Treatise with Reasoning Proof of the First Law of Energy Conservation

Forced Interactions of Material Systems and Their Structures

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ABSTRACT:

The fundamental conservation laws in phenomenological Thermodynamics, including *The First Law of Energy Conservation*, have been traditionally accepted as axiomatic laws that cannot be proven but are never experienced otherwise. In this treatise we have focused on energy concept and reasoned the general proof of energy conservation based on the Newton's Laws of motion and energy redistribution over particulate structures of all material systems. The objective was to put certain physical and philosophical concepts in perspective, and to be as simple but also as rigorous as possible.

The mechanical work-energy principle has been extended to all forms of energy and material structures, and thus effectively proved the general energy conservation law. We know that material system structures are particulate, thus we focused on material systems made of interacting material particles down to the smallest ones known or relevant to us. We analyzed interaction between two material particles using Newton's Law of motion and proved that during their forced interaction energy is transferred from one to another particle in equal amount, thus conserved, and without any interaction a particle energy is not changed, thus overall energy is conserved. Since energy is additive (cumulative) for any structure and redistributed from structure to structure, we extended the reasoning proof to any system size, i.e.: energy between interacting systems is transferred from one system to another in equal amount, and without any interaction a system energy is not changed, thus overall energy is conserved.

The fundamental principle of energy conservation is exceptionally simple but it appears in exceptionally many different forms, which explain universality and unity of simplicity and complexity, but also difficulties to recognize simplicity in complex diversity. Although it is not expected that this treatise with reasoning proof of the first law of energy conservation will be immediately accepted, it is hoped that, at the very least, it will stimulate further discussions within the scientific community.

Outline

I. Introduction

This treatise has an objective to put certain physical and philosophical concepts in perspective, to reason the fundamental laws of nature, as well as to initiate discussion and arguments about these fundamental concepts. In addition to the reasoning proof of *The 1st Law of Energy Conservation*, an overview of the existing knowledge is presented, making this paper longer than necessary, a treatise of the energy and its conservation.

The philosophic axiom "*causa aequat effectum,*" traced to ancient philosophers, represents the most universal and fundamental law of nature, including existence and future, i.e. past and future transformations. By the beginning of the 20th century scientists had established conservation laws governing the following quantities: energy, mass (or matter), linear momentum, angular momentum, and electric charge. Conservation laws have the broadest possible application of all laws in physics and are thus considered by many scientists to be the most fundamental laws in nature. In further scientific development the fundamental conservation laws have been extended to the conservation of elementary particle properties and philosophically unified as conservation of natural symmetries (CPT: charge, parity of space, and time).

The conservation laws are simple and broad – in many ways these laws express all existence and transformations, including unity of diversity, or simplicity of complexity, or continuous transformational existence: mass or charge or momentum or energy cannot transform into nothing or disappear without any trace. Therefore, we may infer that the first property of all existences (i.e., mass, charge, momentum, energy) is their *indestructibility* or conservation.

As such the fundamental laws are taken as axiomatic and many believe they could not be questioned, explained or proven. However, the Einstein's theory of relativity (1905) showed that mass is a form of energy, the two related laws were combined into a single law of the totality of mass and energy conservation. Furthermore, the conservation of mass and charge are related (mass is made up of charged particles: electrons and up/down quarks in nucleus), and conservation of angular and linear momentums are related too. Therefore, everything may and should be questioned, reasoned, explained and possibly proven.

The treatise presented here will reason the fundamental and universal concept of energy as property of particulate and moving (energetic) structure of all material systems, and as energy exchange between interacting systems (structures), and in the process prove the fist law of energy conservation. Some may a priori choose to reject any proof of the fundamental laws of phenomenological Thermodynamics since they have been traditionally accepted as axiomatic laws that cannot be proven but are never experienced otherwise. The others may choose to reject a very simplistic proof like this. In this treatise we will be focusing on energy and trying to reason the general proof of energy conservation based on the Newton's Laws of motion (1687) which correlates (and thus inter-defines) the force, mass and motion (acceleration). In turn, the mechanical work-energy principle will be extended to all forms of energy and material structures, and thus prove the general energy conservation law.

What is energy? In his famous *Lectures on Physics,* Richard Faynman stated (1963): *"It is important to realize that in physics today, we have no knowledge of what energy is."* He probably was trying to make a point of diversity and complexity of many "appearances" of energy forms. However, there is simplicity in complexity. *Energy is defined here as a fundamental property of a physical system and refers to its potential to maintain a system identity or structure and to influence changes (via forced interaction) with other system by imparting work (forced directional displacement) or heat (forced chaotic displacement/motion of a system molecular or related structures).* Energy exists in many forms: electromagnetic (including light), electrical, magnetic, nuclear, chemical, thermal and mechanical (including kinetic, elastic, gravitational, and sound), where, for example, electro-mechanical energy may be kinetic or potential, while thermal energy represents overall potential and chaotic motion energy of molecules and/or related micro structure.

Every physical system posses energy and is capable of interacting with other systems, i.e. exchange energy with other systems. The interaction is a process of forced displacement with energy exchange, equal to force times displacement (scalar product of the two vector quantities). One system is forcing or acting and another is forcibly resisting or reacting (with the same but opposite force), so that energy is exchanged from acting or source to resisting or sink system, and thus conserved within the two systems separated by the displacing interface boundary (even though the interacting forces are the same but they are in opposite direction -- thus importance of which system is acting or reacting). The interactions are distributive (from large systems or structures to smaller systems or structures or sub-systems and substructures), and inversely, interactions are cumulative or additive from small sub-structures and structures to larger systems and structures. By virtue of system existence the forces are balanced (action and reaction) at any instance, and through their interactions (forced displacements) their motions are conserved in time, directionally as momentum vector ($m\vec{v}$), and overall as directionally redistributed energy ($mv^2/2$) over material structures in space. However the energy redistribution is, overall, towards increasing directional randomness (conserved momentum and energy with increase of randomness or entropy). Another complementary treatise with reasoning proof of energy degradation is currently under preparation.

It is appropriate to state here that the intuition and imagination are more important than knowledge. This treatise and reasoning proof of energy conservation will be intuitive and simple but rigorous and universal. As Albert Einstein said: *"Most of the fundamental ideas of science are essentially simple, and may, as a rule, be expressed in a language comprehensible to everyone."* Einstein also made another interesting statement: "*Since the mathematicians have invaded the theory of relativity I do not understand it myself anymore."* It is objective here to emphasize physical concepts and be as simple but also as rigorous as possible and with as little math as possible. The fundamental principle of energy conservation is exceptionally simple but it appears in exceptionally many different forms, which explain universality and unity of simplicity and complexity, but also difficulties to recognize simplicity in complex diversity.

Nothing should be forever accepted as unchallengeable. Although it is not expected that this treatise with reasoning proof of the first law of energy conservation will be immediately accepted, it is hoped that, at the very least, it will stimulate further discussions within the scientific community.

