The Energy Physics of Continuity **in Change**[i]

A unification of the conservation laws as a *Natural Law of Continuity and Form of Development for Individual Complex Systems*

Now also known as — *the* n^{th} *Law of Thermodynamics*

(A physics principle derived by taking the n^{th} derivative of energy conservation – forming an infinite series of conservation laws and reintegrating to display the form of emerging change)

(some might want to jump to the theorem on p4)

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§1. **Abstract**

Ed 5/12/09 - The form of physical processes needed to satisfy the boundary conditions for the conservation laws is considered, along with the form of mathematics needed to explore the emergent phenomena in nature. Asking what needs to occur for natural events to begin and end yields important new insight into both. The constraints of conservation for energy, momentum and reaction forces combine into a single law of continuity in rates of change, and so for transitional processes that allow change without discontinuity.

The main finding is that divergent eruptions of development are needed to do it, with higher accelerations necessarily coming from eruptions of change on a smaller scales. These implied "little bangs" that initiate divergent processes of system development are observable at the beginning of most energy transfer processes as seed events of nucleation that germinate a larger "run-away boom" of organizational

[i] Note: Sections 3 & 4 are excerpt the main theorem from Reconstructing the Physical Continuity of Events (Henshaw 1995). The theorem was originally developed in 1993 and included in the circulated the 1995 paper. Prefatory Sections 1 & 2 are added here along with discussion Section 5.

development that systemizes any new energy flow process. The reasoning appears to be similar to why a period of inflationary change needed to be hypothesized to start the "big bang" of the universe, a kick start to conform the basic laws of physics. What would also be implied is some distinct 'nucleation' or 'seed' event to initiate the boom of developmental process that may result in a an environmental response to stabilize or destabilize the system of energy flows so initiated.

§2. Continuity; Nucleation, Divergence & Response

Ed 5/12/09 - This theorem relates to physical mechanisms by which local systems may emerge to break and make local 'laws of nature' that arise as local systems of conserved change develop. It also relates to the mystery of why so much persistent heterogeneity of complex form is observed in nature to accumulate and be preserved, when the statistical laws imply it should always be decaying. The implied answer is that it comes from local individual developments, not general probabilities, or more simply "it's local". If what we observe is energy flows locally beginning and ending, what is implied by continuity is a local cascade of complex processes of conserved addition to do it, emerging from their environment. When you look for these start-up sequences of conserved addition you often easily find them. They operate within the laws of probability, as the physical mechanisms by which energy is transferred, and necessitating the development of the complex systems to do it. If the forms of systems develop locally, it suggests that time is an accumulative process in general, and not a location on a scale. As such, energy transfer by physical systems seems to involve transient steps of local organizational development and extinction not entirely unlike how both individual organisms and whole species also do in evolution.

Direct observation of the beginning and end of emergent phenomena such as organisms, storms, sparks, eruptions, cultures etc., all display that their primary 'non-linear' behavior is simply beginning and ending. Those beginnings and endings all involve the development of conserved systems of energy flow and other kinds of conserved change, definite in that they occur but indeterminate as to how. The math that fits that mix of definite but indeterminate processes along with the basic laws of physics is what follows. Those transitional periods of change, to the limits of our observation, generally reveal explorable complex processes that temporarily diverge developmentally and organizationally from anything else around them, not displaying an equal cause & effect but emerging order from local gradients that diverges from the prior state and leads to an environmental response. Because they are hard to describe they are mostly just omitted from our catalogs of things we can describe and glossed over. We do not know how to connect divergent mathematical sequences with convergent ones. We do not know how to represent or define an environment. These problems have often been considered impossible or unscientific to address.

What seems to correct the problem is to switch to using our models as questions, leaving things out, rather than representing complex systems with simple rules because simple rules is all we can define. The problem with environmental processes is that they develop independently until they run into something else, i.e., have a form of connection without prior determinism. While all these "missing parts" does foil any attempt to obtain definitive answers based on data alone, having a model of what's missing does serve to raise new high-quality questions, pointing to issues beyond the present evidence, in a way to facilitate new hypothesis and ways to discover information to confirm them or raise other questions.

