Actual Time, Detached Time and Controlled Time:

Physical Paradigms and Energy Constructions

OUTLINE

Overview of the Project

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- A. A unified psychology and physics of freedom is based on muscular movements of actual life.
- B. Multiple kinds of time are generated when muscular movements of actual life are coordinated with detached operations of reason.

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- A. Atwood's machine and Hooke's Law
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- A. Movements and feelings of animal bodies occur in actual time and make up the domain of ***actual life*** that establishes foundations and standards for constructions.
- B. Operations in rational domains, e.g., arithmetic, are learned in actual time but then continue to operate in detached time, sometimes interacting with the independent domain of actual life that is based on muscular movements.
- C. The modern scientific view erroneously presumes that there is full and automatic integration of rational domains with the domain of actual life.
- D. To initiate and develop a new approach, three kinds of energy are constructed: actual energy, conserved energy and virtual energy.

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Overview of the Project

Each of the four parts of this project has a distinct and independent character. Some parts are rigorous and technical and others are based on feelings and speculations. I use a variety of rhetorical styles. Each part has connections with all of the others. Parts can be read in any order.

Part I, the Introduction, presents sweeping views of multiple kinds of experience. First, in part A, the view takes in the "entire spine" of a person: the spinal cord, vertebra and nerve networks that extend down through the pelvis and up through the brainstem and cranial nerves that lie under the brain. In this view, whole-body muscular movements, e.g., itching and scratching, are products of the entire spine. Feelings such as itches are organized in bodily imagery and bodily awareness that are prior to images of external objects and events. Combinations of bodily feelings and external imagery can lead to additional movements such as imitating another person.

Second, in part B, modes of time in rational domains are contrasted with the ***flow of actual time*** that occurs during muscular movements. Rational operations of mathematics and computers occur in ***detached time*** and can be postponed, decomposed, recomposed and reversed in ways that ignore the flow of events in actual time. In ***mimed time***, special detached rational operations resemble limited movements of actual life. Major paradigms of Conserved Energy and Virtual Energy occur in detached time and mimed time.

Part II reviews standard physics paradigms of Conserved Energy that maintain tethers to curves of continuous equipoise and stabilizing equilibrium. When such paradigm are restricted to detached time and mimed time processes, mechanics and thermodynamics appear to coincide.

Mechanics paradigms – Atwood's machine and Hooke's Law – illustrate actual, detached and mimed time operations. Similar thermodynamics paradigms – Ideal Gas and Perfect Gas – are combined in the Carnot cycle and applied using Clausius-Clapeyron relations to traverse the liquid-gas equilibrium curve of water — until equilibrium runs out at the critical point, where the Ising Model reveals unique phenomena, on the edge of freedom.

Part III presents new paradigms as Virtual Energy (VE) devices designed around a Virtual Energy Store or VES. VE is constructed for purposes of development and maintains strategic ambiguities. At first, paradigms conform to restricted Conserved Energy (CE) principles. Development leads to more dissipation; highly dissipative Quad Net (QN) devices are designed to generate conditions of ***Shimmering Sensitivity*** – similar to conditions seen in the Ising Model, but with more powerful activations. An Ising Model ***critical point*** defined in detached time is developed into Quad Net ***critical moments*** occurring in a new ***controlled pulsational time***.

VE designs are organized as four ***kits of parts***: (1) ***pulser devices***, (2) ***force devices and bursting devices***, (3) ***timing devices*** and (4) ***Quad Net (QN) devices***. Kits of VE device parts resemble standard electronics parts such as resistors, capacitors, diodes, microphones, etc. VE designs aim to model biological animals and to be realizable through technologies similar to electronics. I suggest that something like imagery (itches) will be generated during operations of QN devices.

Part IV contrasts VE constructions with the "modern scientific view" that is said to describe "Everything in our universe." Scientific models based on Conserved Energy do not describe itching and scratching or other feelings and movements of animal bodies. New VE paradigms propose methods to model such feelings and movements with devices. QN devices embody a unified psychology and physics based on the principle that, during a critical moment, an exercise of freedom occurs and multiple possible movements change into a single actual movement.

Introduction: Forms of Freedom and Time are Based on Movements of Animal Bodies.

A. A unified psychology and physics of freedom is based on muscular movements of actual life.

In this project, physics and psychology are based on common muscular movements of our animal bodies and on principles of balancing and loss of balance. I suggest that models of feelings and mental operations can also be based on movements and balances. The ***domain of actual life*** is filled with muscular movements and bodily feelings. Please see also a prior project, *How to Solve "Free Will" Puzzles and Overcome Limitations of Platonic Science* (2016) and clarifying observations of William James in Chap. 2 of his *Principles of Psychology* (1890).

Suppose that we start with propulsive movements of a fish that are produced by a spine made of an ordered array of vertebral modules. Movements are produced by the whole body of the fish and exhibit complex patterns, balances, rhythms and flows. In models of patterns, movements of one module are influenced by ongoing movements and feelings in its neighbors, as well as by a triggering wave that travels down the spine. Birds and mammals expand capacities for complex flows like those of fish; and new forms of flow occur in a flock of birds landing on a lake, in a squirrel scooting up a tree or in a human swimmer. Athletes skillfully co-ordinate limbs, feet and hands in flowing patterns, e.g., gymnasts, ice skaters and basketball teams. Other kinds of flowing patterns appear in movements of musicians and dancers.

This project investigates flowing movements of a whole body made of many parts. In the human body, the "entire spine" extends physically down to the coccyx (tailbone) and through nerves, feelings and movements down to the toes. As shown below, the entire spine extends up through the brainstem and includes cranial nerves that carry: (1) signals of sensations of smells, sights, sounds, touch and taste; and also (2) signals that produce movements of eyes, facial muscles and the tongue. I suggest that the entire spine is the foundation of movement and personality.

I suggest that a person's body has separate "parts" — "pelvic parts," "manual (hand/arm) parts," "ear parts," "facial parts" and "eye parts." Feelings, sensations and movements of such parts are based on specific locations in the entire spine. Each part operates "on its own," independently of other parts. A non-spinal "gut" part is located in the muscular alimentary canal and its independent enteric nervous system. Another part of a person is located in a "heart" and in the nerve network that encircles the cardiac muscle — which, I suggest, generates primal feelings of love, fear, anger and empathy. A heart construction has attractive features if social influences are to be modeled; however, influences based on a heart are beyond the scope of this project.

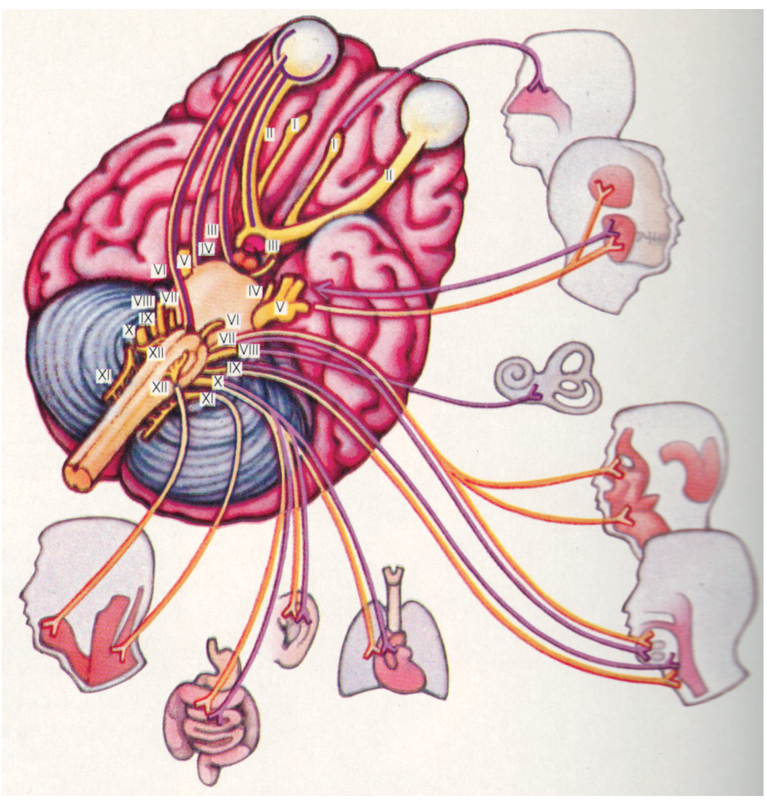
Pelvic parts, found in all tetrapods, produce large-body movements and related bodily feelings based in the pelvis and hind legs. It is convenient to include the gut in a pelvic personality. Acting through a pelvic personality, our bodies exercise freedom, balance on two legs, walk, climb, run, dance and perform animal functions of eating, digestion, excretion and sex.

Manual personality parts interact through a person's fingers with parts of the environment, with the person's own body and with bodies of other persons. Manual movements such as scratching and playing with objects often occur "on their own" and without consciousness. Eye parts have similar independent operations that appear to present good opportunities for modeling because of a rich set of symmetries in muscle and sensors. Hands and eyes work together during exercises of freedom in work and domestic life. Movements of facial parts, along with words and gestures, express a social personality in ways that are sometimes fickle and impulsive.

Text extracts and images below are from J. Fincher, *The Brain: Mystery of Matter and Mind* (1981). They support the view that activity of the entire spine is the primal source of feelings, sensations and movements of actual life, which can arise in a multitude of combinations. In this view, both the cerebellum (generating "bodily awareness" and controlling movements) and the cerebrum (generating "the mind" and rational images) are perching outgrowths of the entire spine, connected to it through cerebellar and cerebral peduncles, thalamus, insula, etc.

I suggest that parts of the human body have different levels of agility and complexity based on their locations in the entire spine: slowest and simplest in the pelvis and progressively quicker and more complex in arms, hands, face, tongue and eyes. Body parts interact with each other during integrated spinal movements; movements may also be subject to cerebellar awareness and to governance of a cerebral mind. Sometimes, certain parts are working together while other parts are inactive; e.g., while sitting at and playing an electronic piano, a musician's hands, ears and mind are working together while pelvic parts may be inactive and facial parts may be operating independently and perhaps expressing emotions.

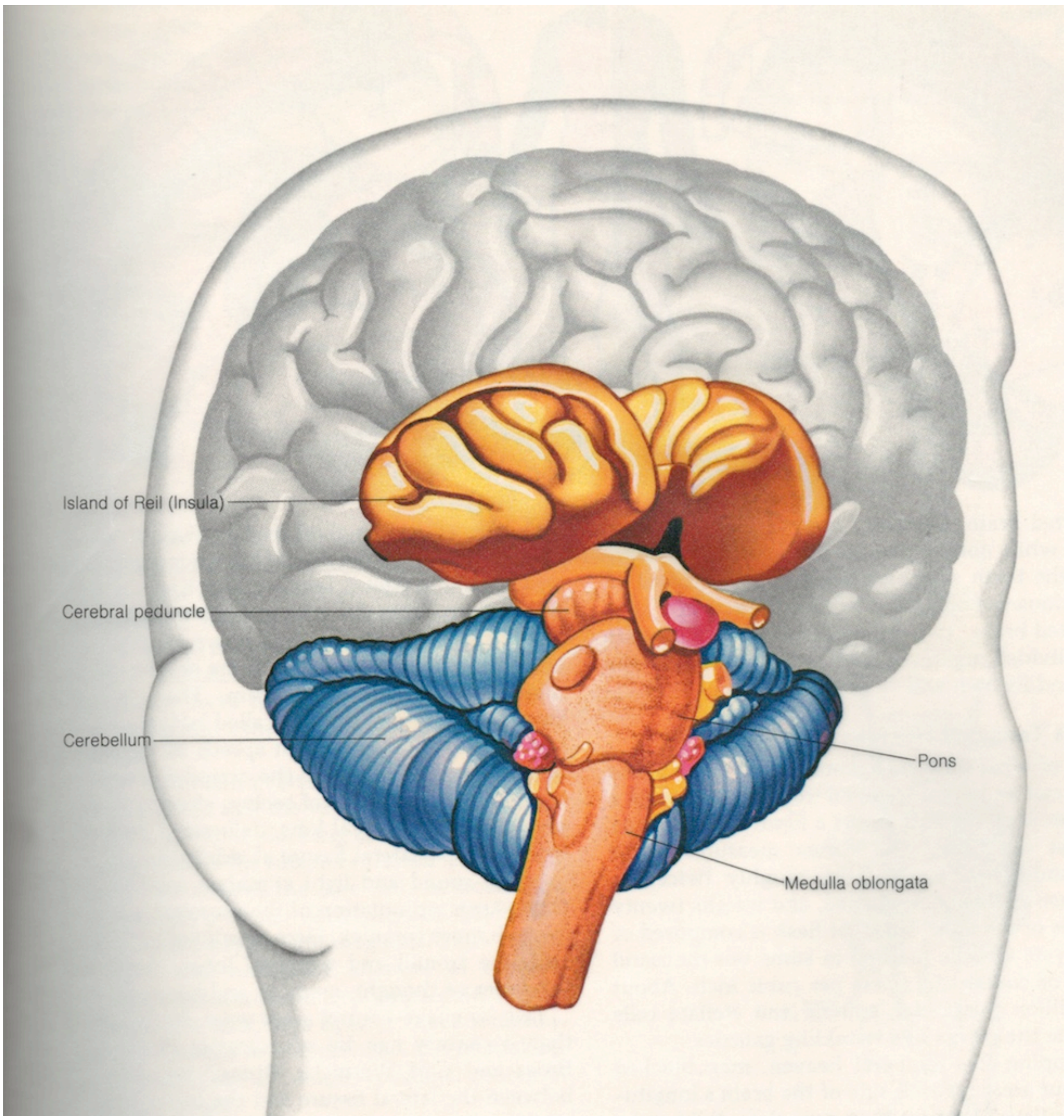
"From the medulla and adjacent areas radiate the twelve pairs of cranial nerves. They serve the sensory and motor needs of head, neck, chest and abdomen…[and] are known by both name and Roman numeral: olfactory (I), optic (II), oculomotor (III), trochlear (IV), trigeminal (V), abducens (VI), facial (VII), acoustic (VIII), glossopharyngeal (IX), vagus (X), spinal accessory (XI) and hypoglossal (XII)."



"Twelve pairs of cranial nerves branch from the brainstem, sending sensory (purple) and motor (orange) fibers to head and body organs. Spot illustrations (clockwise from top) show nasal path to olfactory nerve; trigeminal nerve endings in chewing muscles and sensory facial areas; acoustic nerve connections to the inner ear; facial-nerve motor fibers to face and scalp; sensory fibers from taste buds; wide-ranging vagus-nerve involvement in eardrum, lungs and stomach; and spinal-accessory nerve fibers that control head and shoulder movement; hypoglossal nerve leads to tongue." (This list omits ocular nerves: sensory optic nerve and motor oculomotor, trochlear and abducens nerves.)

In the image of the brain below, also from Fincher, the pons and medulla oblongata are located near the top of the spinal cord that extends down the back towards the tailbone. The brainstem (medulla oblongata, pons and obscured midbrain) provides connections for the cranial nerves shown in the previous image. I suggest that the entire spine has its “head” in the brainstem, and that the brainstem often takes the lead in producing integrated full-body movements.

Closely attached to the brainstem, the cerebellum contains some 75% of all the neurons in the brain. I suggest that the cerebellum generates and controls complex sequences of muscular movements, bodily feelings and sensations in an imaginary “theater of bodily awareness.” The physical principle of freedom that originates in the spine is further developed in the cerebellum. The cerebrum, shown here as background, has its own distinct specialized images of the body, powerful integrating capacities and large storehouses of memories and forms that participate in exercises of freedom, but it only influences movements of the spine indirectly via other parts.



B. Multiple kinds of time are generated when muscular movements of actual life are coordinated with detached operations of reason.

Scientific methods treat time as a numerical quantity that can be perfectly represented by a mathematical variable and precisely measured by standardized clocks. Such a shallow and rigid treatment ignores the rich flowing textures of temporal forms and rhythms that personal experience continuously weaves from memories of the past; from movements, feelings and perceptions of the present; and from anticipations of the future. "Permanence" and "reversibility" of the mathematical variable are contrary to the character of actual life where "the moving finger writes; and, having writ, moves on." (*Rubaiyat* of Omar Khayyam.)

In this project, multiple kinds of time are identified and developed through three energy concepts. Part II discusses standard Conserved Energy (CE) paradigms of physics; Part III discusses new Virtual Energy (VE) paradigms. Part IV additionally discusses actual energy that flows in animal bodies and that VE paradigms aim to emulate.

Of ***first*** importance, therefore, is ***actual time*** that tracks movements of and changes in material bodies. Some bodies that move and change in actual time have a simple constitution – a falling iron weight or a snowflake growing in a cloud – and others are living animal bodies with complex cells and organs. Moving and changing animal bodies occupy the domain of ***actual life*** that is foundational in this project. This is a material domain with a "real" or "objective" actual time based on presumptive agreements among persons about the ordering of events (which event occurs first or second), comparisons of speeds (which bodies move faster and slower) and comparisons of time periods (which time period is shorter or longer) — thus defining a ***common actual time***. (See J. Piaget, *The Child's Conception of Movement and Speed*, 1946, transl. 1970.)

Principles of freedom distinguish my materialism from scientific materialism. Science seems to be committed to a materialism in which "theories of mechanics" (Newton's, Einstein's, statistical, quantum) and "mechanisms" (chemical, computational) are presumed to describe and control all movements of and changes in material bodies. Such mechanical commitments exclude freedom. I hold to contrary principles, like those stated in Truesdell's *Rational Thermodynamics* (2d ed. 1984) at 424: "Different models have different uses." Also: doctrinaire commitments "reflect a failure to come to grips with the real complications of nature. Beyond the easiest and long-mastered special cases, nature is too intricate for any inclusive theory."

I suggest that movements and changes of actual life – e.g., itching and scratching – confound all-inclusive theories. While seated, I bend down; my right index finger precisely scratches an itch on my left ankle, which lifts to meet the hand. I suggest that such itching and scratching is produced in my spine through an exercise of freedom and that all the vertebra in my spine participate in such productions. Preening of birds provides a more pointed example.

I suggest that the feeling of an itch is needed to guide scratching. Similarly, a visual goal guides walking movements of the body. I suggest that, while producing whole-body movements in their spines in actual time, animal bodies of fish, birds, squirrels and human beings exercise freedoms that are excluded from computational or mechanical theories of science. During an exercise of freedom, an animal body is ready and able to produce multiple possible movements or positions. In models of such bodies, cyclical operations generate recurring critical moments. During each critical moment, multiple possible movements change into a single actual movement.

Second: ***detached time*** operates in ***imagination***, a domain that is occupied by ***images***. Images include actual bodily and emotional feelings and awareness, perceptions of events, objects, other persons, memories, plans, consciousness, theories and laws. Many images are directly connected to ongoing actual events. I suggest that imagination has a special area called ***reality*** in which actual events appear to be determined in ways beyond our control. Reality imposes rules on our behavior. We presume, at least until error is shown, that everyone shares a common reality. Other images are "not real" and are based on fantasies, books, screens, individual notions, etc.

Important classes of ***detached images*** need not be directly connected to ongoing actual events. "Detached" means that images occur independently of muscular movements and actual time. Detached images based in memories, engineering designs or fantasies of future success can be slowed down, sped up or skipped over in ways that are impossible for events in actual time. When actual events can be partially detached from reality, e.g., in a videogame or theatrical rehearsal, a clock can be reset to a start time and alternative possibilities can be attempted.

Detached time operates in domains occupied by detached images. For example, detached time operates when a person is adding a list of numbers mentally. Some people add numbers quickly in their minds; others are slower. A person might add quickly at work and slowly when contemplating the bill after a family meal at a restaurant. There is no common detached time. In contrast to events occurring in a common actual time, each person has unique memories and plans; persons construct imaginary events in individual ways, e.g., imagining events in a novel.

As discussed in part II of this project, detached time operates in major Conserved Energy (CE) paradigms of mechanics and thermodynamics. Such paradigms begin at a static point of origin and return to rest between movements, perhaps through relaxation. Successions of rest states and relaxations follow curves of "continuous equipoise" and "stabilizing equilibrium." In such paradigms, apparent movements are constructed on foundations of continuous rest and relaxation. Such apparent movements occur in detached time and differ from muscular movements of animal bodies. First, in their foundations, detached movements lack momentum; restricted forms of momentum must be grafted on. Even more important is the attempt to exclude or minimize ***dissipation*** or "bodily heat energy" that is always present in the actual lives of animal bodies. Such dissipation is presumptively minimized in important CE paradigms such as Hooke's Law, the Carnot cycle and Clausius-Clapeyron relations. When restricted momenta and minimized dissipations are grafted onto equipoise paradigms, static detached tethers are maintained. Classes of movements permitted under CE paradigms remain narrow.

"Paradigms" is an ambiguous term. See Thomas S. Kuhn, "Second Thoughts on Paradigms" in his *The Essential Tension* (1977). Here, the term refers to a rational construction that is applied to a repertoire of actual movements. CE paradigms succeed but only in limited actual domains.

Detached time also operates in computer operations where movements repeat incessantly without change. Such repetitions require ***time invariance***: movements are repeated exactly regardless of time of production. Operations follow the ancient "principle of sufficient reason" that requires an explicit agent of change and that excludes movements and changes that happen on their own, like those of animal bodies. (See the *Free-Will Puzzles* essay.) Time invariance is based on a static environment and a fixed production system. Laboratories and consumer electronics devices produce exact repetitions for prolonged periods. In contrast, animals can be ***trained*** to produce – or they may practice on their own – movements that resemble exact repetitions. An animal will often adapt to changes and perform modified movements in novel environments.

Movements and operations that are repeated in detached time, e.g., arithmetic, can conform to principles of ***postponement*** and ***decomposition*** where details of movements are changed without changing results. Postponement means that timings between movements can be stretched out. Decomposition means that a large movement can be broken up into a sequence of smaller fragmentary movements, perhaps in various different ways. Fragmentary movements can then be ***composed*** – put together in a sequence – perhaps to recover the original movement, perhaps in a novel way. Such compositions occur in music, chess and knitting.

In certain kinds of compositions, changes in the ***ordering*** of movements – which of two movements is performed first and how movements are grouped in sequences – leave results unchanged. For example, numbers can be added in any order without changing the sum.

Other movements in detached time are ***reversals*** of original direct movements, also called "inverses" — subtracting where there was addition or backtracking in imagination to a prior position. In detached time, a composition of a direct movement followed by a reversal movement produces a "zero" or ***null movement*** that is said to be the same as no movement at all.

Mathematical groups are made of repeated, composed and ordered movements, reversal movements and null movements that all occur in detached time. Arithmetic and other mathematical structures can be constructed from such groups.

Imaginary movements in detached time – e.g., movements in mathematical groups – differ from movements of animal bodies in actual time – e.g., romping on the floor with the kids – where trying to repeat movements, decompose movements, postpone movements or alter orderings of movements will usually change results. Actual movements are never reversible: two actual movements cannot add up to a null, even if an appearance of restoration is achieved.

Third (following actual time and detached time) is ***controlled time*** that occurs when operations in rational domains co-exist with movements of and changes in bodies in the domain of actual life. Co-existence includes a large variety of interactions between rational and bodily domains. Images in rational domains can predict, command, trigger, inhibit or modify bodily movements; and perceptions and feelings in the actual domain can lead to or influence rational operations. A collection or ***repertoire*** of practiced movements in a fixed environment (work station, tennis court, kitchen) can be controlled by rational selections. Controlled actual movements can conform to rules of mathematical groups in limited ways under such conditions.

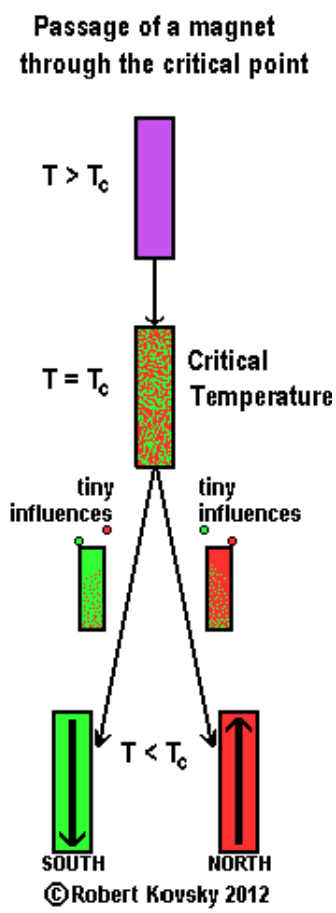
Controlled time occurs in musical performances where movements of a musician are under the control of a conductor or ensemble or internal beat. Repetitive beats and cycling melodies provide gist for operational controls; but performances in actual time also require individual exercises of freedom on the part of each musician.

In a similar way, the design of a piano keyboard with distinct white and black keys in an invariant array defines a pianist's movements; they are controlled by means of notes printed on sheet music. When a pianist first picks out a tune from a new piece of sheet music, it is clear that rational methods based in vision are controlling movements of fingers. It may take many repetitions before the pianist is able to produce the different parts of the composition, to put parts together and to integrate them into a musical whole. After the pianist has fully learned the piece and fingers are quickly "moving on their own" and "expressing feelings," rational methods are no longer in control. A whole person is producing flowing movements that combine beats, rhythms, melodies, harmonies, emotions, rational forms and artistic skills.

In controlled-time applications, rational methods fit only partially with ranges and repertoires of movements of bodies. A rational application is specific to particular kinds of actual movements; attempts to apply the same rational methods to different kinds of movements can be risky. Riding a bicycle in traffic has greater risks than driving an automobile and requires greater physical capacities and skills even though basic rational methods are much the same. Risky situations impose speed limits on actual movements if they are to be controlled by reason. Rational methods must operate quickly enough to "keep up with" actual movements and to interact with bodies that manifest the ongoing physical principle of momentum. Otherwise, the bicycle rider loses control of the bicycle and of the rider's own body.

In ***mimed time***, a special kind of controlled time, a ***domain clock*** supposedly tracks events that take place in a part of reality designed to resemble an imaginary domain, such as a theatrical stage or a classroom demonstration of a physics paradigm. Mimed time resembles actual time but it is also possible to manipulate mimed time in ways that conflict with actual time, e.g., stretching, omitting or restarting time. Conserved Energy paradigms such as Hooke's Law and the Carnot cycle first operate in detached time. Then, in mimed time, restricted momentum and minimized dissipation can be added; and the result is used to a design a steam turbine that operates in actual time, subject to certain practical limitations and restrictions.

Part II of this project pursues a course of progressive development and constructs a series of Conserved Energy paradigms that lead to the Ising Model, which is on the edge of freedom.

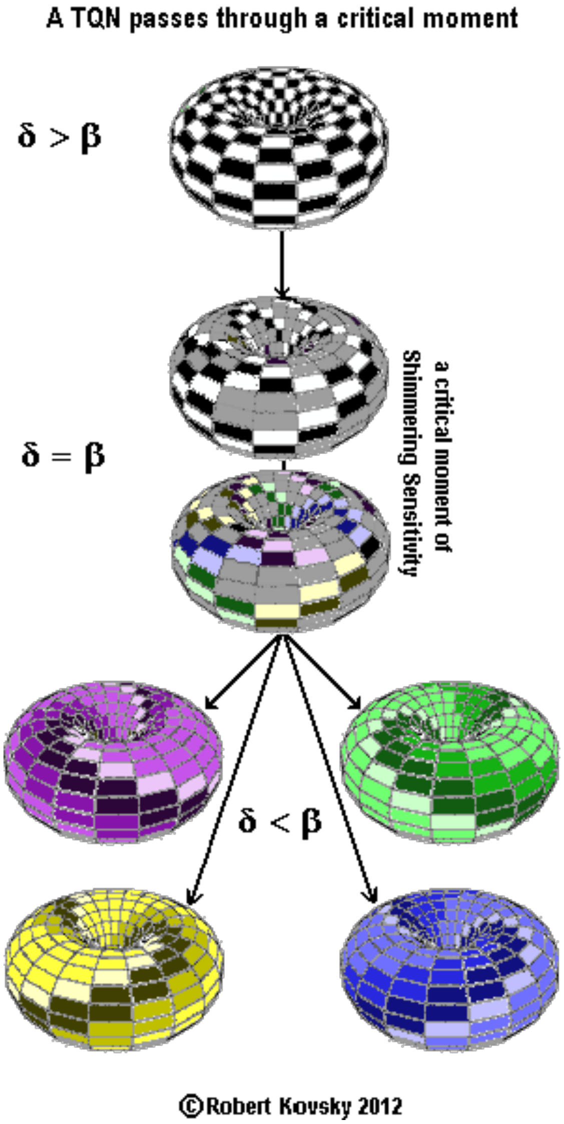


The mathematical Ising Model describes a change or transformation in an actual magnetic body made of iron that occurs as temperature changes: at low temperatures, the body has either a North polarity or a South polarity; at high temperatures it has no polarity. When a hot un-polarized magnetic body cools through a sharply-defined "critical temperature," the whole body suddenly changes and acquires either a North or a South polarity.

A whole-body change is called a ***phase change.*** Phase changes are found in many kinds of bodies and have many forms and variants. Familiar phase changes occur when a body of liquid water freezes into solid ice — or evaporates into an atmospheric gas.

An un-polarized magnetic body is in one form or phase and a polarized body is in another form or phase. Applying the Ising Model of a phase change, a magnetic body "chooses" between a North polarity or a South polarity as temperature cools through the critical temperature or ***critical point***. During repetitive phase changes in a fixed environment, a "tiny change in influence" (polarity of a nearby magnet) can change the result. Physical principles of the Ising Model paradigm have applications in magneto-optical computer memory devices. Each magnetic element in the device stores a bit of information: perhaps a North element stores a "1" and a South element stores a "0." An element is first heated by a laser beam and then subjected to a North or South magnetic influence while cooling.

Virtual Energy (VE) paradigms of part III follow a course of progressive development similar to that of part II but with new kinds of controlled time constructions.



Elements of VE constructions are variable temporal patterns of movement rather than stable states. Phase changes involving temporal patterns depend on ***timing intervals*** that are controllable, such as β and δ in the adjacent figure. ***Quasi-static critical point*** phase changes of the Ising Model become ***activated cyclical critical moments*** in VE constructions. Large assemblies of devices make up a body and produce integrated patterns when they are synchronized and pass through critical moments together. The whole body participates in selections.

VE paradigms operate with variable energy flows rather than with energy quantities that add up to a constant, as in CE. VE paradigms aim to operate like animal bodies that speedily choose from and combine rich repertoires of movements. In anticipated VE paradigms, an engineered organism operates cyclically; and a whole-body selection occurs during each cycle. During each selection, multiple possible movements change into a single actual movement. VE paradigms aim to apply to biological activity such as the beating of a bird's wings to reach a certain perch and to psychological activity such as chopping vegetables according to a recipe as well as to technological activity of a QN device assembly that models movements of an animal spine.

In Virtual Energy paradigms, there is a ready pool of "abundant" energy available; controls operate by opening, squeezing and interrupting flows of energy and by adjusting competing dissipations ("body heat" in animals, "waste heat" in CE). Such paradigms aim to apply to ordinary biological activities where energy consumption and muscular force productions involve friction, work loading and opposing muscles; and where activations, energy consumption and resulting forces are influenced by signals originating from multiple locations and subject to multiple influences, e.g., influenced by pain from a pulled muscle.

Various temporal patterns, activations, dissipations and phase changes appear in ***kits of parts*** that are used to construct models of muscular movements and related images (such as feelings and perceptions). A kit of parts is a collection of devices that embody certain principles. Distinct and different principles operate in various kits and parts that are used in constructions.

In this project, kits of parts are developed from individual primal pulsers into Quad Net devices that have a collective character. A collective device — e.g., the Toroidal Quad Net ("TQN") in the previous figure, is constructed from "Quad Net," a square array of hundreds or thousands of interconnected elemental pulsational devices in a sheet of elastic material that models neuronal tissue. Elastic materials can be stretched and connected into shapes of a cylinder or torus. A chief feature of QN is potential production of multiple possible patterns of pulsations. However, only one actual pattern can be produced during each cycle. I suggest that cylindrical engineered organisms that move like worms or eels can be built from QN devices.

Anticipated ***sensory-motor modules*** built from kits of parts produce images and movements. In cyclical operations of QN modules, balance is first established and then lost during a phase change – and finally balance is restored, ready for another round. During each phase change in such a module, a flicker of an image is generated and a muscular movement is selected. In an anticipated model for preening of a bird, modules operate like vertebrae. A goal of designs is to show how an image of an itch referred to an active location on the skin surface can select ongoing actual movements of the spine, with a "beak" at the end that touches the skin at the active location. A similar design would model movements of an animal's eye that bring the eye to focus on an "edge of an object" that is located in a visual field. Further possible designs in this line suggest a more general activity of locating objects in a "world" and reaching for them.

Other designs would model movements of "stop on red; go on green" that are based in memory. Each cycle of operations both generates a perceived image, red or green, that is located at a "traffic light" in the external environment and also matches that image with one reconstructed from memory; a change in matchings in detached time triggers processes that switch movements of the body in actual time. During repetitive activity in imagination, a delicate balance is first held in one way and then shifted to the other way – with resulting movement of a balanced body that is equally ready to stay or to move.

II. Actual Time, Detached Time and Mimed Time Paradigms of Conserved Energy

Summary of part II.

In part II, standard physics paradigms are developed into variant forms. Discussions aim at specific conclusions and bypass mathematical details. Paradigms discussed in part II present features that are then reconstructed in new paradigms of Virtual Energy Thermodynamics (VET) discussed in part III.

Chief features of ***equipoise*** and ***equilibrium*** in CE paradigms are reconstructed as ***balancing*** and ***flowing*** paradigms embodied in VE devices. A body that is actively balanced, e.g., a bird in flight, is ready to produce multiple next movements; but only one next movement can actually be produced. Actual movements flow into each other. In QN paradigms, balance is cyclically lost and restored. QN paradigms aim to show how a loss of balance can select one actual movement from multiple possible movements, influence other ongoing movements and generate imagery that can be coded in memory and then later partially re-generated and matched to fresh imagery.

In contrast to balance and flow, CE paradigms are based on rest states and are maintained in conditions of equipoise. In some CE paradigms, rest or equipoise persists for indefinitely long periods of time; in others, movement passes continuously through positions of equipoise; and, in still others, transient perturbations and relaxations are separated by periods of equilibrium. Scientific theories presume that paradigms tethered to rest, equipoise and equilibrium determine "everything that happens in our universe." In contrast, VET paradigms begin with streams of pulses and produce stationary, steady and jumpy movements, as well as exercises of freedom, by means of device operations that depend on, e.g., material properties of devices, histories of operations, influences from other devices and large-scale processes of Shimmering Sensitivity.