II. Criticality of Language, Idealizations and Terminology: *Understanding and Defining Concepts and Phenomena*

Existing language terminology defines known concepts, phenomena and experiences, thus it cannot explain precisely new concepts without "misuse and abuse" of existing terminology until new one is established. Due to "misuse of language" and individual perception of reality the scientific history has witnessed many useless and on occasion harsh debates including lost friendships. Trying to understand, reason and explain fundamental concepts is a daunting endeavor, and different from understanding other concepts derived from the fundamental ones. However, there is factual reality that we should be always aware of and guided by. The fundamental interactions and their inter-relations along with subtle reasoning may help to resolve ambiguities and close the needed loops. "Going in circle" does not mean we are not going anywhere as long as we succeed in comprehension if the "circular" subtle interactions, including interrelated causes and effects. A barrier between our understanding and reasoning explanation is a language ambiguity, which could be partially offset by more objective and more primitive mathematics, but a price paid is the discrepancy between reality and mathematical idealizations and simplicity but sometimes unnecessary complexity. Another critical tool for resolution of reasoning ambiguities is experimental ingenuity with observation and quantification of reality, and again the price paid is the discrepancy between reality and experimental limitations, including inevitable and unconscious errors and uncertainties. We must bear in mind that new ideas and concepts (a way one perceive reality) are not only difficult for a reader to grasp but equally difficult and excruciating for an author to express, as it is experienced here. There is a need of using synonyms, redundant and imaginative explanations, quotation marks for words that are not quoted, and similar, since new or creative ideas, concepts and explanations are to be expressed with existing word terminology.

The fundamental "*cause-and-effect*" concepts and phenomena are often simple, but they are usually manifested in many different forms and are mutually coupled or interrelated. We often need to make different simplifications and idealizations in order to be able to isolate and then understand and analyze the phenomena. Real properties and processes are often coupled and we usually need to idealize and decouple them to focus on one issue and better understand and explain it. For example, any thermal process is coupled with mechanical expansion and vice versa and we may decouple those, like idealizing an isochoric process with heat transfer only, or isentropic process without heat transfer, excluding thermal radiation, etc. We may idealize systems, like ideal gas or incompressible fluid, etc., or boundaries, like ridged, adiabatic, etc., or processes, like frictionless or non-dissipative, quasi-equilibrium or reversible, etc. The emphasis here will be on the thermo-mechanical interactions where the conservation of energy was historically first "stuck" and re-established (The 1st Law of Thermodynamics), however it could be easily extended to other interactions involving electro-magnetic, electro-chemical, or nuclear processes. We will idealize and define the most essential concepts and related nomenclature used in this treatise (in some logical order) as follows:

System (also *Particle* or *Body* or *Object*) refers here to any, arbitrary chosen but fixed material physical system in space (from a single particle to system of particles, occupying system volume within its own enclosure interface or system boundary, separating itself from its surroundings), which is subject to observation and analysis. A system is made of material sub-systems with certain structure or substructure, down to the most fundamental elementary particles that we are not capable of looking further into and consider them to be material points. The elementary particles are “forcibly bound” in larger particles which posses mass and energy in space, thus have dimensions, and are capable to “forcibly bound and or interact” with each other and form larger structures with forced fields in space, and so on. We know that physical systems are made of very small and discrete particles on sub-nucleus, atomic and molecular scale, see Fig. 1, but also may be considered as continuum media, with integrated average particle properties at larger scales.

Energy is fundamental property of a physical system and refers to its potential to maintain a system identity or structure and to influence changes (via forced interaction) with other system by imparting work (forced directional displacement) or heat (forced chaotic displacement/motion of a system molecular or related structures). Energy exists in many forms: electromagnetic (including light), electrical, magnetic, nuclear, chemical, thermal and mechanical (including kinetic, elastic, gravitational, and sound), where, for example, electro-mechanical energy may be kinetic or potential, while thermal energy represents overall potential and chaotic motion energy of molecules and/or related micro structure.

Mass refers to system measure of inertia (resistance to system acceleration or motion change as a whole). Much of the mass of a nucleon (proton or neutron) resides in form of energy of the gluons which bind quarks into nucleon (not yet fully understood), while the residing energy of photons’ electromagnetic field which bind electrons to nucleus is very small, see Fig. 1. We may postulate, especially after Einstein’s energy-mass correlation, that mass is a kind of spinning energy in all directions within elementary particles which give rise to its inertia, i.e. forced resistance to change of its motion (acceleration) in all directions as an integral particle mass or an integral system mass. Statements about quarks (elementary particles) which make protons and neutrons and their bindings must be taken with a grain of salt, since interactions between elementary particles are not yet well understood, and they are believed to be material points (wit zero dimensions) since their structure is not known at all.

Forced Field refers to “conservative or reversible or elastic” force distribution in space responsible for particle and/or system structure or mass-energy distribution in space. The binding energy of any structure is “stored” within that structure and represents potential energy which could be partially released if a system structure is transformed. i.e. restructured into another structure, like in nuclear or chemical reactions. Forced field is a displacement gradient of related potential energy of a system.

Motion refers to system (and its structure) activity that manifests in its displacement in space and time, thus defining space coordinates and time. System motion could be resolved into different components as spinning around its center of mass, vibration, rotation around other systems, and linear translation. Spinning and twisting/vibrations around a system’s center of mass may not directly influence interactions with other systems but contribute to that system stored energy and may be a cause-and-effect of the related forced fields. However the translational motion is bound to interact with other systems via collision (also may be enhanced in part by rotation and vibration at the time of collision), and such random motion of system structure (molecular and related substructure) gives rise to temperature (particulate kinetic energy) and pressure (particulate change of momentum rate per unit area in direction normal to the area), and similar, see Fig. 1.

Interaction (also *Collision* or *Process***)** refers to energy exchange via farced displacement in time between two material systems -- a generalized collision, i.e. a "cause-and-effect" process. Interaction involves and thus define, or inter-define force, mass and motion, the latter being relative space displacement in time with reference to the two interacting systems. We may be lost at the elementary particle scale or sub-scale due to our inability to observe the phenomena with the tools we comprehend (the photons and electromagnetic waves are the finest resolution tools we comprehend now), or we may be lost at the large scale in "curved space" for similar reason. However, we have accumulated a lot of observations in a long time over a large space scale that we could rigorously reason the first law of energy conservation at phenomenological thermodynamic scale, which is subject of this treatise.

Structure or **Equilibrium State** (also *System Identity State* or *System Properties*) refers to apparently quasi-static structure with sustained macro system properties (which are statistical averages of corresponding micro-structure properties), like temperature, pressure, volume, entropy, energy and others. If an isolated system's properties are non-uniform, the spontaneous interactions, given enough time, will take place towards equalization of their statistical averages over space and time, and towards uniformity of macro properties which is in effect the maximum probability of all possible microstates for a given macro state, i.e towards an equilibrium state with maximum entropy. For example the random kinetic energy of micro-structure will equi-partition its kinetic energy (i.e. redistribute kinetic energy statistically equally among all its particles) and thus equalize its temperature and pressure, and in turn all other properties.

Relativity refers to properties of a system with reference to other systems or a chosen reference system, since all observations and interactions are between the systems. Our observations and comprehensions of the systems are limited with our existence, including sensing and mental tools, as well as our space and time scales, so that subject of this treatise is referring to phenomenological, thermodynamic properties and interactions, which may be extended inward and outward as long as we are aware of relativity and uncertainty outside of observed extreme space and time scales. As already mentioned, we may be lost at the elementary particle scale or sub-scale due to our inability to observe the phenomena with the tools we comprehend (the photons and electromagnetic waves are the finest resolution tools we comprehend now), or we may be lost at the large scale in "curved space" for similar reason.

Interface boundary (or *Boundary* for short) refers to "real" or imaginary boundary surface in space to separate systems or sub-systems or their parts from each other. In reality the interface boundary between the systems is irregular and time-changing surface defined by the interaction forces separating the two systems. If diffusion of one system structure into the other system structure is negligible than the boundary may be idealized as impermeable. Similarly if heat transfer or deformation or any interaction are negligible, we may idealize the boundary as adiabatic or rigid or isolated, respectively, and so on.