The general mathematical questions of describing nature with divergent mathematical series may have been most thoroughly studied by Robert Rosen. His short 1995 essay[i] describes how a mathematics of predictable convergent sequences, excluding the study of improper' divergent sequences fails to match the variety of behaviors of nature. In his observation, both emergence in complex systems and in life are subjects only seen in divergent processes which science would need to use divergent sequences to study.

The present theorem demonstrates that the beginnings and endings of energy flows require divergent sequences to be described mathematically. That identifies a key feature of life and emergence that a study of divergent sequences is needed for, substantiating Rosen's complaint. Because defining true environments for equations is more than difficult, and because the divergent processes of most interest already have their own environments… is a further reason for a switch of method from representational to exploratory mathematics seems called for. Instead of using math in isolation, a way to use it to raise questions open system environments seems required. One general way to do that, for example, might be to replace environmental parameters

[i] Robert Rosen 1996 "On the Limitations of Scientific Knowledge" in On the Limits to Scientific Knowledge, John Casti & Anders Karlqvist eds, Perseus; collecting ten papers presented a 1995 Stockholm workshop of the same name sponsored by the Swedish Academy of Sciences; link to scanned copy http://www.synapse9.com/ref/Rosen_On_Limitations_of_Sci.pdf

with strategic queries. A mathematically assisted study of 'divergence and response'[i] is then an interactive discovery process using conventional scientific tools and a map of local information gaps within developmental processes, a work I started in the 1970's that led to the present analysis of the problems of mathematical physics that would need to be solved that way.

§3. Theorem on the Natural Limits of Rates of Change

ed 9/9/08 - The principle of energy conservation, that energy cannot be created or destroyed but only moved from place to place will be shown to imply that such transfers cannot occur instantaneously. That implies a requirement for derivative continuity in both physical motion and other energy transfer processes. It also forms a general implied requirement for continuity in organizational change for energetic physical systems, because energy transfer processes use the organization of physical systems to operate. Organizational change in open systems seems generally indefinable and unmeasurable because it is distributed and often embodied in passive environmental potentials that are hard to identify or measure. That is what is usefully exposed by identifying the form of continuities connecting the dots.

The demonstration that divergent sequences are required to enable physical processes to begin or end with continuity begins by presenting the basic conservation laws as a hierarchy. The conservation of energy, the conservation of momentum and the conservation of reaction forces are related as derivatives and integrals of each other, one law stated differently for scales, velocities, and accelerations of change. That one law can be represented as an infinite hierarchy of successive derivative laws. The familiar statement of the three basic physical laws is shown in the first three equations in column a of table 2.2 "Conventional Form". They are repeated in column b "Unified Form" altered by substituting derivatives of distance (**s**) for acceleration (**a**) and velocity (**v**), and in the case of energy conservation, the conventional term $\frac{1}{2}v^2$ is replaced by the integral of its derivative ($\int v \cdot dv$), a quantity having the same derivative rank as distance (**s**). They all have the same form of statement; that the sum of each of the derivatives of energy does not change. The general principle of continuity is then

[i] Author's archive of studies using various methods www.synapse9.com/drwork.htm

derived by successively differentiating as a limit and concluding that the sums of all derivative rates of energy flows within a closed system are conserved.

To this point little has been said about what is in the 'closed system' and how it might relate to the open systems in which we observe the behaviors of life and other things to begin and end. If within the closed system there are visible and invisible regions, with energy appearing in one place from an unobservable source, the conservation laws tell you little about the bounding quantities of energy available. They do tell you something about the bounding rates of change in energy flow though, which turns out to be quite useful. The issue leads toward discovering how to identify behaviors exhibiting temporary conservation of organizational change, and how to use it as a temporary stand-in for energy flow. In practice one very frequently has sound evidence that change is being conserved in a system but no good information as to where or how. Determining whether the system is displaying divergent or convergent developmental change offers a starting point for exploring that.

