't a reel of film, there is no cosmic computer storing an array of state vectors indexed in time. Even if the film was run in reverse, each sequence would need to be calculated afresh and the system will then evolve ergodically, forwards or backwards. It is a mistake to think the state vector would be the same either way – the result is incomputable and unknowable. Thus there is no disparity between microscopic laws and macroscopic irreversibility.

To conclude, on the author's current state of experimental enquiries (let alone other reports by other parties[7, 10-13]), unless there is some deux ex-machina, along the lines of suspending kinetic theory (so that the ferrofluid working substance won't relax magnetically) or some conspiracy with electromagnetic theory (to avoid the transfer of power), given the favourable analysis of losses in the system, a completed device would most likely show the effect predicted.

This work has been supported, primarily by a private research grant from a private investor (Richard Edward Balding), the author's input and the South Western Regional Development Association (SWRDA) and supervised at the Future Energy Group, The University of London, Queen Mary.

Appendix: 1st order phase change demon

Originally a column with an hygroscopic solution was envisioned (fig 10a,b) where the head of water condensed at height would be sufficient to force water out of a reverse osmosis membrane. This setup was meant to make a "phase changing catalyst" (fig 10a) which would reside in a closed, isolated system (with gravity) containing water in the liquid and vapour phases.

The analysis is tedious; it is learnt that the column would be several kilometres high (thought there is still enough vapour pressure to drive into solution at the top of the column). Flow losses would realistically result in a trickle of water at the base and render the device impractical for power generation but a paradox would still remain (fig. 11).