Isolated system refers to a system with an idealized isolated boundary enclosure which does not allow for any interaction with its surroundings. In reality there are no such idealized boundaries since it is impossible to prevent all interactions with the surroundings. Isolated system should not be confused with a system "left alone in the universe," since such system will spontaneously expend and or radiate into the "empty" universe (there is no "empty" universe either!). A good approximation of an isolated thermo-mechanical system is a thermos or insulated vacuum bottles, or a ridged container with surrounding temperature equal to the system temperature.

Ideal gas refers to idealization of real gasses at high temperature (high molecular velocities) and low pressure (high separation between the molecules) as if a gas molecules are material points with real velocities and mass but zero space dimension (material points) and without any intermolecular forces. This idealization simplifies the ideal gas molecules' interactions as random elastic collisions only. Since this idealization provides for convenient analysis of random molecular motion and is not much different from reality, the corresponding kinetic theory of ideal gasses has explained and proved many thermal phenomena (see Fig. 1).

Work refers to controlled energy transfer when one system is exerting force in specific direction and thus making a purposeful change (displacement) of the other systems. It is inevitably (spontaneously) accompanied, to a larger or smaller degree, with dissipative (without control) energy transfer referred to as *heat* (see below, and for more details in next Section).

Mechanical Energy refers to the energy associated with ordered motion of moving objects at large scale (kinetic) and ordered elastic potential energy within the mechanical structure (potential elastic), as well as potential energy in gravitational field (potential gravitational).

Temperature refers to the average translational kinetic energy during thermal interaction of disordered microscopic motion of molecules and atoms. The concept of temperature is complicated by the particle internal degrees of freedom like molecular rotation and vibration and by the existence of internal interactions in solid materials which can include so called collective molecular or atomic behavior. All of those motions could contribute to the kinetic energy during particle interaction. When two objects are in thermal contact (i.e. interaction of random motion of their particles), the one that tends to spontaneously lose energy is at the higher temperature. In general, temperature is a measure of the tendency of an object to spontaneously exchange energy with other object until their temperatures equalize, that is until their interacting particle kinetic energy equi-partition (statistically equalize).

Heat refers to inevitable (spontaneous) energy transfer due to temperature differences, to a larger or smaller degree without control (dissipative) via chaotic (in all directions, non purposeful) displacement/motion of system molecules and related microstructure, including thermal radiation, as opposed to controlled (purposeful and directional) energy transfer referred to as *work* (see above, and for more details in next Section).

Internal Thermal Energy refers to the energy associated with the random, disordered motion of molecules and potential energy of intermolecular forces, as opposed to the macroscopic ordered energy associated with ordered "bulk" motion of system structure at large scale, and excluding internal binding energy within atoms (nuclear) and within molecules (chemical).

Internal (Total) Energy refers to the energy associated with the random, disordered motion of molecules and intermolecular potential energy (thermal), potential energy associated with chemical molecular structure (chemical) and atomic nuclear structure (nuclear), as well as with other structural potentials in force fields (electrical, magnetic, elastic, etc.). It refers to the "invisible" microscopic energy on the subatomic, atomic and molecular scale as opposed to "visible" mechanical, bulk energy.

Absolute Zero Temperature refers to a system state where the random kinetic energy of its structure (molecules if system is made of molecules, or a lattice random vibration if a system is made of crystalline lattice of molecules or atoms, which give rise to the temperature) is zero (see definition of temperature above). However the motion within the system structure (binding motion within nucleus, atom and molecule) is sustained to maintain identity of the system and prevent the collapse and disintegration of the system structure as such.

Thermal radiation refers to spontaneous electromagnetic radiation (photonic radiation) induced by random collision of elementary system structure (atoms and molecules), which is in turn due to kinetic energy of random motion of the system structure, i.e. system temperature. During random thermal interactions the electrons' energy levels are changed within atoms, thus emitting photons, i.e. electromagnetic thermal radiation. It is also the final energy redistribution to the smallest (finest) structure known to man. Also, it is the price paid to maintain equilibrium state with the random thermal motion, and if not compensated from other sources outside of the system, the system will radiate away its thermal energy and cool towards absolute zero temperature.

III. Energy: *From Work to Heat to General Concept*

As already stated, energy is a fundamental concept indivisible from matter and space, and energy exchanges or transfers are associated with all processes (or changes), thus indivisible from time. Actually, energy is "the building block" and fundamental property of matter and space, thus fundamental property of existence. Energy transfer is needed to produce a process to change other properties. Also, among all properties, the energy is the only one which could be converted to mass and vice versa: $E=mc^2$ (known in some literature as "*mass energy*," the c is the speed of light in vacuum), thus the mass and energy are interrelated.

Any and every material system in nature possesses energy. The structure of any matter and field is "energetic," meaning active, i.e., photon waves are traveling in space, electrons are orbiting around an atom nucleus or flowing through a conductor, atoms and molecules are in constant vibration or random thermal motion, etc., see Table 1 and Fig. 1 & 2. Thus energy is a property of a material system, and together with other properties defines the system equilibrium state or existence in space and time.

Energy is manifested as work or heat when it is exchanged or transferred from one system to another, as explained next (see Fig. 3).

Work is a mode of energy transfer from one acting body (or system) to another resisting body (or system), with an acting force (or its component) in the direction of motion, along a path or displacement. A body that is acting (forcing) in motion-direction in time, is doing work on another body which is resisting the motion (displacement rate) by an equal resistance force, including inertial force, in opposite direction of motion. The acting body is imparting (transferring away) its energy to the resisting body, and the amount of energy transfer is the work done by the acting onto the resisting body, equal to the product of the force component in the motion direction multiplied with the corresponding displacement, or vice versa (force multiplied by displacement component in the force direction), see Fig. 4. If the force ($\vec{F}$) and displacement vectors ($d\vec{s} = d\vec{r}$) are not constant, then integration of differential work transfers from initial (1) to final state (2), defined by corresponding position vectors $\vec{r}$, will be necessary, see Fig. 5.

The work is a directional energy transfer, however, it is a scalar quantity like energy, and is distinctive from another energy transfer in form of ***heat*** due to random motion (chaotic or random in all directions) and collisions of system molecules and their components.

Work transfer cannot occur without existence of resisting body or system, nor without finite displacement in the force direction. This may not always be obvious. For example, if we are holding a heavy weight or pushing hard against a stationary wall, there will be no work done against the weight or wall (neglecting their small deformations). However, we will be doing work internally due to contraction and expansion of our muscles (thus force with displacement), and that way converting (spending) a lot of chemical energy via muscle work, then dissipating it into thermal energy and heat transfer (sweating and getting tired).

Heat is another mode of energy transfer from one system to another due to their temperature difference. Fire was civilization's first great invention, long before people could read and write. However, true physical understanding of the nature of heat was discovered rather recently, in the middle of the nineteenth century, thanks to the development of the kinetic theory of gasses. Thermal energy and heat are defined as the energy associated with the random motion of atoms and molecules. Prior concept of heat was based on the caloric theory proposed by the French chemist Antoine Lavoisier in 1789. The caloric theory defines heat as a massless, colorless, odorless, and tasteless, fluid-like substance called the *caloric* that can be transferred or “poured” from one body into another. When caloric was added to a body, its temperature increased and vice versa. The caloric theory came under attack soon after its introduction. It maintained that heat is a substance that could not be created or destroyed. Yet it was known that heat can be generated indefinitely by rubbing hands together or from mechanical energy during friction, like machining, mixing or similar. Finally, careful experiments by James P. Joule published in 1843, quantified correlation between mechanical work and heat, and thus put the caloric theory to rest by convincing the skeptics that heat was not the caloric substance after all. Although the caloric theory was totally abandoned in the middle of the nineteenth century, it contributed greatly to the development of thermodynamics and heat transfer.