3.1 Basic Related Formulas of Work for reference

$\boldsymbol{W} = \frac{1}{2}\boldsymbol{mv}^2 = \frac{1}{2}\boldsymbol{m}\cdot\left(\frac{\boldsymbol{ds}}{\boldsymbol{dt}}\right)^2$	Work, Energy of accelerating a mass to a velocity
$F = ma = m\cdot\frac{dv}{dt} = m\frac{d^2s}{dt^2}$	Force corresponding to acceleration for a mass (a first derivative of Work)

3.2 Relation of Limiting Rates

If, at the n'th derivative level $\quad \boldsymbol{r_n < c_n} \quad$ 2.1-0

in any finite period $\quad \boldsymbol{r_n = r_{n+1}\cdot\Delta t + k_n}$

by substitution $\quad \boldsymbol{r_{n+1}\cdot\Delta t + k_n < c_n}$

and $\quad \boldsymbol{r_{n+1} < (c_n - k_n) \div \Delta t}$

let $\quad \boldsymbol{(c_n - k_n) \div \Delta t = c_{n+1}}$

so that

at the n+1 derivative level $\quad \boldsymbol{r_{n+1} < c_{n+1}} \quad$ 2.1-1

3.3 Laws of Conservation and Continuity

Column c in Table 1 "Limiting Rates" lists physical limits of energy transfer, starting with the speed of light as the limiting velocity in line 2, $v_j < c$ (3.2.2c). Because it takes time for a derivative to accumulate change in an integral, as for an acceleration to change a velocity, the limits of one rate applies to the others. That is shown in Table 1 , as follows:

For: **i**, **j**, **l**, **n** - integers; $\mathbf{k_i}$, $\mathbf{c_i}$, u_i - constants; **c** speed of light
m – mass; **a**-acceleration; **v** - velocity; **s** - distance; **t** - time
r-rate; Δ-finite difference; **d** – differential

Table 1 An infinite series of derivative conservation laws

	a) Conventional Form	b) Unified Form	c) Limiting Rates
1. Conservation of Energy • sum of energies is constant • 0 derivative level	$\sum_i \frac{1}{2} m_j \cdot v^2{}_j = k$	$\sum_i m_j \int v_j \cdot dv = k$	$s_j < c \cdot t + k_1$
2. Conservation of Momentum • sum of momentums is zero • 1st derivative level[1]	$\sum_i m_j \cdot v_j = 0$	$\sum_i m_j \frac{ds_j}{dt} = 0$	$\boldsymbol{v_j < c}$
3. Conservation of Reactions • sum of forces is zero • 2nd derivative level	$\sum_i m_j \cdot a_j = 0$	$\sum_i m_j \frac{d^2 s_j}{dt^2} = 0$	$a_j < c_2$
4. Unnamed • Sum of 2nd accelerations zero • 3rd derivative level		$\sum_i m_j \frac{d^3 s_j}{dt^3} = 0$	$r_j < c_2$
5. Principle of Continuity • Sum of higher accelerations zero • n'th derivative level		$\sum_i m_j \frac{d^{n2} s_j}{dt^n} = 0$	$\boldsymbol{r_{j_n} < c_n}$

§4. Theorem on the Divergence in Individual Events

ed 9/9/08 - We now consider some individual energy flow within an open system S. You might represent that as the movement of a mass (m) which begins at rest. A finite force (f) to move it can't be applied instantaneously because that would imply a step change in acceleration, and an infinite force (2.2-2c), as well as the higher rates of change than allowed by the general principle of continuity (2.2-3c,4c,5c). For it to develop any positive velocity its acceleration will need to have been positive for a finite period. The same is then true for it to achieve a positive acceleration, it's rate of increasing acceleration, and every other underlying acceleration, will need to have been positive for finite periods. For there to be a change from rest to motion every underlying acceleration needs to have been maintained for a prior finite period during which all underlying rates are positive. If they all start at zero and none can be infinite acceleration is not possible. The implication is that accelerating anything from rest is either: a) impossible, b) requires energy conservation to not always apply, c) that nothing begins or ends or is ever at rest, or d) doing so requires a trick. One of the plausible 'trick' ways to resolve the contradiction is for things that do begin and end to do so with divergent accelerations, a burst of development or "little bang". It would then be a demonstration to observe divergent accelerations and bursts of developmental change where motion or other energy transfer systems appear to begin and end.