In CET paradigms, rest starts with two equal weights in conditions of equipoise; then equipoise develops into continuous equipoise. Equipoise is extended to an elastic body governed by Hooke's Law, which defines a linear relationship between equilibrated positions and forces. Subject to restrictions, gravity, momentum and dissipation are connected up to mechanical equipoise paradigms. Development leads to variable equipoise positions in an ideal gas; to tiny flows of a perfect gas that are used to model equilibrium and relaxation; to steady production based on equipoise and equilibrium in the Carnot cycle and then to enthalpy in steam turbines; to equilibrium mixtures of liquid water and vapor governed by Clausius-Clapeyron relations; and to stable and unstable conditions of magnetic bodies near the critical point of the Ising Model. In certain paradigms, a ***critical point*** divides two distinct ranges of activity; and it also identifies a singular form of activity that belongs to both ranges and that permits changing the range, a form of activity that serves, in other words, as a crossover point. A "critical point" both marks a boundary and also has unique features that suggest new developments.

Each paradigm, CE or VE, is constructed in an imaginary domain and consists of ***operations*** that are imaginary movements of imaginary bodies. An imaginary ***domain clock*** operates in such a paradigmatic domain and defines a continuous time. (VE paradigms also include pulsational time.) In major CET paradigms, the domain clock mimics an actual clock and ***mimed time*** of the domain clock exactly resembles actual time for a certain period but is also under the researcher's control. Other imaginary domain clocks operate in detached time in ways that are contrary to actual time, e.g., stretching time, stepping time, resetting time to 0 and even reversing time. As an example, Hooke's Law operates first in detached time and then, after development, operates in mimed time as the Simple Harmonic Oscillator.

A. Atwood's machine and Hooke's Law

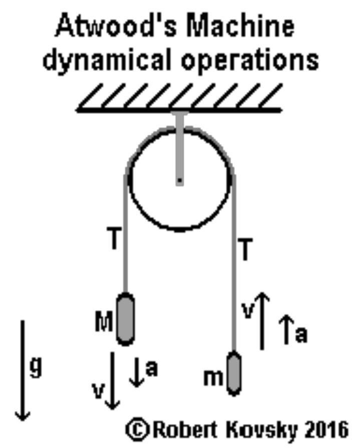
Overview. Chief paradigms in part II are topics in thermodynamics, kinetic theory and statistical mechanics. For a broader perspective, discussion starts with classical mechanics paradigms that operate in distinct kinds of time.

1. Atwood's machine

Important physics paradigms operate in actual time, e.g., Newton's and Einstein's gravitational theories that describe actual movements of celestial bodies and Maxwell's electromagnetic theory that is tethered to the actual speed of light. Such paradigms are ***dynamical*** in contrast to ***static*** paradigms that follow. ***Atwood's machine*** exemplifies dynamical applications of Newton's Laws in actual time; then, it is adapted for static equipoise operations in detached time.

a. Atwood's original machine with unequal weights operates in actual time.

Invented by George Atwood (1745-1807) to measure gravitational acceleration (g), the machine is a classic example of conserved-energy mechanics. (Marion, 261, n. 1; Goldstein, 18, 25-26.)



The adjacent figure shows an idealized and simplified version of Atwood's machine: a rope hangs over a pulley, connecting two masses. Under the influence of gravity g, the heavier mass M falls, lifting up the lighter mass m. In this version, neither the rope nor the pulley has any mass. These "mass" limitations can be overcome in more advanced versions.

A restriction on operations is that the rope must be uniformly taut or tense; the tension is denoted by T. This ***taut rope condition*** binds movements of the rope and of the two masses into a single movement with a single velocity "v" and a single acceleration "a." Both masses move with equal magnitudes of v and a, but in opposite directions.

The taut-rope condition restricts movements and operations that can be permitted. Permissible movements must be ***smooth***, with changes in time that can be described by math functions that have continuous derivatives. ***Impulsive movements*** are prohibited. For example, a brief interruption of movement by grabbing, holding and then releasing one mass would send a jerk through the rope, contrary to the taut-rope condition. These "movement" restrictions cannot be overcome; advancements would require incorporation of values for material properties of the rope; material properties may be variable and are outside the reach of the paradigm.

In this paradigm, operations are strictly limited. Movement is in one direction only. The only effective force is gravitational. Idealized movements require a "perfect vacuum" with no air resistance. This version has no place for friction that might drag at the pulley or heat the rope.

In experiments involving Atwood's machine, acceleration "a" is observed to be constant. The chief aim of the paradigm is to state such acceleration in terms of the sizes of the masses M and m and of the value of g, the acceleration due to gravity.

Answer: $a = [(M - m)/(M + m)] \times g$. Equivalently: $g = [(M + m)/(M - m)] \times a$.

When m is close to M, a is much smaller than g; and a can be measured easily and precisely in a laboratory. At slow speeds, problems of friction, imperfections and wear are reduced.

Suppose that the machine is first held in a fixed position and that masses are released at time $t = t_0$. Acceleration is fixed and velocity v increases uniformly with time; or $v = a \times (t - t_0)$. Momentum equal to $(M+m) \times v$ is also acquired. While there is rope left to run through the pulley, velocity and momentum will continue to increase.

Discussion of Atwood's machine serves to introduce definitions and methods that are developed in later paradigms, both CET and VET. During dynamical operations of the original Atwood machine, bodies in the paradigmatic domain move at rates determined by values of g, M and m; and bodies acquire a changing momentum. The paradigmatic clock can be bound to an actual clock stating a national standard. Researchers have no control over such an actual time standard or actual clock. Movements occur in ***actual time***.

In Atwood's original machine, a stationary state is only in preparation for a movement and requires the holding hand of a researcher or mechanical substitute. Unless held, an Atwood's machine with unequal weights will move on its own.

In discussions below, actual dynamical operations are distinguished from equipoise and equilibrium operations in mechanics and thermodynamics (detached time) and also from operations in VE designs (pulsational time). Actual time operations of Atwood's original machine with unequal weights stand in contrast to equipoise paradigms with equal weights set forth below, which operate in detached time and mimed time.

Actual time operations of Atwood's machine contrast with operations of the Hooke's Law paradigm that is first defined for stationary states and then carried over uncritically in the Simple Harmonic Oscillator to movements. Quantities involved in Atwood's machine – m, M and g – are grounded in actual experience; a chief property in Hookes' Law and the SHO appears in the form of "k," a "spring constant" that exists only in imagination. In practice, the value of k is adjusted to make actual measurements better fit the paradigm. The value of k so derived applies only to a specific piece of material over a specific range of movement. Specifying k requires a rational construction that forces a fit between certain limited phenomena and a mathematical form. In contrast, the value of g determined using Atwood's original machine, with an easily appended adjustment for height above sea level, can be used anywhere on or near the surface of the Earth with a high level of precision.

Extending the melting ice paradigm, above, suppose that M/m can be continuously varied, e.g., that a researcher can investigate processes in which M/m varies within the range $.1 \leq M/m \leq 10$. The range of variation divides into parts. When $M > m$, motion is accelerated in one direction; when $M < m$, motion is accelerated in the other direction; and when $M = m$, motion is not accelerated and may be absent altogether. In traversing the range, the point $M = m$ is a ***critical point*** that divides the two sub-ranges of movements. It is a central point of balancing that has special classes of movements and operations.

b. Special versions of Atwood's machine operate with equal weights.

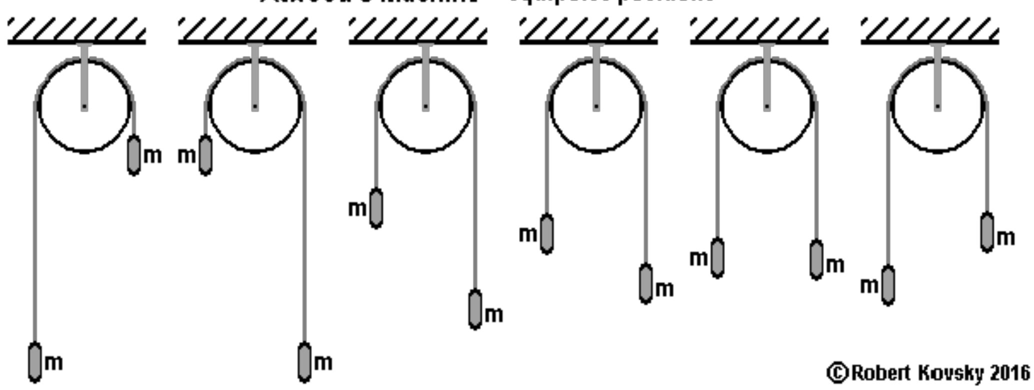
i. If equal weights are moving, the machine continues to operate in actual time.

Suppose that M = m. According to the Answer previously stated, a = 0. If v ≠ 0, equal weights move at a constant velocity. Such movements occur in actual time just like movements in the machine with unequal weights.

ii. In an equipoise machine with equal, stationary weights, adjustments and operations occur in detached time.

In special ***equipoise*** versions of Atwood's machine, M = m, a = 0 and v = 0. As shown in the figure below, equal masses can be put into a large number of ***equipoise positions***. An equipoise position is stationary and never changes on its own; however, a researcher can adjust positions of masses to any point within a range of positions. Operations in an equipoise machine are defined as ***adjustments*** between variable stationary positions established by equal and opposing forces. Equipoise machines have practical uses, e.g., in an elevator.

Atwood's Machine – equipoise positions



Presumptions and restrictions are imposed on operations of the equipoise machine. Adjustments between stationary positions don't fit easily within conservation rules: energy must be expended to put masses into movement at the start of an adjustment and to stop movement at the end.

Presumptively, the machine operates with what I call ***easy glide***. "Easy glide" refers to movements of floating waterfowl and coasting ice-skaters; and to movements around a ball-bearing bicycle wheel hub, on an air track in a physics class, in empty space or on a slick surface. Movements can continue with little reduction or need for additional work and sometimes gliding movements, e.g., those of birds, can be steered. Presumptively, slow "quasi-static" movements with easy glide reduce energy expenditures needed for adjustments to a negligible amount.

As in the original machine, there is no place for friction or dissipation in this equipoise paradigm.

Operations of the equipoise machine occur in detached time, as described in the Introduction. Adjustments between stationary positions can be postponed. Sizes of adjustments to stationary positions are variable within the range of movement. A big adjustment can be decomposed into several small adjustments. Small adjustments can be composed into a big adjustment. Details of decompositions and compositions can be re-ordered without changing results.

For any designated adjustment in the equipoise paradigm, there is a reversal adjustment that restores masses to their positions prior to both adjustments. An adjustment followed by its reversal adjustment is a composed adjustment that can be said to be a null adjustment. Adjustments, compositions, reversals and null adjustments make up a system of movements that can be modeled by a mathematical group within limits defined by the apparatus.

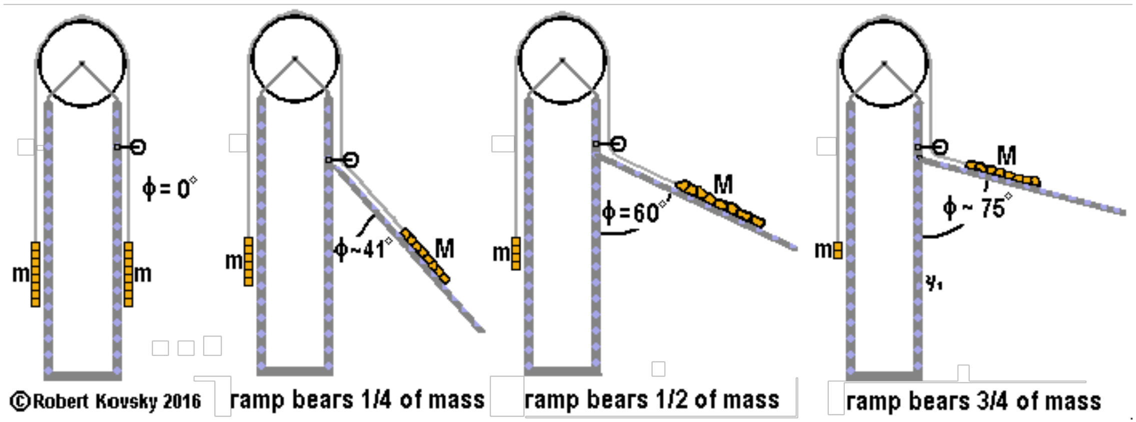
Decomposition, postponement and reversal features of operations in detached time are absent from actual time operations of Atwood's original machine where $m \neq M$. Such actual dynamical movements are never reversible; reversed movements would resemble the "unreal" movements in a movie that is run backwards. In dynamical operations of Atwood's original machine, movements cannot be composed and attempts to postpone or decompose ongoing movements would cause interruptions and violate the taut-rope condition of operations.

c. In further developments based on Atwood's machine, some operations occur in actual time and others in detached time.

i. Equipoise operations on ramped machines occur in detached time.

The figure below shows developmental construction of ***ramped Atwood machines***. In such a machine, one weight easily glides on a ramp held at a fixed angle from the upright. The machines in the figure show only equipoise positions but actual dynamical operations are also possible. In equipoise positions on ramped machines, the two masses are not equal; the smaller mass m that is hanging straight down is in equipoise with a larger mass M on a ramp; and $m = M \times \cos\varphi$ where φ is the angle the ramp makes with the upright member. When $\varphi = 0$, the ramp disappears and both masses hang free. For fixed φ and a suitable M/m ratio, operations of the equipoise ramped machine are "much the same as" operations of the original equipoise machine. Such operations occur in detached time and can be organized by group concepts.

Equipoise positions in a ramped Atwood's machine



For a ramped machine, the factor $\cos\varphi$ is shown by the "rectangle of forces" in the figure below.

A ramp splits a force

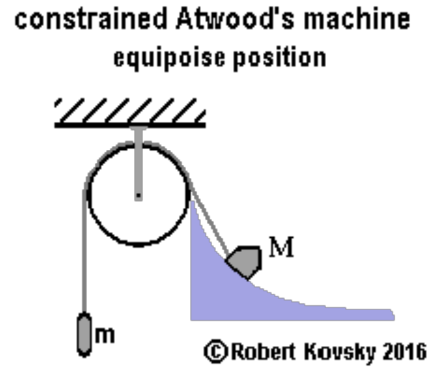
The force of gravity – $M \times g$ – is ***split*** by the ramp into two forces: (1) a force parallel to the ramp, called the "active force" and denoted F_A; and (2) a force perpendicular to the ramp, called the "bound force" and denoted F_B. $F_A = M \times g \times \cos\varphi$ and $F_B = M \times g \times \sin\varphi$. According to Newton's Third Law, the bound force is opposed by a force denoted F_N that is produced by the ramp in a direction normal or perpendicular to the surface. Hence, $F_B + F_N = 0$. The active force is opposed by the force that comes from the free-hanging weight and that passes through the tension of the rope, denoted as F_W. Hence, $F_A + F_W = 0$.

Denote the force of gravity as F_G. $F_G = F_A + F_B = -(F_N + F_W)$.

In subsequent paradigms, the split between forces will develop into a split between energies; and bound force will develop into "bound energy," also called "entropy." Similarly, the active force develops into "free energy." Splits pass through manifestations in Hooke's Law, the Ideal Gas, the Carnot cycle, Enthalpy, Gibbs Free Energy and Clausius-Clapeyron relations. These CE paradigms operate in detached time with a static core; operations are based on equipoise states.

ii. A machine constrained by a curved slope operates in detached time.

The adjacent figure shows a ***constrained machine***. The left side is the same as in the original machine, with a hanging mass m. On the right side, the "constrained" and larger mass M rests on a curved slope that bears a fraction of the weight. Perhaps there is a slot track, like a cable car but without friction: the larger mass glides easily on the slope when a force is applied; and it rests in a stationary condition at the specific position on the slope where forces are in equipoise as determined by the ratio M/m = cosφ, where cosφ for a ramp is suitably modified for a curve.



A ***continuity argument*** is used. The slope varies from nearly vertical close to the pulley to nearly horizontal far from the pulley. Where the slope is nearly vertical, equipoise means that the constrained mass M is only slightly larger than the loose mass m. Where the slope is nearly horizontal, equipoise means that M that is much larger than m. Assuming that the size of m remains constant, the position on the slope where forces are in equipoise will vary with the size of the constrained mass M. A scale can be constructed on the curved slope where each position on the scale corresponds to a distinct value for M/m.

For such purposes, the curve for the constraint must be "concave upward." In other words, it must be continuous and with a second derivative that is always less than 0, as shown in the figure. Were the second derivative to be equal to 0, it would be like a ramped machine with many positions of equipoise. A curve with a positive second derivative, "concave downward," does not support stable operations. A discontinuity in the curve would violate the taut-rope condition.

Definition of an equipoise operation in the constrained machine starts with that of the prior equipoise operation and then adds another component. It combines an adjustment between positions on the curve with a corresponding adjustment between sizes of the constrained mass M. The change in mass and change in position must occur together smoothly, with a relationship that is defined by the condition of equipoise and by the shape of the curved slope.

Suppose that the larger mass M has an iron framework with a mass somewhat larger than m and also has ice as a filling material. As ice melts and drips away, the total mass of M progressively diminishes and the equipoise position creeps up the slope. The rate of creep is controlled by controlling the rate at which ice melts. In such "quasi-static" operations, each equipoise position is equivalent to a stationary position and could be frozen with a blast of cold air; but stationary positions appear to connect up into action, like an animated cartoon.

Similar constrained arrangements and creep operations are constructed below in paradigms of Perfect Gas, Carnot cycles, Clausius-Clapeyron relations and the Ising Model. Such paradigms operate in detached time. Movements, adjustments and changes can be decomposed, composed, reversed and postponed.

In these paradigms, imaginary creeping movements glide easily through a series of equipoise positions on a curved surface. There is ***continuous equipoise*** that makes such movements possible. Later paradigms repeat this key feature in forms of reversible adiabatic processes and the liquid-water equilibrium line in the phase diagram of water: appearances of action are based on a curve of continuous equipoise and on detached time operations tethered to the curve.

iii. Oscillations of a constrained Atwood's machine operations occur in actual time around equipoise positions set in detached time.

Suppose that the two masses in a constrained machine are in static equipoise. Then suppose that a researcher displaces positions of the masses while maintaining a taut rope: one mass is moved up and the other mass is moved down. If the masses are held at the displaced positions and then released, the masses move back towards the equipoise positions. The force driving the movement is based on the curvature of the slope. If the slope is a straight line with a constant grade between the original position and the displaced position, the two weights will continue to be in equipoise at the displaced position. In other words, displacement will not result in a change in forces if the slope is a straight line; and weights that were in equipoise before displacement will still be in equipoise after displacement. A net force (that causes movement) requires a change in slope and a continuously changing net force requires a continuously changing slope.

Assuming a simple concave upwards slope and a taut rope, when masses are displaced, held in position and then released, they move towards the original static equipoise position and acquire a common velocity of movement denoted by v; and they also acquire total kinetic energy denoted by $[½(M+m) \times v^2]$. The masses pass through the original static equipoise position at maximum speed, slowing afterwards until they reach an extreme position at the "far end" of the range-of-movement (ROM) on the other side, where they momentarily pause before beginning a reverse movement. Presuming an absence of friction or dissipation, the reverse movement proceeds until the masses return to the original displacement position that marks the "near end" of the ROM. There, movement pauses, before repeating the prior cycle.

If the slope were concave downwards, a displacement would cause the weights to move away from the original equipoise position; and movements would run to the end of the range of motion.

Neglecting friction and other dissipations that would slow and eventually stop such movements, the foregoing ***oscillations*** would occur in actual time, like movements of the original Atwood's machine occur in actual time. Extending the definition of actual time used for the original machine, movements would occur at rates determined by values of g, M, m, the slope defined over its operational length and the starting positions. If movements of the paradigm were to be calculated using Newton's Laws and realized in a laboratory, actual timings of movements could be predicted from the calculations, at least to the extent that friction and other forms of dissipation can be eliminated from the laboratory apparatus. Movements in the laboratory domain would aim to conform to movements in the paradigm domain – and any discrepancy would be attributed to shortcomings in realization in the laboratory. Movements in the two domains would be bound together.

iv. Adding dissipation to Atwood's machine paradigms

Dissipation in an Atwood's machine paradigm can be introduced, e.g., by adding friction to the pulley or by imagining immersion of a machine in a dense gas or a liquid. It is possible to imagine negligible dissipation and then to increase dissipation incrementally.

First, suppose that equipoise versions of Atwood's machine are immersed in water. In equipoise versions of the paradigm, operations remain much the same after immersion. Two masses at rest in equipoise will remain at rest in both a free-air machine and a dissipative machine. Equipoise positions do not change as dissipation is increased. Adjustments require more energy under dissipative conditions but such energy costs are ignored in equipoise operations. Adjustments are slower under dissipative conditions but adjustments are never "instantaneous" and can be postponed. The same as prior to dissipation, an adjustment operation in a dissipative equipoise machine can be decomposed into a series of adjustments; intermediate adjustments can be postponed; and adjustments can be reversed – all without changing results of operations.

In contrast to the indifference of equipoise operations to dissipation, dynamical operations of Atwood's original machine are substantially changed if dissipation is introduced. In a standard model of frictional dissipation, a new force opposes the force of gravity so that acceleration a is reduced: $a_d = a_o - cv$, where a_d denotes the acceleration in the dissipative machine; a_o denotes the acceleration in the original machine; v denotes the momentary velocity of movement; and constant c is a constant in a linear relation between v and a_d. As v increases, frictional force increases and a_d diminishes. If v were to reach the value $v_t = a_o/c$, a_d would have diminished to 0 and there would be no more acceleration. For this reason, v_t is called the "terminal velocity."

The linear term cv provides a rationalized form of dissipation that is mathematically convenient. Suppose that v starts at 0 and gets closer to terminal velocity as time passes. The mathematical expression for changing velocity is $v = v_t \times [1 - \exp(-c \times (t - t_0))]$ where exp is the exponential function and t_0 is the instant when weights are released. At the start of the movement, when t is close to t_0, the velocity is close to 0. As time passes, v approaches v_t but never reaches v_t.

Similar forms of dissipation are used below in the simple harmonic oscillator and the perfect gas. The Quad Nets functional, the mathematical basis of VE device operations, employs a similar form based on dissipation inside a Virtual Energy Storage body or VES.

d. Conserved Energy in gravitational paradigms conflates actual time, mimed time and detached time operations.

Constructions of Conserved Energy (CE) in gravitational paradigms use three distinct kinds of energy: (1) ***kinetic energy*** carried by a moving body; (2) ***work*** performed in moving a body upward against the force of gravity; and (3) ***potential energy*** that is stored in a relationship between the body and a presumed "gravitational field" during such an upward movement.

Kinetic energy occurs in actual time and causes changes in actual movements of colliding bodies; such changes directly depend on the relative speed between bodies. A work process $[W = \int F \times dx]$ occurs in mimed time; the formulation does not involve time and the speed of movement of the body can change without affecting the result. Potential energy, detached from movement, exists in detached time in a "field" structure described by a mathematical group. Movements in the potential energy structure occur in detached time or mimed time as needed.

Thus, in basic gravitational paradigms, three different kinds of energy appear to be convertible into each other and conversions are presumed to occur perfectly and automatically. E.g., in Atwood's machine, potential energy is converted into kinetic energy. The sum of energy before conversion is equal to the sum after conversion. The sum remains constant during conversions.

Problems with such paradigms are illustrated by the launch of a rocket carrying a satellite into orbit around Earth. Suppose that we reduce an actual launch to a paradigm. Rearward projection of hot expanding gases produces force that lifts the rocket. First, a large force must be produced that is equal to the weight of the rocket and that puts the rocket into dynamical balance. Then "something more" must be produced to accelerate the rocket. There is a considerable period of time between "ignition" and "liftoff" during which forces are insufficient to put the rocket into balance. Energy in fuel burned during this period is not converted into work, potential energy or kinetic energy — but is "dissipated." Similar dissipations are required after liftoff to keep the rocket in dynamical balance. Such dissipations are not "wasted" energy. They are a necessary expenditure, They also require adjustments to a paradigm based on conservation principles.

To minimize dissipation in a rocket liftoff paradigm, it would be necessary at the start to instantaneously apply an upward force equal to the weight of the rocket, plus the "something more" that gets the rocket into actual motion. The amount of that "something more" depends on the position and velocity of the rocket that is desired when the mission is finally accomplished by release of the satellite. Rates of fuel consumption at every moment during the flight would have to be calculated to find the most efficient trajectory towards that final moment. The entire trajectory must be determined before the first "something more" can be calculated.

Instantaneous application of a very large force is problematical. It would be like a collision, which is often damaging to soft structured bodies such as animal bodies. Bodies without structure – e.g., billiard balls – are said to be ***homogeneous***. Collisions between rigid homogeneous billiard balls can be said to conserve energy and to be ***elastic***. Only special classes composed of particles and rigid homogeneous bodies participate in elastic collisions.

Exact application of a start force is problematical. Physics paradigms treat a starting movement the same as subsequent movements: $m \times \Delta v = F \times \Delta t$ regardless of v. In actual life, $v = 0$ is special. Additional force must be applied at the start to overcome sticking. A start force begins at a higher level and then quickly drops to a lower level, e.g., we feel a jerk when a train starts.

In sum, conversions of force into kinetic energy or potential energy, e.g., during a satellite launch, always include dissipations that require limitations and adjustments to the paradigm.

Similar difficulties beset conversions of kinetic energy into work or potential energy, e.g., with gunshot ballistics as an exemplar; and likewise with conversions of potential energy to other kinds of energy, e.g., by dropping a mass from a height or by means of a waterwheel.

Dissipative conversions present problems for a conservation principle. It might be thought that problems could be overcome by constructing a fourth kind of energy called "dissipated energy." E.g., when a bullet is fired into the ground, its kinetic energy is converted into dissipated energy. Then, four kinds of energy would add up to a constant. However, there does not appear to be any way to convert dissipated energy into kinetic energy, work or potential energy. Dissipated energy becomes "waste energy" or whatever is needed to support assertions that a constant is being maintained. To avoid such problems, basic CE paradigms minimize or ignore dissipation.

2. Hooke's Law and the Simple Harmonic Oscillator (SHO).

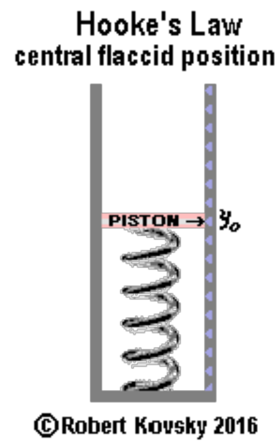
a. Hooke's Law begins with static positions and operations in detached time.

As discussed by Marion at 128-129, Hooke's Law applies to a constrained body where we can "take the origin to be at the position of equilibrium." If there is a small displacement from equilibrium, "then there exists some force which acts to restore the [body] to its equilibrium position." For small displacements in certain simple systems, the restoring force will be linear to the displacement. In symbols, $F(x) = -kx$. (Marion's Eqn. 6.2.)

"Physical systems which can be described in terms of Eqn. 6.2 are said to obey *Hooke's Law*. A large class of physical processes which can be treated by applying Hooke's Law are those involving elastic deformations. As long as the displacements are small and the elastic limits are not exceeded, a linear restoring force can be used for problems of stretched springs, elastic strings, bending beams, etc. … But, as always, the calculations are only *approximate*, since essentially every real restoring force in Nature is more complicated than the simple Hooke's-Law force."

In the Hooke's Law paradigm shown in the figure below, a cylindrical container, vertically oriented, is closed at the bottom. Initially, the orientation does not affect the results, as in "outer space." One end of a Hooke's Law spring is attached to the bottom of the cylinder and the other end of the spring is free to move up or down. A piston initially devoid of mass is attached to the free end of the spring; the piston slides and rotates easily inside the cylinder and steadies movements and positions. [Below, cylinder and piston re-appear in CE paradigms of Ideal Gas and Carnot Cycle and in VE paradigms of duet and wavemaker.]

Of central importance in the Hooke's Law paradigm is a ***static*** position (y_0) where the spring is resting in a "flaccid" condition of loose immobility. In the y_0 position, it is easy to jiggle the free end of the spring up or down a little bit; but, to go beyond the little bit, a substantial force must be imposed. It is presumed that, when jiggling or force ceases, the spring returns immediately to the central static position. It is a default position of rest.

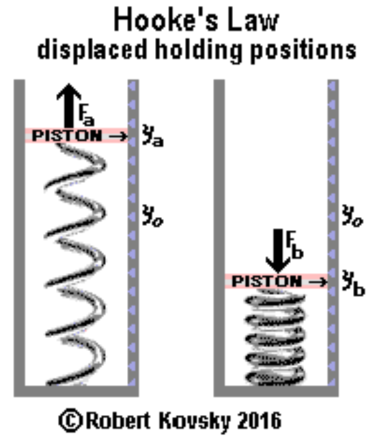


The central static position y_0 is called "y zero." In the absence of gravity, it does not change if mass is added to the piston. The y_0 position serves purposes like those of zero in arithmetic. It is a central position with symmetrized operations up and down, within a range of motion. There is a condition of balance. Nothing happens when the device is left at y_0 and no force is needed to hold it there.

A period of time at the y_0 position can be prolonged indefinitely. While the device remains at the y_0 position, the domain clock can slow, stop or go backwards without changing any results.

The central y_0 position is the only position that fully manifests all of the foregoing indifferences. Indifferences are shed in subsequent developments and the position of y_0 in the cylinder is moved; but the foundational importance of y_0 is maintained.

Next, suppose that a researcher displaces the piston from the y_0 position, as in the adjacent figure. To track displacements, introduce a variable y. Suppose that the piston begins at position $y = y_0$ and that the piston is then moved to and held at a position $y = y_a$ that is different from $y = y_0$. In contrast to the loose immobile condition at $y = y_0$, it is necessary to impose a "holding force" F_a on the piston at $y = y_a$ or the piston will move back towards $y = y_0$. At a different position, e.g., $y = y_b$, a different holding force is needed, namely, F_b. F_b differs from F_a in both magnitude and direction. Displacement $(y_a - y_0)$ is greater than displacement $(y_b - y_0)$; the magnitude of F_a is greater than that of F_b.

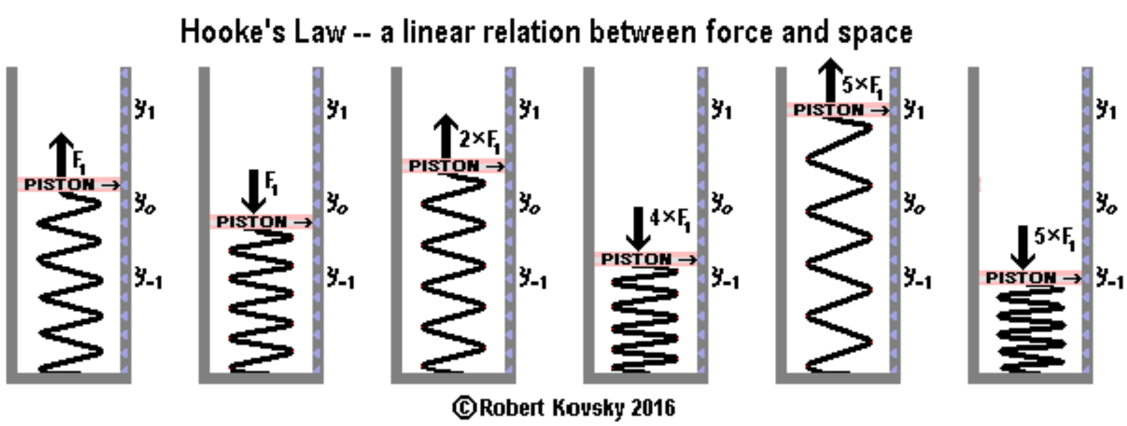


The holding force is defined in this paradigm as $F_h = k \times (y - y_0)$ where k, the ***spring constant***, is a positive real number with appropriate dimensional units. The spring constant has the same value for all displacements $(y - y_0)$ where y is within a defined range of movement. The required holding force is in the same direction as that of the displacement from $(y = y_0)$.

A stationary paradigm such as Hooke's Law qualifies for application of Newton's Third Law of Motion. ("For every action there is an equal and opposite reaction.") Therefore, a holding force F_h is matched by an equal and opposite force F_s that is attributed to the spring. This spring force, $F_s = - k \times (y - y_0)$, is said to come out of the elastic properties of the spring. In other words, each stationary position is maintained by a pair of equal and opposing forces, a holding force and a spring force. This approach is supported by the experience of a person exerting a force against a spring where the person feels a force coming from the spring.

$F_s = - k \times (y - y_0)$ is called "Hooke's Law" after its inventor, Robert Hooke (1635-1703). The figure below show operations of Hooke's Law that resemble those of the equipoise Atwood's machine. The range of movement (ROM) is the space between y_1 and y_{-1}. The piston is moved to multiple positions within the ROM and the force required to hold it is measured at each position. If the displacement is doubled, a doubled holding force is required. The same principles applies in finer detail: a change in displacement of a specific percentage is matched by a change in holding force that has the same specific percentage. This is a ***linear relationship***.

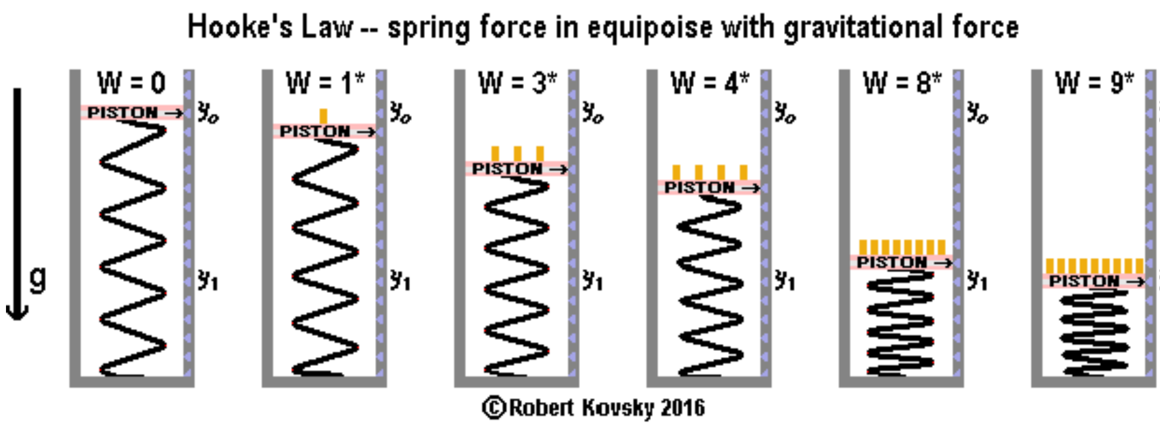
As in the flaccid version, the holding force defined by Hooke's Law does not depend on the mass of the piston or spring. Hence, massless elements are shown in the figure.



Static positioning and equipoise operations in the Hooke's Law paradigm occur in detached time. In other words, movements between equipoise positions and measurements of the holding force at various equipoise positions can be re-ordered and re-scheduled without changing results and for any movement between equipoise positions, there is a reversal movement that combines with the original movement to make a null movement.

b. The Hooke's Law paradigm with gravitational force operates between equipoise positions in detached time.