Heat, *thermal radiation*, *internal thermal energy* and *temperature* are interrelated but different concepts. If the two system interaction is achieved via quasi-stationary interface (no net-directional interface boundary displacement, but the system structures will exchange energy via random collision and random small-scale displacement of their small-scale, molecular structure, the random structural motion energy of one system will be transferred in kind as *heat* to another system structure, due to their temperature difference. *Temperature* is not directly proportional to *internal thermal energy* since temperature measures only the particle kinetic energy part during particle interaction, so that two systems with the same temperature do not in general have the same internal energy. The internal thermal energy includes motion energy of all particles (all molecules if the system structure is molecular), including translational, rotational, and vibration kinetic energies, as well as binding potential energy between the particles, but not the binding potential energy within the particle itself, like chemical and nuclear energy. The *kinetic temperature,* as defined from the kinetic theory, is directly proportional to the average kinetic energy of gas molecules since the rotation and vibration part could be neglected (molecules are considered material points). However, in reality the concept of temperature is complicated by the particle internal structure (more degrees of freedom) like molecular rotation and vibration and by the existence of internal interactions in solid materials which can include so called collective behavior, see Fig. 1. All of those motions could contribute to the kinetic energy during particle interaction. Such complications have led to the adoption of more general approach to the concept of temperature in the study of thermodynamics: *temperature* is a measure of the tendency of an object to spontaneously exchange energy with other object until their temperatures equalize, that is until their interacting particle kinetic energy equi-partition (statistically equalize). When two objects are in thermal contact (i.e. interaction of random motion of their particles), the one that tends to spontaneously lose energy is at the higher temperature. Furthermore, during random thermal motion and related structure collisions the electrons are shifted to different energy states within atoms, thus releasing photonic *thermal radiation* and effectively reducing the system thermal energy. For a thermal equilibrium to be maintained an incoming thermal radiation of the same magnitude will be required if no other modes of energy transfer are present.

Heat may be transferred by three distinctive mechanisms: conduction, convection, and thermal radiation, see Fig. 6. *Conduction* is the transfer of energy due to interaction between the more energetic particles of a substance, like atoms and molecules (thus at higher temperature), to the adjacent less energetic ones (thus at lower temperature). *Convection* is the transfer of heat between a solid surface and the adjacent moving fluid, and it involves the combined effects of conduction and fluid motion. *Thermal radiation* is the transfer of heat due to the emission of electromagnetic waves (or photons) which are product of thermal interactions between energetic particles of a substance as explained above.

The Joule's experiments of establishing the equivalency between work and heat paved the way of establishing the concept of internal thermal energy, to generalize the concept of energy, and to formulate the general law of energy conservation. The total internal energy includes all other possible but mechanical energy types or forms, including chemical and nuclear energy, which are in essence the binding motion energies (spinning, vibration, etc.) which give rise to the related forced fields and binding potential energies. This allows extension of the well-established law of the mechanical energy conservation to the general law of energy conservation, known as the *First Law of Thermodynamics*, which includes all possible energy forms that a system could possess, and heat and all types of work as all possible energy-transfers between the systems. The law of energy conservation will be elaborated later.

Energy, Work and Heat Units. Energy is manifested via work and heat transfer, with corresponding *Force*×*Length* dimension for work ($N\cdot m$, $kg_f m$, and $lb_f ft$, in SI, metric and English system of units, respectively), and the caloric units, in *kilocalorie* (*kcal*) or *British-thermal-unit* (*Btu*), as heat needed to increase a unit mass of water (at specified pressure and temperature) for one degree of temperature, so that the water specific heat at prescribed temperature is 1 $kcal/(kg\ {}^0C)$ = 1 $Btu/(lb\ {}^0F)$ by definition, in metric and English system of units, respectively. It is first demonstrated by Joule and refined later by others that 4187 $N\cdot m$ of work, when dissipated in heat, is equivalent to 1 *kcal*. In his honor, 1 $N\cdot m$ of work is named after him as 1 *Joule*, or 1 *J*, the SI energy unit, also equal to electrical work of $1\ W\cdot sec = 1\ V\cdot A\cdot sec$. The SI unit for power, or work rate, is *Watt*, i.e., 1 $J/sec = 1\ W$, and also corresponding units in other system of units, like *Btu/hr*, etc. The *Horse Power* is defined as 1 HP=550 $lb_f{\cdot}ft/sec = 745.7\ W$. Other common units for energy, work and heat, are given in Table 2.

IV. The Reasoning Proof of Energy Conservation:
Work-Heat-Energy Principle

Why it was so difficult (and excruciating throughout the history) to fully account for and prove energy conservation. The reason is that energy, while being conserved during diverse processes (the 1st Law), it is also redistributed and virtually “lost or dissipated out of sight” over vast and diverse material structures of the surroundings (the 2nd Law), making it difficult, if not impossible, to be everywhere observed and fully accounted for. For example, when a ball is dropped from a height and accelerated by gravity downwards, its kinetic energy appeared to be lost after hitting the ground and coming to the stop, since the energy redistribution effects around impact surroundings are often unnoticeable. It took great minds a lot of times through history, until the middle of nineteenth century, to figure out the mechanical energy redistribution into the thermal energy, and thus energy conservation, within the affected systems’ material structure, i.e., transfer into energy of their atomic and molecular motions, that is, into thermal energy. There are many other interrelated known (and yet to be discovered) phenomena along with our improvisations (i.e. idealizations) and distractions of our mind to fully comprehend, i.e., to fully account for all causes-and-effects. For example, when a ball hits the ground, the Earth is literally shaken and vector momentum is conserved too. There are no such things as “fully ridged” or “fully elastic” support boundary or “fully adiabatic” interface boundary. When a ball hits the ground, during the forced interactions, the interaction forces (actions and reactions, including inertial and elastic forces) will be balanced at any instance, but will be redistributed (dissipated), along with its directional motion (momentum, *mv*-vector quantity) and “scattered towards randomized” motion (energy, $mv^2/2$ scalar quantity), and totality of all redistributed momentum and energy over more and more structure in space and time, up to and including thermal radiation, will be conserved. However in any locality the total momentum and energy may and will be changed depending on the net momentum and energy redistribution to and from the surroundings. Therefore, when a ball hits the ground, the rest of the Earth without ball is shaken through the supporting structures and interactions, and its center of mass will be moved with infinitesimally small acceleration and velocity, due to immensely large mass; however the mass center of Earth with the ball before falling, will stay in place after the fall. Due to elastic and inertial properties of the affected structures the vibrational motion will be set and dissipated with (inertial, elastic and dissipative) redistribution through ever increasing material structures, thus the totality of momentum and energy will be conserved. Similar reasoning could be scaled down and up, from elementary particles (the smaller structures known to man) to largest planetary, star and galaxy structures in the universe, to everything our mind could comprehend.