One class of mathematical functions that has derivatives of the same sign for finite periods and closely associated with physical processes resulting in bursts of organizational change and energy release, are the exponentials. They do not quite satisfy the requirements, though, for not having any point of beginning or ending. They can only be arbitrarily started and stopped with discontinuities that would violate the conservation laws. What is needed then for both change and continuity is an emergent exponential-like progression of some kind, appearing at each observable scale to begin with an implicit but possibly unobservable seed of change on a smaller time and energy scale. That sounds a little fantastic, perhaps. Because the proof is an exercise in narrowing down the difference between what needs to be found and what is generally found, all that needs to be demonstrated here is scientifically useful progress in doing that.

For example, a fire may start with a spark, definitively, but that start may be unobservably small and brief relative to the scale and course of the fire. Every scale of organization requires a different mode of description because they each make different sense, and so it is rather natural for each mode of description to leave out the others. Why each different mode of description leaves out the others is open to question, of course, but it could be a property of how we describe things, of our own mental models, rather than of the things being described. Continuity of change appears to imply that every scale of behavior requires other scales for their beginnings and endings to occur. This principle that continuity seems to require invisible scales of behavior is not well recognized even if we do commonly see smaller undescribed functional scales of behavior in most kinds of behaviors. We also commonly see exponential-like progressions at the beginning and end of all kinds of systems and processes seeming to have definite beginnings or ends. It is possible that it just means that each scale of organization needs its own separate process of development, another implication one could look for confirmation of.

The polynomial form of an exponential function directly results from the successive integration of a constant. A starting point is provided by an assumed event of a different kind on a smaller time and energy scale, providing a "seed" for a divergent process to and the "little bang" of explosive development to begin a larger system from "next to nothing" to satisfying the conservation laws. Oddly, this "unhidden pattern" is clearly visible in large classes of events as how nature links scales of organization, like fertilization for reproduction, or a spark to start a flame or an idea to start an industry, displaying divergent processes in-between. This way of connecting scales of organization makes it theoretically possible to have smooth change with definite beginnings and ends. The proof is as follows.

For some large **n,** the **n**th derivative rate r_n is taken as finite and between some lower and upper bound pair of constants representing the limiting propagation rates for the process of energy transfer:

$$u_n > r_n > l_n \qquad 3.1$$

Integrating the **n**th derivative rate with integration constant $\mathbf{c}_{n-1}$ also chosen between some upper and lower bound limits of propagation rates for the process at that level of acceleration:

$$r_{n-1} = \int r_n = r_n \cdot t + c_{n-1} \qquad 3.2$$

In general, as the number of derivative levels **n** increases and the number of times $\mathbf{r}_n$ is integrated $\boldsymbol{i}$ equals **n** the form of polynomial expansion approaches that of an exponential.

$$f(t) = r_0 = \frac{r_n}{(n-1)!} \cdot t^{n-1} + \frac{c_{n-1}}{(n-2)!} \cdot t^{n-2} + \ldots c_{n-i} \qquad 3.3$$

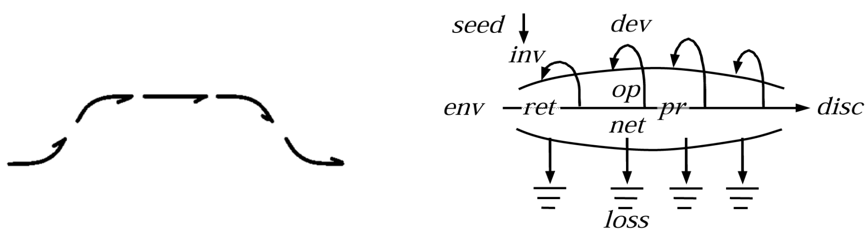
One of the further directions of exploration is to establish that there are particular upper and lower bound propagation rate limits, $\mathbf{u}_n$ and $\mathbf{l}_n$. The universal limit used in 2.1 above to establish the form of sequence required is the universal propagation rate limit of the speed of light. For any particular energy transfer process, the starting 'seed' acceleration would not be arbitrary, but would have limits defined by the process itself, somewhere between the highest and lowest potential propagation rates for the larger scale process being considered. For example, the bounding limits for propagating a fire are what break the chain. At too high a rate of propagation a flame becomes an explosion and blows itself out. At too low a rate a spark cools before igniting anything else. Just looking for how that principle applies to any given process of beginning tends to be quite informative. It provides a way to follow a lead and explore the whole domain of behaviors in which the process develops.