As introduced in prior versions of the Hooke's Law paradigm, it is necessary to impose a "holding force" in order to maintain a position of equipoise that is different from $y = y_0$. The equivalent of a holding force can be imposed by the influence of gravity on a mass or weight w, as shown in the figure below. An equipoise position is maintained by a spring force that is equal to the gravitational force. In this version, the Hooke's Law paradigm operates as a "scale," both in the sense of a physical device to weigh objects and also as a rational device to connect variations in total weight on a piston with marks on a line.



An operation starts in one equipoise position with a certain weight and then adds or subtracts weights while controlling the movement to a second equipoise position. Control means that a movement is smooth, not jerky, and is slow enough to ensure smoothness, as in equipoise Atwood's machines. The Hooke's Law with gravitation paradigm has a feature that is absent from Atwood's machine paradigms: two different kinds of forces stand in equipoise in contrast to operations that use the single force of gravity.

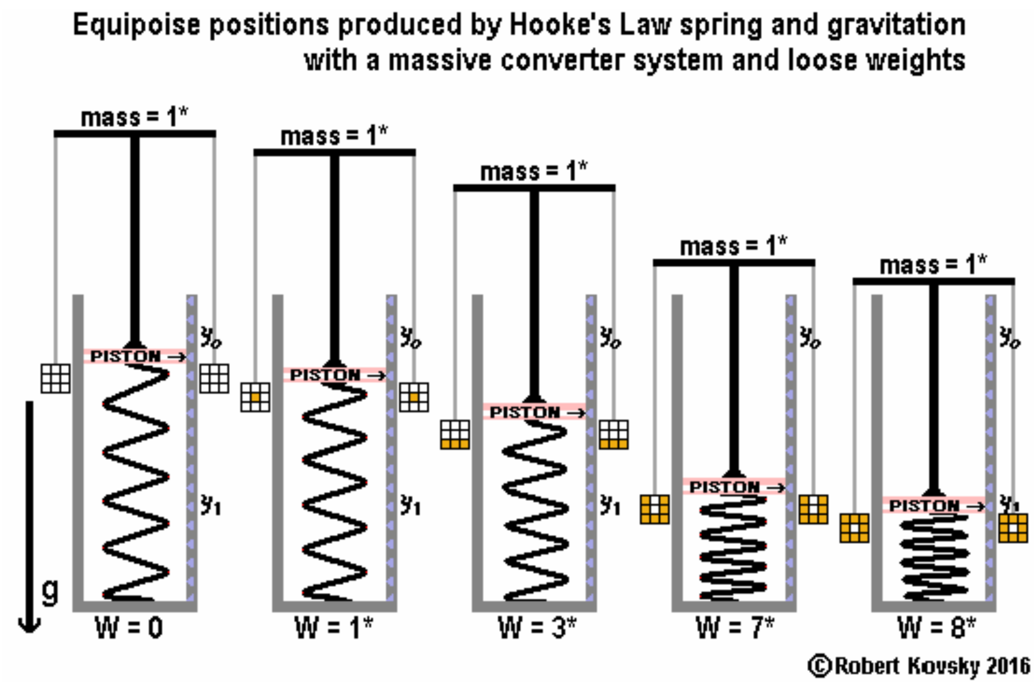
Several restrictions are imposed on equipoise operations of this paradigm. Each weight size W will stand in equipoise at only a single position on the scale. Movements are confined within a ROM. Since weight must be positive, one end of the ROM is set at $y = y_0$. An empty piston is held at position $y = y_0$. The other end of the ROM, denoted as $y = y_1$, is set by limits of the system. The maximum weight W_M is held at $y = y_1$. A weight W can be any size between 0 and W_M. In the figure above, $W_M = 9^*$. The unit of weight, 1*, is denoted by an orange marker.

In easy physics paradigms, forces are combined by additions and subtractions. The addition or subtraction of a constant force of gravity to a linear spring force produces a linear sum. Therefore, the "Hooke's Law spring with gravitational force" paradigm operates with a linear scale, meaning that equal division marks in the ROM denote equal increments of weight.

Equipoise operations of this paradigm again manifest detached time features. One big adjustment can be broken up or decomposed into several small adjustments and details of such a decomposition can be highly variable. Second, timings can also vary: a movement between equipoise positions can be postponed without changing the operation. Third, each adjustment has a reversal adjustment. Results are independent of decompositions and postponements; and operations can be likewise be sequenced in ways that have equivalent results.

c. Equipoise operations of the Hooke's Law with gravity paradigm can be controlled so as to model smoothly connected movements in detached time.

The figure below shows the Hooke's Law with gravity paradigm in a revised version. Weights are relocated, with a pair of masses suspended by ropes. The supporting apparatus and ropes have a total weight of 1*. Equipoise operations previously discussed are not modified by these developments: beginning from an equipoise position, a change in weight is coordinated with a smooth movement to a changed equipoise position. As before, everything operates without friction and ropes are always taut. As before, operations conform to the rules of a mathematical group within a limited ROM. As before, operations occur in detached time.



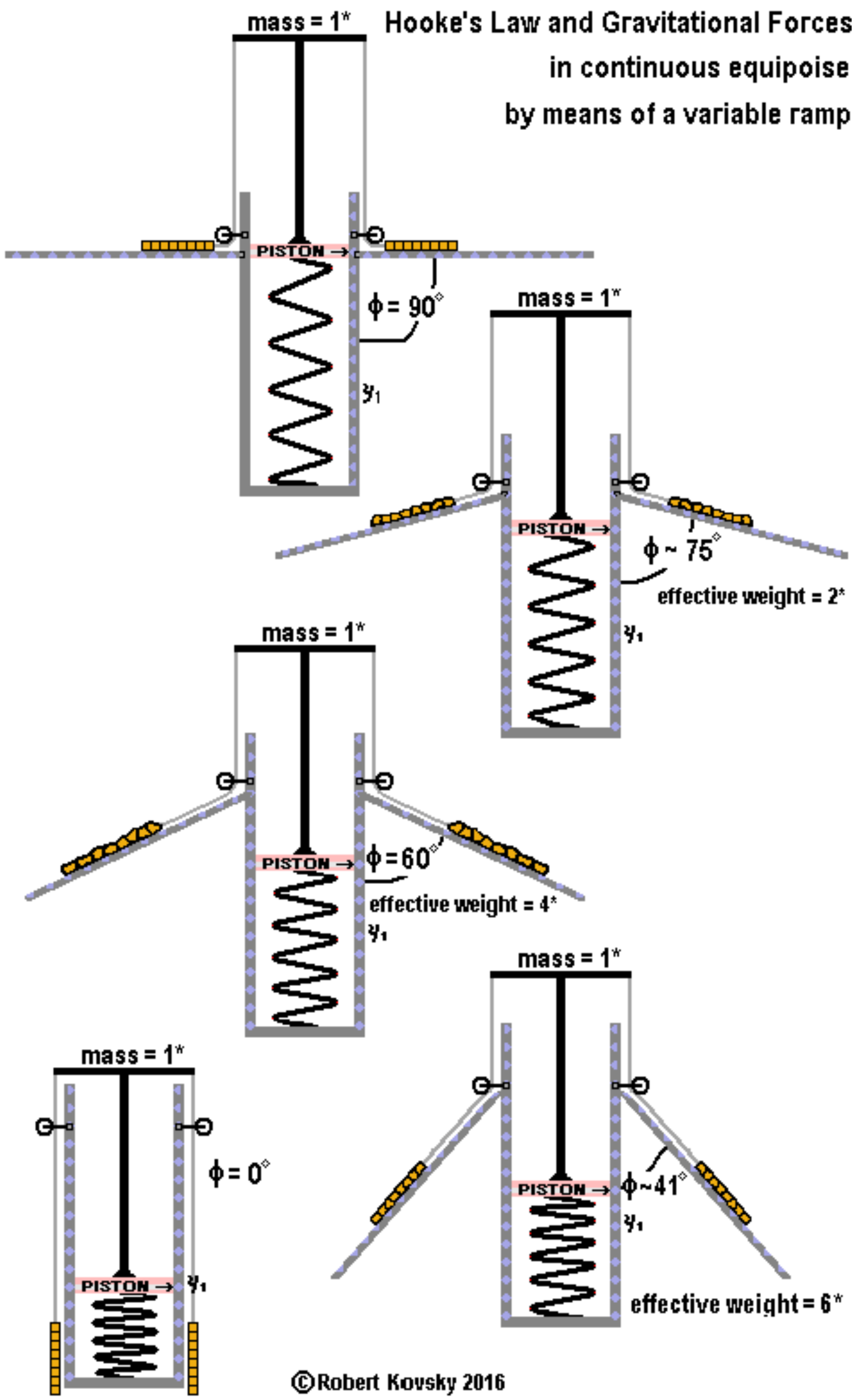
A ***ramped*** version of a Hooke's Law spring in equipoise with gravity, shown in the adjacent figure, introduces a new variable φ, which specifies the angle between the ramp and the vertical. Weights glide easily on the ramp and the angle φ ranges between 0° and 90°.

When φ=90°, the whole weight is supported by the ramp and the spring force has only the mass of the apparatus, 1*, to oppose it; the equipoise position of the weight is $y = y_0 + 1$ for any weight.

When φ=0°, the position is the same as in the prior loose weight version.

At an intermediate point, the position of weights on the ramp varies according to φ.

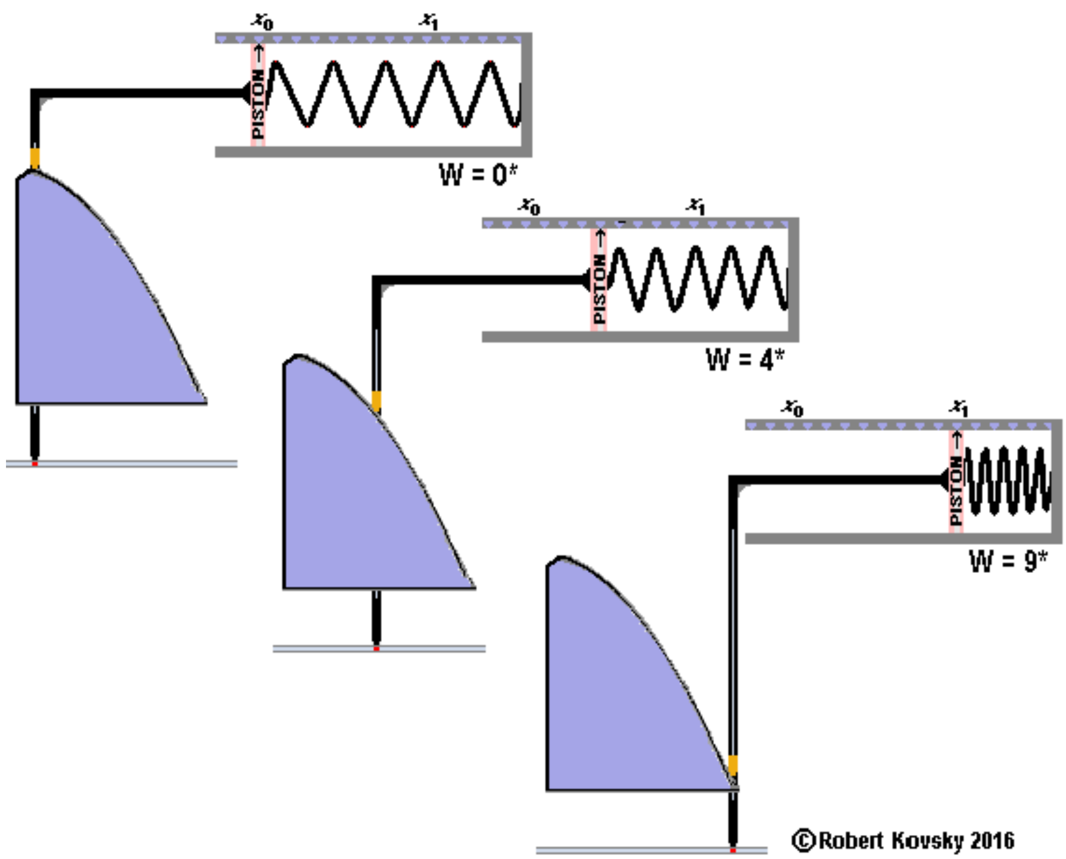
It is possible to imagine that φ starts at 90° and then continuously shrinks to 0. As φ shrinks, the weight goes down on the ramp and the spring compresses. Spring force and gravitational force are in continuous equipoise, i.e., in equipoise at each position. There is never any momentum.



As in the ramped Atwood's machine, the weight glides easily on the ramp and the ramp produces a force perpendicular (or "normal") to the weight. At each position, three forces are in equipoise: the force of gravity, the force of the spring passing through the taut rope and the force of support by the ramp. Three different force directions are involved and the forces add to a null. At any specific angle φ, both the force of gravity and the normal force of the ramp against the weight are constant; therefore, for any suspended weight within the range 0* to 8*, there is a position on the scale where forces add up to 0. The desired position exists and it is unique.

A variance of φ also varies the split between forces. The gravitational force F_g is balanced by the sum of the spring force F_s carried by the rope and the supporting force F_n provided by the ramp. $F_g = -(F_n + F_s)$. If φ=90°, F_n/F_g, = 1; if φ=0°, $F_n/F_g = 0$; changes occur smoothly as φ changes from 0° to 90. This is the same split as in the Atwood's machine.

Next, forces and movements are re-constructed. The following paradigm combines a curved slope similar to that in the constrained Atwood's machine paradigm with the ramped Hooke's law paradigm. In this paradigm, the spring force operates in the horizontal direction, the gravitational force operates in the vertical direction and the supporting force is defined by the curved slope in a way that carries out the requisite force split. Instead of $F_g = -(F_n + F_s)$ in the ramped machine, the split is $F_n = -(F_g + F_s)$. Again, all results are produced under conditions of continuous equipoise and continuous easy glide with a slight force.



The piston apparatus terminates in a vertical member with a red tip at the bottom. The tip glides easily in the track underneath the curved slope. The piston apparatus weighs 1* and glides easily in the cylinder. (If needed, balancing members could be added.) The apparatus holds the "bolt" in a channel in the vertical member; the orange bolt (weighing more than 8*) glides easily in the vertical channel under the influence of the force of gravity and two contact forces. As to one contact force, the vertical channel presses on the bolt in the horizontal direction with a contact force F_s equal to that generated by the spring. The curved slope supports the bolt in a direction normal to the slope with a variable contact force that depends on the position.

In the paradigm, three forces are "added" within the bolt, which is in equipoise when the forces sum to zero. The requirement of equipoise at each position determines the shape of the curve. A continuity argument is used. When the piston is at x_0, the slope is horizontal; as in the original y_0 Hooke's Law paradigm, the piston can jiggle a little bit: the spring moves easily at that position and the weight glides easily on the flat surface. Moreover, the condition of easy glide continues at every position on the slope. Forces sum to zero all along the slope and adjustments with negligible energy costs move the bolt between positions. In other words, there is a condition of continuous equipoise all along the curved slope. As in other detached time systems, movements along the curve can be decomposed and re-composed, postponed and reversed. Movements can be said to conform to those of a mathematical group within a limited ROM. Apparent movements can be constructed, but lacking the momentum of actual movements.

A similar apparatus, but with a different curve, illustrates the reversible adiabatic process in the thermodynamics of the Ideal Gas constructed below. Instead of a spring holding energy in a cylinder, it is the gas that holds energy. Potential energy stored in an Ideal Gas is like energy stored in a spring. In the reversible adiabatic process, as in the Hooke's law curved-surface paradigm, the apparatus glides easily between positions; forces based on a curved surface and on the two potentials – stored gas energy and gravitational potential – are in continuous equipoise. There is a close connection between such mundane ***stored gas energy*** or ***bound energy*** and the concept of ***entropy*** that has been inflated into a cosmic principle.

d. Dynamical oscillatory operations of the SHO occur in mimed time.

Equipoise operations of the Hooke's Law paradigm are of chief importance in this project. Most physics treatments focus on dynamical movements of the Hooke's Law paradigm, which then becomes the simple harmonic oscillator (SHO) paradigm.

During dynamical movements of the SHO, the paradigm domain clock operates in mimicry of actual time and events occur in mimed time. We prepare for such operations while in detached time by holding the piston with mass m at position y_1 that is different from y_0. Then, we simultaneously start the domain clock at $t = 0$ and release the piston. In developing the paradigm to describe dynamical operations, it is presumed that Hooke's Law continues to apply, namely $F_s = -k \times (y - y_0)$. A sizable force is produced by the spring and there is no gravitation force or holding force; hence, the mass accelerates according to Newton's First Law of Motion: $a = F/m$. Equating the two F's leads to the familiar solution:

$y = (y_1 - y_0) \times \cos(\omega t)$ where $\omega^2 = k/m$.

ω has a dimension "per sec" and is called the "angular frequency." Movements that follow a $\cos(\omega t)$ form are called ***oscillations***. In the paradigm, oscillations occur with a period $\tau = 2\pi/\omega$. The period τ does not depend on the magnitude of the displacement $(y_1 - y_0)$ or on anything other than k and m.

Examination of the movements of the dynamical SHO shows that y_0 retains its central position even though it is not a position of rest. Rather it is the position of maximum speed of the mass. Positions of momentary rest occur at positions y_1 and y_{-1}.

The oscillatory SHO paradigm applies to certain actual phenomena. Transmissions of sounds in bodies of air, water and metals are described by SHO principles operating at a molecular level. Quantum mechanical applications based on SHO principles include semiconductors like silicon. Math-like "harmonics" in music go back to Pythagoras in the 6^{th} century B.C.E. Musical vibrations are described as oscillations; and vibrating musical instruments made of wood, metal and animal materials can be tuned exactly to frequencies that have a mathematical basis. For more examples of applications of the SHO, actual springs run clocks and watches with good precision and a similar paradigm applies to the pendulum clock, which can be even more precise.

Viewing SHO applications from a critical perspective, conformity of an actual material to the requirements of Hooke's law occurs, if at all, only approximately and only over limited ranges of motion. A wooden beam bears a substantial weight while bending proportionately; but it departs from Hooke's Law and breaks if the weight is too heavy. Overdriven musical instruments produce buzzing noises. Unlike imaginary springs in the SHO, nearly all actual solids do change with use; and deformations leave traces that, after many repetitions, have a cumulative effect. A piece of metal that is repeatedly flexed and released may develop "fatigue," including cracks that lead to fracture. Violins sound different after having been played for many years.

Especially troublesome is the all-too-easy inflation of Hooke's Law defined for a static holding force into a dynamic principle. In other words, a movement is said to be constructed from a succession of equipoise positions that are defined in detached time. As noted by Truesdell (79):

> First, in mechanics the concept of force originated in statics and was carried over bodily, if with much delay and discussion, to motions, If the restoring force exerted by a spring is proportional to the increase of its length in a static experiment, will it still be so when a ball is attached to the end and set into oscillations, especially if the experiment is performed in a spaceship in orbit around the moon? Indeed, does it make sense to talk about forces at all in a moving system? The forces, it seems, might be affected by the motions, yet we are supposed to know the forces first in order to determine what the motion will be. These questions, and far subtler ones of the same kind, were asked in the seventeenth century; today the freshman is trained specifically not to ask them.

Thus, a distinction between the Atwood's machine and SHO paradigms appears in the respective force relations. As to the former, Newton's Laws of Motion are generally stated for moving bodies and apply to static bodies only as a special case that fits within the general case. Hooke's Law is defined for the static case and is then generalized without limit to apply to moving bodies.

Mimed time operations of the SHO manifest features different from those of actual time operations of Atwood's machine. Quantities involved in Atwood's machine – m, M and g – are referenced to actual bodies and movements. In the SHO, material properties appear in the form of "k," the spring constant that exists only in imagination. An actual body conforms to a "spring constant" description only for a limited range of movement and only in an approximate way. When laboratory measurements are made, the value of k is adjusted to make measurements better fit the paradigm.

The SHO paradigm would be useless if all materials had the same k, like all earth-bound bodies have the same g. For example, musical vibrations can be modeled by the SHO. A vibrating string on a violin or piano has its frequency tuned by an adjustment of tension. Suppose that we construct a relationship between k and tension of a spring or a string. However, a relationship that works for string instruments does not work for wind instruments, where tones are based on an air column in a pipe and frequencies of vibration can be adjusted by movements of the mouth of the performer (embouchure) or by inserting an additional length of pipe, such as a brass horn "crook" that changes the key. In Atwood's machine, a single formula is precisely applied to a compact body of actual phenomena; in the SHO, a highly variable construction is manipulated for approximate conformity to various kinds and ranges of phenomena.

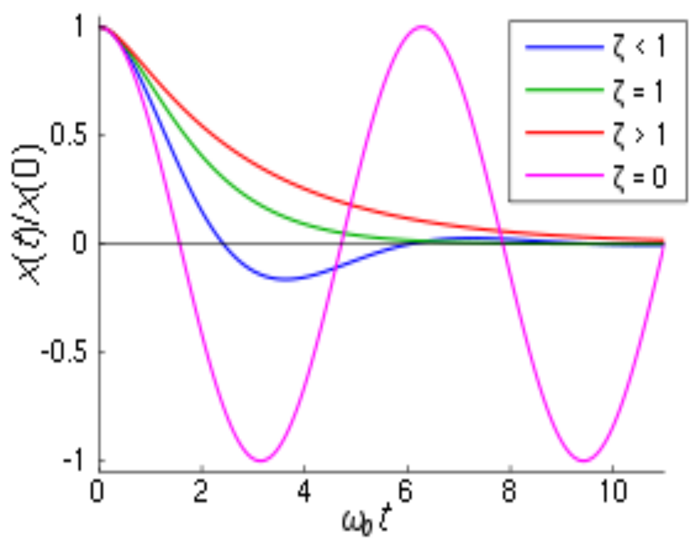
The distinction between actual time paradigms and controlled time paradigms is clearly shown by the ωt form of time that is used in the SHO. Actual time such as that used in dynamical operations of Atwood's machine cannot be stretched or compressed like an ωt form of time. Musical tempi also employ a stretchable ωt form of time, where ω appears in the form of metronome marks, e.g., ♩ = 80 or 80 beats per minute. Few performers maintain a metronomic beat but most, in contrast, vary the tempo to suit a mood or general approach, like an *accelerando* near the end of a lively movement.

e. Dissipative operations of the SHO are movements in mimed time based on positions and movements defined in detached time.

A major development of the SHO is the introduction of an additional influence that is called ***damping*** (in mechanical paradigms) or ***dissipation*** (in broader classes of paradigms), which model internal heating, heat discharges and friction in actual bodies. Dissipation provides an additional means of control for the SHO and suggests further controlled time operations.

The image and caption below are copied from https://en.wikipedia.org/wiki/Damping and show aspects of dissipative operations. Each trace follows a separate movement of a dissipative SHO as measured by a domain clock that mimics actual time. Each movement starts from a position y=1 and a speed v=0 that is defined in detached time. Times in the various traces can be directly compared as if an otherwise invariant system is run with variable amounts of dissipation.

The "damping ratio" ς tracks the amount of dissipation that affects such a movement. If $\varsigma = 0$, there is no dissipation; oscillatory movements continue indefinitely. If $\varsigma < 1$, there is small dissipation; oscillations die out — but, at least in the first return to the equipoise position, there is an "overshoot" or passing beyond the equipoise position, which occurs in the image below at about $\omega_0 t = 6$. If $\varsigma \geq 1$, the larger dissipation prevents an overshoot. The value $\varsigma = 1$ identifies the least dissipation that will avoid an overshoot. It is a "critical" value. Critical value operations of the SHO provide the fastest return to static equipoise that avoids an overshoot.



<u>Caption</u>

Time dependence of the system behavior on the value of the damping ratio ζ, for

undamped (cyan),

under-damped (blue),

critically damped (green), and

over-damped (red) cases,

for zero-velocity initial condition.

As mentioned in Wikipedia, a mechanical door-closer may have a "damped spring" to return a door to the closed position after being opened. Critical damping provides the fastest closing that avoids having the door bang into the door-frame. Some door-closing devices have an adjustment to make it easier to achieve this standard of performance.

Critical damping operations introduce important features that re-appear in critical point operations of the Ising model and in critical moment operations of Quad Net devices. In such critical paradigms, there is a boundary between two kinds of operations; and operations at the "critical point" not only mark the boundary but also have special features of their own.

B. Ideal Gas and Perfect Gas.

1. **Summary**.

In this project, ***ideal gas*** is the name of a class of thermodynamics paradigms that date from Boyle's Law in the 17th century. Operations in ideal gas paradigms consist of movements between equipoise positions in detached time. So-called laws of energy conservation and entropy increase that were stated by Rudolf Clausius and others in the middle part of the 19th century are based on ideal gas paradigms and on detached time paradigms of Carnot cycles and Clausius-Clapeyron relations.

In contrast, perfect gas paradigms and larger "kinetic theories" are mechanics constructions of the latter part of the 19th century. Perfect gas paradigms start in a domain of overlapping detached time and actual time called "equilibrium" and are then developed in ways that mimic movements in actual time. Perfect gas paradigms thus operate in mimed time.

This project employs the foregoing definitions but other investigators use terms differently. See J. S. Rowlinson, "James Joule, William Thomson and the concept of a perfect gas," http://rsnr.royalsocietypublishing.org/content/64/1/43.article-info (Notes and Records: the Royal Society journal of the history of science).

According to Rowlinson, such paradigms were not immediately accepted by all the founders of thermodynamics. William Thomson (1824–1907), developer of modern thermometric scales and later achieving the status of Baron Kelvin, declared that: "a mere quicksand has been given as a foundation of thermometry, by building from the beginning on an ideal substance called a perfect gas, with none of its properties realized rigorously by any real substance, and with some of them unknown, and utterly unassignable, even by guess…"

Results showed that "kineticists were justified in saying that a perfect gas is acceptable as the working substance of a Carnot engine. What may have aroused Thomson's apparently exaggerated fulminations may have been the behaviour of this gas when not at equilibrium. The application of the original form of the kinetic theory to a perfect gas leads, for example, to the prediction that such a gas has an infinite viscosity and infinite thermal conductivity."

Ideal gas paradigms and perfect gas paradigms converge in simple applications where equipoise operations of an ideal gas are equated with equilibrium operations of a perfect gas. In other words, "quasi-static" equilibrium operations in actual time would be indistinguishable from equipoise operations in detached time. When developed into paradigms of irreversible and disequilibrium processes, however, ideal gas paradigms and perfect gas paradigms have distinctly different characters.

(A third class of "statistical mechanics" paradigms also converges, in the simplest applications, with classes of ideal gas paradigms and kinetic theory paradigms. As discussed below, statistical mechanics constructions are tightly bound to equilibrium conditions and operate exclusively in detached time.)

2. the ideal gas paradigm operates in detached time

a. equipoise positions of the ideal gas paradigm

The adjacent image shows an ideal gas paradigm. A body of gaseous material at uniform temperature T is confined inside a cylinder of volume V. The cylinder is tightly enclosed but has a movable, massless piston – like the piston used in Hooke's Law and the SHO – which is maintained in a static position by equality of upward force from pressure of the gas inside the cylinder (p) and downward gravitational force from a weight on the piston (W) combined with atmospheric pressure (*).

As shown in the image below, equipoise positions can be changed. For example, a researcher can add a weight on the piston. Hot or cold liquid can be introduced into the base of the cylinder to heat or cool the gas. A new volume may be required for equipoise to be re-established. The range of positions in the ideal gas paradigm resembles the scale of equipoise positions of the SHO plus gravity or in the constrained Atwood's machine. In ideal gas paradigms, mechanical forces and gas pressure forces add up to equipoise at each static position. Different static positions depend on different gas temperatures and different weights on the piston.

The ideal gas paradigm requires a perfect seal between the piston and the cylinder that provides frictionless sliding and that also prevents gas from leaving or entering the cylinder. Further requirements are that: the whole apparatus and all of its parts – including the piston, the cylinder and the base – are perfectly insulated and have no capacity to store heat – as a result, heat can neither enter nor leave the cylinder, except through the heat transfer element in the base of the cylinder. Heat is stored only in the body of the ideal gas. A "standard" operating environment is at sea level of the Earth, modeled by a fixed atmospheric pressure and a fixed gravitational force.

With a perfect seal and insulation and a fixed environment, "static" conditions can be maintained for an indefinite period of time. A static position is maintained by a balance or equality between the upward pressure of the gas within the cylinder and the sum of the downward forces on the piston. The downward force or "weight" provided by atmospheric pressure is denoted by "1*." Added forces are measured in units of 1*; various weights in the image are W=0, W=1*, W=2*, W=5*. A "standard" value of 1* is about 14.5 pounds per square inch (psi).

The temperature of the ideal gas is denoted by "T." Using standard parlance, T is measured by degrees Kelvin (°K), with the same spacing as degrees Celsius (°C) but with a different zero. Water freezes at the "standard temperature," 0 °C or about 273 °K. At T = 0 °K, "absolute zero," an ideal gas is inert. It is impossible to reach absolute zero: T must always be greater than 0 °K.

The changing volume of the cylinder occupied by the ideal gas is denoted by "V." Changes are also tracked by y, called ***the expansion***: y × A = V where A denotes the area of the cylinder.

To define gas pressure, apply Newton's Third Law of Motion. The upward forced exerted on the piston by the gas within the cylinder holds in equipoise the weight from atmospheric pressure * plus added weight W. Such force is expressed as pressure and denoted as p = (1* + W)/A.

The definition of the character of an ideal gas – called its ***equation of state*** or ***constitutive relation*** – is based the foregoing rules and requirements for measuring values of variable quantities and is provided by the following formula:

p × V = n × R × T, generally written pV=nRT and based on variable quantities p, V and T discussed above.

Because T must always be greater than 0, both p and V must always be greater than 0.

Equivalently: F × y = nRT, relating force F = (1* + W), expansion y and temperature T in °K.

In the formulae, "R" denotes the "universal gas constant," a fixed number with a value that depends on the dimensional units used to define quantities in the laboratory where R is measured, e.g., depending on whether distance measurements are in inches or centimeters. R is the same fixed number for all gases that conform to the ideal gas paradigm.

The symbol "n" refers to the quantity of the gas; there is a "standard" where n = 1 denotes 1 mole of gas; a mole is standardized as a specific number of molecules or a specific volume. It is often convenient to ignore n and to assume a standard 1 mole.

The generality of the ideal gas law permits an arbitrary choice of dimensional units; and units can be chosen for pedagogical convenience. Suppose that we define a specific expansion ξ such that y = 1ξ occurs when the only weight on the piston is atmospheric pressure (F = 1*, W=0) and the temperature is 300 °K, just a bit above room temperature. Then: applying the ideal gas law, 1ξ × 1* = [nR] × 300 °K. (1* is many miles or kilometers in length and would amount to a substantial fraction of the height of the atmosphere above Earth.) The following table lists some of the equipoise positions that can be produced with such a system. Each position is defined by the ideal gas law and any two of: (a) temperature, (b) expansion, (c) force (weight) on the piston.

Temperature T =:				
1200 °K	F = 4* W = 3*	F = 2* W=1*	F = 1.33* W=0.33*	F = 1* W = 0
900 °K	F = 3* W = 2*	F = 1.5* W=0.5 *	F = 1* W = 0	
600 °K	F = 2* W = 1*	F = 1* W = 0		
300 °K	F = 1* W = 0			
expansion y =:	1ξ	2ξ	3ξ	4ξ

When corresponding properties of actual gases are investigated, experiments show that, within limited ranges of temperatures, the ideal gas law serves as a good approximation to a large class of actual gases but by no means all, The adjacent image is copied from Morse Figure 3-3 at page 26 and shows the ideal gas as a straight line at the center where the ratio pV/nRT is, by definition of the ideal gas, identically equal to "1.00" for all pressures. Morse states that: "Figure 3-3 shows curves displaying the departure from the ideal gas law of the equations of state of a few gases. We see that, except for gases near their temperature of condensation, such as CO_2 at 300° and H_2O at 600° the ideal gas law is correct to within a few per cent over a wide range of pressures and temperatures."

b. processes involving an ideal gas are operations that take place in detached time

The form pV=nRT is subject to mathematical methods that imply a thread of connections or "analytic continuity" between nearby values of variables. It is possible to imagine a sequence of equipoise positions of the ideal gas paradigm that resembles mathematical continuity and to imagine movements between equipoise positions that follow the mathematics. Such imaginary movements between equipoise positions that follow mathematical forms are called ***processes***. Processes are: "Basic, explicit, and mathematically precise assumptions." (Truesdell, 83.)

Imaginary processes of the ideal gas paradigm resemble equipoise operations of the SHO. Both occur in detached time. An imaginary movement between static positions can be decomposed or postponed without changing the forces or temperatures that produce particular static positions.

The image below shows a series of equipoise positions that are part of an ideal gas paradigm with a single body of gas. In the first position, the temperature of the ideal gas T = 300 °K, y stands at 2ξ and F = 1* + 5*. In the second position, T = 600 °K, y = 4ξ and F = 1* + 5*. In the third position, T = 900 °K, y = 6ξ and F = 1* + 5*). Out of many equipoise positions that could have been chosen, these all have the same weights (and pressure).

In imagination, equipoise positions in the image constitute a succession of momentary states that occur during a single process in which a body of ideal gas is progressively heated so that it expands and lifts the piston. Suppose that, initially, the expansion x = 2ξ and that the weight is maintained at F = 1* + 5*. Then imagine that the ideal gas is slowly heated from 300 °K and pushes the piston up. To start, a little bit of heat is put into the gas so it gets a little bit hotter. In symbols, T goes to (T + ΔT), where ΔT is small, perhaps 1 °K. Then, in the imaginary process, the added force from hotter gas will push the piston up an additional Δy where Δy = [nR/(1* + W)] × ΔT. Everything inside the brackets […] is fixed and there is a linear relationship between ΔT and Δy. Hence, little ΔT's can be added up to make a big ΔT.

The foregoing construction of a process becomes part of the ideal gas paradigm. It is called an "isobaric" process because the pressure remains the same. However, nothing is actually moving. The ideal gas paradigm does not include actual movements of the piston but only imaginary or constructive movements. In order to actually move, weights have to acquire momentum.

Movements and operations in detached time are imaginary. In such operations, it is easy to imagine a series of "little bitty movements" and to combine them to construct a 'big" movement. Decomposition is equally simple. In such compositions and decompositions, energy costs of changes are disregarded. Jerky movements easily turn into smooth movements and smooth movements easily turn into jerky movements. Similarly, imaginary movements of ideal gas processes in detached time can be speeded up or slowed down without any costs.

c. a reversible adiabatic process is produced by continuous equipoise operations that occur in detached time and mimed time.