As already stated we must bear in mind that new ideas and concepts (a way one perceive reality) are not only difficult for a reader to grasp but equally difficult and painful for an author to express. We know that material system structures are particulate, thus we will be focusing on material systems made of interacting material particles down to the smallest ones known or relevant to us. We will analyze interaction between two material particles using Newton's Law of motion and prove that during their forced interaction energy is transferred from one to another particle in equal amount, thus conserved, and without any interaction a particle energy is not changed, thus overall energy is conserved. Since energy is additive (cumulative) for any structure and redistributed from structure to structure, we will extend the reasoning proof to any system size, i.e.: energy between interacting systems is transferred from one system to another in equal amount, and without any interaction a system energy is not changed, thus overall energy is conserved, see Fig. 7.

According to the Newton Law of motion a material particle or any system will not change its motion unless acted upon with an external force; thus momentum vector and/or kinetic energy will stay unchanged. This is the most fundamental law in nature which defines the relationship between system mass, motion and force, and thus defines unity of all three concepts: mass, motion and force. This is the starting point in this treatise and everything else will be built from here. Motion is displacement in time so that the above fundamental law interrelates mass, displacement, time and force. However, there is no imaginary force, but a forced interaction of one system onto another, where the interacting forces (including inertia forces) are balanced between the two interacting systems (action and reaction at any interface surface-boundary). Therefore there is only interaction force, i.e. equal action and reaction force between the two particles or systems in equilibrium motion, and with the subtle difference between the two forces during forced interaction with motion change, i.e. momentum and energy interchange or transfer. The subtle difference is that during interaction one particle or system is decelerating (called acting system or source) in order to accelerate the other particle or system (called reacting or resisting system, or sink), thus producing relative forced displacement (called change or process) between the two particles or systems. The relative forced interactions (forces and displacements in time) are always with reference to interacting material systems at any scale, from elementary particles to galaxies in the universe. The further complexities arise due to diverse forms of material particles and systems (their different forced, elastic-like structures) which are extending from a material particle in form of continuously-like and progressively-decaying forced fields away from a particle, like strong and weak nuclear force fields around nucleons or gravitational field around a mass particle or electromagnetic field around a charged particle, which in turn give rise to overlapping and cumulative interactions in space and time. However the fundamental concept of forced interaction is the same for every particle and forced field around it, providing that the motion in form of directional momentum and redistributed scalar energy is conserved.

A system in stable equilibrium will only change its (stable or most favorable or most probable) state, i.e. its established equilibrium properties, if it is forcefully displaced (changed) in space and time. For a system change to happen, it is necessary for its structure to be forcefully displaced by another system. During a forced displacement through the mutual interface-boundary surface, one system will be acting (forcing in the displacement direction) while the other system will be forcefully resisting the displacement in opposite direction. The systems will be competing for existence in space and time and in so doing exchange energy between them. The acting system (forcing in displacement direction) or energy source will be departing or transferring its energy to the resisting system or energy sink. Due to equity of acting and reacting forces and equal mutual forced displacement, the transferred energy will be the same and thus the total energy conserved.

Newton formulated the general theory of motion of objects due to applied forces in 1687. This provided for concepts of mechanical work, kinetic and potential energies, and development of solid-body mechanics. During interaction (collision) of two material particles (or systems for that matter), the acting system (A) will accelerate reacting system (R) with average force F_A along displacement d_{AR}, see Figs. 7, 8 & 9, i.e.:

$$(1)\qquad \underbrace{\int_0^{d_{AR}} F_A ds}_{W_{F_A}} = \int_0^{d_{AR}} \left(m \underbrace{\frac{dV_R}{dt}}_{a_R} \right) ds = \int_0^{d_{AR}} \left(m \frac{dV_R}{ds} \underbrace{\left\{ \frac{ds}{dt} \right\}}_{V_R} \right) ds = \int_{V_{R1}}^{V_{R2}} m V_R dV_R = \underbrace{\frac{1}{2} m \left(V_{R2}{}^2 - V_{R1}{}^2 \right)}_{KE_{R2} - KE_{R1}}$$

$$\left(W_{F_A} \right) = \left(KE_{R2} - KE_{R1} = E_{R2} - E_{R1} \right) = \left(\Delta E_R \right)$$

At the same time the acting system (A) will decelerate under equilibrium reaction force of system (R), $\vec{F}_R = -\vec{F}_A$, along the same displacement, $\vec{d}_{AR}$, see Figs. 7, 8 & 9, i.e.:

$$(2)\qquad \underbrace{\int_0^{d_{AR}} F_R ds}_{W_{F_R}} = \int_0^{d_{AR}} \left(m \underbrace{\frac{dV_A}{dt}}_{a_R} \right) ds = \int_0^{d_{AR}} \left(m \frac{dV_A}{ds} \underbrace{\left\{ \frac{ds}{dt} \right\}}_{V_A} \right) ds = \int_{V_{A1}}^{V_{A2}} m V_A dV_A = \underbrace{\frac{1}{2} m \left(V_{A2}{}^2 - V_{A1}{}^2 \right)}_{KE_{A2} - KE_{A1}}$$

$$\left(W_{F_R} \right) = \int_0^{d_{AR}} F_R ds = \left(KE_{A2} - KE_{A1} = E_{A2} - E_{A1} \right) = \Delta E_A = \int_0^{d_{AR}} \left(-F_A \right) ds = = -\Delta E_R$$

The above correlation is known as the "*work-energy principle.*" The work-energy principle could be easily expended to include work of gravity force and gravitational potential energy as well as elastic spring force and potential elastic spring energy, see Fig. 8.

$$(3)\qquad \underbrace{\int_0^{d_{AR}} F_A ds}_{W_{F_A}} = \int_{s_1}^{s_2} (ks) ds = \left(PE_{R2} - PE_{R1} = E_{R2} - E_{R1} \right) = \left(\Delta E_R \right)$$

$$= \int_0^{d_{AR}} \left(-F_R \right) ds = -\left(KE_{A2} - KE_{A1} = E_{A2} - E_{A1} \right) = -\Delta E_A$$

Therefore, during an interaction between two material particles or systems, the acting system energy will be reduced and transferred in the same amount to the resisting system so that the totality of energy of the two interacting systems is unchanged, i.e. conserved:

$$\begin{aligned} &\Delta E_A = -\Delta E_R \\ &(E_{A2} - E_{A1}) = -(E_{R2} - E_{R1}) \\ &(E_{A2} + E_{R2}) = (E_{R1} + E_{A1}) = const \end{aligned} \tag{4}$$

The "existence" or any structure in nature (material system, called system for simplicity) is defined or described by its mass (measure of inertia) and its "structural" interacting forces (action and reaction forces: consists of structural elastic and field forces, and inertial forces). According to the Newton's Laws, all the forces (including inertial forces) must be balanced for any system all the time. This defines natural symmetry (action ad reaction) or "forceful-competing" of martial structures for existence in space and time, otherwise the material structures will "collapse and disappear" to non-existence. That means that a net action forces must be balanced with the sum of net reaction forces (in case of static or quasi-static equilibrium) and net inertial forces (in case of dynamic interaction or process). An inertial force is due to a system mass resistance to acceleration (change of motion state) and is proportional to mass times negative acceleration, i.e. it is balanced with (i.e., equal to) the net-resultant of all action and reaction forces (the Newton 2nd Law). A special case of the 2nd Law is if inertial force is zero, i.e. if action and reaction forces are balanced. The two relevant consequences of the zero inertial force are: (1) for any boundary interface surface (no mass, thus regardless of acceleration) the action and reaction forces are balanced (the Newton 3rd Law), and (2) for any non-accelerated system (with mass but no acceleration, the Newton 1st Law). Therefore, in essence, the all tree Newton Laws of motion are fundamentally the same, where the 1st and 3rd Laws are special cases of the 2nd Law when acceleration or mass are zero, respectively.