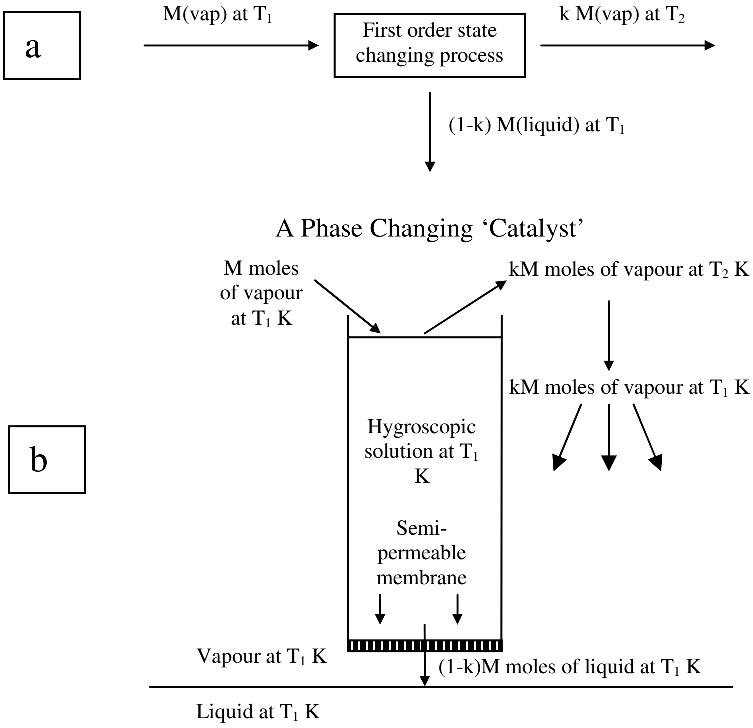


Figure 10a,b – Hygroscopic "phase changing catalyst" column demon

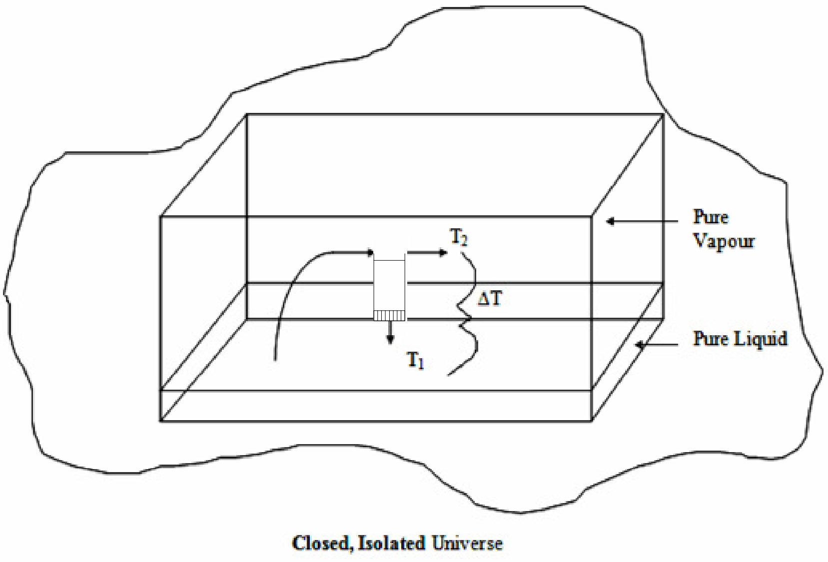


Figure 11 – Device in two phase system

References

1. Kittel C., Kroemer H., *Thermal Physics*. W. H. Freeman and Company, San Francisco. Vol. 2nd ed. 1980.
2. Abbott M. M., Van-Ness H. G., *Thermodynamics with Chemical Applications*. Schaum's Outlines, McGraw-Hill. 1989.
3. Maxwell, J.C., *Theory of Heat*. Longmans, Green and Co., London Vol. Chap. 12. 1871.
4. Szilard L., *On the Decrease of Entropy in a Thermodynamic System by the Intervention of Intelligent Beings*. Physik Z., 1929. **53**: p. 840-856
5. Jaynes, E.T., *The muscle as an engine*. 1983(http://bayes.wustl.edu/etj/articles/muscle.pdf).
6. Wang-Ho M., *The Rainbow and the Worm: The Physics of Organisms*. 2nd ed: World Scientific.
7. V. Čápek, D.P. Sheehan., *Challenges to the Second Law of Thermodynamics*. 2005: Springer.
8. Landau, L., *A Course in Theoretical Physics: Statistical Physics*. Vol. Vol. 5. 1996: Butterworth Heinemann.
9. Landau, L., *A Course in Theoretical Physics: Kinetics*. Vol. Vol. 10. 1981: Butterworth-Heinemann.
10. D.P. Sheehan, D.J.Mallin, et al, *Experimental Test of a Thermodynamic Paradox*. Found Phys, 2014. **44**.
11. D'Abramo, G., *Thermo-charged capacitors and the Second Law of Thermodynamics*. Phys. Lett. A, 2010. **374**: p. 1801-1805.
12. Sheehan, D.P., *The Second Law of Thermodynamics: Foundations and Status*. Found Phys, 2007. **37**: p. 1653-1658.
13. Santhanam P.G., Gray D.J. and Ram R.J., *Thermoelectrically Pumped Light-Emitting Diodes Operating above Unity Efficiency*. Physical Review Letters, 2012. **108**(9): p. 097403.
14. Smoluchowski, M., *Experimentell nachweisbare, der Ublichen Thermodynamik widersprechende Molekularphenomene*. Phys. Zeitshur., 1912. **13**.
15. Brillouin, L., *Science and Information Theory*. Academic Press Inc., New York 1956. Chaps. 13, 14.
16. Feynman, L., Sands, *The Feynman Lectures on Physics*. Addison-Wesley, Reading, Massachusetts. Vol.1, 1989.
17. Harvey L. S., Rex A.F., *Maxwell's Demon: Entropy, Information and Computing*. Adam Hilger, Bristol 1991.
18. Cornwall R. O., *Novel Thermodynamic Cycles involving Ferrofluids displaying Temporary Magnetic Remanence*. 2013(http://vixra.org/abs/1311.0078).
19. Rosensweig, R.E., *Ferrohydrodynamics*. Cambridge University Press. 1998.
20. Haile J. M., *Molecular Dynamics Simulation*. 1997: John Wiley and Sons.
21. Kapitaniak, T., *Chaos for Engineers*. Springer 1998.
22. Jordan D. W., Smith P., *Nonlinear Ordinary Differential Equations*. Clarendon Press Oxford. Vol. 2nd ed. . 1991.