Constructions in this stage combine features from curved-slope versions of the SHO paradigm and the Ideal Gas paradigm. When operating against gravity and lifting a weight, the cylindrical Ideal Gas arrangement and the cylindrical SHO arrangement maintain similar continuous equipoise operations on a curved slope. The two curved slopes have different mathematical forms. The form for the SHO is a parabola; the corresponding form for the curved slope used with the ideal gas produces a ***reversible adiabatic process***. Reversible adiabatic processes are suited for rational constructions because they operate in detached time and mimed time.

3. perfect gas paradigms

a. perfect gas paradigms that are restricted to equilibrium conditions can operate equivalently in actual time, detached time and controlled time.

Equipoise operations in detached time serve as steps that lead to ***equilibrium operations*** with a higher level of activation and multiple time forms. In equipoise operations, equal and opposing forces hold each other in stationary but variable positions. In equilibrium operations, equal and opposing flows produce a steady but variable condition.

Flows provide enlarged opportunities for control and innovation. Rational constructions using flows apply to many situations beyond the reach of static positions. Unlike static positions, flows can occur in actual time with rates that can be related to material properties.

In equilibrium paradigms, a body of material (gaseous, liquid or solid) can take on a variety of ***equilibrium conditions***. Seen from a large-scale perspective, a body in an equilibrium condition is devoid of movement or change. For example, distilled water sitting in a closed container at room temperature is in equilibrium – chemically, kinetically and thermally. The equilibrium condition, like conditions at equipoise positions, continues for an indefinite period of time. Changes can be decomposed into smaller changes and can be postponed. As with equipoise positions of the ideal gas, changes between equilibrium conditions are outside the equilibrium paradigm; but, unlike ideal gas paradigms, perfect gas paradigms can be extended and varied so as to apply to some changes.

Equilibrium paradigms presume that a body in an equilibrium condition in a steady environment will remain in that condition unless moved or changed by an external influence. The simplest paradigms presume that any such movement or change is proportional to the external influence (a linear response). Further: it is presumed that if a body is isolated from all external influences, it will tend towards an equilibrium condition. A body left alone long enough in a steady environment will end up in equilibrium and stay there until moved by an external force.

Equilibrium requires conceptual isolation of the body. Perfect isolation is not possible in actual life. Any actual body radiates heat and receives heat radiated from other bodies. Some bodies conduct heat to other bodies. If a body remains in an equilibrium condition, and if no energy transfer occurs except by transfers of heat, the heat received must be equal to the heat radiated or conducted away. This requirement is troublesome to achieve in actual life but can be met by surrounding an inanimate body with walls at the same temperature as the body.

Equilibrium presumptions apply to some inanimate bodies that lack internal sources of energy; such presumptions do not apply to living animal bodies. Living bodies never reach equilibrium. An animal will sleep for a while and then start moving on its own. Vegetable seeds also fail to fit the equilibrium model: they can remain inert for centuries and then spring into life.

Despite limitations, equilibrium has important uses. Branches of chemistry, e.g., biochemistry, are solidly rooted in equilibrium. Equilibrium operations in gases are explored in a branch of thermal physics called ***kinetic theory***. A kinetic theory is rational or axiomatic. The foundational construction of a perfect gas is stated in Morse at 14.

> Let us assume a very simplified model of a gas, one consisting of N similar atoms, each of mass m and of "negligible" dimensions with negligible interactions between them so that the sole energy of the *i*th atom is its kinetic energy of

translation…

> The gas is confined in a container of internal volume V, the walls of which are perfect reflectors for incident gas atoms. By "negligible dimensions" we mean the atoms are very small compared to the mean distance of separation, so that collisions are very rare and most of the time each atom is in free motion. We shall call this simple model a *perfect gas of point atoms*.

It is also stated that "collisions are elastic." Of pivotal importance is the interplay between such elasticity, the restriction that "the sole energy … is … kinetic energy" and the restriction that "collisions are very rare." Suppose that two identical elastic atoms traveling at the same speed but in opposite directions collide directly head-on and then rebound in reversed directions. At the center-point of the collision, both atoms come momentarily to rest: applying Conserved Energy principles, the previous kinetic energies must be stored in elastic materials like that used in the SHO. But then, the sole energy is not kinetic. Because "collisions are very rare," energy stored in elastic materials might be ignored; but then changes occur very slowly. Similar problems beset the "perfect reflectors" in walls, which can be resolved by having the walls at the same temperature as the gas so that the walls and the gas are all at equilibrium together. Even this solution creates problems with changes because both walls and gas have heat capacities – but such problems are disregarded in kinetic theories.

A perfect gas, so defined, can be put into equilibrium conditions and also conditions where equilibrium is lacking. For an example of disequilibrium conditions, suppose that the container of the gas is divided into two equal regions by an insulated wall. On one side of the wall, a high density of atoms is maintained in equilibrium; on the other side of the wall a low density of gas atoms is also in equilibrium. At first, the two regions have no interaction. Next, suppose that tiny holes are opened in the insulated wall and that small flows of atoms pass through the wall. Flows will pass through in both directions but flows through the wall from the high density side will be heavier than flows from the low density side. As a result, the densities on both sides of the wall will change and conditions on both sides will depart from equilibrium. Eventually, the flows and changes will remove all difference in the densities and equilibrium will be restored.

To deal with such cases, James Clerk Maxwell (1831-1879) invented a concept that Truesdell (414-415) calls a "molecular density function *F*" and that Morse (162-63) calls it a "probability density *f*" or a "probability distribution." Morse states: "Probability distributions are the connecting link between atomic characteristics and thermodynamic processes." Truesdell concurs: "Thus the kinetic theory yields for equilibrium, duly defined, exactly the same gross differential equations as does … a corresponding ideal gas."

Truesdell provides an analytic definition. "MAXWELL regarded as being appropriate to equilibrium any molecular-density function *F* such as to be unaltered by collisions." Allowable flows under this definition would "include arbitrary expansions and rotations" and "represent something a little broader that what we think of in ordinary mechanics as equilibrium. WANG's definition of *local equilibrium* in the kinetic theory is $F(\mathbf{x}, \mathbf{v}, t) = F(\mathbf{x}, \mathbf{v}) = F(\mathbf{x}, -\mathbf{v})$. That is, *F* shall be steady and invariant under reversal of velocities."

In other words, there is a large class of *F* functions that apply to flows of atoms. If every flow of atoms were to be reversed, many *F* functions would change. For example, if flows in the disequilibrium situation described above were to be reversed, differences in densities would increase with time. Such events do not happen in actual life. Fortunately for perfect gas theories, equilibrium functions *F* as defined by WANG would be unchanged were such reversals to occur.

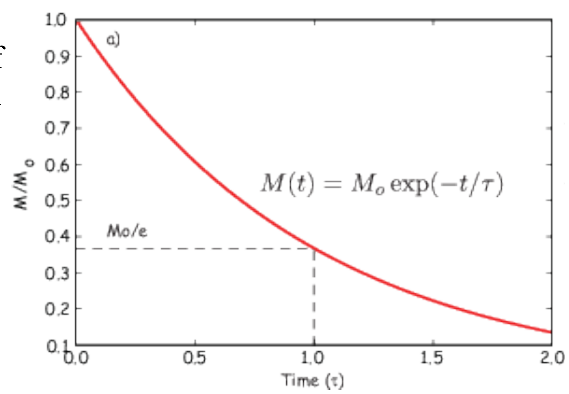
Alternatively, a definition of equilibrium is that *F* shall be steady and invariant under reversal of ***time***. If time reverses, velocities also reverse and the result would equivalent to that based on WANG's definition. As in the ideal gas paradigm, a body in equilibrium in the perfect gas paradigm would continue in equilibrium "the same" if time were to be reversed.

Another resemblance between classes of equipoise operations – e.g., in Atwood's machine, in the SHO and in the ideal gas – and the class of equilibrium conditions in a perfect gas – is that they are special classes that contain only a small fraction of possible operations. Special features that facilitate mathematical development also suggest that such development has only a limited reach.

b. disequilibrium and relaxation

In the SHO, oscillatory movements in mimed time are based on equipoise positions set in detached time. Hooke's Law is defined for fixed positions and carried over into movements. Similarly, perfect gas paradigms of Maxwell and Ludwig Boltzmann (1844-1906) begin with equilibrium conditions maintained under steady conditions in detached time and investigate departures from equilibrium. Under steady conditions, a small departure of a from equilibrium leads to a return to equilibrium. In some cases, operations can be related to certain specific classes of actual phenomena.

In the paradigm, after a small departure from equilibrium, a perfect gas ***relaxes*** with a rate of relaxation that is, at each moment, proportional to the departure from equilibrium; the constant of proportionality is determined by material properties, like the spring constant in Hooke's Lw. Such relaxation is expressed by the "exponential decay form" exp(-t/τ). Exponential decay forms also appear in the dissipative SHO when the damping ratio ς > 0.



The period τ is called the "relaxation time." After one τ period, a departure from equilibrium has diminished more than 63%. After two τ periods, the departure has diminished more than 86%.

The exponential decay form is smooth and continuous through multiple derivatives. In the dissipative form of Hooke's Law, a change in rate resulting from friction is similarly defined as proportional to the rate. Simple proportional relations also appear in ideal gas paradigms.

Such simple proportional definitions are called ***linear***. Linear forms are smooth and continuous. On the other hand, linear methods often fail to apply to jumpy or discontinuous movements. As to some situations and tasks, ***non-linear*** methods work better. Virtual Energy Thermodynamics is designed to work with jumpy and discontinuous movements.

Morse (206-207) assimilates the relaxation time τ to the average time between collisions of the gas atoms. This is because "the distribution can return to equilibrium in one collision time." "Detailed calculations for the few cases which can be carried out, plus indirect experimental checks … indicate that it is not a bad approximation…"

Truesdell provides a more critical view of "molecular interactions." "In kinetic theory, these interactions are called 'collisions' and are visualized as motions of pairs of molecules subject to their mutual attraction or repulsion alone. On the one hand, the gas is regarded as a vast multitude of speeding molecules; on the other, to describe the details of a collision the entire universe is supposed empty except for two molecules."

"Physicists no longer regard the molecules of even helium or hydrogen as mathematical points or spheres following the laws of the Newtonian mechanics of conservative systems. Moreover , the kinetic theory contradicts those laws, for they obey the reversibility theorem, while the kinetic theory …represents the gas as a dissipative material…[and] rests upon a peculiar stochastic hypothesis of quasi-equilibrium: The pairs are statistically independent not only before but also after each encounter. … The interest of the kinetic theory is purely rational, not physical."

C. Carnot cycles and Clausius-Clapeyron relations

1. **Summary**.

The Carnot cycle is a thermodynamics paradigm that has many uses. Most electrical power plants run on steam and are based on the Carnot cycle. It was introduced by Sadi Carnot (1796-1832), a military engineer, in *Reflections on the Motive Power of Fire* (1824).

In one kind of construction, Truesdell defines the Carnot cycle as an axiomatic sequence of processes operating in an imaginary "heat engine," e.g., as an idealized steam engine. Truesdell derives or deduces the First and Second Laws of Thermodynamics from Carnot cycle processes. In other words, Conserved Energy, the content of the First Law, and Entropy, the content of the Second Law, can be derived from axiomatic presumptions in the form of cycling processes. "Carnot cycles are ordinary, sound elements of mathematics, and reasoning based upon them can be good, sound geometry." (Truesdell, 32.)

The Carnot cycle operates in detached time but has an irreversible and productive character. In the Carnot cycle, costly heat turns into productive work. On the other hand, processes also produce waste heat. Fortunately, processes can be arranged so that there is a net gain in productive work.

The components of Carnot cycles are ***adiabatic processes*** and ***quasi-static isothermal processes***. As discussed above, such processes are imaginary movements of imaginary bodies and take place in detached time and mimed time.

As shown in connection with the Ideal Gas, an adiabatic process consists of imaginary movements between equipoise positions in detached time, similar to equipoise adjustments of Atwood's machine and the SHO. An isothermal process employs equilibrium adjustments that occur either in detached time or in mimed time, in a form called ***quasi-static*** that is highly restrictive. In brief, Carnot cycles are rational constructions based on imaginary movements in detached time and mimed time so as to mimic certain actual movements in actual time. If actual movements are smooth and limited to well-defined ranges, imaginary mimicry can be valid and useful.

Paradigms based on the Carnot cycle help to identify areas of useful application for Conserved Energy principles. Conversely, the limited reach of axiomatic presumptions helps to identify phenomena, chiefly "the critical point," where Conserved Energy has diminished utility.

a. The Carnot cycle

Two representation of the Carnot cycle are shown below, Morse's Figure 5-1 (p.49) and Truesdell's Figure 1A.1 (p. 90). The definition according to Morse states:

> A Carnot cycle operates between two temperatures, a hotter, T_h, that of the heat source, and a colder, T_c, that of the heat sink. Any sort of material can be used…And any pair of mechanical variables can be involved, *P* and *V* or *J* [stress] and *L* [strain] or $\mathscr{H}$ [magnetic field] and $\mathscr{M}$ [magnetization] (we shall use *P* and *V* just to make the discussion specific). The cycle consists of four quasi-static operations: an isothermal expansion from 1 to 2 (see Figure 5-1) at temperature T_h, withdrawing heat [] from the source and doing work []; an adiabatic expansion from 2 to 3, doing further work [] but with no change in heat, and ending up at temperature T_c; an isothermal compression at T_c,. from 3 to 4 requiring work [] to be done on the system and contributing heat [] to the heat sink at temperature T_c, ending up at state 4, so placed that process 4 to 1 can be an adiabatic compression, requiring work [] to be done on the system to bring it back to state 1, ready for another cycle (Figure 5-1). This is a specialized sort of cycle but it is a natural one to study.

Morse further states (p. 50): "We note that, since all the operations are quasistatic, the cycle is *reversible*; it can be run backwards…"

Truesdell's representation shows two Carnot cycles: a smaller $\mathscr{C}$ and a larger $\mathscr{C}_0$; his representation "serves to define a Carnot cycle $\mathscr{C}$ within $\mathscr{C}_0$." The set of all possible $\mathscr{C}$'s makes up "the *Carnot web* that corresponds to $\mathscr{C}_0$." Important functions "depend … upon the cycle $\mathscr{C}_0$ that engenders the web." Features of each $\mathscr{C}$ resemble corresponding features of $\mathscr{C}_0$ so that $\mathscr{C}_0$ governs the web and all possible $\mathscr{C}$'s within $\mathscr{C}_0$.

In a fashion similar to Truesdell's web, Morse presents an "Arrangement of two Carnot cycles so their combined effect is equivalent to one cycle between the temperature extremes." (Figure 5-3 at 54.) He uses two engines where the lower temperature of the first engine is the higher temperature of the second engine and heat discharged from the first engine during its stroke 3 to 4 is absorbed by the second engine during its stroke 1to 2. Figure 5-4 (p. 57) similarly shows a "Reversible cycle [] simulated by a combination of several Carnot cycles." "In principle we can build up a combination of Carnot cycles to simulate any kind of reversible cycle…" (P. 58.)

b. "quasi-static" operations in an isothermal process combine detached time features with mimed time features in constructions suitable for steady flows.

(Morse, p. 39.) "Of course the process must be that slow, stepwise kind called quasistatic, if we are to use our thermodynamic formulas to calculate its change." "remove enough heat from the gas, keeping its volume constant meanwhile, to lower is temperature… we could do this relatively quickly (but not quasistatically) by placing the gas in thermal contact with a constant-temperature heat source at temperature ξ. Such a source, sometimes called a *heat reservoir*, is supposed to have such a large heat capacity that the amount of heat contributed by the gas will not change its temperature. In this case the gas would not be in thermal equilibrium until it settled down once more into equilibrium at t=tξ. To carry out a quasistatic process, for which we could use our formulas to compute the heat added, we should have to place the gas first into contact with a heat reservoir at temperature $T_1 - dT$, allowing it to come to equilibrium, then place it in contact with a reservoir at $T_1 - 2dT$, and so on.

(Morse, p. 40) "Thus, thermodynamic computations, using an appropriate quasistatic process, can predict the change in [state variables] for any process, fast or slow, which begins and ends in an equilibrium state. But those calculations cannot predict the amount of intake of heat or the production of work during the process unless the process differs only slightly from the quasistatic one used in the calculations."

Morse 42, "perfect gas ,,, perfect isothermal energy transformers, changing work into heat or vice versa without holding any of it along the way. The transformation cannot continue indefinitely, however, for physical limits of volume or elastic breakdown or magnetic saturation of the like will intervene."

Truesdell at 37, quotes and criticizes Bridgman. "It has always been a reproach to thermodynamics that its handling of irreversible phenomena was inadequate or even impotent. We are now finding out how to deal with large and important groups of irreversible phenomena by methods in the spirit of thermodynamics. … It is possible, I believe, to go even further in the treatment of irreversible phenomena in the spirit of thermodynamics. Classical thermodynamics defines the entropy only of those states of the body which can be reached from a standard state. Such a definition rules out on principle most of the matter of daily life, because most states can be subject to no reversible displacement whatever – any plastically deformed metal is an example, or any biological system." (Truesdell's developments beyond "classical thermodynamics" do not extend to "biological systems.")

3. the Carnot cycle is used for detached time models of steady production processes.

4. Detached time investigations of phase changes use constructions (Clausius-Clapeyron relations) that resemble Carnot cycles and lead to the critical point.

The Carnot cycle presented above uses a working substance, e.g., an ideal gas, that is maintained as a single phase. The cycle is constructed from reversible adiabatic processes and quasi-static equilibrium isothermal processes. As shown by Carnot and Clausius, the same methods can be applied to phase changes, e.g., a change from liquid water to steam, subject to limitations. In this paradigm, there is a kind of engine that uses cycles of pumping with pressure/evacuation and heating/cooling to store energy in a vapor phase kept at equilibrium with a liquid phase.

The principles were stated in *The Feynman Lectures on Physics, Vol. I* (1963):

> **45–3 The Clausius-Clapeyron equation**
>
> The vaporization of a liquid is another application of the results we have derived. Suppose that we have some liquid in a cylinder, such that we can compress it by pushing on the piston, and we ask ourselves, "If we keep the temperature constant, how does the pressure vary with the volume?" In other words, we want to draw an isothermal line on the P-V diagram. The substance in the cylinder is not the ideal gas that we considered earlier; now it may be in the liquid or the vapor phase, or both may be present. If we apply sufficient pressure, the substance will condense to a liquid. Now if we squeeze still harder, the volume changes very little, and our isothermal line rises rapidly with decreasing volume, as shown [below] in Fig. 45–3.

If we increase the volume by pulling the piston out, the pressure drops until we reach the point at which the liquid starts to boil, and then vapor starts to form. If we pull the piston out farther, all that happens is that more liquid vaporizes. When there is part liquid and part vapor in the cylinder, the two phases are in equilibrium—liquid is evaporating and vapor is condensing at the same rate. If we make more room for the vapor, more vapor is needed to maintain the pressure, so a little more liquid evaporates, but the pressure remains constant.

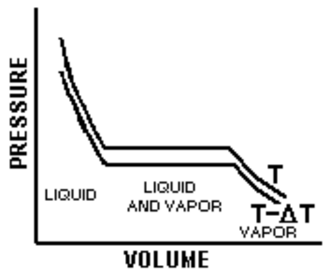


Fig. 45–3. Isothermal lines for a condensable vapor compressed in a cylinder. At the left, the substance is in the liquid phase. At the right, the substance is vaporized. In the center, both liquid and vapor are present in the cylinder.

On the flat part of the curve in Fig. 45–3, the pressure does not change, and the value of the pressure here is called the *vapor pressure at temperature T*. As we continue to increase, the volume, there comes a time when there is no more liquid to evaporate. At the juncture, if we expand the volume further, the pressure will fall as for an ordinary gas, as shown at the right of the *P-V* diagram. The lower curve in Fig. 45-3 is the isothermal line at a slightly lower temperature $T-\Delta T$. The pressure in the liquid phase is slightly reduced because liquid expands with an increase in temperature (for most substances, but not for water near the freezing point) and, of course, the vapor pressure is lower at the lower temperature.

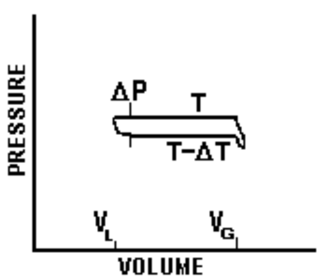


Fig. 45–4. Pressure-volume diagram for a Carnot cycle with a condensable vapor in the cylinder. At the left, the substance is in the liquid state. A quantity of heat L is added at temperature *T* to vaporize the liquid. The varpor expands adiabatically as *T* changes to $T-\Delta T$.

We will now make a cycle out of the two isothermal lines by connecting them (say by adiabatic lines) at the ends of the flat sections, as shown in Fig. 45–4. The little jiggle in the lower right-hand corner of the figure will make little difference and we will neglect it. We are going to use the argument of Carnot, which tells us that the heat added to the substance in changing it from a liquid to a vapor is related to the work done by the substance as it goes around the cycle. Let us call ***L*** the heat needed to vaporize the substance in the cylinder. As in the argument immediately preceding Eq. (45.5) [Eq. 45.5 is Feynman's statement of the Carnot cycle], we know that $L(\Delta T/T)$ = work done by the substance. As before, the work done by the substance is the [enclosed] area, which is approximately $\Delta P(V_G - V_L)$, where ΔP is the difference in vapor pressure at the two temperatures T and $T - \Delta T$, V_G is the volume of the gas, and V_L is the volume of the liquid, both volumes measured at the vapor pressure.

Setting these two expressions for the area equal, we get $L\Delta T/T = \Delta P(V_G - V_L)$ or

$$L/T(V_G - V_L) = \partial P_{vap}/\partial T. \quad (45.14)$$

Equation (45.14) gives the relationship between the rate of change of vapor pressure with temperature and the amount of heat required to evaporate the liquid. This relationship was deduced by Carnot, but it is called the Clausius-Clapeyron equation.

Now let us compare Eq. (45.14) with the results deduced from kinetic theory. Usually V_G is very much larger than V_L. So $V_G - V_L = V_G = RT/P$ per mole. If we further assume that L is a constant, independent of temperature–not a very good approximation–then we would have $\partial P/\partial T = L/(RT^2P)$. The solution of this differential equation is

$$P = \text{const } e^{-L/RT}. \quad (45.15)$$

Let us compare this with the pressure variation with temperature that we deduced earlier from kinetic theory. Kinetic theory indicated the possibility, at least roughly, that the number of molecules of vapor above a liquid would be

$$n = (1/V_A)\, e^{-(U_G - U_L)/RT}, \quad (45.16)$$

where $U_G - U_L$ is the internal energy per mole in the liquid minus the internal energy per mole in the gas., i.e., the energy needed to vaporize a mole of liquid. Equation (45.15) from thermodynamics and Eq. (45.16) from kinetic theory are very closely related because the pressure is nkT, but they are not exactly the same. However, they will turn out to be exactly the same if we assume $L - U_G$ = const, instead of L = const. If we assume $L - U_G$ = const, independent of temperature, then the argument leading to Eq. (45.15) will produce Eq. (45.16).

This comparison shows the advantages and disadvantages of thermodynamics over kinetic theory: First of all. Eq. (45.14) obtained by thermodynamics is exact, while Eq. (45.16) can only be approximated, for instance, if U is nearly constant, and if the model is right. Second, we may not understand correctly how the gas goes into the liquid; nevertheless, Eq. (45.14) is right, while (45.16) is only approximate. Third, although our treatment applies to a gas condensing into a liquid, the argument is true for any other change of state. For instance, the solid-to-liquid transition has the same kind of curve as that shown in Figs. 45–3 and 45–4. Introducing the latent heat for melting, M/mole, the formula analogous to Eq. (45.14) then is $(\partial P_{melt}/\partial T)_V = M/[T(V_{liq} - V_{solid})]$. Although we may not understand the kinetic theory of the melting process, we nevertheless have a correct equation. However, when we *can* understand the kinetic theory, we have another advantage. Equation (45.15) is only a differential relationship, and we have no way of obtaining the constants of integration. In the kinetic theory we can obtain the constants also if we have a good model that describes the phenomenon completely. So there are advantages and disadvantages to each. When knowledge is weak and the situation is complicated, thermodynamic relations are really the most powerful. When the situation is very simple and a theoretical analysis can be made, then it is better to try to get more information from theoretical analysis.

D. Ising model, critical point and critical opalescence.

1. Universality principles of critical point phenomena

2. Shimmering

   a. Collective selections in magnets and in the Ising Model

   b. Non-local correlations

   c. Evanescent flickering fragments of possible results

   d. Critical opalescence

3. Sensitivity

   a. The plunge to zero and sharp switching

   b. Infinite initial susceptibility

III. Controlled Time Paradigms of Virtual Energy Thermodynamics

Summary of part III.

The goal is construction of engineered organisms that exercise freedom, e.g., moving like an eel.

Paradigms of Virtual Energy Thermodynamics (VET) are set forth as ***device designs*** and are organized in four ***kits of parts***. Designs for ***pulser devices*** and ***Quad Net devices*** are endpoints of a range of pulsational activities; endpoints are sometimes called "low-level" and "high-level" respectively. Low-level pulsing is simple and tethered to a fixed beat with a period τ_0; in Quad Nets, high-level Shimmering Sensitivity generates the quickest and most complex repertoires.

As in the 2006 *Quad Nets* article, the course of construction in this project leads from low-level to high-level activity through a series of device paradigms and progressively constructs the ***Quad Net VES functional*** as a form of Virtual Energy. Constructions start with the ***primal pulser paradigm*** that produces a fixed beat like a musical metronome. Additional pulser paradigms are set forth, e.g., variable pulsers, dissipative pulsers and multi-pulsers.

The next stage of development starts with multi-pulsers and leads to ***force fiber devices*** that resemble muscle fibers and to their drivers, ***burster devices***. Arrays of bursters and force fibers produce various simple movements, e.g., with "wavemakers" and inside "a tube for transport."

Timing devices, the third stage, includes new versions of a prior Toggle that resembles a computer flip-flop and An Ear for Pythagorean Harmonics. Cylindrical designs combine timing devices, burster devices and force fiber devices in rudimentary worm-like engineered organisms.

A final stage of development leads to ***Quad Net devices***. Quad Net devices are intended to resemble biological ***neuronal groups*** and to produce co-ordinated whole-body movements like those of vertebrates, with greater sensitivities, enlarged repertoires of movements, faster changes and momentary generation of images that match images of prior events recalled from memory.

A Quad Net (QN) is a square array of hundreds or thousands of ***elemental devices*** arranged like cells in a stretchable grid. There is a repetitive tiled pattern. Through stretching and connecting, arrays takes shapes of a cylinder or toroid; and arrays can be layered. An elemental device in a QN starts with a pulser, burster or timing device and adds additional features. Each elemental device is connected to neighbors and all the elemental devices in a QN array are collectively driven. Waves may pass through layers of arrays. Similar to phase changes in the Ising Model, pulsational patterns in a QN body go through integrated transformations. In anticipated designs, multiple QN layers and bodies are interconnected and driven in synchronized cycles and sequential patterns; and bodies pass collectively through unified and integrated transformations.

All of the foregoing constructions are ***elemental***: devices consist of well-defined parts and their operations involve an axiomatic "Virtual Energy Store" (VES) in each device. In a further development, this project also introduces ***materialistic models*** that can resemble variations and unique features that are seen in actual animal bodies and in their movements and changes.

In other words, in the actual domain of muscular movements, each animal body has unique capacities and limitations that appear to be based on its genetic constitution and individual experience. VE designs aim to model such unique features with ***material embodiments, material environments*** and ***material interactions***. In sum, an elemental or axiomatic foundation of movement repertoires can be further developed by means of individualized bodies with over-layers of material variations.

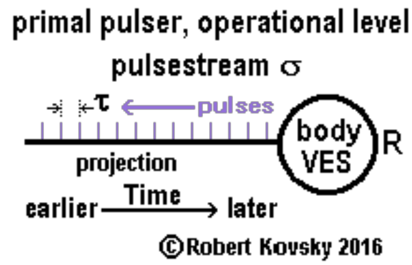
A. Pulser devices

1. elemental pulser devices

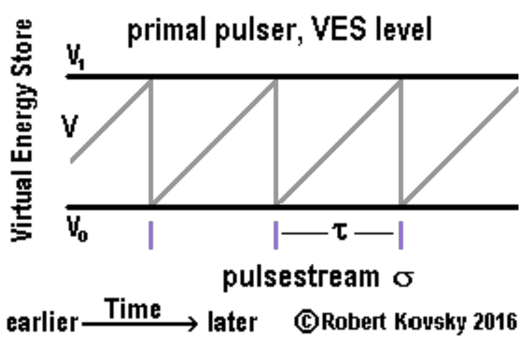
a. primal pulser — a metronomic beat is based on a Virtual Energy Store.

The ***primal pulser*** is the point of origin for Virtual Energy (VE) devices in this project. The figure below shows the primal pulser on the ***operational level***. Two kinds of time coincide in the design: mimed time of the paradigmatic domain clock and pulsational time of the pulser. Mimed time can be stretched or compressed and runs from "earlier" to "later." Pulsational time is a new kind of controlled time based on ***R***, the fixed flow of VE into the body of the device.

The ***body*** produces ***pulses***; pulses travel away from the body on a ***projection***. Because the inflow R is fixed, pulsing occurs with a steady beat, like a metronome. VE is stored in the ***Virtual Energy Store*** (VES), which converts stored VE into a ***pulsestream***, denoted by $\boldsymbol{\sigma}$. Between any two successive pulses there is a uniform ***pulse period*** $\boldsymbol{\tau}$. A purple ***pulse chart*** resembles an oscilloscope trace of electrical impulses in a wire.



Each pulse carries 1 unit of VE, called a ***bang*** and symbolized by "!." The operational definition of the primal pulser is $R \times \tau = !$. Each pulse lasts for an ***instant***, which is the shortest period of time used in designs; and a pulse travels instantaneously on the projection to reach a destination such as a timing device discussed below. That is, an instant is required to transmit and deliver the pulse. A principle of design is that halving or doubling the duration of an instant does not change results. In math-like parlance, an instant is a like a point and lasts for an infinitesimal period of time. Thus, the pulse chart denotes the instants of pulse discharges as seen in mimed time.



In the paradigm, the body of the device contains a Virtual Energy Store or VES. VE flows into the VES and ***charges*** the VES. VE is stored in the VES until the amount reaches one bang; then a 1! pulse is instantaneously discharged via the projection. VE storage and discharge are depicted in the adjacent graph. The quantity of VE in the VES is tracked vertically; paradigmatic mimed time is tracked horizontally; and pulses are noted below the V_0 line.

Variable V tracks the quantity of VE stored in the VES and varies between V_0 and V_1. Except at instants of discharge, the value of V at instant t is stated as: $(V - V_0)/(V_1 - V_0) = [R \times (t - t_a)]/!$, where t_a denotes the last previous instant of discharge. When V is a bit less than V_1, $(t - t_a)$ is a bit less than τ. During an instant of discharge, the value of V drops from V_1 to V_0.

The quantity $(V_1 - V_0)$ measures the capacity of the VES for storing VE, one bang in this case. The VES of the primal pulser is fully charged on a cyclical schedule.

Instantaneous discharges of the primal pulser are convenient for rational constructions, e.g., for designs that conserve energy; but they present potential problems for realization. Problems can be overcome in various ways. Devices with extended discharge periods are introduced below. Simple timing devices can introduce delays. If VE principles are embodied in electronics devices, operations will be instantaneous compared to movement times of massive bodies.

In this design, VE is ***conserved*** at the operational and VE levels: all the VE that enters into the device through R is changed into pulses and discharged in σ. Input VE = output VE, allowing for a cyclical amount in storage. Conservation means that $(V_1 - V_0) = !$ in addition to $R \times \tau = !$.

The VES rationalization in the primal pulser resembles that used by Rudolf Clausius (1822-1888) in his invention of Internal Energy in Conserved Energy Thermodynamics. Like a body of steam that stores Conserved Energy and converts it from heat to work in a stream engine, a VES in a device body can be said to store and convert one form of energy into another form.

In other words, Internal Energy in a steam engine rationalizes the conversion of heat into work. The VES in the body of the primal pulser rationalizes the conversion of a fixed VE flow (R) into a steady stream of pulses (σ). R has no temporal variation but σ has a temporal variation measured by τ. The primal pulser changes a timeless flow into measurable time. A continuous and constant flow goes in and discontinuous pulses come out.

Operations of the primal pulser differ from those of CE paradigms in part II, which revolve around conditions of equipoise and equilibrium. In the primal pulser, activity never ceases and there is never a condition of rest, equipoise or equilibrium. Operations of the primal pulser revolve around the instant of pulse discharge and the corresponding drop of VE in the VES; all other moments are preparatory for that instant. A discharge of a primal pulser takes place during an instant of change and is outside the range of movements that can be constructed from equipoise and equilibrium operations.

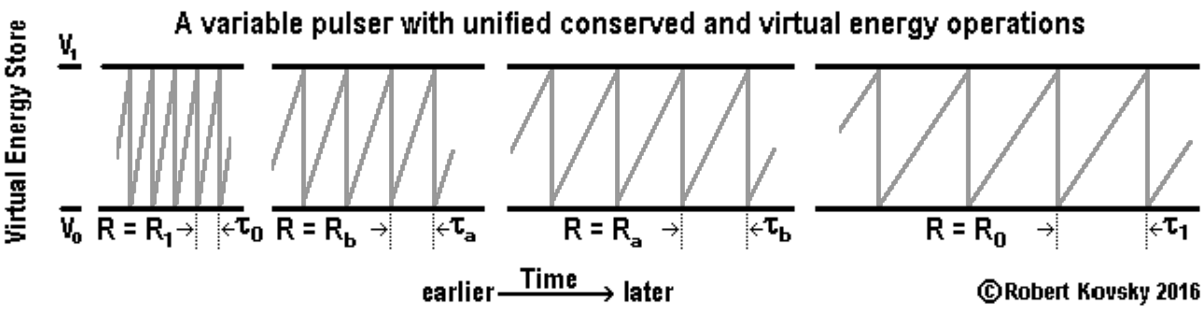
The primal pulser is a ***time generator***, like a metronome that sets the beat for a piece of music. It operates with a new variable kind of controlled time called ***pulsational time*** where R, the rate of inflow of energy is the controlling or independent variable. In contrast, fundamental CE paradigms operate in detached time and mimed time where energy is specified by states referenced to equipoise positions that can be tracked along a curve.

Comparing essential operations, the primal pulser is an active device with a flow of VE that is being converted while the Ideal Gas and its offspring are passive bodies that produce stationary positions that have a fixed amount of CE. A static Ideal Gas paradigm operates in detached time while an ideal conservative primal pulser not only operates in mimed time but also generates pulsational time defined by $\tau = !/R$.