With most observed event processes their beginning displays an exponential-like period rather than a simple exponential. There is no constraint in the above analysis requiring complex systems developing at constant rates, just that they be bounded within natural limits. Perhaps the more surprising result is the reverse implication, those organizational processes in nature identified by the divergent way they conserve their own accumulations, identify the emergence of conserved organization as a means of transforming energy, and a transitory form of energy themselves. Where such questions lead may not be immediately clear, but a path for exploring them is provided.

§5. Balancing the budgets for the 'business' of nature

ed 8/10/10 – (excerpt from Henshaw 2010) If moving energy is the 'business' of nature, where one draws an accounting boundary defines what you are accounting for. Any boundary can be considered as a question of what is available outside, what's crossing the boundary, or what happens inside. Sustaining the energy resources inside a boundary is the same arithmetic for either your home or the global economy. It's universal, because energy is not created or destroyed, and takes costly processes to get it or use it. As affordable environmental resources become scarce you could either improve ways to bring energy in, or to reduce what you use. If the boundary is a growth system, then neither of those solutions work, except momentarily perhaps. Increasing use of resources that are increasingly costly as you use them becomes absolutely unaffordable with abrupt natural limits as the cost exceeds returns. For complex environmental systems one has no equations but if you can measure the total you can watch to see how nature integrates the behavior of the whole and read a great deal from that. If you cannot add up everything crossing the boundary "total" is undefined, and so are "change", "direction of change" or "acceleration", or even the ability to use the measure to scientifically refer to the system as a physical subject of discussion.

Because energy flow requires first building an energy flow process (Henshaw, 2010) the general narrative of change for energy systems is development from small beginnings leading to small ends, involving assembly and disassembly of the process. In time series data that appears as growth and decay, generally found confined within a definite boundary as a network "cell" of complex processes. Narrative is a necessity for complex systems science, as an aid to exploratory investigation, requiring care in collecting "just the facts" as a precedent to studying how to fit them together (Allen et. all. 2001), which is presented here as "just the facts" about the subject of an identified individual physical system. To trace their energy flows is like "follow the money" for detective work, locating the coordination of energy and self-organization animating the process.



Life cycle of development and decline

Net energy uses in individual system

Figure 1 Simplified Development Cycle and Process Succession diagrams of typical complex systems.

One can outline a rudimentary energy budget (Equation 3,4) to satisfy the conservation of energy and internal needs of system development, products and losses. The system needs to maintain positive *net* energy, beginning with a *seed* resource, used in starting the system for *inv*esting and *ret*urning net energy from the *env*ironment as it uses its seed or net returns to *devel*op itself and *oper*ate to produce internal *pr*oducts while maintain *net* energy throughout, all of which results in *loss*es and *disc*ards. These energy uses are implied for all energy using systems, needing to add up and operate, and so provide a start for exploring how any individual complex energy using processes begins, operates and ends. These questions about energy use over time observably apply to most systems and serve as things you know about any individual system before knowing how any part works. They are largely necessities for changing scale in working processes implied by energy conservation (Henshaw, 2010).

$$E_{in} = E_{seed} + E_{inv} + E_{ret} + E_{dev} + E_{op} + E_{net} + E_{loss} + E_{disc} \quad (1)$$

$$E_{net} > 0 \quad (2)$$

It does take effort to account for a whole system's energy budget, which starts as just a map of missing information about it, once you locate its boundary so you can define the task of coming to an estimate of the total energy uses. The simple kind of powerful conclusion that gives you immediately is that not every part can rely on energy use far below average, like what you see. Further exploration both fills in some gaps and creates better questions. Going back and forth between the subject and different perspectives of it is the methodology that maintains the focus of attention on the complex system as an individual physical object, making this physical rather than statistical science, about physical subjects that remain beyond one's own full imagining.