The totality of energy is redistributed on systems' structures and substructures and is additive, i.e. cumulative, see Fig.9. During any interaction (process) at any scale level, the energy will be transferred from any and all acting to any and all reacting particles and thus be conserved. Furthermore, the so called potential energies, like elastic mechanical energy or chemical or nuclear energy, are in essence binding-force energies of the underlying substructures and are stored within spinning (including vibrating and twisting) energy of the elementary particles. Therefore, the forced interaction is provided by the transfer of motion energy ($mv^2/2$) of elementary particles from acting system or source to reacting system or sink. Thus, interaction is a process of accelerating one system structure on the expense of decelerating another system structure, from the bulk scale (mechanical energy), to inter-molecular scale (thermal energy), to inter-atomic scale (chemical energy), to inter-nucleus scale (nuclear energy), to electromagnetic scale, including thermal radiation, the smallest scale known to man. Or figuratively, we may say that forced-displacement-interactions are energy transfer processes where one structure is unwinding or decelerating in order to wind or accelerate another stricture. How simple, logical, and rigorous!

V. Energy Forms and Classifications:

Energy-Transfer versus Energy-Property

Any and all changes (happening in space and time) are caused by energy exchanges or transfers from one substance (*system* or *subsystem*) to another. A part of a system may be considered as a subsystem if energy transfer within a system is taking place, and inversely, a group of interacting systems may be considered as a larger isolating system, if they do not interact with the rest of the surroundings. Energy transfer may be in organized form (different types of work transfer due to force action) or in chaotic disorganized form (heat transfer due to temperature difference). Energy transfer into a system builds up energy-potential or generalized-force (called simply potential for short, like pressure, temperature, voltage, etc.) over energy-displacement (like volume, entropy, etc.). Conversely, if energy is transferred from a system, its energy potential is decreased. That is why net-energy is transferred from higher to lower energy potential only, until the potentials equalize, i.e. the equilibrium establish.

There are many forms and classifications of energy, see Table 3, all of which could be classified as *microscopic* (or internal within a system microstructure) and/or *macroscopic* (or external as related to the system mass as a whole with reference to other systems). Furthermore, energy may be 'quasi-potential' (associated with a system equilibrium state and structure, i.e. system property) or 'quasi-kinetic' (energy in-transfer from one system or one structure to another, in form of *work* or *heat*).

Every material system state is an equilibrium potential 'held' by forces, i.e., the forces 'define' the potential and state – action and reaction; otherwise a system will undergo dynamic change (in time), or quasi-kinetic energy exchange towards another stable equilibrium. Atoms (mass) are 'held' by atomic and electromagnetic forces in small scale and by gravity in large scale, see Fig. 2a, otherwise mass would disintegrate ('evaporate' or radiate into energy) like partly in nuclear reactions – *nuclear* energy. Molecules are 'held' by electro-chemical bounding (valence) forces (chemical reactions – *chemical* energy). Liquids are 'held' by latent intermolecular forces (gas condensation, when kinetic energy is reduced by cooling – *latent thermal* energy). Solids are 'held' by 'firm' intermolecular forces (freezing/solidification when energy is further reduced by cooling – *latent thermal* energy again). *Sensible thermal* energy represents energy of random molecular motion and is related to temperature of a system. 'Holding' potential forces may be 'broken' by energy transfer (e.g., heating, high-energy particles interaction, etc.). States and potentials are often 'hooked' (i.e. stable) and thus need to be 'unhooked' (or to 'be broken' by so called activation energy) to overcome existing 'threshold' or equilibrium, like in igniting combustion, starting nuclear reaction, etc.

As stated above, energy can be directional (purposeful or organized) and chaotic (dissipative or disorganized). For example, mass-in-motion, *mechanical kinetic* energy, and electricity-in-motion, *electrical kinetic* energy, are organized kinetic energies (Fig. 2b), while *thermal* energy is disorganized chaotic energy of motion of molecules and atoms (Fig. 2c). System energy may be defined with reference to position in a vector-force field, like *elastic potential* (stress) energy, *gravitational potential* energy, or *electromagnetic* field energy. There are many different energy forms and types (see Table 3). We are usually not interested in (absolute) energy level, but in the change of energy (during a process) from an initial state (*i*) to a final state (*f*), and thus zero reference values for different energy forms are irrelevant, and often taken arbitrarily for convenience. The followings are basic correlations for energy changes of several typical energy forms, often encountered in practice: motion kinetic energy ($E_K=KE$) as function of system velocity (v); spring elastic potential energy (E_{Ps}) as function of spring deformation displacement (x); gravitational potential energy ($E_{Pg}=PE_g$) as function of gravitational elevation (z); and sensible thermal energy ($E_U=U$) as function of system temperature (T):

$$(5)\qquad \Delta E_K = \frac{1}{2}m\left(v_f^{\,2} - v_i^{\,2}\right)\ ;\ \ \Delta E_{Ps} = \frac{1}{2}k\left(x_f^{\,2} - x_i^{\,2}\right)$$

$$\Delta E_{Pg} = mg(z_f - z_i)\ \ ;\ \ \Delta E_U = mc_v(T_f - T_i)$$

If the reference energy values are taken to be zero when above initial (*i*) variables are zero, then the above equations will represent the energy values for the final values (*f*) of the corresponding variables. If the corresponding parameters, spring constant *k*, gravity *g*, or constant-volume specific heat c_v, are not constant, then integration of differential energy changes from initial to final state will be necessary.

Energy transfer via work *W* (net-out), and heat transfer *Q* (net-in), may be expressed as product of related energy-potentials (pressure *P*, or temperature *T*) and corresponding energy-displacements (change of volume *V* and entropy *S*, respectively), i.e.:

$$(6)\qquad W_{12} = \vec{F}\cdot\vec{d} = \left[(P\cdot \underbrace{A\vec{n})\cdot\vec{d}}_{\Delta V}\right] = P\cdot\Delta V_{12}\Big|_{P\neq const} = \int_{V_1}^{V_2} P\cdot dV$$

$$(7)\qquad Q_{12} = T\cdot\Delta S_{12}\Big|_{T\neq const} = \int_{S_1}^{S_2} T\cdot dS$$

Note, in Eq. (6), that force cannot act at a point but is distributed as pressure (*P*) over some area *A* (with orthogonal unit vector $\vec{n}$), which when displaced will cause the volume change *?V*. Also note that it is custom in some references to denote heat transfer in and work transfer out as positive. In general, “in” (means “net-in”) is negative “out” (means “net-out”) and vice versa.

In general, energy transfer is taking place at a system boundary interface and is equal to the product of energy-potential or generalized-force and the corresponding generalized-displacement:

$$dE_{Transfer} = dQ_{netIN} - \left[\sum dW_{netOUT}\right] = dQ_{netIN} + \left[\sum dW_{netIN}\right] =$$

$$(8)\qquad = TdS + \left[\underbrace{-PdV}_{COMPR.} + \underbrace{sdA}_{STRETCHING.} + \underbrace{td(A\cdot s)}_{SHEARING} + \underbrace{Vdq}_{CHARGING} + \underbrace{\vec{E}\cdot d(V\vec{P})}_{POLARIZATION} + \underbrace{m_o\vec{H}\cdot d(V\vec{M})}_{MAGNETIZATION} + \underbrace{\cdots}_{ETC.}\right]$$

Where the quantities after the last equal sign are: temperature and entropy; pressure and volume; surface tension and area; tangential-stress and area with tangential-displacement, voltage and electrical charge; electric field strength and volume-electric dipole moment per unit volume product; and permeability of free space, magnetic field strength and volume-magnetic dipole moment per unit volume product; respectively.