An exemplary range of movement is $.001 \text{ sec} \le \tau \le .01 \text{ sec}$. The corresponding frequency range is 100 to 1000 Hz, which covers the chief tones used by the human voice. This range is roughly conformable to periods and rates seen in movements of animals. Technological designs, of course, could be much quicker. However, my impression that quicker operations of neurons would not contribute much to quicker movements of animal bodies. Rather, movements appear to be limited by the musculo-skeletal system, with its inertial masses, dissipations and requirements for coordination. Hummingbirds are quicker than elephants because of differences in sizes of body parts, not because of differences in brain power.

b. conservative variable pulsers operate within ranges of values

The operational definition of the primal pulser ($R \times \tau = !$) resembles the constitutive relation of an Ideal Gas ($p \times V = [nR]\, T$). Like an isothermal process in a Perfect Gas where various values of P and V maintain a fixed T and a fixed energy, a ***conservative variable pulser*** operates with variations in R and τ, while maintaining the fixed size of a pulse. The figure below shows variable operations that conserve energy, maintain the fixed 1! size of a pulse and produce a range of values for τ.



The operational definition of the variable pulser ($R \times \tau = !$) is a ***reciprocal relationship*** that connects variations in τ with variations in R through coordinated movements in opposite directions, all while maintaining a fixed pulse size. As R decreases from its maximum (R_1), τ increases from its minimum (τ_0); and vice-versa. Let τ be a real variable that can take any value in the closed interval $[\tau_0, \tau_1]$ and let R be a real variable that can take any value in the closed interval $[R_0, R_1]$. The reciprocal relationship is easily stated at endpoints: $R_0 \times \tau_1 = ! = R_1 \times \tau_0$.

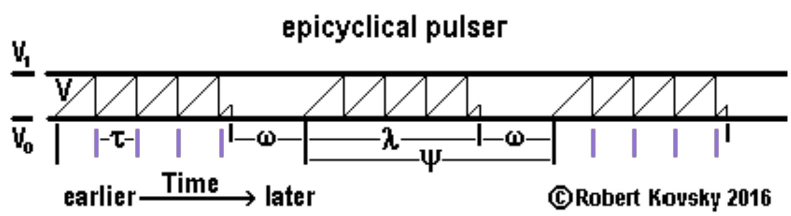
When τ is uniform, it is possible to define a ***frequency,*** $\nu \equiv 1/\tau$. In other words, if R and τ are fixed or change slowly — e.g., less than 1% per cycle — activity can be tracked in terms of a fixed or slowly changing ν. Then the operational definition can be stated as $R = \nu \times !$.

It is possible to construct a relationship between ν and R when changes are slow; it is a ***linear relationship***. $(\nu - \nu_0)/(\nu_1 - \nu_0) = (R - R_0)/(R_1 - R_0)$. Note that $\nu_0 = 1/\tau_1$ and $\nu_1 = 1/\tau_0$.

If $(R - R_0)$ slowly increases by a certain percentage, $(\nu - \nu_0)$ increases by the same percentage. In other words, ν and R stretch together in the same direction, rather than in opposite directions. When more VE goes in, 1! pulses come out faster. Linear relationships stated with values of ν are often more convenient for development than trying to work with reciprocal relationships stated with values of τ. See the timing devices design for An Ear for Pythagorean Harmonics discussed below. However, ν is a quantity that is derived from the more foundational quantity, τ, and only under certain restrictions. A period τ is directly measured from two successive pulses. A frequency ν requires a calculation or device operation based on numerous successive pulses separated by a fixed or slowly-changing period.

c. epicyclical pulsers

"Cycles within cycles" is a pervasive construction technique in VE device designs. A general technique uses a longer cycle, often denoted by ψ, to organize shorter cycles, often denoted by τ. The technique of cycles within cycles is illustrated in an ***epicyclical pulser*** shown in the figure below. At the heart of the epicyclical pulser, a device similar to the primal pulser produces pulses with period τ. Activity is also controlled according to a longer period ψ. Each ψ period is composed of shorter periods: λ, the ***active period***, and ω, the ***silent period***. Active periods and silent periods alternate with each other. During the active part of the ψ period (λ), the epicyclical pulser operates exactly like a primal pulser. During the silent part of the ψ period (ω), the epicyclical pulser is turned "off;" the inflow of VE is closed; and any VE in the VES drains away to a "dissipated VE stream" (discussed below in connection with the material embodiment) so that, when the next ψ period starts, the VES stands at V_0.



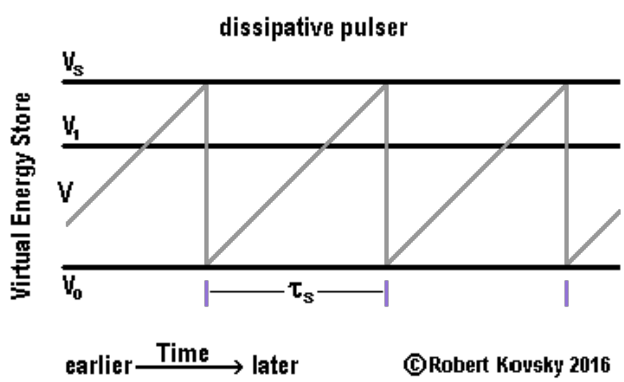
d. dissipative pulsers

A ***dissipative pulser*** can produce a pulsestream with a longer τ. Additional VE is required for production of each pulse. Such additional VE is not converted into pulses – each pulse continues to carry one bang of VE – but is instead dissipated as a cost required to produce longer pulse periods. Such dissipated VE is carried away in the dissipated VE stream previously mentioned.

The VES definition for a dissipative pulser paradigm shown in the figure below is more complex than that for the primal pulser. A third VES level is introduced, namely V_s. V_s becomes more important in devices discussed below. In pulser paradigms, V_s can be fixed or variable but is subject to the restriction that $V_s \geq V_1$.

The dissipative pulser does not discharge when the amount of stored VE reaches V_1; instead, VE continues to accumulate in the VES until the quantity of VE reaches V_s and only then is a pulse discharged. The operational definition is: $\tau_s = (V_s - V_0)/R$.

$(V_s - V_0)/(V_1 - V_0) = \tau_s/\tau_0$ states the number of bangs in $(V_s - V_0)$. Here, $\tau_0 = !/R$ is introduced as a standard base unit of time in VE paradigms.



Suppose that cyclical dissipation defined as $(V_s - V_1)$ is variable. When $(V_s - V_1) = 0$, operations are the same as for a conservative primal pulser. At the other end of the range of variation, define V_Z as the maximum value of V_s, denoting the highest dissipation that can be produced in the device. Then $\tau_Z = (V_Z - V_0)/R$ is the longest obtainable pulse period. V_s takes on values in the range $[V_1, V_Z]$ and τ takes on values in the range $[\tau_0, \tau_Z]$.

A pulser device with a variable dissipation has a set of pulse periods like the variable pulser. Development has thus introduced a third control variable V_s in addition to R and τ.

According to the operational definition [$\tau_s = (V_s - V_0)/R$], the pulse period τ_s would not change if $(V_s - V_0)$ and R were to change together in equal proportions. Suppose that a pulser has both a variable dissipation and a variable R. Two such pulsers can produce identical pulsestreams, one with higher dissipation and higher R, the other with lower dissipation and lower R.

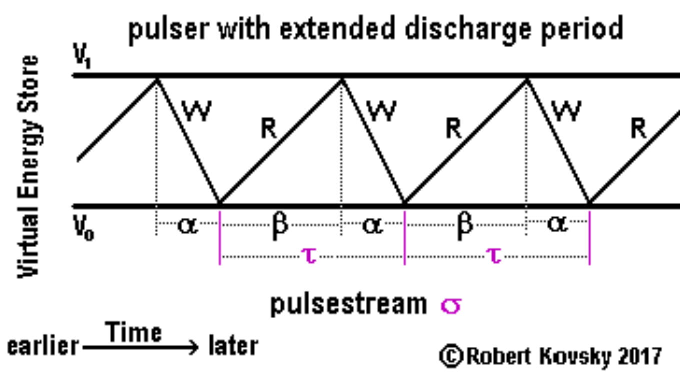
e. Pulsers with extended discharge periods

In the figure below, the pulser has an ***extended discharge period*** rather than the instantaneous discharge of the primal pulser. An extended discharge period starts when V reaches V_1. The quantity of VE in the VES is reduced through discharge and discharge proceeds at rate W until the instant V reaches V_0. At that instant, a 1! pulse is discharged as in the primal pulser and VE starts flowing into the device, charging it at rate R as in the primal pulser.

Conceptually, a new ***preparation area*** is introduced as part of the device: VE that is discharged from the VES during the discharge period accumulates in the preparation area until the quantity reaches one bang; and then a 1! pulse is discharged over the projection.

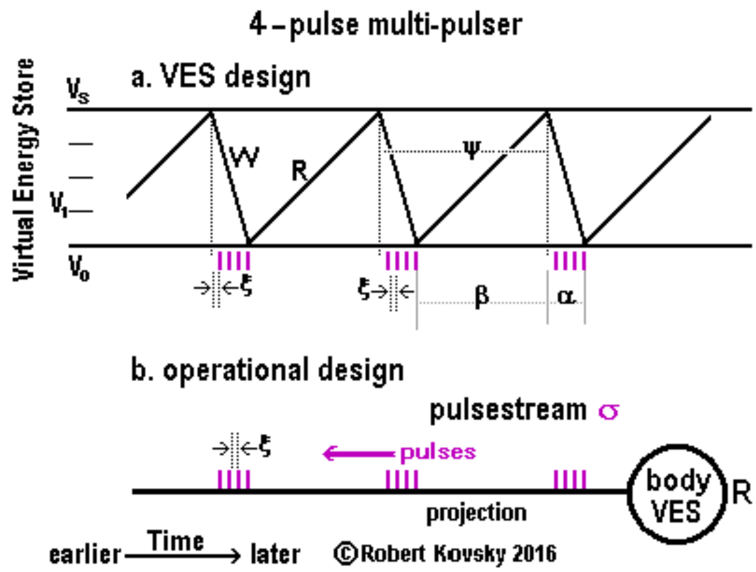
If charging and discharging operations are sharp and coordinated, they can approach a standard defined by Conserved Energy principles. No charging occurs while the device is discharging. No discharging occurs while the device is charging. Charging periods alternate with discharging periods. During the extended period of discharge, a full bang of VE is gathered in readiness for instantaneous discharge at the conclusion.

As shown below, the discharging period is denoted by α. The charging period is denoted by β. The period of time between pulses, τ = β + α. ***Timing intervals*** α and β are controllers for pulsers with extended discharge periods; α and β can be more convenient than R and W.



f. Multi-pulsers produce bursts; each burst contains a series of pulses

A further development is the ***multi-pulser paradigm*** shown in the figure below. The VES in this design combines features from prior pulser models and anticipates those in upcoming designs for force devices and bursters. In this design as in the dissipative pulser, V_s is the V level at which discharge is triggered. Here, $(V_s - V_0)$ contains 4 bangs of VE that are used to produce a "burst of 4 pulses" during an extended discharge period. Pulses in a burst are equally spaced with a period ξ between pulses.



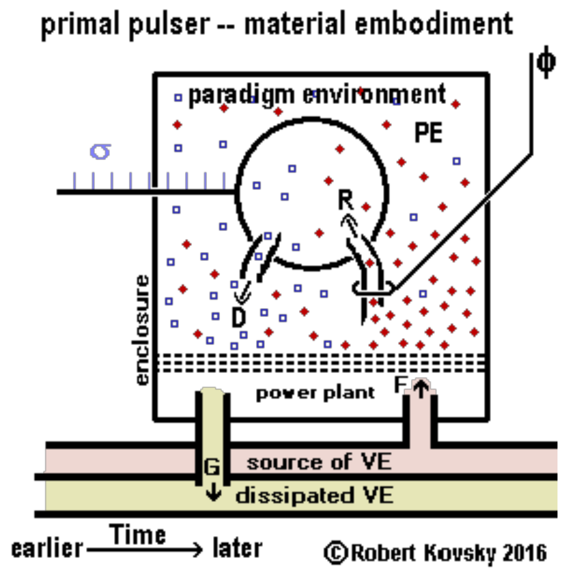
Suppose that we view activity that starts just after the discharge of the last pulse in a burst, when the VES level is at $V = V_0$; then V in the VES increases at the linear rate R for a period of time β until $V = V_s$; and then all the stored VE is discharged at a linear rate W for a period of time α, producing 4 pulses with a period ξ between pulses. Recall that $\tau_0 = !/R$. Then, $\beta = 4\tau_0 = 4!/R$ and $\alpha = 4\xi = 4!/W$. The period between bursts is $\psi = 4(\tau_0 + \xi)$.

Operations require that a full bang of VE must be discharged when the first pulse is produced. Hence, when the discharge period starts, there is a period of 1ξ while VE gathers in a preparation area, similar to the α period in the extended discharge pulser discussed above. At the conclusion of 1ξ, a pulse is discharged. A further 1ξ gathering period is needed for each of the subsequent pulses. After 4 pulses have been discharged, V has come down to V_0 and another cycle commences. This design can conform to conservation principles if paradigmatic operations are sharp and coordinated like those in the multi-pulser.

2. enlarged classes of pulser paradigms are based on a material embodiment

a. defining a material embodiment

As a further level of definition, the primal pulser has a ***material embodiment*** that is shown in the figure below. An ***enclosure*** surrounds the primal pulser; inside the enclosure, the device is immersed in a ***paradigm environment***, denoted by PE. The PE may have properties that depend on a variable chemical constitution or recent history. Distinct from the pulser but within the enclosure, there is a ***power plant*** that is fueled by a ***source of active VE*** through an inlet “F” and that has an outlet “G” for ***dissipated VE***. G connects to the ***dissipated VE stream*** that is like an automobile exhaust pipe or radiation fins on the CPU of a personal computer.



VE is carried by active VE particles moving inside the PE, shown as red stars (*). Active particles flow into the pulser through an inlet tube and constitute R. In the pulser, VE is absorbed from active particles and put into the VES at a steady rate. Used particles, shown as blue boxes (□), are discharged through drain D.

The inflow rate R is controlled by pulsestream φ, which operates like a sphincter muscle in an animal body. In initial paradigms, φ is adjusted so that R is kept at a uniform or constant value. In anticipated large-scale models, devices in an independent network produce variable φ values, which control variable activations of VE modules and which also distribute limited VE.

The power plant takes in used particles, re-charges them and returns them as active particles to the PE. As models of biological activity, the power plant resembles mitochondria, *’s resemble ATP and □’s resemble ADP. In initial paradigms, the power plant is well supplied by with VE and can produce “more than enough” *’s. The power plant also processes dissipated VE.

Functioning of the φ system resembles that of certain brain cells called “astrocytes” that are part of non-neuronal networks generally called ***glia***; glia do not process pulses like neurons but do interact among themselves and control blood supplies to neuronal groups. There is no attempt here to sum or balance source VE, dissipated VE, VE in pulses, VE in particles, VE in the φ system and VE stored in materials – as might be done in Conserved Energy Thermodynamics.

Electronics systems provide an analogy. Many electronics systems have a ***power supply*** that is independent of operational parts. The power supply connects to a standard AC source of 110 volts/60 Hz and turns that standard AC source into particular needed signals, such as 6 volts DC. Power supplies in electronics systems are dissipative and produce heat radiated into the air. Two competing systems may rank equally in performance and durability but one dissipates more heat.

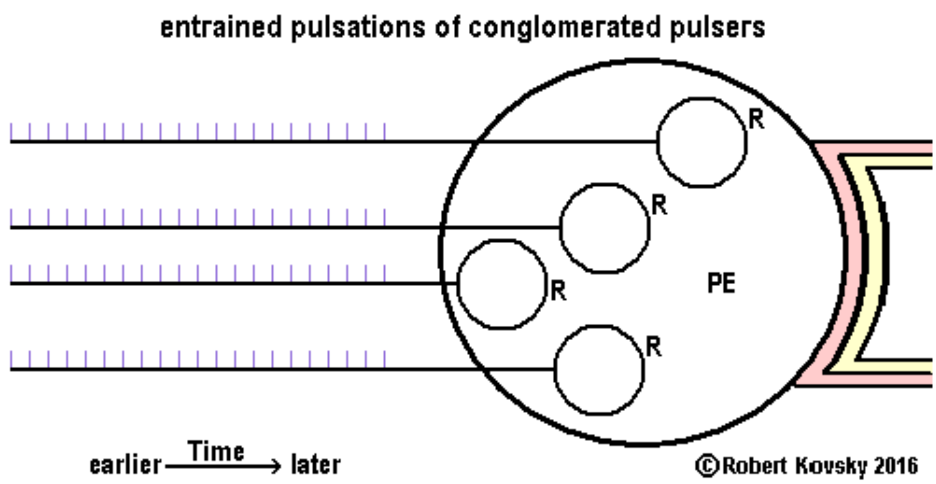
Some electronics designs include a power supply module but others only indicate points at which power is to be supplied. In elemental designs in this project, the power plant is easily neglected. Rates of VE inflow such as R are presumptively fixed or under tight control. VE is available in sufficient quantities for such purposes. Desired operations in elemental designs are produced by features of the VES and operational interconnections, not by a limit or constraint on VE.

b. synchronization and entrainment in a conglomerate of pulsers.

Material embodiments provide opportunities for new paradigms that reach beyond operations stated in elemental designs . In a ***conglomerate of pulsers***, shown in the figure below, four ***identical*** pulsers share a paradigmatic environment (PE). In other words, the pulsers have a common design and they share a common R but each pulser has its own individual projection and specific bodily location. Each pulser is like a primal pulser except for the shared PE; each pulser has sufficient VE for operations; and each pulser produces a pulsestream with a τ that is "the same" for all four pulsers.

Suppose that the R of each particular pulser is adjusted so as to reduce discrepancies between the instants of that pulser's discharges and instants of discharge of other pulsers. I suggest that, because the pulsers have the same definitions at all levels, such adjustments will produce pulse productions with a common τ, but with each pulser operating on its own.

The conglomerate paradigm additionally introduces a material principle of ***entrainment***, which states that discharges of such identical and independent pulsers operating in a shared paradigmatic environment become ***synchronized*** and that all the pulsers in the conglomerate ***discharge together within a single instant***. Any deviation from synchronization will be corrected. The principle of entrainment is a rational construction that appears to fit actual biological activity. In the paradigm, as a result of entrainment, the whole conglomerate is pulsing and beating as a single device with four operationally identical output projections. Looking forward, entrainment is used for production of entrained waves of muscle-like twitches that move massive bodies in flowing patterns and in sensoria based on entrainments of fine-scale sensations. Looking forward to Quad Net devices, entrainment is to be developed into a principle of competing fragmentary entrainments that change into a single whole-body entrainment as a system of interconnected devices passes through a critical moment.



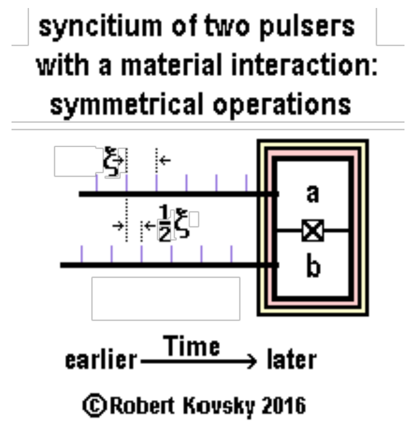
c. material interactions in a syncytium of two coupled pulsers

In a ***syncytium***, adjacent devices interact by means of a material medium. They share a ***VE base***, which includes a common VE supply and a common drain for dissipated VE. In these respects, a syncytium resembles a conglomerate. Unlike a conglomerate, each device in a syncytium operates in a distinct paradigm environment (PE) and has independent device operations.

To start, two identical coupled devices operate in identical paradigmatic environments. ***Coupling*** is a pervasive design technique that re-appears in later paradigms, leading to ***balancing*** paradigms that model movements of animal bodies with bilateral symmetry (left and right).

In another course of paradigmatic development, a "syncytium" becomes a form of structure that joins elemental devices into strings and layers, leading to large-scale constructions of modules that can function like organs of an animal body. In this initial paradigm, material properties of a syncytium are modeled by specifications of direct-contact interactions of adjacent devices.

i. operational design for a two-pulser syncytium with alternating discharges and symmetrical operations



The adjacent figure shows operations of a syncytium of two identical pulsers ***a*** and ***b***. The two pulsers have independent operations and a common VE base. Operations are based on separate VE inflows at the common rate R in each pulser. Pulsers participate in a ***material interaction*** that operates through a ***junction*** that connects them. The junction is denoted by a box-like element between the pulsers. Depending on the design, VE can pass through the junction in one or both directions. VE passes from the discharging pulser to the ***charging pulser***. Two sources of VE (from R and through the junction) are added or combined in the VES of the charging pulser.

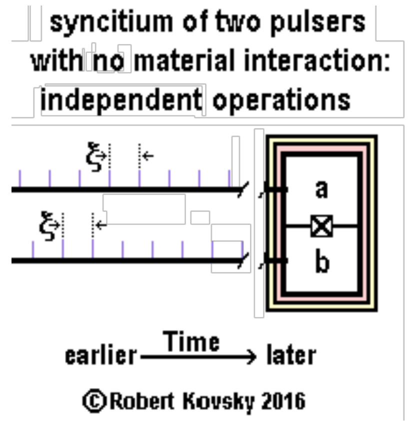
In initial paradigms, changes of VE in a VES resemble changes of CE in the Internal Energy of steam in a steam engine or changes in binding energy during chemical reactions in a mixture of reagents. An addition or conservation principle is used. Similar to such CE applications, VE transferred via this material interaction has a ***permanent character*** that lasts until discharge.

(In contrast, VE interactions in the original *Quad Nets* designs and in certain designs below have a ***temporary character*** where VE suddenly added by way of interactions is dissipated or lost if the addition does not result in immediate discharge of the charging device.)

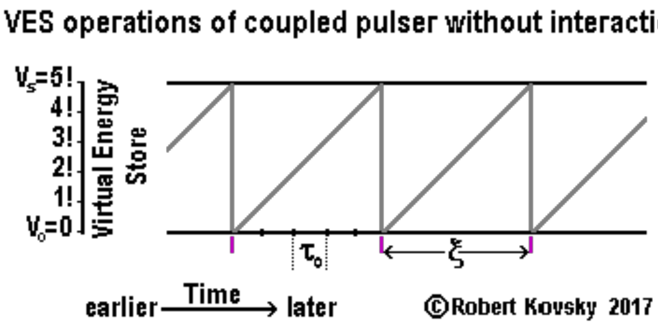
The pulsers in this design have symmetrical and alternating operations; each pulser discharges pulses with a period ζ between pulses; equivalent operations occur in the two pulsers; and ½ζ separates pulsations of the two pulsers.

ii. underlying VES operations with no interaction

A preliminary design shown in the adjacent figure has ***no*** material interaction through the junction. It is as if two identical pulsers were completely independent. Although the pulse charts are shown together, there is a break in the projections to indicate the lack of a connection between the pulse patterns. One line could shift with respect to the other without changing any operations. In contrast to the conglomerate of pulsers, there is no tendency for these devices to pulse synchronously or to participate in any other relationship.

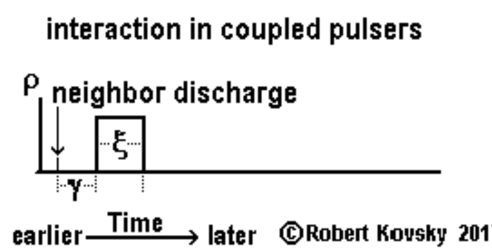


Operations of the VES in a "no interaction" syncytium pulser, shown below, are based on the dissipative pulser discussed above. In the "no interaction" design, R flows into the VES of the device at the rate of 5! per ζ and the size of the VES, ($V_s - V_0$) is 5!. During discharge, 1! is converted into a pulse and the remaining 4! are dissipated.



iii. definition of an interaction.

An exemplary transfer of VE by means of an interaction is depicted in the adjacent figure. During the interaction, VE is absorbed into the VES of the charging pulser at a rate ρ. Specifications of the interaction state its ***strength S***, ***delay γ***, ***dispersion ξ*** and ***details***. The strength S of the interaction specifies the total volume of VE that is absorbed by the charging pulser or $S = \int \rho dt$.



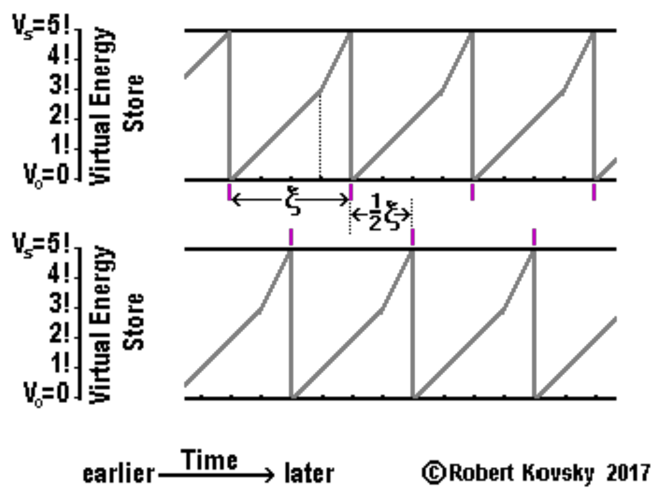
Delay γ specifies the time interval between discharge by the neighboring pulser and the first addition of VE to the VES of the charging pulser, after passage through the junction. Dispersion ξ denotes the spread-out arrival of VE at the charging device. In contrast to the instantaneous discharge and movement of a whole pulse over a projection, the transfer of VE through a junction generally occurs after a delay and over an extended period, in a "dispersed" way. Details of the interaction specify, e.g., whether the junction is bi-directional or unidirectional and whether increases in VE from interactions have a permanent or temporary character.

iv. Virtual Energies are added in the VES

Finally, VE from an interaction is added to VE from R . Specifications of interactions are chosen to produce alternating, symmetrical signals shown in (i) above. The delay specification $\gamma = \tau_0$. (As above, $\tau_0 = !/R$.) Dispersion is specified by the square-wave distribution shown above with $\xi = \tau_0$. The strength of the interaction S is 1!; $\rho = R$ for the period τ_0. VE from interactions is stored in the VES until discharged. The junction operates symmetrically.

As shown in the figure below, each cycle has a longer part and a shorter part. The two parts are divided by a vertical line in a representative cycle in the figure. In the longer part, of duration $3\tau_0$, VE is stored at the rate of R, the same as for an uncoupled pulser. In the shorter part, of duration $1\tau_0$, the increase of VE in the VES is a combination of 1! from source R and 1! from interaction ρ. The sum is 2!. The interaction speeds up the pulsational period so that $\zeta = 4\tau_0$. Every period ζ, 4! of VE flow into the VES from R, 1! is received from ρ through the junction, 1! is discharged as a pulse and 1! is transferred in a material interaction to the other pulser.

VES operations of coupled pulsers with 1! interaction



Summing up in the style of CET, 3! in the VES are dissipated per cycle in a coupled pulser while 4! are dissipated per cycle in an uncoupled pulser where $\zeta = 5\tau_0$. Over a common period of $20\tau_0$, uncoupled pulsers dissipate 16! in 4 cycles and coupled pulsers dissipate 15! in 5 cycles.

In this design, passages through the junction alternate: first VE passes in one direction; then it passes in the other direction. In effect, 1! of VE is "tossed" back and forth between the pulsers through the junction. If operations are symmetrical, the passages do not interfere with each other.

Suppose that, in a "perturbation," a discharge of one pulser is advanced by a little bit, perhaps by a researcher adding VE to its VES. The advanced pulser discharges before all the VE from the prior neighbor discharge has been absorbed. Assuming that delay and dispersion occur inside the junction, VE from the advanced discharge impinges on the junction from one direction while VE from the neighbor discharge is still passing through the junction from the other direction.

For simplicity, presume that there is dissipative subtraction between flows of VE that are traveling in opposite directions through the junction. Then, presuming a linear junction, the perturbation is resolved. After a jog and wobbles of decreasing size, signals return to the prior alternating form. Much the same happens if a researcher introduces a delay perturbation.

B. Force fiber devices and bursting devices

Force fiber devices are elements in models of muscles. ***Twitching movements*** produced by such devices aim to resemble twitches of animal muscle fibers. ***Bursting devices*** ("bursters") produce signals called ***pulse bursts*** that drive force fiber devices. Pulses are the same as in pulser designs. The earlier ***bursters project*** (www.quadnets.com/bursters.html) has a more detailed presentation.

1. A signal that produces a twitch of a force fiber device consists of a burst of pulses.

Operations of force devices and bursters use a common unit of pulsational time, called a ***tick*** that is produced by an external "master clock." Perhaps a fixed tick is equal to 0.1 second; then, a twitching movement of a force fiber device lasts for five ticks or 0.5 second, similar to twitches of animal muscle fibers. Another possibility is that the master clock produces a tick with a variable period. In further possibilities, module clocks replace the master clock.

Designs in this project use a time structure called a ***Ψ-form*** that is easily represented in codes. The figure below shows an eight-tick Ψ-form for signals. In such signals, a ***burst*** containing a variable number of pulses is contained in the first three ticks of the Ψ-form, which is called the ***activity period***. The activity period lasts for three ticks regardless of the number of pulses. The last five ticks of the Ψ-form are the ***resting period***. After completion of the 8-tick Ψ-form, there may be more resting or a new Ψ-form can start with a new activity period.

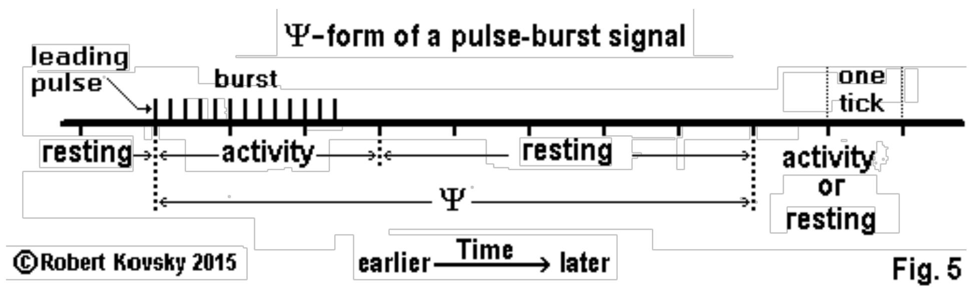


Fig. 5

A signal Ψ-form starts with the first pulse in the burst, called the ***leading pulse***. Pulses appear at the uniform rate of 5 per tick starting with the leading pulse. The number of pulses in a burst, the ***pulse number*** (denoted by "n"), can range from 1 to 15. The burst in the figure above has 13 pulses or n=13.

As shown in the figure below, the strength of a primal twitch of a force fiber device corresponds to the number of pulses in the burst that drives it, with a linear variation between the pulse number and the force produced, which is denoted by $\mathcal{F}_n$. $\mathcal{F}_n = n\mathcal{F}_1$, where $\mathcal{F}_1$ denotes the force produced by the smallest burst signal for which n=1.

Repertoire of pulse-burst signals and forces of a twitching force fiber device

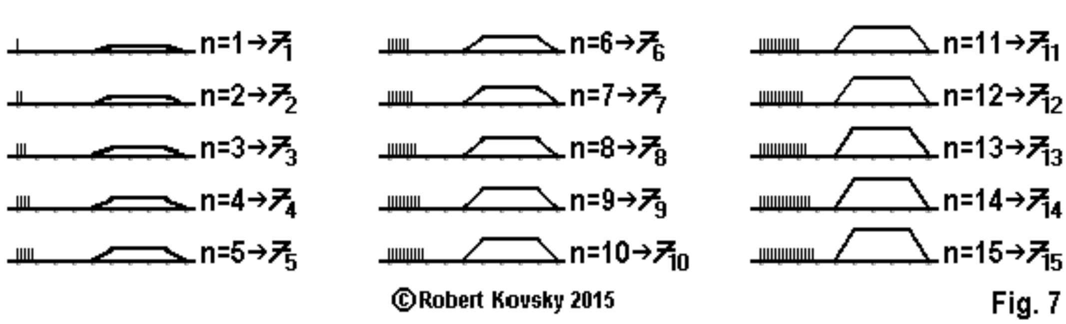


Fig. 7

2. A primal twitch is produced by a rigidly affixed and fully extended force fiber device.

As shown in the figure below, a force fiber device has two chief parts: (1) a signal ***detector*** which receives pulse burst signals; and (2) an ***effector***, which produces the twitch repertoire shown in the figure above and which can thus perform mechanical work, e.g., lifting a weight.

For the initial definition, that of the ***primal twitch***, the force fiber device is fully extended to its maximum length and tough un-stretchable fibers at ends of the device are rigidly affixed to supports. A contractile force pulls the terminal fibers inwards but there is no movement.

A pulse burst signal is denoted by `SSS`. Arrival at the detector of the leading pulse of a burst starts the detector Ψ–form: the detector ***notices*** the burst for three ticks, coded by `NNN` in its Ψ–form. During the next tick, coded by P, there is joint ***processing*** in detector and effector. The P tick starts the Ψ-form of the effector. Processing is followed by a ***forceful contraction*** ("twitch") of the effector, coded by q and Q. As shown in the previous figure, contraction starts at a minimum and ramps up during tick 2 to the specified level. Tick 2 is coded by "q." After a steady force for the next three ticks, coded by Q, the strength level ramps down during effector tick 6, again coded by q. The effector ***recovers*** during tick 7, coded by R. Then it waits for a new twitch in a ***ready*** condition, coded by r. The detector also recovers (R) after processing a burst but continues to be blocked (`XXX`) from receiving a new burst until expiration of its 8-tick Ψ–form. Then the detector becomes ready (r) to receive a new burst signal.

twitching of force fiber device driven by pulse bursts

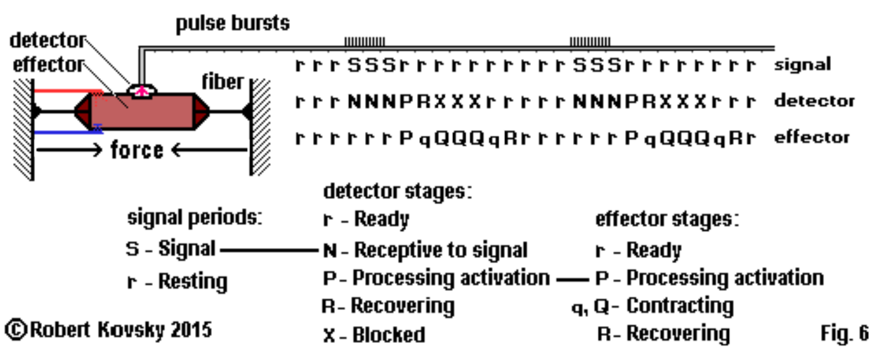


Fig. 6

3. A mobile force fiber device incorporates variations in the force of a twitch that depend on fiber length.

A rigidly affixed device can neither move nor perform work on an external object, no matter how much Virtual Energy it is consuming.

A first development of the force fiber device is based on behavior of a typical muscle producing voluntary movements: when such a muscle shortens, it exerts less tension or force.