It sounds rough but it does help frame inclusive questions needed reach conclusive answers. For asking inclusive questions about the world economy, for example, one can see in the total energy budget (Figure 1) how the relation between money and energy changes in remarkably regular fashion. That translates to a steady average rate of energy use for every dollar of GDP. "Average" is certain to be a better estimate than zero for any estimate of personal or business energy use assessment. Any product or service does actually require and support highly diverse business services throughout the world economy, and markets do select products to use the least energy possible. If some service supplier were an inefficient energy user a business would stop using them because it would reflect in their price.

All combined, average global energy use per dollar is not a farfetched initial estimate, at least. One important direct result is readily apparent. If you account for your own impacts on the earth as being "about average" for every dollar spent, it matters much more what your income is than what you spend on. Add it up and see. That illustrates another way a whole system view starkly contrasts with the popular use of persuasive arguments and symbolic values. It puts the arguments and symbolic values in context, grounding them in the practicalities of living in a physical world in which nature adds everything up using the conservation of energy.

This provides a very effective way to go back and forth between measures of the whole and learning new meanings for the behaviors of its parts. Fairly accurate direct measures of the energy used by either business choices or whole business systems is possible using the System Energy Analysis (SEA) method of accounting for the energy required to deliver business products (King et. all., 2010). The study defines a new standard for measuring EROI (energy return on energy invested) for business choices. When counting up the total energy a business uses the conventional approaches have nearly all been to add up what was visible. The SEA method uses the global boundary to account for a business system by asking what energy uses were required for it to operate and using "average" for the specific energy uses identifies that are unaccountable. In the case study, which seems typical, the difference is a matter of about a 500% increase in the estimate of the embodied energy costs of operating the business. These things will surely take some time to understand, but there's little doubt that not every business can be using energy at a rate 80% below average per dollar either, but that is largely how our prior methods of accounting added it up. Still, the facts may seem easier to establish than giving them meaning. As with any other learning process it starts off wherever you start, and by going back and forth between different views you reach a point in your mind where it starts coming together.

Understanding how both the natural costs of energy and our societal energy overhead costs are rising and reducing our operating net energy is another way to look at the whole system energy budget. It's possible the energy available on earth will not continue to be cheap enough to run our world economy designed only for running on cheap energy, or large sectors of it. Studies on that question were begun by Charles Hall with his work on EROI, the energy returned on energy invested, noting the drop in oil energy return on investment from 100:1 to 15:1 in the last century. One of his interesting recent papers (Hall, C. A. S., et. al., 2009) introduces the idea that as our energy resources cost more energy to develop, and our society keeps accumulating more energy costs, there is a theoretical probability of a crossing point where our form of civilization could not physically operate.

It is suspected by many observers that this kind of energy bankruptcy and failure of economic sectors unable to adapt to expensive sources of energy may have already started happening. There was an exceptionally high demand for oil and a sharp rise in energy prices before the 2008 economic collapse, but with global oil supplies not responding as usual (Hamilton, J.D., 2009). That is exactly what the phenomenon discussed as "peak oil" would show, that with high prices, high demand, and plenty of warning, industry was unable to meet the demand and driving escalating prices. An net energy budget is like a financial budget with regard to needing a positive balance. For some economic sectors, drifting over that line and becoming unable to maintain a positive energy balance might make investors pull out and bring about a financial bankruptcy. That on present trends, maybe even in the next ten or twenty years, losing more sectors of our formerly healthy society for natural causes, in effect, or failing as a whole, is a bit of a shock. This is a very young science, but based on the most well established principle of physics, so the questions seem rather pointed and appropriate, and should be followed up.

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