The total system energy stored within the system is:

$$(9)\qquad E_{Sys}=\underbrace{E_K+E_{Pg}+E_{Pdeff.}}_{E_{Mechanical}}+\underbrace{\underbrace{E_{Uth}}_{Thermal}+E_{Uch}+E_{Nucl}+E_{El}+E_{Magn}+\underbrace{\ldots}_{Etc.}}_{Internal\ (total)}$$

Where the quantities after the equal sign are: kinetic, potential-gravitational, potential-elastic-deformational, thermal, chemical, nuclear, and magnetic energies, etc.

VI. The First Law of Energy Conservation: *Unity and Universality of Energy*

Mechanical energy conservation was first established for bodies in motion. The "*work-energy principle*," derived above using the Newton Laws of motion, demonstrates the energy conservation during the forced-interaction between two material particles or systems in motion. The work-energy principle could be easily expended to include work of gravity force and gravitational potential energy as well as elastic spring force and potential elastic spring energy.

During a free gravity fall (or free bounce) without air friction, for example, the potential energy is being converted to kinetic energy of the falling body (or vice versa for free bounce), and at any time the total mechanical energy (sum of kinetic and potential mechanical energies) is conserved, i.e. stays the same, see Fig. 10. The mechanical energy is also conserved if a mass freely vibrates on an ideally elastic spring, or if a pendulum oscillates around its pivot, both in absence of dissipative effects, like friction or non-elastic deformation. In general, for work of conservative forces only, the mechanical energy, E_{mech}, for N isolated systems, is conserved since there is no dissipative conversion in thermal energy and thus no heat transfer, i.e.:

$$(10)\qquad E_{mech}=E_K+E_{Pg}+E_{Ps}=\sum_{j=1}^{N}\left(\frac{1}{2}mv^2+mgz+kx\right)_j=const$$

The mechanical work-energy concept could also be expended to fluid motion by inclusion of elastic pressure force and potential elastic pressure energy (referred in some references as flow work), see the Bernoulli equation below. For flowing or stationary fluid without frictional effects, the mechanical energy, including fluid elastic-compression energy, $PV=mP/r$, is conserved, as expressed by the Bernoulli or hydrostatic equations below, see also Fig. 11.

$$(11)\qquad \frac{E_{mech}}{m}=\frac{1}{m}(E_K+E_{Ps}+E_{Pg})=\left.\underbrace{\frac{v^2}{2}+\frac{P}{r}+gz}_{\substack{\text{Bernoulli}\\ \text{equation}}}\right|_{v=0}=\underbrace{\frac{P}{r}+gz}_{\substack{\text{hydrostatic}\\ \text{equation}}}=const.$$

Work against conservative (also known as internal, or volumetric, or space potential field) and/or inertial forces, is path-independent and during such a process the mechanical energy is conserved. However, work of non-conservative, dissipative forces is process path-dependent and part of mechanical energy is converted (dissipated) to the thermal energy, see Fig. 12a.

When work of non-conservative forces W_{nc}, is exchanged between *N* isolated systems, from an initial (*i*) to final state (*f*), then the total mechanical energy of all systems is reduced by that work amount, i.e.:

$$W_{nc,i\to j} = \left(\sum_{j=1}^{N} E_{mech,j}\right)_i - \left(\sum_{j=1}^{N} E_{mech,j}\right)_f \tag{12}$$

Regardless of the traveled path (or displacement), the work against conservative forces (like gravity or elastic spring in above cases) in absence of any dissipative forces, will depend on the final and initial position (or state) only. However, the work of non-conservative, dissipative forces (W_{nc}) depends on the traveled pat since the energy is dissipated during the force displacement, and mechanical energy will not be conserved, but in part converted (via dissipation and heat transfer) into the internal thermal energy, See Eq. (12). This should not be misunderstood with total energy conservation, which is always the case, and it must include both work and heat transfer, see below.

As already stated, there are many different types of work transfer into (or out of) a system which will change the corresponding energy-form stored in (or released, discharged out of) the system. In addition to work, energy may be transferred as heat associated with change of the internal thermal energy of a system. Furthermore, different forms of stored energy are often coupled so that one type of energy transfer may change more than one form of stored energy, particularly due to inevitable dissipative conversion of work to heat, and in turn to internal thermal energy. Conversely, heat and internal energy may be converted in other energy forms. In absence of nuclear reaction (no conversion of mass into energy, $E=mc^2$), mass and energy are conserved separately for an isolated system, a group of isolated systems, or for the universe. Since the material system structure is of particulate form, then systems' interactions (collisions at different scale-sizes) will exchange energy during the forced displacement -- and similarly to the mechanical energy conservation -- the totality of all forms of energy will be conserved as explained in previous Sections, see Fig. 12, which could be expressed as:

$$\underbrace{\sum_{All\ \ i's} E_{i,Trans.}}_{BOUNDARY} = \underbrace{\Delta E_{Change}}_{SYSTEM} \quad or \quad \underbrace{\sum_{All\ \ j's} W_{j,netIN} + \sum_{All\ \ k's} Q_{k,netIN}}_{BOUNDARY} = \underbrace{\Delta E_{netIncrease}}_{SYSTEM} = \Delta E_{Sys} \tag{13}$$

Energy interactions or transfers across a system boundary, in form of work, $W_{netIN} = \sum W_{IN} - \sum W_{OUT} = -\left(\sum W_{OUT} - \sum W_{IN}\right) = -W_{netOUT}$, and heat, $Q_{netIN} = \sum Q_{IN} - \sum Q_{OUT}$, will change the system total energy, $\Delta E_{Sys} = E_{Sys,2} - E_{Sys,1}$. The boundary heat or work transfers are process (or process path) dependent for the same ΔE_{Sys} change, see Fig. 12a, except for special cases for adiabatic processes with work interaction only (no heat transfer), or for caloric processes with heat interaction only (no work transfer), see Fig. 12(b&c). For the former adiabatic processes the system boundary work transfer is path independent for the same ΔE_{Sys} change, but the entropy change and thus the final state is path dependent, except for special cases like isentropic process or isochoric process (Joules experiment), etc. For the latter caloric processes without work interactions (no volumetric expansion or other mechanical energy changes), the system boundary heat transfer, as well as the final state, is path independent for the same ΔE_{Sys} change. Furthermore, the internal thermal energy is conserved by being transferred from one system to another via heat transfer only, known as "*caloric* fluid." This demonstrates the value of the caloric theory of heat that was established by Lavoisier and Laplace (1789), the great minds of 18th century. Ironically, the caloric theory was creatively used by Sadi Carnot to develop concept of reversible cycles for conversion of caloric heat to mechanical work as it "flows" from high to low temperature reservoirs (1824) that later helped in dismantling the caloric theory and establishing the 2nd Law of Thermodynamics. The caloric theory was discredited by establishing the "*heat equivalent of work*, e.g. *mechanical equivalent of heat*" by Mayer (1842) and experimentally confirmed by Joule (1843), which paved the way for establishing the *First Law* of energy conservation and new science of *Thermodynamics* (Clausius, Rankine and Kelvin, 1850 and later). Prejudging the caloric theory now as a "failure" is unfair and unjustified since it made great contributions in calorimetry and heat transfer, and it is valid for caloric processes (without work interactions). The coupling work-heat interactions and conversion between thermal and mechanical energy are outside of the caloric theory domain and are further developed within the First and the Second Laws of Thermodynamics. Another treatise with reasoning proof of the 2nd Law of energy degradation is under preparation by this author and will detail related phenomena.