The definition of force generated by a shortened elemental force fiber device is modified so that $\mathcal{F} = n\mathcal{F}_1 - j(\ell_1 - \ell_x)$. The fiber length ℓ_x varies between a minimum ℓ_0 and a maximum ℓ_1. If $\ell_x = \ell_1$, the device is fully extended and the new $\mathcal{F}$ reduces to the previous $\mathcal{F} = n\mathcal{F}_1$. The $j(\ell_1 - \ell_x)$ term states a reduction in the force of a twitch of a contracted device. The constant j resembles a spring constant k in Hooke's Law paradigms. It is presumed that the value of j can be set by a researcher to suit the application.

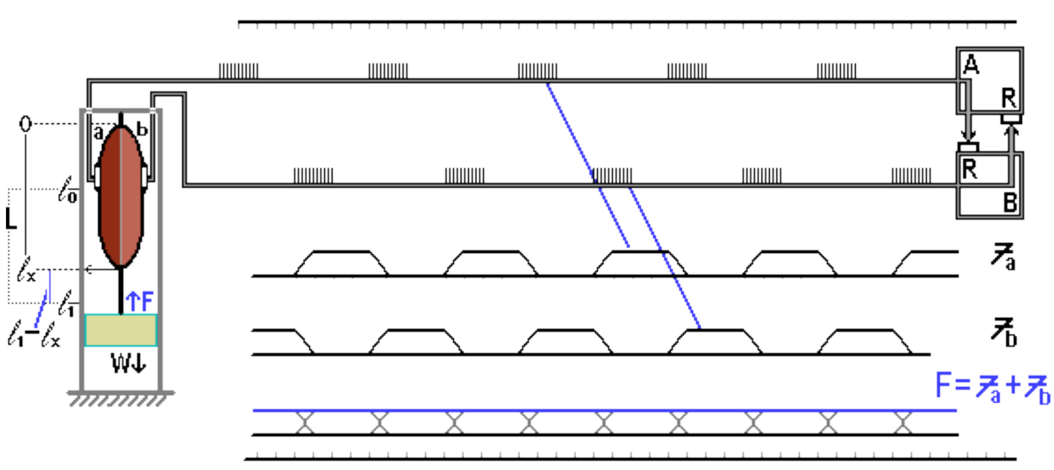
4. Two force fiber devices operating as a duet are driven by reciprocating and repeating bursting devices to produce steady forces that hold a weight.

The left-hand side of the figure below shows two force fiber devices, a and b, coupled together in a ***duet***. The two force fiber devices share physical connections that carry forces; they produce alternating forces that combine to hold a weight W steady inside a supporting and constraining cylinder. Similar to movements in cylinders of Hooke's Law and the Ideal Gas, the weight can only move up and down; the only forces are provided by gravity and by the duet.

The right-hand side of the figure shows two ***coupled repeating bursting devices*** ("bursters"), denoted by R and identified as A and B. The bursters are connected reciprocally and produce pulse bursts on reciprocating projections and output projections. In other words, on discharge of a burster, two twin bursts of pulses are produced, one on a projection to a force fiber device and the other on a projection to the other burster. One pulse burst drives force production and the other burst sets pulse production. Bursters and force fiber devices are designed to work together.

In this design, the duet produces a steady but variable force **F**. Duet fibers share a variable length, denoted by ℓ_x. Quantity $\ell_1 - \ell_x$ ranges from $\ell_1 - \ell_x = 0$ at full extension to $\ell_1 - \ell_x = L$ at full contraction, where $\ell_x = \ell_0$. L denotes the range of motion (ROM). The strength of **F** is equal to $\mathcal{F}$, the central twitch strength in the ramp form. A steady **F** is patched together from alternating twitches; a successor twitch ramps up just as a predecessor twitch ramps down. In the figure below, a blue line denotes a steady force: $F = \mathcal{F}_a + \mathcal{F}_b$. Ramping parts of twitches are shown in gray below the steady blue line. If bursts with n pulses are delivered on an alternating schedule to both force fiber devices, the duet produces a steady force F_n that is made up of alternating $\mathcal{F}_n$ twitches. In the figure, $W = nF_1 - j(\ell_1 - \ell_x)$ or $(\ell_1 - \ell_x) = (11F_1 - W)/j$, since n = 11.

Steady force produced by a duet:
two joined force fiber devices driven by two reciprocating bursting devices



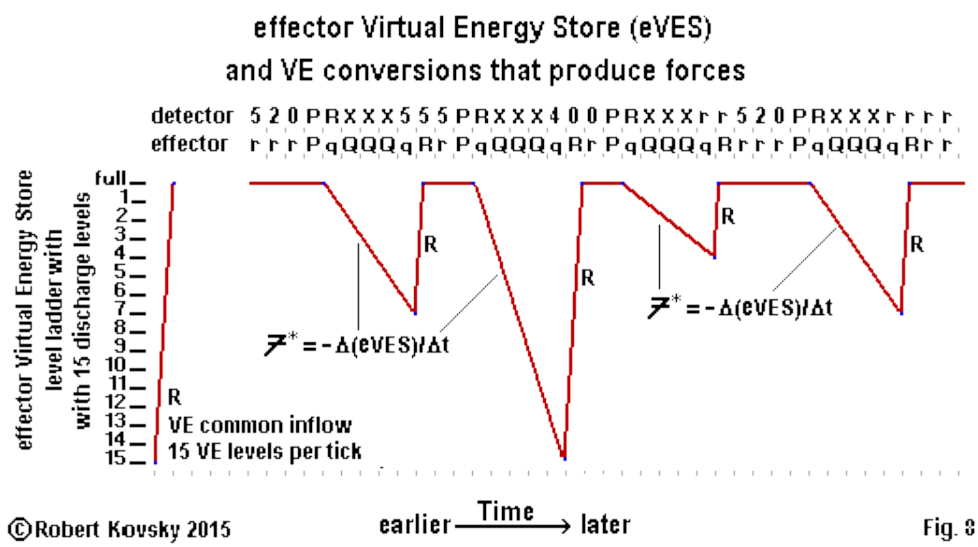
 earlier —Time→ later Fig. 9

Coupling of devices produces smooth balancing in imaginary designs. For purposes of practical development, smooth operations might be achieved with larger numbers of devices (a "chorus") and serried banks or ranks of devices that have overlapping force patterns. Such "scaling up" is added through development of strings of devices discussed below.

5. A Virtual Energy Store controls operations of a force fiber device.

As shown in the figure below, a force fiber device contains an ***effector Virtual Energy Store*** (eVES) that is developed from the VES of the multi-pulser. In this design, discharges can be partial and variable. A ***level ladder*** in the detector ranges over 15 levels for discharge of the eVES in the effector; this range matches the range of the repertoire of pulse burst signals. During discharge, stored VE is converted to produce a force with a strength level set by the input signal. Such conversion of eVES produces a steady ***raw force*** $\mathcal{F}$* that is then reduced through dissipation to produce the final ramped twitch force $\mathcal{F}$. During the first three ticks in the detector Ψ-form, in the `NNN` period (e.g., a 520 period in the figure below) each pulse in an arriving burst pushes the ***n indicator point*** in the eVES ***level ladder*** down one step. During the 4th or P tick, a corresponding terminal discharge point is set in the effector, marked by blue dots at the low points in traces in the VES level in the figure below.

Then, during 5 q and Q ticks, the effector converts stored VE into a transient force or twitch. The eVES level decreases from "full" to the level set by the pulse burst. The raw force of the twitch is defined as $\mathcal{F}^* = -[\Delta(\text{eVES})/\Delta t]$. The raw force varies in a direct and linear way with the discharge level: doubling the discharge level means doubling the raw force. To get a ramped shape, VE is dissipated and the raw force is reduced during the first or "start-up" tick and during the final or "run-down" tick. A contracted device dissipates more energy and has a smaller force, as specified by the j factor.



In sum, the force fiber device twitches in response to an input burst. Each twitch is distinct from other twitches and is responsive to a single burst. Each pulse burst is processed the same as every other pulse burst and the force level can even change between opposite extremes from one twitch to the next.

In the example of coding below, pulse bursts arrive every 8 ticks in a string of Ψ-forms. The code omits r and X symbols for purposes of simplicity and denotes the variable force strength by a, b, c and d in the various bursts and twitches:

```
det:  NaNPR   NbNPR   NcNPR   NdNPR
eff:     PqQaQqR PqQbQqR PqQcQqR PqQdQqR
```

6. A Virtual Energy Store controls operations of a bursting device.

The figure below shows operations of a burster Virtual Energy Store (bVES) in a repeating bursting device ("burster"). Discharges of pulse bursts (OOO) in a burster resemble discharges of twitches (qQQQq) in a force fiber. Output bursts "repeat" input pulse bursts: output n=input n. For purposes of illustration, pulse bursts arriving at the detector in the figure below are the same as those arriving at the force fiber detector in the previous figure, rather than repeating signals.

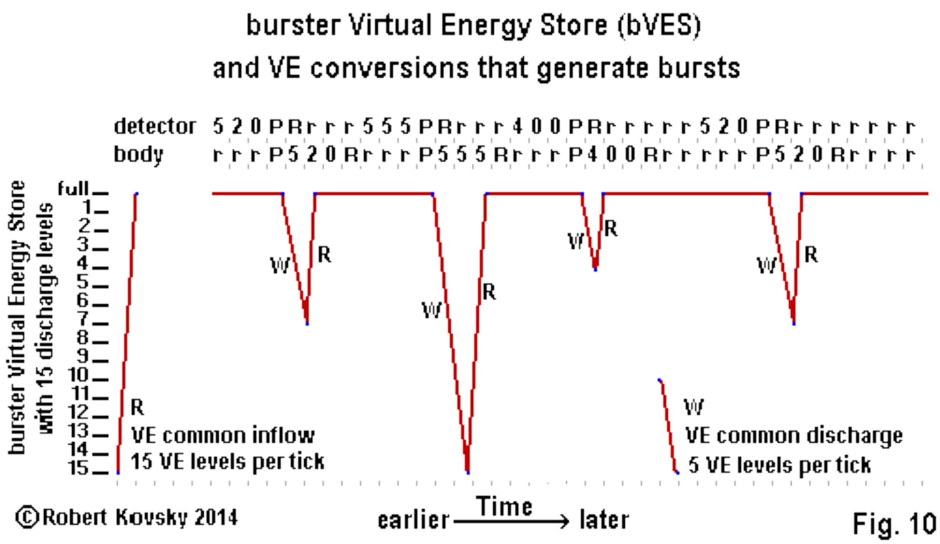


Fig. 10

Comparison of bVES operations with those of the prior eVES shows that, in both devices: during 3 initial N ticks, an incoming signal sets a level of discharge in a VES; processing occurs during a 4^{th} P tick; discharge begins at the start of the 5th tick. Both refills follow the same form.

Conversions of VE to pulses differs from conversions in the twitch design where an eVES discharge has a fixed period of time (5 ticks) and the rate of discharge [Δ(eVES)/Δt] varies according to the discharge level. In the burster device, a bVES discharge occurs at a fixed rate W (5 pulses per tick) for a variable period. In the figure above, discharge takes less than 1 tick for the 400 burst and a full three ticks for the 555 burst.

Another difference involves timing of VE discharges. In the force fiber device, VE discharge starts exactly "on the tick" – at the beginning of the first q tick. The raw force ratio Δ(eVES)/Δt reaches full value immediately and dissipation during a ramping tick allows for further control. In contrast, the burster device has a strict specification that resembles that seen in multi-pulsers, where VE for the first pulse must gather before discharge. Here the leading output pulse must appear exactly on the tick. Hence, VE discharge must start prior to the start of the first O tick, namely, 1/5 of a tick prior thereto. In other words, in order to have a leading pulse ready at the commencement of the first output tick, VE discharge must begin 0.8 of the way through the prior P tick and VE must gather for 0.2 ticks. Presumptively, the processing tick can accommodate necessary gathering of VE, perhaps with a fine-tuning adjustment. In initial designs, the external master clock sets a ticking beat that controls and synchronizes operations of all devices.

Adapting that for force fiber devices, the following code for a burster device shows pulse bursts received by the detector and discharged by the projection; pulse numbers appear as a, b, c and d.

```
det:   NaNPR   NbNPR   NcNPR   NdNPR
proj:     POaOR   PObOR   POcOR   POdOR
```

7. Two opposing duets produce a spectrum of balancing positions.

The figure below shows two equal and opposing duets, each affixed at one end and connected to the other duet at the other end. Outside the figure, a pair of reciprocating bursters sends bursts to the left duet with pulse number m; similarly, an independent pair of reciprocating bursters sends bursts with pulse number n to the right duet. The paradigm establishes relations between pulse numbers and spatial locations in a spectrum of balancing positions. It aims towards projects that mimic movements of eyes of animals, as previously suggested in *Eyes that Look at Objects*.

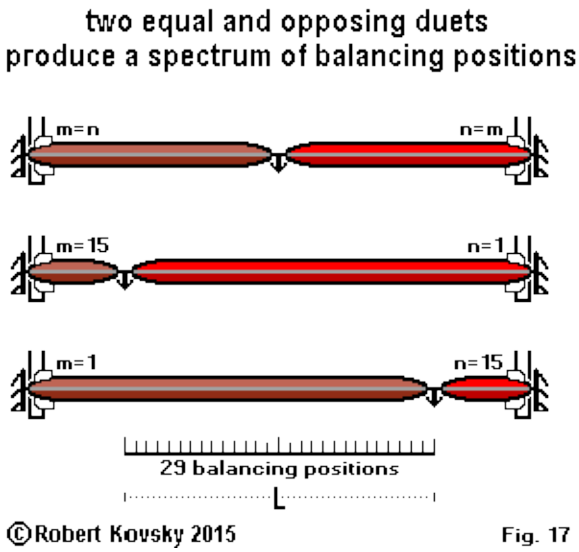


Fig. 17

The top image shows the duets in center-point balancing, where equal pulse bursts are sent to the two duets; that is, m=n. When signals are equal, the indicator arrow is centered and the location is called ***midline***. Equal forces and a centered indicator at midline can occur for pulse numbers of any size, from 1 to 15.

The range of motion in the paradigm is denoted by L. An end-of-range position occurs when one duet is driven by bursts with pulse number 1 and the other duet is driven by bursts with pulse number 15. At such limit positions, one duet is fully extended and the other duet is fully contracted.

In this version, devices at full extension have a length that is 5 times the length of devices at full contraction. That is, for each force fiber device, $\ell_1 = 5L/4$ and $\ell_0 = L/4$. $L+2\ell_0$ is the distance between points of affixation; and the distance from each such point to midline is 3L/4.

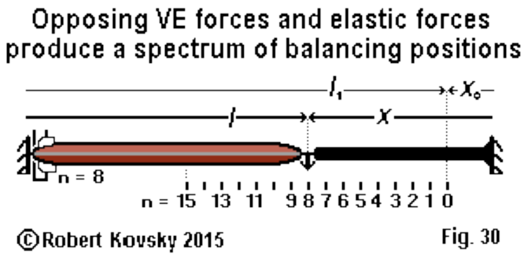
Recall the definition of force for a contracted device: $\mathcal{F} = n\mathcal{F}_1 - j(\ell_1 - \ell_x)$. To adapt it, let x be measured from midline, with positive values to the right. Then, balancing is expressed by: $F_m = F_n$, where $F_m = mF_1 - j(3L/4+x)$ and $F_n = nF_1 - j(3L/4-x)$. For duets to be in balance at extreme positions (e.g., x=L/2), $15F_1 - 5jL/4 = F_1 - jL/4$; or $j = 14F_1/L$.

In the $j = 14F_1/L$ system, 29 equally spaced balancing positions are defined by $x/L = (n-m)/28$, where $-\frac{1}{2}L \le x \le \frac{1}{2}L$. When n>m, balancing positions are to the right of midline. When m>n, balancing positions are to the left. Except at endpoints of the range of movement, multiple pairs of (m,n) hold the balance.

8. In “wavemaker” designs, an array of force fiber duets, driven by increasingly complex burster hookups, produces various waves and other movements.

a. A force fiber duet opposing an elastic fiber produces a spectrum of balancing positions similar to that produced by two opposing duets.

The figure below shows a force fiber duet that opposes and balances forces produced by an elastic fiber. Similar to the preceding opposing duets paradigm, there is a linear spectrum of balancing positions.



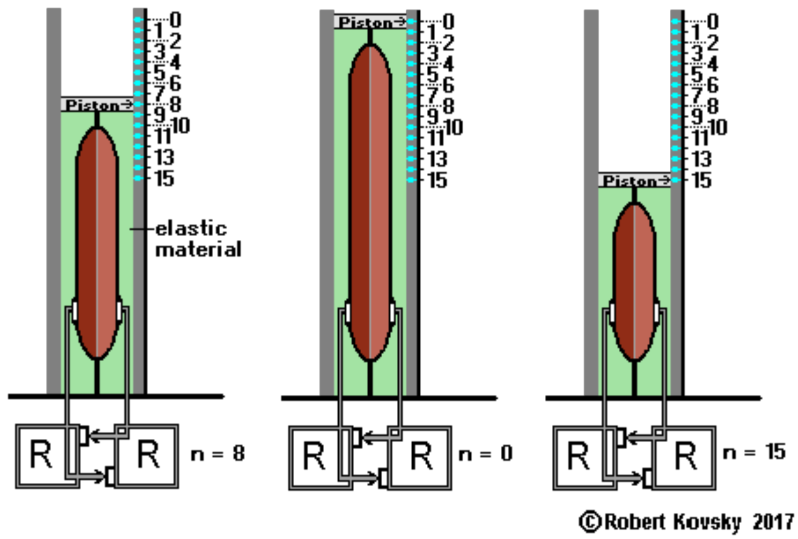
Balancing positions in the adjacent figure are defined by $nF_1 - j(l_1 - l) = k(x - x_0)$, where k is the “spring constant” of the elastic fiber. Contraction of the duet and stretching of the elastic fiber are equal, so $(l_1 - l) = (x - x_0)$; and $l_1 - l = nF_1/(j+k)$. When $n = 0$, the elastic fiber is fully relaxed at $x = x_0$ and, at $l = l_1$, the force device has a minimal tension presumed to be nil. Forces rise on both sides when n increases, but with a differential; and the balancing position shifts.

b. A movement module containing a force fiber duet and elastic materials can produce a spectrum of holding positions and move between positions.

In this paradigm, a movement module takes on variable lengths. Inside a module, a force fiber duet provides a variable contractile force. The duet is imbedded in bulk elastic material, e.g., urethane foam, that provides the opposing stretching force. The length of the module varies according to the pulse number of bursts sent to the duet.

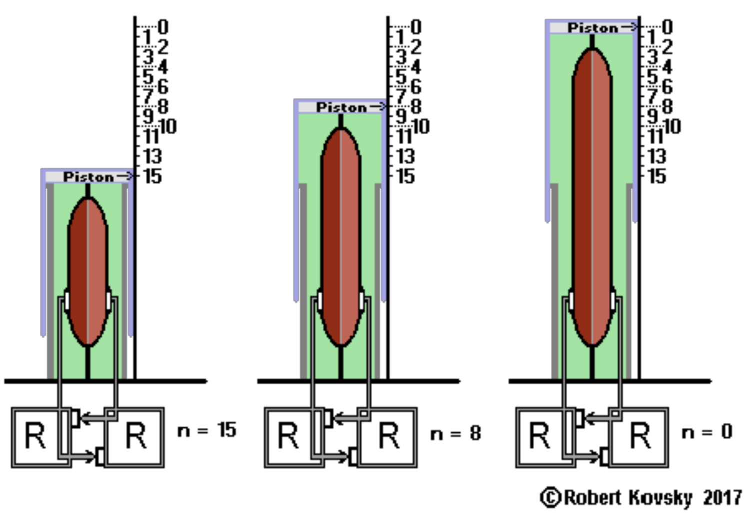
In the adjacent figure, a variable balance of forces is produced in a cylindrical container, similar to that used in defining the primal twitch, above. A force fiber duet stretches between a fixed end and an end attached to a movable piston. Contractile forces produced by force fiber devices are opposed and balanced by expansionary forces from compressed elastic materials. Force fiber devices are driven by repeating and reciprocating bursters that maintain specific pulse numbers n.

linear spectrum of balancing positions produced by opposing VE and elastic forces (clindrical version)



The figure above shows operations for n = 8, n = 0 and n = 15. Linearity in the nearby scale that shows ROM is based on the elastic fiber paradigm. Endpoint operations are produced with n = 0 and n = 15. When n = 0, bursters are silent, force fibers have nil contractile force and elastic material are fully expanded. Maximum activations and compression of materials occur when n = 15. The design has 16 holding positions, which make up a linear spectrum or scale in space.

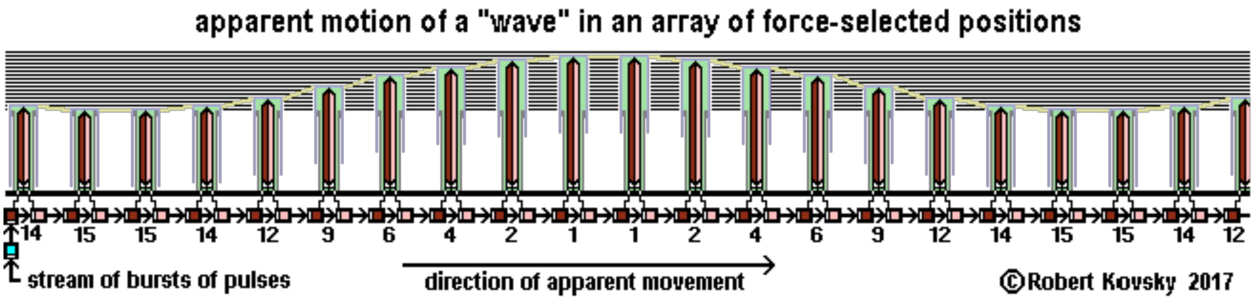
same: capsule version



An improvement to the paradigm leads to the ***capsule version*** shown in the adjacent figure, where a slightly wider upper cylinder glides easily over a slightly narrower lower cylinder; the lower cylinder is fixed and the upper cylinder is mobile. The capsule is self-contained and distinct from the bursters attached to it. The capsule will stay the same while burster designs are developed. The three examples from the previous cylindrical version are shown in the capsule version.

c. A "primal wavemaker" produces changing vertical movements in an array of capsules, creating an appearance of moving like a horizontal wave.

An array of capsules and bursters called a "primal wavemaker" is shown in the figure below. In this design, the top surface of each capsule is physically attached to the top surfaces of its neighbors by elastic bands that maintain a continuous surface over the array, like a skin. Such elastic bands stretch easily and have negligible energy storage.



A researcher injects a stream of pulse bursts into the array at the lower left corner of the figure. Bursts of a particular size move from left to right in successive transfers between bursters. At any particular capsule, a discharge of the left, darker burster ***leads*** the subsequent discharge of the right, lighter burster, which thus ***follows***.

In a first operation, each leader burster drives a darker force fiber and sets the discharge level of its follower burster. During a second operation, each follower burster drives a lighter force fiber and sets the leading burster at the neighboring downstream capsule; this is a ***shift*** operation. The two operations alternate, producing a full shift every eight ticks. As a result of continual shifting, capsules move in vertical positions and create an apparent collective "wave" of movement.

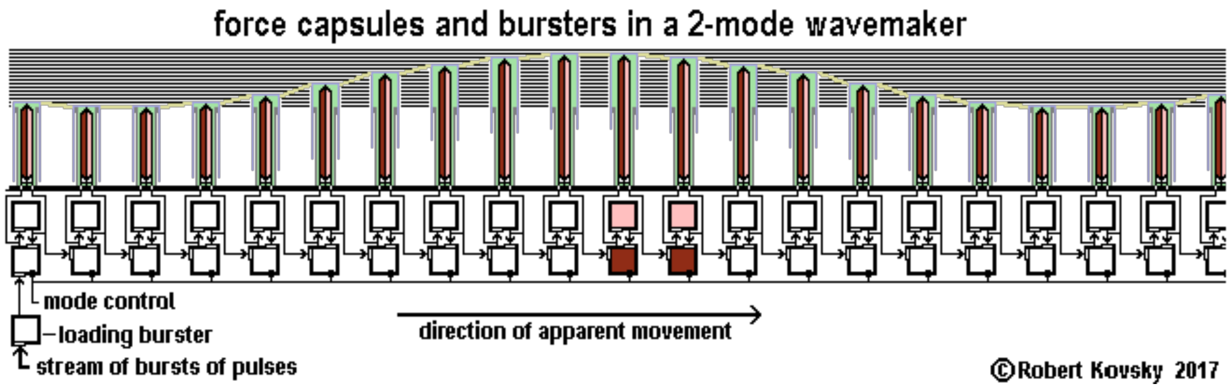
To start, rates of shift of pulse bursts are slow ("quasi-static") in comparison with relaxation times of elastic materials. Movements between positions are limited to small changes; e.g., in the figure, changes between pulse numbers are in the range of [0, 3] with a parallel range of changes in positions. Stretching of elastic bands is similarly restricted to a small range.

An exemplar of operations is provided by four successive bursters in the array, call them C, D, E and F. Each burster processes signals with a detector ("det") and a projection ("proj"). The code extract below describes a flow of successive signals n, o, p, q, r, s and t in C, D, E and F. At the start of the extract, burster C detects signal p (as it arrives); and burster F discharges signal n (its only appearance). Signal o is being transferred from burster D to burster E.

```
Operational chart for C, D, E and F in the primal wavemaker

C-det    NpNP    NqNP    NrNP    NsNP    NtNP     ...
C-proj      POpOR   POqOR   POrOR   POrOR   POtOR ...

D-det        NpNP    NqNP    NrNP    NsNP    NtNP ...
D-proj   OoOR   POpOR   POqOR   POrOR   POsOR     ...

E-det    NoNP    NpNP    NqNP    NrNP    NsNP     ...
E-proj      POoOR   POpOR   POqOR   POrOR   POsOR ...

F-det        NoNP    NpNP    NqNP    NrNP    NsNP ...
F-proj   OnOR   POoOR   POpOR   POqOR   POrOR     ...
```

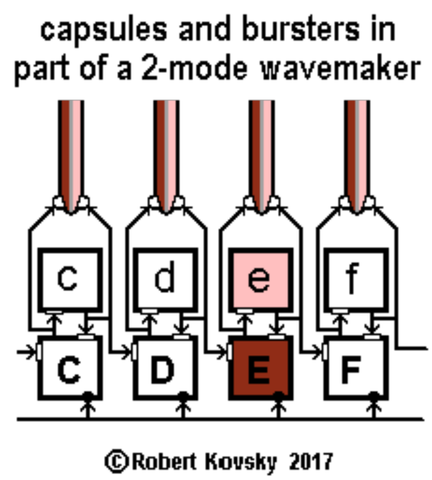
d. In a 2-mode wavemaker, the array of capsules and bursters can either hold a fixed position or process a stream of bursts of pulses, according to mode control pulses.

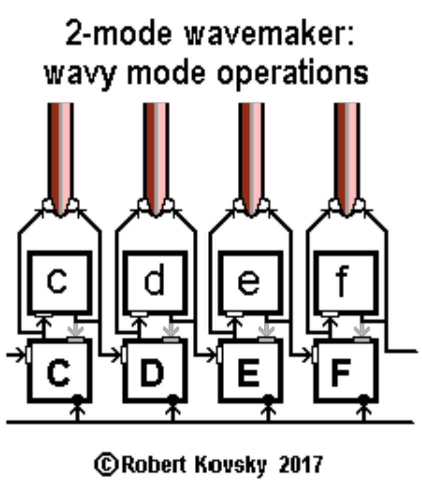
The figure below shows development of the array of capsules and bursters. This paradigm has two modes of operations, a wavy mode like that produced by the previous array and a holding mode that maintains a steady position. Individual pulses over the ***mode control*** input change the mode for a cycle. Mode control pulses anticipate timing device designs described below.

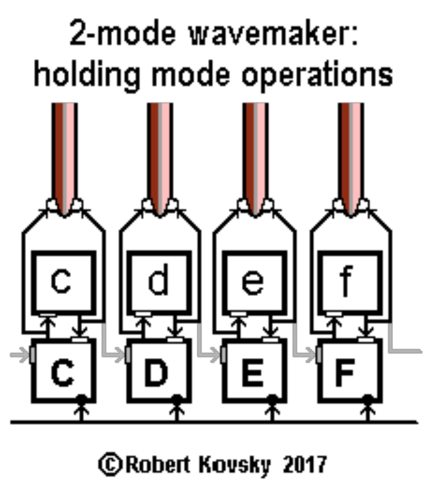


In the adjacent figure. a closer view of 4 exemplary capsules and 8 driving bursters in the 2-mode wavemaker shows a repeating pattern that connects across edges, called a "tiled construction." In each tile, an encapsulated duet of force fiber devices is driven by a couple of bursters. Each burster couple shares a letter; C-c, D-d, E-e, F-f — and the capital letter indicates the (darker) leading burster.

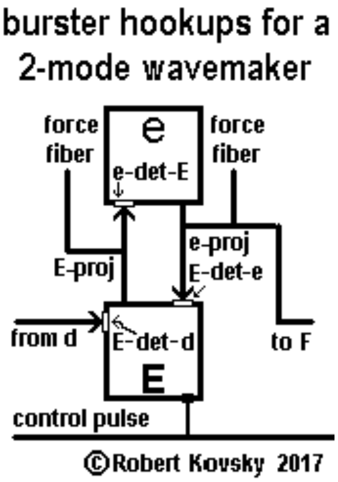
A leading burster has two detectors. One detector receives bursts from the leader's own follower; the other detector receives bursts from the upstream following burster. Only one detector is operative during a particular tick, based on signals (or their absence) over the mode control line.







The adjacent figures show the two modes. In each figure, one detector in each leading burster is blocked and the grayed projection to it has no function. Wavy mode operations are the same as in the primal wavemaker. In holding mode, capsules and attached bursters operate without interaction or change.



Burster connections for an exemplary burster couple in the two-mode wavemaker are shown in the adjacent figure. The detector of the following burster e, labeled e-det-E, receives pulse bursts from the leading burster E. The projection from burster e is labeled e-proj; it (1) drives a force fiber device; (2) sends bursts to leading burster E through its detector E-det-e; and (3) sends bursts on a projection that connect to burster F. E has a second detector labeled E-det-d that receives pulse bursts from burster d in the D-d couple. E's projection, E-proj, sends bursts to a force fiber device and to e through e-det-E. E receives control pulses over the mode control line.

There are two versions of the 2-mode wavemaker. In Version A, the holding mode is the default mode; that is, the holding mode operates in the absence of control pulses. In Version B, the wavy mode is the default mode. The operational chart below encodes a change in an exemplary E-e burster couple in a Version A wavemaker on receipt of a control pulse. The reciprocating burst signal prior to the change is denoted s. That is, prior to the change, one burster's discharge OsO matches the other's burster's receipt NsN. During a change, signal r is imported from burster d in the D-d couple. The pulse received over the mode control line is denoted ~. That pulse is timed to arrive at the start of the 8th tick of a Ψ-form of E; and it switches the active detector in the next Ψ-form of E for the first 4 ticks.

Operational chart for bursters E and e (holding mode default)

```
E-control                   ~
E-det-d  XXXXXXXXXXXXXXXXXXXXNrNPXXXXXXXXXXXXXXXXXXX . . .
E-det-e      NsNP    NsNP    XXXX    NrNP   NrNP     . . .
E-proj   OsOR   POsOR   POsOR   POrOR   POrOR  POrOR . . .
e-det-E  NsNP    NsNP    NsNP    NrNP    NrNP   NrNP . . .
e-proj      POsOR   POsOR   POsOR   POrOR   POrOR    . . .
```

The operational chart for e and E can be simplified through use of ***condensed code***, where each symbol represents 4 ticks. The following chart is equivalent to the chart above. The arrival of the E-control pulse occurs at the start of the first tick in a 4-tick unit of condensed code and this determines how 4-tick units of code are defined. Prior to a shift, an s pulse burst is maintained in holding operations. Arrival of the control pulse (~) causes a switch in the receptive detector to E-det-d for four ticks, leading to the detection of the r pulse burst and the establishment and maintenance of the r pulse burst in steady operations thereafter.

As above but with 1 symbol = 4 ticks

```
E-control     ~
E-det-d  XXXXXrXXXXXX
E-det-e   s s X r r
E-proj   s s s r r r
e-det-E  s s s r r r
e-proj    s s s r r
```

The snippet of code below that is labeled "`shift step`" represents an exemplary movement in the C-D-E-F bank of bursters and force devices. Before the shift step, operations are steady, with burst q in burster couple C-c, burst r in D-d, burst s in E-e and burst t in F-f. After a shift step, signals are again steady, with burst q shifted to D-d, burst r shifted to E-e and burst s shifted to F-f. Burst t has been shifted away, perhaps into G-g. A new burst has arrived, namely, burst p, which has been shifted to C-c. That is:

```
shift step
qrst
pqrs
```

Condensed code in the operational chart below tracks operations of C-D-E-F during the foregoing shift step operation. Before the shift, bursts are denoted as q, r, s and t, reading down the left side. After the shift, bursts are denoted as p, q, r and s, reading down the right side. Shifts occur at specific locations in the coding, e.g., a compact set of three symbols (q ~ q) denotes the shift of q from `c-proj` to `D-det-c`.

```
Operational chart for a shift step

C-control     ~
C-det-b  XXXXXpXXXXX
C-det-c   q q X p p
C-proj   q q q p p p
c-det-C  q q q p p p
c-proj    q q q p p

D-control     ~
D-det-c  XXXXXqXXXXX
D-det-d   r r X q q
D-proj   r r r q q q
d-det-D  r r r q q q
d-proj    r r r q q

E-control     ~
E-det-d  XXXXXrXXXXX
E-det-e   s s X r r
E-proj   s s s r r r
e-det-E  s s s r r r
e-proj    s s s r r

F-control     ~
F-det-e  XXXXXsXXXXX
F-det-f   t t X s s
F-proj   t t t s s s
f-det-F  t t t s s s
f-proj    t t t s s
```

Separate shift steps can follow each other in an arbitrary fashion so long as 8 ticks (or a multiple thereof) pass between any two control pulses. The ***shifting episode*** below is produced by 5 control pulses with intervals of 8 ticks.

```
shifting episode
qrst
lmno
```

```
Operational chart for shifting episode

C-control      ~ ~ ~ ~ ~
C-det-b  XXXXXp o n m l XXXXX
C-det-c   q q X X X X X l l l
C-proj   q q q p o n m l l l
c-det-C  q q q p o n m l l l
c-proj    q q q p o n m l l l

D-control      ~ ~ ~ ~ ~
D-det-c  XXXXXq p o n m XXXXX
D-det-e   r r X X X X X m m m
D-proj   r r r q p o n m m m
d-det-D  r r r q p o n m m m
d-proj    r r r q p o n m m m

E-control      ~ ~ ~ ~ ~
E-det-d  XXXXXr q p o n XXXXX
E-det-e   s s X X X X X n n n
E-proj   s s s r q p o n n n
e-det-E  s s s r q p o n n n
e-proj    s s s r q p o n n n

F-control      ~ ~ ~ ~ ~
F-det-e  XXXXXs r q p o XXXXX
F-det-f   t t X X X X X o o o
F-proj   t t t s r q p o o o
f-det-F  t t t s r q p o o o
f-proj    t t t s r q p o o o
```

Pulse burst patterns during the shifting episode are "the same as" pulse patterns in the primal wavemaker. The operational identity remains while there is a flow of control pulses every 8 ticks. As noted above, a version A array is in holding mode in the absence of control pulses. In a version B array, operations are in wavy mode in the absence of control pulses but they are subject to a hold for 8 ticks on arrival of a control pulse. A flow of control pulses every 8 ticks in a version B array can hold the pattern indefinitely.

e. Further development of the wavemaker array adds operations of a third "substitutionary mode" where signals are changed throughout the array.

The figure below shows further development of the wavemaker array. New ***substitutionary bursters***, denoted by script $\mathcal{C}$, $\mathcal{D}$, $\mathcal{E}$ and $\mathcal{F}$ send signals to a new set of detectors in bursters C, D, E and F respectively. E.g., $\mathcal{E}$ sends control pulses and bursts to E through a new detector E-det-$\mathcal{E}$. New projections sent from a remote location, e.g., a source under the control of the researcher, carry pulse bursts to the substitutionary bursters during the first three ticks of a Ψ-form. The substitutionary bursters immediately send control pulses to their respective leading burster, each of which switches its receptive detector to a signal from the substitutionary bursters in the next Ψ-form. Arrival of a control pulse from $\mathcal{E}$ blocks the junction that receives mode control pulses for a lengthy period, perhaps a dozen cycles, while the substituted pattern become established.

Substitutions occur over the entire array at one time. The general conception is that another group of burster devices is operating at the remote location. Remote burster devices can participate in collective operations, such as synchronous collective operations of Quad Net devices. The whole wave movement is generated at a single time and distributed to the substitutionary bursters. Substitutionary movements can supersede wavy movements. Then it is collective cycling activity of a group of Quad Net devices that drives the wave of apparent movements in the array of force capsules.

9. A tube for transport moves an object: encircling force devices tighten and relax in waves, with timings controlled by reverse triggering of an array of bursters.

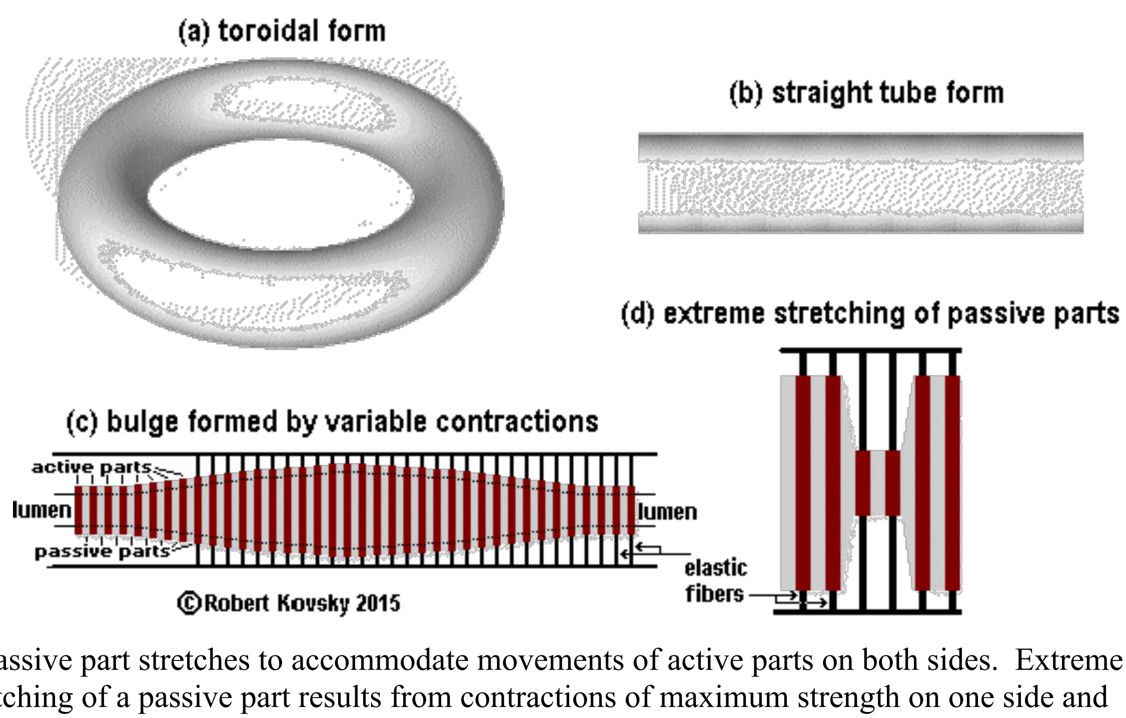
a. A tube for transport is built from sections with a uniform design that combines a rigid tube, elastic materials and a Virtual Energy force device.

Movements in this design occur inside a rigid tube that is like a plumber's tube made of polyvinyl chloride (PVC). A toroidal form is symmetrical as to all portions (Fig. 28(a)). Movements inside a toroid are similar to movements near the central portion of a straight tube form (Fig 28(b)). Each form has certain uses. The symmetries of a torus simplify analysis while straight tubes are easier for figures. Differences between the two forms diminish as the number of internal parts increases. Here, the two forms are treated as equivalent.

Internally, a tube for transport is a tiled construction with two kinds of parts, arrayed in an alternating sequence: active parts (red) are powered by Virtual Energy and passive parts (gray) have negligible energy values. (Fig. 28c, 28d.) Each part is a smaller toroid or donut shape with an inside hole. Connected insides of parts/toroids form a central channel or ***lumen***. The lumen is internally bounded or covered by a slick elastic membrane that is attached to the inner sides of all the parts, forming an internal toroid or straight tube as the case may be.

An active part produces a contractile force that is opposed by ***elastic fibers*** affixed to the inside of the rigid tube. A variable pulse-burst signal produces variable contractions; an array of variable contractions can form a ***bulge*** that moves an enclosed object, e.g., a ping pong ball.

A tube for transport: large-scale view



A passive part stretches to accommodate movements of active parts on both sides. Extreme stretching of a passive part results from contractions of maximum strength on one side and minimum strength on the other side. (Fig. 28.d.) To minimize stretching of passive parts in this design, pulse numbers of burst signals differ by at most "one pulse" between any active part and a neighboring active part. Bulges are rather flat. Rounder bulges could be formed with greater stretching of passive parts. In this delicate design, force differences are minimized.

b. Inside a tube for transport, the aperture opening of each section is set by a variable balance between elastic forces and forces from a force fiber duet.

As shown in the figure below, an active part in a tube for transport uses the duet force device previously discussed, modified into a circular force device with variable radius r. The duet produces contractile forces that are balanced by forces produced by elastic fibers, each attached at one end to a sleeve element around the duet and at the other end to the inside of the tube.

Variable aperture openings form a linear series. Fig. b views a bulge from inside. When an active part is in a fully relaxed condition, it has a pulse number of 0 and an aperture radius of r_1.

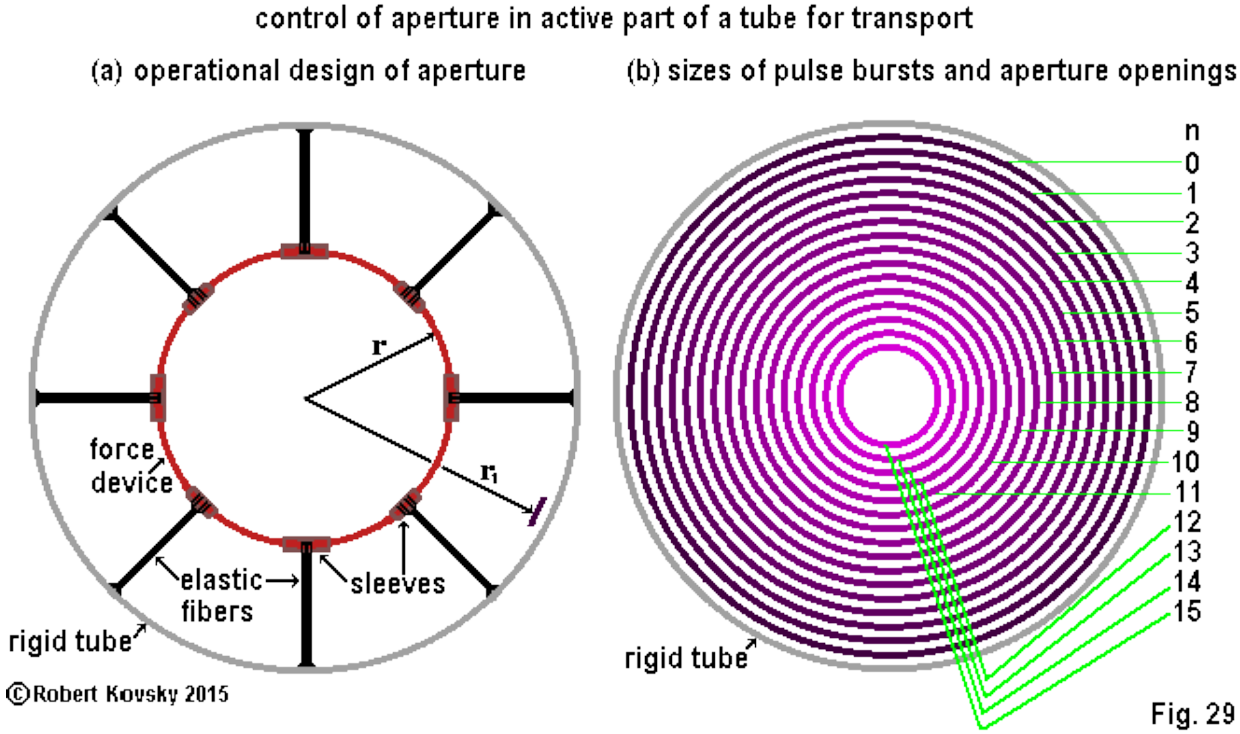


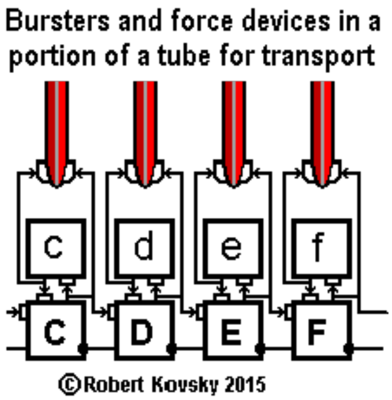
Fig. 29

Recall the elastic fiber paradigm above that balances forces from a duet with those of an elastic fiber. The length contraction of the duet depends on the pulse number: $l_1 - l = nF_1/(j+k)$. Application of the foregoing principles to the operational design of the aperture here leads to $r = r_1 - nF_1/(2\pi j + mk)$ where k is the "spring constant" for one elastic fiber and m is the number of elastic fibers, or m=8 in Fig. 29. A further refinement would hold mk fixed while the number of elastic fibers is increased. Conceptually, as the number of elastic fibers increases, they become a membrane that has a continuous elastic sleeve around the force device. It is anticipated that, as part of development, such a membrane will separate two modules in a tiled construction that resembles a segmented worm.

c. An array of bursters produces changes in aperture openings and moves an object (e.g., a ping pong ball) through the lumen of a tube for transport.

A tube for transport moves an object enclosed in a bulge – e.g., a ping pong ball — by shifting a pattern of aperture openings. When a movement occurs: first, space opens in front of the object; next, the opening of space spreads back over the top; then, once over the top, opening becomes closing – and force devices near the back of the object push it forward into the open space.

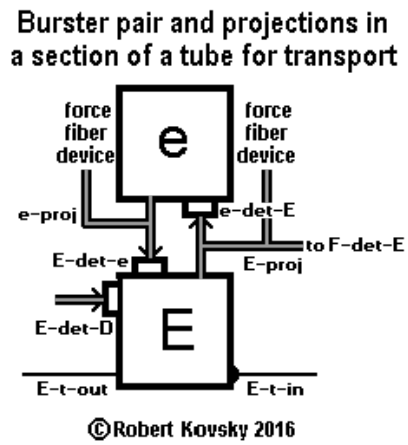
Movements inside a tube for transport thus combine forward movements caused by pushes at the back and opening movements that start at the front and spread back over the top. The latter movements depend on "reverse triggering." In some respects, shifting inside a tube for transport resembles movements in a wavemaker – and there are also distinct differences.



The adjacent figure shows an arrangement of VE force fiber devices and bursting devices in a portion of a tube for transport. The large-scale layout of force fiber devices and coupled bursters – C-c, D-d, E-e and F-f – is the same as for the wavemaker. Differences appear in attachments of projections. During a shift, E is set by D rather than by d, as in the wavemaker.

In the adjacent image, burst signals arrive at e only through e's detector, labeled ***e-det-E***, that receives bursts on a projection from burster E that is labeled ***E-proj***. In addition to carrying signals to e-det-E, E-proj sends the same signals to a force fiber device and to detector F-det-E on burster F.

Similarly, a burst signal from e is carried on ***e-proj*** to a force fiber device and to a detector on E labeled ***E-det-e***. E also receives a signal from D at detector ***E-det-D***.



As in wavemaker designs, only one of two detectors (E-det-e and E-det-D) can be receptive to signals at any moment; the other detector is blocked. Default operations are that E-det-e is receptive and E-det-D is blocked; default aperture openings are kept steady.

During a shift cycle, the receptive detector is switched from E-det-e to E-det-D. E receives a burst signal from D instead of from e. The cycle starts with the arrival of a trigger pulse from F over ***E-t-in***. During the cycle, a trigger pulse is discharged onto D over ***E-t-out***. As with the wavemaker, it is possible to produce multiple shifting operations; in a sequence of shifts, E receives a pulse burst from D and passes it to F. In such movements, pulse bursts travel in the direction of object movement and trigger pulses travel in the reverse direction.

The snippet of code below, labeled "`shifts to`," represents a single shift step of movement in the C-D-E-F bank of bursters and force devices. Before the shift, signals are steady, with burst q in burster couple C-c, burst r in couple D-d, burst s in couple E-e and burst t in couple F-f. After a shift, signals are again steady, with burst q in burster couple D-d, burst r in couple E-e and burst s in couple F-f. A new burst signal p has shifted onto couple C-c from burster B to the left of the figure; and burst signal t has shifted off the figure, onto G-g. That is:

```
shift step
qrst
pqrs
```

In the operational chart for bursters e and E below, activity starts with discharge by E of signal OsO, detected as NsN at e. After steady holding, a trigger pulse arrives via E-t-in (~) at the start of E's 8th tick. Eight ticks later, a trigger pulse is discharged over the E-t-out line (!). Between trigger pulses, the receptive detector is switched from E-det-e to E-det-D for four ticks; and the new signal NrN, arriving through E-det-D, takes up occupancy in the E-e pair.

```
Operational chart for shift step
E-t-in                      ~
E-det-D  XXXXXXXXXXXXXXXXXXXXNrNPXXXXXXXXXXXXXXXXXXX . . .
E-det-e      NsNP    NsNP    XXXX    NrNP   NrNP     . . .
E-proj   OsOR   POsOR   POsOR   POrOR   POrOR  POrOR . . .
e-det-E  NsNP    NsNP    NsNP    NrNP    NrNP   NrNP . . .
e-proj     POsOR   POsOR   POsOR   POrOR   POrOR     . . .
E-t-out                                 !
```

As before, charts are simplified by means of condensed code. Prior to a shift, an s pulse burst is maintained in steady operations. Receipt of a trigger pulse (~) causes a switch of the receptive detector to E-det-D for one cycle, leading to the detection through E-det-D of the r pulse burst, which becomes established in steady operations.

```
Operational chart for shift step (condensed code)
E-t-in          ~
E-det-D  XXXXXrXXXXX
E-det-e   s s X r r
E-proj   s s s r r r
e-det-E  s s s r r r
e-proj    s s s r r
E-t-out          !
```

The operational chart below tracks operations of sections C, D, E and F during a shifting operation. Code lines have been re-arranged to show that the wave of trigger pulses moves in the reverse direction — from F to E to D to C — while the signal pattern p-q-r-s-t moves in the forward direction, from C to D to E to F, causing forward movement of the object in the lumen.

The movement of trigger pulses is in the direction that is opposite to that of burst transmission and actual movement of the object. Triggering is "reversed." In other words, forward projection and reverse triggering both control movement but in different ways. Forward projection controls the ***strength*** of the movement while reverse triggering controls the ***timing*** of the movement.

The following "`shifts to`" code snippet represents a shift step movement.

```
shift step
qrst
pqrs
```

```
Operational chart for a shift step

C-t-out              !
C-det-B  XXXXXXXXXXXp XXXX
C-det-c   q q q q q X p p
C-proj   q q q q q q p p p
c-det-C  q q q q q q p p p
c-proj    q q q q q q p p
C-t-in              ~

D-t-out            !
D-det-C  XXXXXXXXXq XXXXXX
D-det-d   r r r r X q q q
D-proj   r r r r r q q q q
d-det-D  r r r r r q q q q
d-proj    r r r r r q q q
D-t-in             ~

E-t-out            !
E-det-D  XXXXXXXr XXXXXXXX
E-det-e   s s s X r r r r
E-proj   s s s s r r r r r
e-det-E  s s s s r r r r r
e-proj    s s s s r r r r
E-t-in           ~

F-t-out          !
F-det-E  XXXXXs XXXXXXXXXX
F-det-f   t t X s s s s s
F-proj   t t t s s s s s s
f-det-F  t t t s s s s s s
f-proj    t t t s s s s s
F-t-in         ~
```

Each shift step is produced through a distinct wave. Separate shift steps can follow each other in an arbitrary fashion so long as 8 ticks (or a multiple thereof) pass between any two trigger pulses. The ***shifting episode*** set forth below is produced by 5 trigger pulses with 8 ticks between successive trigger pulses.

```
shifting episode
qrst
lmno
```

```
Operational chart for a shifting episode

C-t-out               ! ! ! ! !
c-det-C  q q q q q q p o n m l l l l l l
c-proj    q q q q q q p o n m l l l l l
C-det-c   q q q q q X X X X X l l l l l
C-proj   q q q q q q p o n m l l l l l l
C-det-B  XXXXXXXXXXXp o n m l XXXXXXXXXX
C-t-in              ~ ~ ~ ~ ~

D-t-out             ! ! ! ! !
d-det-D  r r r r r q p o n m m m m m m m
d-proj    r r r r r q p o n m m m m m m
D-det-d   r r r r X X X X X m m m m m m
D-proj   r r r r r q p o n m m m m m m m
D-det-C  XXXXXXXXXq p o n m XXXXXXXXXXXX
D-t-in            ~ ~ ~ ~ ~

E-t-out           ! ! ! ! !
e-det-E  s s s s r q p o n n n n n n n n
e-proj    s s s s r q p o n n n n n n n
E-det-e   s s s X X X X X n n n n n n n
E-proj   s s s s r q p o n n n n n n n n
E-det-D  XXXXXXXr q p o n XXXXXXXXXXXXXX
E-t-in          ~ ~ ~ ~ ~

F-t-out         ! ! ! ! !
f-det-F  t t t s r q p o o o o o o o o o
f-proj    t t t s r q p o o o o o o o o
F-det-f   t t X X X X X o o o o o o o o
F-proj   t t t s r q p o o o o o o o o o
F-det-E  XXXXXs r q p o XXXXXXXXXXXXXXXX
F-t-in        ~ ~ ~ ~ ~
```

10. Wavemaker arrays of “oars” that produce propulsive movements help to explore departures from quasi-static operations and show how more highly activated operations depend on properties of materials.

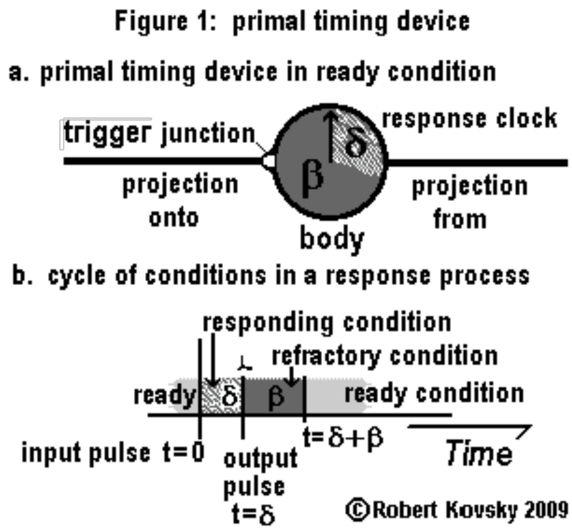
(See Cuellar, “BR3: a biologically inspired fish-like robot actuated by SMA-based artificial muscles,” at http://oa.upm.es/36254/1/WILLIAM_HERNAN_CORAL¬_CUELLAR.pdf)

C. Timing devices

1. The primal timing device

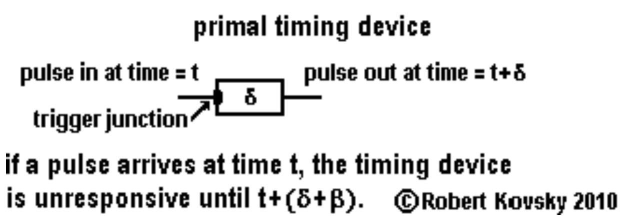
a. operational definition

As shown in Fig. a below, the primal timing device has a ***body*** and two projections: (1) a ***projection from*** that carries output pulses away from the body and (2) a ***projection onto*** that carries input pulses to the body and that attaches to the body through a ***trigger junction***. As shown in Fig. b, the body of the device has a ***cycle of three conditions***, namely, "ready," "responding" and "refractory." If the body is in the ready condition, a pulse arriving via the projection onto will pass through the trigger junction and start a cycle of changes in the body. The cycle is tracked by the dial pointer in Fig. a below, which starts to move in a circle when a pulse arrives. The dial pointer in Fig. a, once set in motion, goes around in a circle or cycle, then stops at the starting point and awaits another input pulse.



The cycle is described by ***timing intervals δ*** and ***β***. First, the body enters into the responding condition for a specific period of time, the ***responding period***, denoted by "δ." At the conclusion of the responding period, the body discharges a pulse on the projection from and the bodily condition changes from responding to refractory, remaining in the refractory condition for a specific period of time, the ***refractory period***, denoted by "β." During the responding period and refractory period, the junction is ***blocked*** and an arriving pulse will have no effect. After the conclusion of the refractory period, the junction is ***opened*** and is ready to receive another input pulse.

In the chart of Fig. b above, beginning with a ready device, the clock is started when the input pulse arrives. After the responding period, δ, the body discharges a pulse and enters into the refractory period, β, before returning to the ready condition after a total cycle time of δ+ β.



A symbolic element for schematic designs is shown in the adjacent figure, along with definitions of timing intervals.

The function of the primal timing device is to repeat a pulse with a delay of δ. The range of performance is limited by the requirement that the minimum period between pulses is δ+β. Similar functions of primal repetition are manifest in pulsers and repeater bursting devices.

The simplest combination of timing devices is a "couple" of timing devices that resembles earlier paradigms of coupled pulsers with a material interaction and a couple of reciprocating bursters that drive a force fiber duet. See Fig. a below. Each timing device triggers the other device; timing intervals δ = 1.0 and β = 0.9 sustain such activity.

Suppose that device B discharges a pulse at clock time 0.0, as shown in Fig. b below. Receiving the pulse, device A is changed into a responding condition, which lasts from clock time 0.0 to 1.0 for the timing interval of δ =1.0. Then. at clock time 1.0, A discharges a pulse and becomes refractory for the timing interval of β or 0.9, becoming ready at clock time 1.9. Meanwhile, starting back at 0.0, device B passes through its refractory period and becomes ready at clock time 0.9 in sufficient time to be triggered by the pulse discharged by device A at clock time 1.0. Device B discharges again at clock time 2.0 and the cycle repeats. The signal on either projection is a steady pulse train with a period τ = 2δ between any two successive pulses. See Fig. c.

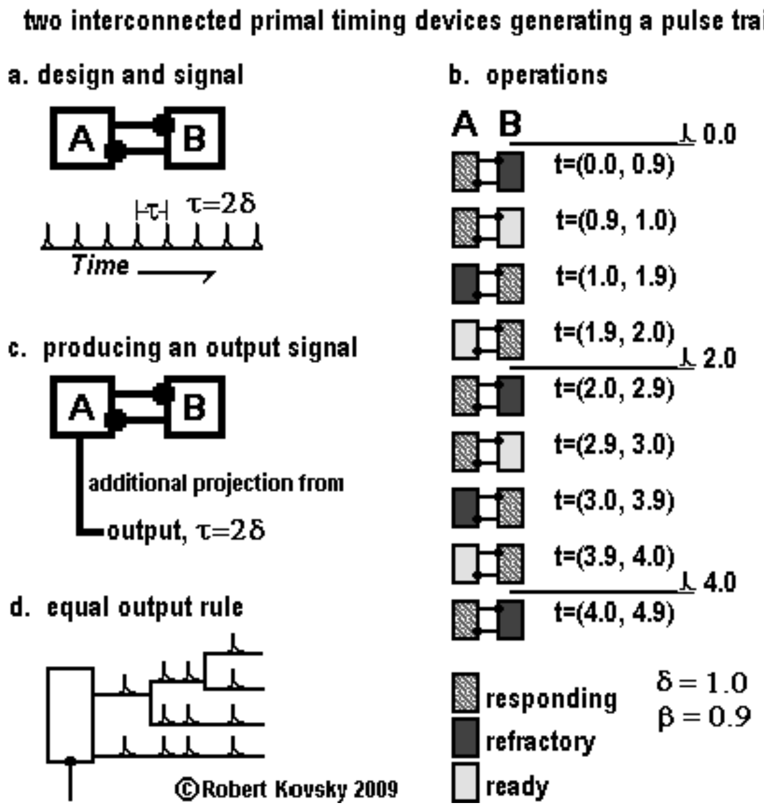


Fig. d illustrates the "equal output rule" of timing device design. If projections from are added to a device or if a projection from is ramified (split), all the resulting projections from carry pulses in an identical fashion. It is presumed that other operating features can be adjusted so as to maintain this rule. E.g., the device produces enough VE to activate several projections from simultaneously. Or a large projection from carrying large pulses subdivides to multiple mid-sized projections from carrying mid-sized pulses, each of which then subdivides further into a large number of small projections where each such projection carries small pulses of 1!. An application of the equal output rule is shown in Fig. c where an additional projection from is attached to device A for the purpose of producing an output signal.

b. The VES definition of the primal timing device is based on a more highly developed form for the VES called the Quad Net VES functional.

In pulsers and bursters, Virtual Energy Stores in primal devices appear to conform to conserved energy principles. Input VE = output VE; and VE in the VES is stored without change for an indefinitely long period. The V trace in the VES is specified by a line with a slope R. In contrast, VES operations in the primal timing device are dissipative and the V trace is curved.

Begin with an "isolated" dissipative device, namely, one not connected to another device. Operations start with a pulse discharge triggered by a researcher at time t_a. The VES is charged by inflowing VE at rate R but is also subject to a dissipative process that is proportional to the amount of VE in the VES. Let D denote a ***dissipation factor*** and suppose that D x $[V - V_0]$ denotes the rate of loss of VE through dissipation. Equation 1 states the growth in value of V.

(1) $d[V - V_0]/dt = R - D \times [V - V_0]$.

In (1), the higher V rises, the greater the dissipation. As V increases, dissipation increasingly affects the VES; the trace becomes nonlinear. Growth of V slows and reaches a maximum $V = V_0 + R/D \equiv V_m$. Equation (1) resembles models in mechanics paradigms of a frictional force that becomes stronger as velocity increases. When D = 0, the linear model returns.

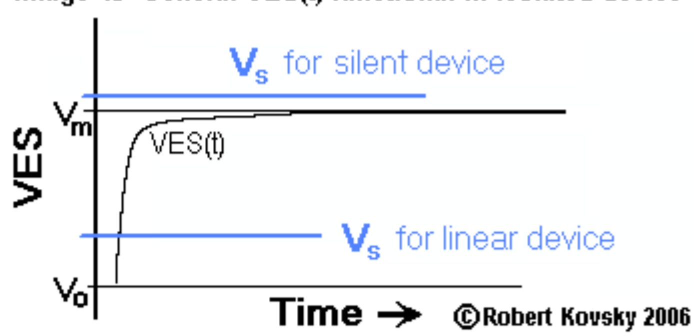
(2) $V = V_0 + [(R/D) \times (1 - \exp(-D(t - t_a))]$ solves (1) where t_a is the instant of the most recent pulse discharge of the device.

The trace in Image 45 from the 2006 *Quad Nets* essay shows the largest possible range for operations of a VES that operates according to the foregoing dissipative principles. In the more general construction that follows, the V trace becomes a ***functional*** that generates different V functions depending on device specifications and operations, e.g., the value of V_s and whether V_s is fixed or changes in a cyclical fashion. In operations of bursters and force fiber devices, prior to discharge, V_s is held just above the "full level" in the eVES or bVES. Then, during the discharge period, V_s is driven down at a specified rate for a specified period of time.

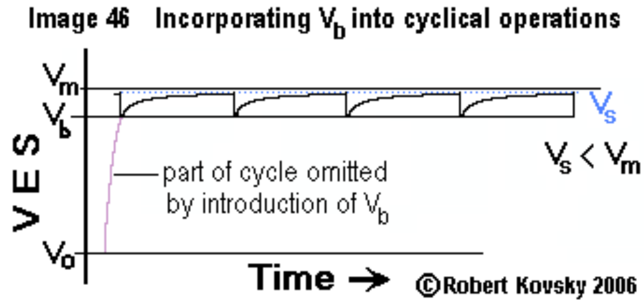
When V_s is close to V_0, there is little dissipation and linear operations.

When $V_s > V_m$. there may never be a discharge. An isolated device is ***silent*** while V approaches V_m. Below, an interaction will be added, which causes V to jump above V_s.

Image 45 General VES(t) functional in isolated device



For further development, modify the device so that V is not reset all the way to V_0 upon a discharge. Rather, there is only a "partial discharge," down to ***V_b***, a ***base VES level***. In the adjacent figure, V_s (in blue) is a little bit ***less*** than V_m. and the device discharges when $V = V_s$. After discharge, the device begins recharging at V_b rather than at V_0. It is necessary that $V_s – V_b > 1!$ and thus sufficient to produce a pulse.

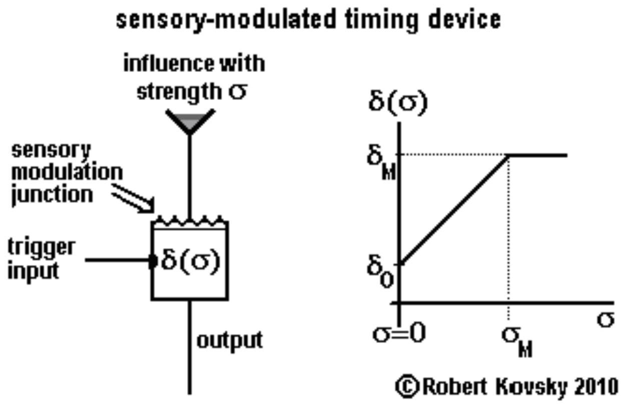


In the primal timing device, V_s is a little bit ***more*** than V_m and VE must be absorbed from an input pulse in order that the amount of VE stored in the VES become greater than V_s. Operations are specified by (1) specifications of the VES function and V quantities, which are similar to those shown above for the cyclical case above where V_s is a little bit less than V_m; and (2) specifications of the interaction resulting from an input pulse, which are similar to those used for the material interaction between coupled pulsers discussed above.

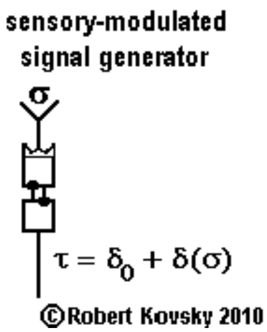
To simplify the discussion, assume that the interaction is conservative. A pulse carrying 1! of VE that arrives at the trigger junction is converted into 1! of VE absorbed by the body of the timing device. This assumption is arbitrary when compared to possible activities at a synapse between nerve cells. Conversions of energy at a synapse would appear to be subject to multiple influences and would appear to occur over a range of values. “Booster” activity at a synapse might amplify the transmission of energy so that the amount of energy absorbed by a receiving neuron from an input pulse is greater than that carried by the input pulse. As usual, speculations find a natural resting point in a conservative principle.

Assuming a conservative interaction, it is appropriate that $V_s – V_m = 0.1!$. That is, V_s is just a bit higher than V_m. Then let $V_r = V_m – 0.9!$ and V_r is the “readiness value.” Operations include blockage of the trigger junction when the amount of VE in the VES is less than V_r. When the VES level is greater than V_r, the trigger junction is open and an arriving input pulse will be absorbed and cause the discharge of an output pulse. V_b is set so that the time required for the VES to climb from V_b to V_r is equal to β.

c. Sensitive timing devices generate variable signals as a result of external stimuli.



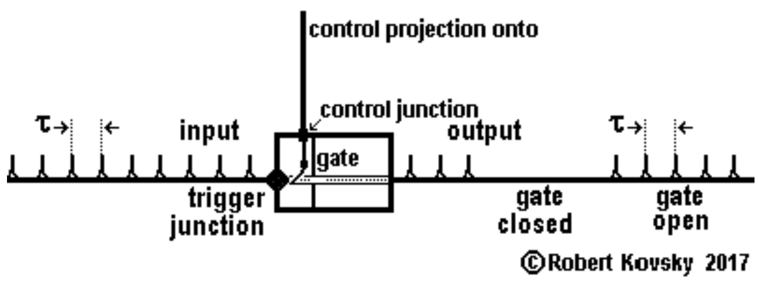
q
l



3. Gated timing devices

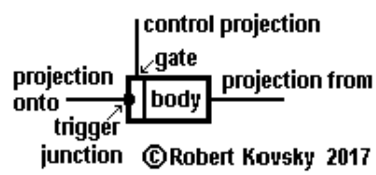
In a ***gated timing device***, depicted in the image below, a ***gate control*** is attached to the trigger junction; and the combination becomes a ***gated junction***. The gate can be in two positions, called ***open*** and ***closed***. In the first device, the gate is normally open. When the gate is open, a pulse arriving over the projection onto will activate the body and cause a discharge the same as in the primal timing device. When the gate is closed, a pulse arriving over the projection onto is blocked, similar to blockage of the trigger junction after arrival of a pulse but continuing for a longer period. A pulse arriving over the ***new control projection onto*** causes blockage of pulses for a ***closure period*** denoted by λ, which is substantially longer than the period of input pulses, denoted by τ. Perhaps λ = 6τ. At the conclusion of the closure period, the gate returns to an open condition – at least unless further control pulses arrive. Each control pulse starts a new closure period. If control pulses arrive in a steady stream with a period shorter than λ, pulses will be continuously blocked in an ongoing way.

principle of gate timing device

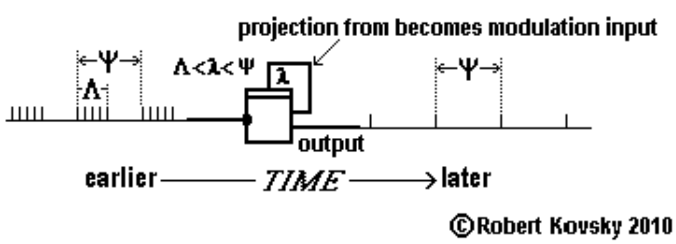


The adjacent image shows a symbolic element for the normally open gated timing device, which is used in schematic diagrams for device designs.

normally open gate device
schematic element

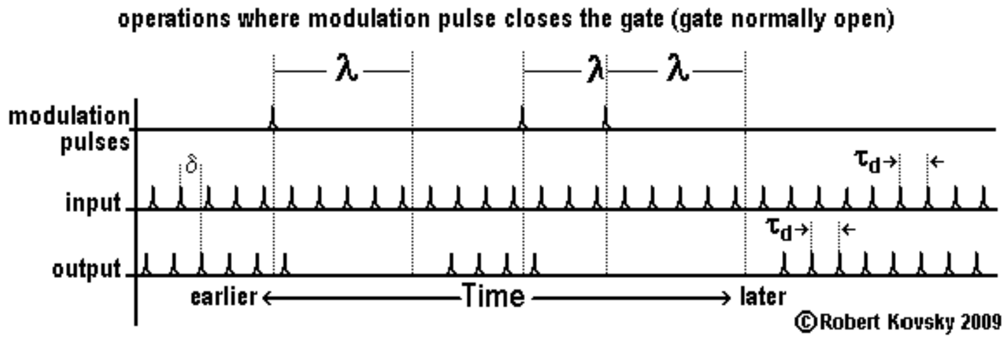


nomally open gate device stripping pulse bundles

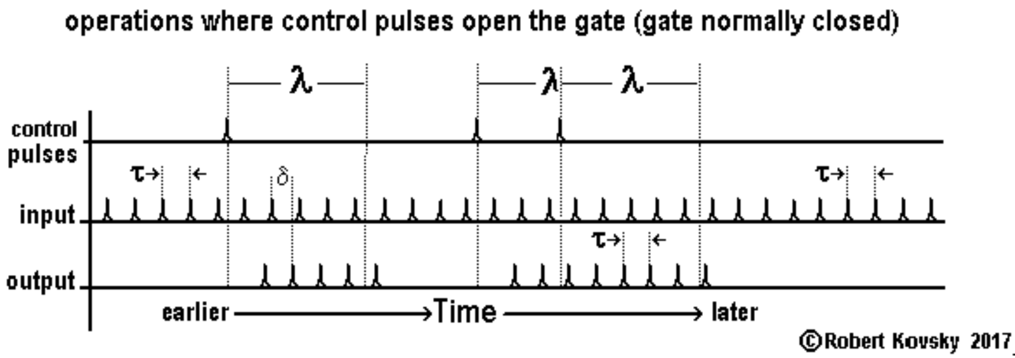


The adjacent image shows an earlier version of the symbolic element where the control projection was called a "modulation" input. Here, a projection from is connected as the modulation input (or control input). If a bundle of pulses (fitting within certain limits) arrive at the gate, the first pulse in the bundle passes through but later pulses are blocked.

The gated timing device resembles traditional gated devices such as electrical relays, vacuum tubes and point junction transistors. Generally, such gated devices come in pairs or sets, where one member is "normally open" and another member is "normally closed." In a "normally open" device shown above, the gate is "closed" by control pulses. The figure below (using the "modulation" label) shows details of operations of the normally open gated timing device.

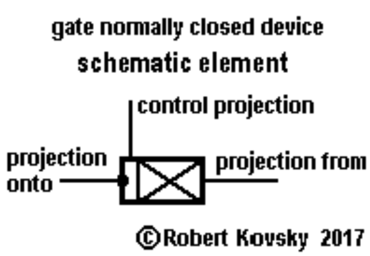


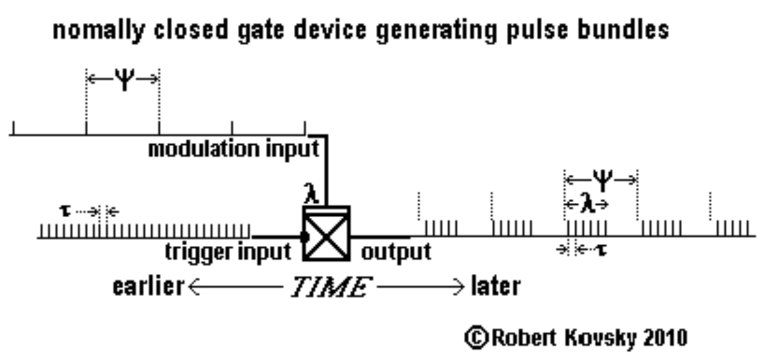
Operations of the normally open gated timing device are contrasted with those of the ***normally closed gated timing device*** shown below. Identical inputs are shown in the two figures, leading to a splitting of the input signal into two complementary signals.



In the normally closed gated timing device shown in the figure above, the gate is temporarily opened and then returns to a closed condition. In other words, when a pulse arrives over the control line, the gate is opened for an ***open period*** denoted by λ. During the open period, pulses arriving via the projection onto will trigger the timing device and produce pulses at the projection from. At the conclusion of the open period, the gate is closed – at least until further control pulses arrive. If control pulses arrive fast enough in a steady stream, the gate will be held continuously open in an ongoing way.

Two versions of symbolic elements for the normally closed gated timing device are shown below. The earlier version is shown in an application that produces pulse bundles of certain kinds.





Gated timing devices are used in the Toggle design shown below, a module in *An Eye for Sharp Contrast* that uses earlier versions of schematic elements. The action resembles toggle activity of electrical lamp switches and logical flip-flops. The complete Toggle Module is shown in Fig. d. Two output lines are marked "A" and "B." The input τ signal appears as active output on either the A line or the B line; and the other line is silent. Which output line is active and which is silent is subject to change. A "switch pulse" exchanges the active output line and the silent line.

The Toggle embodies the principle of "exclusion," as shown in a simple form in Fig. a. When signal A is active, pulses from A close the gate in device B and the output signal from B is blocked or excluded.

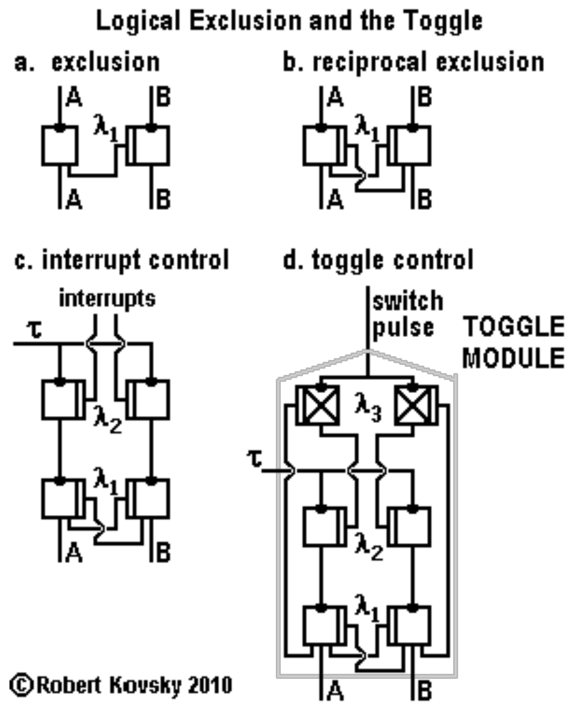


Fig. b shows the next step in the construction. Suppose that steady signals arrive at both the A and B inputs. There are two equal but distinct branches in a reciprocal relationship. The active output from one branch silences output from the other branch. The active/silent split can be maintained with either branch as the active branch. Reciprocal exclusion resembles the "exclusive or" relation in logic and "either-or" in common experience.

Operations in Fig. b can take place in a variety of ways. Suppose that both inputs are silent and then that both become active but at different times. The first input to become active "seizes control" for that branch and blocks output from the other branch.

Or suppose that both inputs in Fig. b are running and branch A is in control. If input A is "interrupted" or blocked by a researcher while input B continues running, B will seize control and hold control even after input A has returned to activity.

Fig. c shows development of the reciprocal exclusion arrangement to provide for interrupt switching. A pulse through one interrupt line blocks the signal in the targeted branch but not in the other branch. If side A is in control, a pulse through the interrupt line on the A side will switch control to B.

Fig. d, the final Toggle Module, provides for automatic routing of a switch pulse. The switch pulse passes through the gate normally closed device where the gate is kept open by the active output of the controlling branch; hence the pulse interrupts the active output. The branch with the inactive output is not affected by the interruption and thus seizes control.

4. Swinging gate timing devices

The adjacent Figure shows a ***swinging gate normally open timing device*** where the gate of a normally open gated timing device is further controlled by pulses arriving over a secondary control projection. If the gate is closed, a secondary control pulse will re-open the gate, with a timing interval ξ needed for operation of the gate. Closed and open periods are both variable in comparison to the normally open gated timing device where the closed period is a fixed value λ.

The adjacent figure shows a swinging gate timing device connected to remove every other pulse from the pulsestream and thus to double the period between pulses. If the gate is closed, an arriving trigger pulse will be blocked but it will also open the gate. If the gate is open, arrival of a pulse will close the gate and cause discharge of an output pulse. The function is the same as the "two-pulse timing devicer" discussed in previous publications.

The adjacent figure shows a swinging gate timing device connected to perform the function of the "difference device" discussed in previous publications. Suppose that steady pulse streams M and N arrive at the device and that M pulses are more frequent than N pulses or $\tau_M < \tau_N$. It is possible to use a frequency, defining $\mu = 1/\tau_M$ and $\nu = 1/\tau_N$. The greater frequency of pulses over M is expressed as $\mu > \nu$. If the gate is open, an N pulse will close it and prevent the next M pulse from passing through. If the gate is closed, the next M pulse will open the gate. The effect is that each N pulse blocks an M pulse and the result is defined as $\pi = \mu - \nu$.

The ***balancing unit*** design in the adjacent figure uses two difference devices with reciprocating projections.

5. Elementary engineered organisms are built from timing devices, bursting devices and force fiber devices and move on their own.

D. Quad Net devices, critical moments and Shimmering Sensitivity

IV. Foundations for the Construction of Virtual Energy

A. Movements and feelings of animal bodies occur in actual time and make up the domain of ***actual life*** that establishes foundations and standards for constructions.

The ***domain of actual life*** is foundational in my constructions. I presume that healthy adult persons share a common repertoire of ***muscular movements and related bodily feelings of actual life*** and that, more generally, birds and mammals have something similar. We all have personal bodily experience of itching and scratching; and birds, dogs and cats manifest similar experience. In all vertebrates, actual life includes possibilities of multiple different movements and various relations between movements and ranges of movement, e.g., relations involving choice, strength, timing, triggers, exclusion, sequencing and synchronization. Such relations may depend on bodily feelings, the foundational source of ***images*** to be progressively developed.

In my approach, muscular movements and bodily feelings are prior to images of objects such as external things, places and other persons. A child must know "stop" and "go" prior to learning "stop on red and go on green" at a traffic light. Images that directly influence movements are included in the domain of actual life. Discussion is deferred as to images that influence images.

My restricted psychologies aim to work with VE device constructions and target specific activities where models of image processing are congruent with VE concepts. For example, anticipated models of piano performances, parlor games and trial court decisions are based on "kits of parts," namely, repertoires of specific movements and images.

A general psychology of actual life is founded on muscular movements of persons in ordinary activities of life, e.g., eating, family, home-making, hygiene, sleep, travel, conversations, markets, work, exercise, consumer of entertainment. Of first importance are whole-body movements and large-scale movements involving multiple spinal regions, e.g., scratching the left ankle with the right hand. Spontaneous, impulsive and purposeful whole-body movements of birds and squirrels resemble those of children and provide exemplars of exercises of freedom in actual life.

Overall psychological guidance is provided by Jean Piaget (1896-1980), who described a ***practical intelligence***, "an intelligence before language," that arises from and then controls ***sensory-motor coordination of actions***. In a course of development, such coordination begins during infancy in reflexive actions and then develops in forms of practical intelligence during the first months and years of life before progressive reconstruction into mental operations. (See Piaget, *Play, Dreams and Imitation in Childhood* (1946, 1951 transl).) Piaget and colleague Bärbel Inhelder (1913 – 1997) wrote about such intelligence (emphases added):

> Essentially ***practical*** – that is, aimed at getting results rather than at stating truths – this intelligence nevertheless succeeds in eventually solving numerous problems of action (such as reaching distant or hidden objects) by constructing a complex system of ***action-schemes*** and organizing reality in terms of spatio-temporal and causal structures. In the absence of language or symbolic function, however, these constructions are made with the ***sole support of perceptions and movements*** and thus by means of ***sensory-motor coordination of actions***, without the intervention of representation or thought.
>
> [Piaget & Inhelder, *The Psychology of the Child* (1969) at 4. "A ***scheme*** is the structure or organization of actions as they are transferred or generalized by repetition in similar or analogous circumstances."]

B. Operations in rational domains, e.g., arithmetic, are learned in actual time but then continue to operate in detached time, sometimes interacting with the independent domain of actual life that is based on muscular movements.

Operations in ***rational domains*** are often independent of muscular movements and bodily feelings of actual life. Operations in rational domains generate images, perform many functions and often control or try to control movements of actual life.

For purposes here, constructions in rational domains include arithmetic, maths, computers and physics theories; common maps and descriptive language; money transactions; civil and criminal laws; device designs; and other symbolic functions based in the mind. In contrast, actual traffic signals and words of command are more closely connected to movements and thus belong in the domain of actual life. As discussed in the Introduction, movements of actual life occur in actual time while rational operations can occur in actual time, detached time or controlled time.

Rational domains are occupied by mental activities but actual life does not always require mental activity, e.g., a normal three-year-old eating or climbing stairs. We initially encounter mental constructions through engagements with an environment, e.g., as children playing with toys or reading books. Such initial engagements occur in actual time, typically requiring both eye movements and hand movements. Repeated engagements with permanent objects lead to a network of constructions in the mind that can be explored and elaborated in detached time. (E.g., in ways set forth in Piaget, *Construction of Reality in the Child* (1936).)

Regardless of roots in domains of actual life of infancy, rational domains in adults are separate from and independent of muscular movements of actual life. Thus, a domain in the imagination of each adult person of ordinary intelligence is occupied by the counting numbers "1, 2, 3, 4" and so forth. The mental domain is independent of bodily experience although it may have arisen during infancy while counting on fingers.

Independent activities in separate domains of actual life and rationality correspond to a division between body and mind. In my psychological models, Piagetian practical intelligence is tethered to movements of the body and to the entire spine that extends up through the cranial nerves. Practical intelligence is also based in the cerebellum that is richly endowed with neurons and that perches at the top of the entire spine, controlling movements of the body. Rational intelligence operates in the mind that is based in the cerebrum, which perches behind the top of the entire spine and which interacts with the entire spine through intermediate parts such as the thalamus.

In actual life, bodily movements are often integrated with mental imagery. Movements in the two domains are performed together. A simple example occurs during a weight-lifting session at the gym. Each ***set*** consists of repeated cyclical movements called ***repetitions*** or ***reps***. Perhaps there are 8 reps to a set of bench press exercises, performed by lying on the back on a flat bench and raising dumbbells up from the chest as far as possible, then lowering them under control. The person counts successive repetitive cycles as 1, 2, 3, 4, 5, 6, 7, 8 — thus coordinating the mental activity of counting with the bodily movements. In addition, there is a ***form*** of the exercise that prescribes details of movement, e.g., that the dumbbells should move smoothly through a full range of motion, in parallel and vertically. The same methods of integration (counting reps and following forms) are applied to arm biceps curl exercises and to squats. Records of exercises, weights, sets and reps are used to track an athlete's progress. Similar rational methods are applied to many other activities, e.g., cooking, collecting and card games.

Primal operations are at one end of a range of potential constructions. From a perspective looking towards the other end, successes of civilization are based on applications of constructions in rational domains to the domain of actual life. For example, one ancient rational system, plane geometry and land surveying, successfully resolves land boundary disputes, in contrast to the fights, wars and feuds of wild animals and uncivilized peoples. Other successes range from following a cake recipe to building a sewage plant or, in a legal case, following the Uniform Commercial Code. Activities of actual life that are based on rational constructions are said to be ***rationalized***. Questions are presented: Can all matters in actual life be rationalized? If not, which matters in actual life can be rationalized? Which matters should be rationalized?

I suggest that there are clear limits to rationalizations. Rational forms are sited in specific mental domains, such as computation or commercial law; and such domains require specific principles and disciplined practices. Rational forms do not generate new forms; rather, new forms are developed through exercises of human freedom, e.g., in internet culture, performance arts, legal rules, international relations, clothing fashions and financial markets. In these activities, it is difficult to predict future events or future rational forms.

I suggest that, in a broad way, activities of actual life often do not fit easily with constructions in rational domains. Sometimes a better fit can achieved through practice, but, even then, only in limited ways. Muscular movements are of brief duration and easily varied, with a transient existence that is often difficult to repeat or to define exactly. Some practiced movements can be repeated and defined exactly, e.g., those used in 19th century ballet academies and performances; but such movements are in special categories and lack the spontaneous and flexible character of movements in ordinary activities of actual life. Spontaneous movements depend on momentary feelings as well as forms of practice. During spontaneous movements, changes occur in response to environmental interactions. Spontaneous movements can be suddenly impulsive or they can occur in integrated flows.

In contrast to flowing spontaneous movements in actual time, detached operations of computers use programmed forms that are subject to "interrupts" through special access ports in hardware. Through the 1960's, typical computer operations were not interrupted; external interactions were unnecessary during "batch processing." Interrupts became important when personal computers appeared in the 1970's. An historical review of PC programming languages might begin with BASIC and go on to c to C++ to java to mobile app; such developments involved progressively greater use of interrupts, often for purposes of network interactivity. Interrupted programs of computers do not generally fit comfortably with spontaneous impulses and flows of actual life.

In contrast to variable and transient movements of actual life, mental images such as numbers have a permanent, even an "eternal" character. Many mental images occur in rigid fixed structures, spaces and forms; they are governed by rules that prohibit changes or deviations.

Suppose that a person encounters a situation or task that is personally novel, e.g., cooking in a friend's kitchen or driving a rental car. Attempts in such encounters to apply detached operations and fixed mental images to transient, variable muscular movements may be frustrated by misfits between requirements of actual life and rational forms in memory. Frustration may be compounded if changing environments undermine foundational presumptions. Fortunately, human beings engaged in actual life are often able to discover and invent means to overcome such frustrations.

C. The modern scientific view erroneously presumes that there is full and automatic integration of rational domains with the domain of actual life.

This polemic against the "modern scientific view" uses arguments of "type and anti-type" or "us vs. them." Shimmering Sensitivity, a physical principle of freedom, opposes the hegemony of mechanism and chance declared by the modern scientific view. Movements produced by flexible spines of fish, birds, squirrels and children have bodily integrity, freedom and flow that apparently cannot be reproduced by computer-controlled rigid-body robots.

As stated by computer intelligence advocate Marvin Minsky (*Society of Mind*, § 30.6):

> According to the modern scientific view, there is simply no room at all for 'freedom of the human will.' Everything that happens in our universe is either completely determined by what's already happened in the past or else depends, in part, on random chance. Everything, including that which happens in our brains, depends on these and only these:
>
> *A set of fixed, deterministic laws.* *A purely random set of accidents*
>
> There is no room on either side for any third alternative. Whatever actions we may 'choose,' they cannot make the slightest change in what might otherwise have been – *because those rigid, natural laws already caused the states of mind that caused us to decide that way.* And if that choice was in part made by chance – it still leaves nothing for us to decide.

I suggest that Minsky's statements are refuted by feelings and movements of household chores. Living alone, I choose when to clean, what to clean and how thoroughly; and accidents happen through haste or negligence. VE paradigms and constructions aim to model the actual life of chores and lead to a "third alternative" for events in our universe that do not conform to the rigid laws and closed-minded classifications of the modern scientific view.

In the modern scientific view, "energy" is a real number that attaches to every particle and to every point in space in our universe. Our universe is presumed to be a storage body for energy, including dissipated energy. All the energy in our universe can be added up and the sum is a ***constant*** with an existence that lasts as long as our universe. Hence, in the modern scientific view, the principle of energy conservation is universally and eternally real, determining actual movements through differential equations such as Newton's Laws of Motion, Laws of Thermodynamics and Einstein's Field Equations. The asserted reality of Conserved Energy (CE) stands in the fore among the "rigid, natural laws" that are said to preclude freedom.

In contrast, Virtual Energy (VE) is presented as a mental invention that has intended applications, chiefly to model rate-based processes where such energy is supplied continually like blood sugar in animals and electrical currents in proposed electronics devices. VE can be conserved in storage bodies; but, in contrast to CE constructions, dissipations of VE participate in working operations during conversions and transformations. Continual dissipations are balanced by inflows of VE, leading towards models with flowing integrated waves of transformational processes — instead of being bound to equipoise, quasi-static and equilibrium CE operations.

A view similar to the modern scientific view was declared by Georg Wilhelm Friedrich Hegel (1770-1831), who wrote: "***What is rational, is actual; and what is actual is rational***." (Hegel, *Philosophy of Right*, Preface, Kaufmann translation in *Discovering the Mind*, vol. I at 222.)

Hegel declared that ***ideas*** are real (Preface, *Philosophy of Right*, S. W. Dyde translation (1896)):

> Against the doctrine that the idea is a mere idea, figment or opinion, philosophy preserves the more profound view that nothing is real except the idea. Hence arises the effort to recognize in the temporal and transient the substance, which is immanent, and the eternal, which is present. The rational is synonymous with the idea, because in realizing itself it passes into external existence. It thus appears in an endless wealth of forms, figures and phenomena. It wraps its kernel round with a robe of many colours, in which consciousness finds itself at home.

Hegel's constructions were popular during the 19th and early 20th centuries but have also been cited as a source of totalitarian ideologies. According to Karl R. Popper in *The Open Society and Its Enemies* (1950 rev. ed.), Hegel constructed a philosophy of "might is right" to ingratiate himself with the Prussian King. Popper argued that Hegel conflated Plato's Forms or Ideas where "the Ideas alone are real" with "ideas in our minds" — "and this allows Hegel to maintain that everything that is reasonable must be real, and everything that is real must be reasonable, and that the development of reality is the same as that of reason."

Hegel wrote:

> Was vernünftig ist, das ist wirklich;
> und was wirklich ist, das ist vernünftig.

Translators differ on the English equivalent for "wirklich," choosing in some cases the word "actual" and in other cases the word "real." Similarly, "vernünftig" is alternatively translated as "rational" and "reasonable." Distinctions between actual and real or between rational and reasonable appear to be obscure in Hegel's philosophy. In a model of everything, where "vernünftig = wirklich," it seems hard to avoid real = rational = actual = reasonable.

The modern scientific view likewise declares that mathematics and eternal certainties control "Everything that happens in our universe … including that which happens in our brains."

My approach avoids such eternals and universals but rather suggests that "reality" may change when "rational" constructions in the mind fit and combine with "actual" movements of the body to make up an integrated, purposeful course of action of a person. When mind and body work together, a person can change reality. I decline, however, to grant a metaphysical status to eternal impersonal totalities such as "reality" or "our universe."

D. To initiate and develop a new approach, three kinds of energy are constructed: actual energy, conserved energy and virtual energy.

Prior to its apotheosis as an eternal universal principle, “energy” had origins in Newtonian mechanics and mechanical paradigms such as Atwood’s machine and Hooke’s Law. In mechanics, energy is a capacity to generate forces and to produce definite movements of inanimate bodies. Forms of mechanical energy (kinetic, gravitational, elastic) are converted into each other according to general principles — in contrast to properties of particular bodies and particular phase changes that are investigated in thermodynamics and materials sciences.

In mechanical paradigms of gravity, particles, rigid bodies and Hooke’s Law, changes in movements are easily rationalized as changes in energy. In thermodynamics, changes in properties of bodies are similarly rationalized and difficulties are glossed over. Thermodynamics rationalizations can match mechanics rationalizations when movements and changes are restricted to equipoise positions, equilibrium conditions and quasi-static movements. In such cases, matching elements cover both mechanics and thermodynamics. Certain restricted applications and constructions in mimed time and actual time can be appended thereto, e.g., through inventions of “enthalpy” and “Gibbs free energy.” Such rationalizations have been inflated into the system of Conserved Energy that is said to govern the Universe.

Theories of Conserved Energy have had solid successes in systems with little dissipation, such as rationalizing movements of celestial bodies, subatomic particles in *vacua* and astronautic vehicles. In designs of power plants and automobile engines, Conserved Energy principles serve economic conservation policies. Extensions of principles of Conserved Energy to chemical reactions have also had solid successes, e.g., as to certain reaction that occur in dilute aqueous solutions; but chemical successes are limited to simple cases and are tethered to equilibria.

When attempts are made to apply principles of Conserved Energy to movements and changes of living animal bodies, however, empirical results show major shortfalls and defects. Active cells in animal bodies ingest energy derived from food; they expend energy through life processes and movements; and they discharge energy in the form of heat and secretions/excretions. These activities cannot be tracked with accuracy and cease only after death. Animal cells and bodies undergo internal changes continually, e.g., during sleep. While inanimate bodies are chiefly moved by exterior causes, internal stores of energy enable an animal body to move on its own. In contrast to robot bodies made of rigid elements tethered to curves of equipoise, human bodies have a flexible spine and capacities for punching, jerking and jumping.

Unlike chemical processes of CE that are defined in equilibrium situations, chemical processes of living bodies occur in situations where equilibrium is never maintained and where degrees of disequilibrium and actual rates of change are of high importance. CE operations in detached time and mimed time regimes are only indirectly connected to actual rates of change.

Chief styles of science include a rational style and an empirical style. Empirical scientists classify natural phenomena and invent concepts to organize regularities they observe. Empirical investigations of Linnaeus led to biological *taxa* and nomenclature, those of Mendel led to theories of genetic inheritance and those of Mendele’ev led to the Periodic Table of elements. Piaget’s psychologies had initial empirical foundations and a growing rational superstructure.

The domain of actual life can be observed by means of an empirical style. Patterns are apparent in diverse movements of diverse kinds of animals, e.g., in classes of movements that I call stationary, steady and saccadic. In saccadic movements – which are jumpy, jerky or sudden – a propulsive stage is followed by a controlling and terminating stage. Birds and squirrels manifest saccadic movements, which also occur in eyes of human beings.

From another angle, I conclude that all vertebrate animals must have bodily feelings that guide movements in ways that are similar to my own. We all itch and scratch.

Empirical evidence thus suggests that there is something fundamental — a something that I call ***actual energy*** — that is inherent in the feelings and movements of an animal body.

In my view, human beings lack a capacity to comprehend actual energy by means of rational forms. I presume that actual energy cannot be reduced to numbers. On the largest scale, the empirical nature of actual energy in animal bodies might be described no better than by Hegel, as quoted above: actual energy appears in "an endless wealth of forms, figures and phenomena. It wraps its kernel round with a robe of many colours, in which consciousness finds itself at home." Other large-scale empirical descriptions of actual energy refer to yogic *prana* and to *qi* in traditional Chinese practices of medicine and bodily training.

These impediments do not foreclose rational modeling so long as limitations are recognized. Principles suitable for a new and limited rational model of actual energy were stated by Teilhard de Chardin in *The Phenomenon of Man* (1955, 1959 English transl.). In the following extracts, I would substitute "body" for his "atom" and "conversion" for his "synthesis." I would omit "entropised" and "from the real evolutionary standpoint" as unnecessary distractions.

> …Energy is the measure of that which passes from one atom to another in the course of their transformations. A unifying power, then, but also, because the atom appears to become enriched or exhausted in the course of the exchange, the expression of structure.
>
> …Though never found in a state of purity, but always more or less corpuscular (even in light), energy nowadays represents for science the most primitive form of universal stuff. Hence we find our minds instinctively tending to represent energy as a kind of homogeneous, primordial flux in which all that has shape in the world is but a series of fleeting 'vortices.' From this point of view, the universe would find its stability and final unity *at the end of its decomposition*….
>
> Let us keep the proofs and indisputable measurements of physics. But let us not become bound to the perspective of the final equilibrium that they seem to suggest. …(pp. 42-43.)
>
> *First Principle*. During changes of a physico-chemical type, we do not detect any measurable appearance of new energy. …
>
> *Second Principle.* In every physico-chemical change, adds thermodynamics, a fraction of the available energy is irrevocably 'entropised,' lost, that is to say, in the form of heat. Doubtless it is possible to retain this degraded fraction symbolically in equations so as to express that in the operations of matter nothing is lost more than anything is created, but that is merely a mathematical trick. As a matter of fact, from the real evolutionary standpoint, something is finally burned in the course of every synthesis to pay for that synthesis. (pp. 50-51.)

A rational style of science, whether based on conserved energy and entropy or on de Chardin's principles, is more adventurous than the empirical style. In the rational style, mental constructions are invented for purposes of trying to apply them to actual phenomena and events. Such attempted applications may or may not succeed; and even if successful may be labeled with judgments such as, e.g., solid, limited, speculative, trivial or trumped up.

Truesdell's style of rational thermodynamics invokes mathematical rigor and is expressively focused and restrictive, avoiding eternal universal presumptions like those of the modern scientific view. His rational constructions have only limited and specific ranges of application. In conscientious constructions, he clearly states his presumptions and limitations.

Truesdell's investigations, like those of other conscientious scientists, presume ***Conserved Energy*** as an axiom. Another axiom leads to a definition for ***Entropy*** that is derived under restrictive conditions from Conserved Energy.

The modern scientific view presumes that there is a universal correspondence between its rational constructions and actual events and calls this presumption "reality." In alternative constructions, I avoid the "reality" of Conserved Energy and, instead, construct ***Virtual Energy***.

The distinction between a "real" construction and a "virtual" construction refers to the physics of light, where a "real optical image" is contrasted with a "virtual optical image." In geometrical optics, both kinds of images are said to be made of many ***light rays***. To form a real image, rays converge at a specific location or ***focus*** in space that is external to any person. E.g., real images appear on movie screens and require a projector that focuses a beam of light. In a virtual image, on the other hand, light rays do not converge in external space; rather, they converge and come to a focus inside an animal's eye that has lenses to focus rays for that purpose. What you see in a mirror is a virtual image. Unlike a real image, a virtual image depends on the presence and orientation of an animal eye that sees by means of muscular activity as well as by means of image processing. Please see my *Free-Will Puzzles* (2016) essay at § 5(a)..

Conserved Energy applications presume identity between rational constructions and actual movements. Like a real image, Conserved Energy is presumed to be independent of the particular body that holds or beholds it. Virtual Energy avoids such presumptions.

It should be noted: VE constructions have achieved progress by conforming to CE principles, e.g., in pulsers in part III.A in this project and by following "quasi-static" paths in burster and force fiber designs. In other words, VE constructions start in an overlap region shared with CE principles but without commitments that CE requires, e.g., to entropy and information. VE constructions can be modified and do develop into variant forms, including classes of dissipative timing devices and Quad Nets. VE constructions are provisional and ready for changes of principles and for new device designs. Some VE paradigms are defined by rules that are arbitrary or restricted, suggesting new, more expansive variations.

In modeling biological organisms by means of devices, initial VE presumptions are that: "more than enough" Virtual Energy is available for multiple kinds of operations but subject to operating principles of control, economy and efficiency; VE continually passes between forms and is subject to conversions and transformations; dissipations are omnipresent and useful.

In anticipated developments, cyclical operations of Quad Net devices create "deadlines" for action. To meet the deadline, a balanced condition is driven into a loss of balance; and the particular direction of loss depends on multiple, momentary influences. A course of movements based on a series of such deadlines produces continual selections. Each whole-body selection is influenced by fixed purposes, by feelings based in movements, by sensations based in the environment, and by other momentary activations, interactions, dissipations and entrainments.

General VE presumption have roots in biological evidence. Mitochondria in biological cells produce plenty of "energy packets" (ATP). Movement proteins (actin and myosin) are omnipresent in cells and structures of animal bodies, including not only large muscles but all organs of the body; and they also act through tiny fibers between adjacent cells in an organ.

I suggest that during highly activated whole-body movements of actual life – e.g., during combat or dancing or sex – essentially all the muscles, organs and trillions of cells located throughout the body participate energetically in the movements. I presume that such whole-body movements of animal bodies cannot be described or controlled by general models or theories of control based on rational structures. Additionally, I presume that each animal body is unique in its material properties and in its balances of processes. Models of animal behavior must remain, at best, partial and provisional.

In the technological domain, on the other hand, it appears that devices based on VE principles might be manufactured that closely conform to paradigms. This approach may be useful for development of engineered organisms that lead to working models of actual life.

I suggest that the focal VE paradigm of Shimmering Sensitivity can be embodied in devices that mimic exercises of freedom in an animal body. As a cycle begins, modules of Quad Net devices generate multiple fragments of activity where each fragment leads to a different movement. Initially, fragments co-exist in a condition that may involve shifting combinations of fragments, variable combinations of devices and competition between possibilities — this is "Shimmering." Next, the process passes through a critical moment and fragments become collectively entrained. Multiple possible movements change into a single actual movement in ways that may be Sensitive to a single influence or to a large number of influences.

I suggest that processes of Shimmering Sensitivity are models for selections or choices in the lives of persons, such as choices made in markets. When you are at a rack of candy bars, each possible movement would pick out a particular candy bar. Your hand may start to pick impulsively first one and then another. You think about it. Finally, during a critical moment, multiple possible picking movements change into one actual picking movement and to an actual selection of one candy bar. Such a selection can depend on a fixed habit; or, alternatively, on flowing influences, on momentary sensitivities or on happenstance events in the environment or one's own body (e.g., a narrow aisle and hip pain prevent stooping). In modeling such a selection, interconnected body parts are engaging in entrained and synchronized operations and they pass through critical moments together: selections of partial movements are integrated and become one unified actual movement. Directed at an achievable goal in a supportive environment, unified movements are produced by a whole body made of many body parts.

William James wrote: "Using sweeping terms and ignoring exceptions, *we might say that every possible feeling produces a movement, and that the movement is a movement of the entire organism, and of each and all of its parts*." In anticipated cylindrical designs for models of aquatic worms and eels and of terrestrial worms and snakes, the whole body of the engineered organism, and each and all of its sensory-motor modules, participate in selections of movements.