The First Law of energy conservation for the control-volume (CV, with boundary surface BS) flow process, see Fig. 13, is:

$$(14)\qquad \underbrace{\frac{d}{dt}E_{CV}}_{\substack{RATE\ OF\ ENERG\\ CHANGE\ IN\ CV}} = \underbrace{\sum_{BS}\dot{Q}_{netIN,i}}_{\substack{BS\ TRANSFER\\ RATE\ OF\ HEAT}} - \underbrace{\sum_{BS}\dot{W}_{netOUT,i}}_{\substack{BS\ TRANSFER\\ RATE\ OF\ WORK}} + \underbrace{\sum_{IN}\dot{m}_j(e+Pv)_j}_{\substack{ENERGY\ TRANSPORT\\ RATE\ WITH\ MASS\ IN}} - \underbrace{\sum_{OUT}\dot{m}_k(e+Pv)_k}_{\substack{ENERGY\ TRANSPORT\\ RATE\ WITH\ MASS\ OUT}}$$

The First Law of energy conservation equation for a differential volume per unit of volume around a point (*x*,*y*,*z*) in a flowing fluid is:

$$(15)\qquad \underbrace{r\frac{De}{Dt}}_{\text{energy change in time}} = \underbrace{-\vec{V}\cdot(\nabla P)}_{\substack{\text{work rate}\\ \text{of pressure forces}}} + \underbrace{\nabla\cdot\left(\vec{V}\cdot t_{ij}\right)}_{\substack{\text{work rate}\\ \text{of shearing stresses}}} + \underbrace{\nabla\cdot\left(k\nabla T\right)}_{\substack{\text{heat rate}\\ \text{via thermal conduction}}}$$

Where, $e = \hat{u} + \frac{\vec{V}^2}{2} + gz$ NOTE: distinguish mass-specific internal energy $\hat{u}$, from velocity *u(y).*

Which after substitution, $\nabla\cdot\left(\vec{V}\cdot t_{ij}\right) = \vec{V}\cdot\left(\nabla\cdot t_{ij}\right) + \Phi$, and using the momentum equation, reduces to:

$$(16)\qquad r\frac{D\hat{u}}{Dt} = -p\left(\nabla\cdot\vec{V}\right) + \Phi_k + \Phi + \nabla\cdot\left(k\nabla T\right)$$

Where, $\Phi_k = k\left(\nabla \cdot \vec{V}\right)^2$ is the bulk viscosity dissipation, and the shear viscosity dissipation function Φ, which is the rate of mechanical work conversion to internal thermal energy for a differential volume per unit of volume, with [*W/m*^{3}] unit, is given for Newtonian fluid as:

(15)

$$\Phi = \frac{d\dot{W}_\Phi}{dV} = \left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right] + m\left[\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2\right] - \frac{2}{3}m\left(\nabla \cdot \vec{V}\right)^2$$

The power or work rate of viscous dissipation (irreversible conversion of mechanical to internal thermal energy) in a control volume *V* is:

(17) $\dot{W}_\Phi = \int_V \Phi dV$ NOTE: distinguish volume *V*, from velocity $\vec{V}$

VII. Concluding Remarks: *Energy is Conserved and Redistributed*

In this treatise we have focused on energy concept and reasoned the general proof of energy conservation based on the Newton's Laws of motion and particulate structures of all material systems. The objective was to emphasize physical concepts and to be as simple but also as rigorous as possible. The mechanical work-energy principle has been extended to all forms of energy and material structures, and thus effectively proved the general energy conservation law. The fundamental principle of energy conservation is exceptionally simple but it appears in exceptionally many different forms, which explain universality and unity of simplicity and complexity, but also difficulties to recognize simplicity in complex diversity.

Only by the beginning of the 20th century scientists had been able to established conservation laws governing the following quantities: energy, mass (or matter), linear momentum, angular momentum, and electric charge. Conservation laws have the broadest possible application of all laws in physics and are thus considered by many scientists to be the most fundamental laws in nature. As such the fundamental laws are taken as axiomatic and many believe they could not be questioned, explained or proven. The conservation laws are simple and broad – in many ways these laws express all existence and transformations, including unity of diversity, or simplicity of complexity, or continuous transformational existence: mass or charge or momentum or energy cannot transform into nothing or disappear without any trace. Therefore, we may infer that the first property of all existences (i.e., mass, charge, momentum, energy) is their *indestructibility* or conservation. Why it has been so difficult to fully account for and prove energy conservation. The reason is that energy, while being conserved during diverse processes (the 1st Law), it is also redistributed and virtually "lost or dissipated out of sight" over vast and diverse material structures of the surroundings (the 2nd Law), making it difficult, if not impossible, to be everywhere observed and fully accounted for.

We know that material system structures are particulate, thus we focused on material systems made of interacting material particles down to the smallest ones known or relevant to us.

We analyzed interaction between two material particles using Newton's Law of motion and proved that during their forced interaction energy is transferred from one to another particle in equal amount, thus conserved, and without any interaction a particle energy is not changed, thus overall energy is conserved. Since energy is additive (cumulative) for any structure and redistributed from structure to structure, we extended the reasoning proof to any system size, i.e.: energy between interacting systems is transferred from one system to another in equal amount, and without any interaction a system energy is not changed, thus overall energy is conserved.

The totality of energy is redistributed on systems' structures and substructures and is additive, i.e. cumulative. During any interaction (process) at any scale level, the energy will be transferred from any and all acting to any and all reacting particles and thus be conserved. Furthermore, the so called potential energies, like elastic mechanical energy or chemical or nuclear energy, are in essence binding-force energies of the underlying substructures and are stored within spinning (including vibrating and twisting) energy of the elementary particles. Therefore, the forced interaction is provided by the transfer of motion energy of elementary particles from acting system or source to reacting system or sink. Thus, interaction is a process of accelerating one system structure on the expense of decelerating another system structure, from the bulk scale (mechanical energy), to inter-molecular scale (thermal energy), to inter-atomic scale (chemical energy), to inter-nucleus scale (nuclear energy), to "massless" electromagnetic scale, including thermal radiation, the smallest scale known to man. Or figuratively, we may say that forced-displacement-interactions are energy transfer processes where one structure is "unwinding" or decelerating in order to "wind" or accelerate another stricture. How simple, logical and rigorous!

The treatise presented here rationalized the fundamental and universal concept of energy as property of particulate and active structures of all material systems, and as energy exchange between interacting systems (material structures). Every physical system posses energy and is capable of interacting with other systems, i.e. exchange energy with other systems. The interaction is a process of forced-displacement with energy exchange, equal to force times displacement (scalar product of the two vector quantities). One system is forcing or acting and another is forcibly resisting or reacting (with the same but opposite force), so that energy is exchanged from acting or source to resisting or sink system, and thus conserved within the two systems. By virtue of system existence the forces are balanced (action and reaction, including inertia) at any instance, and through their interactions (forced displacements) their motions are conserved in time, directionally as momentum vector ($m\vec{v}$), and overall as directionally redistributed energy ($mv^2/2$) over material structures in space. However the energy redistribution is, overall, towards increasing directional randomness (conserved momentum and energy with increase of randomness or entropy). Another complementary treatise with reasoning proof of the 2nd Law of energy degradation is currently under preparation.

We will conclude by restating definition of energy again: ***Energy** is fundamental property of a physical system and refers to its potential to maintain a system identity or structure and to influence changes (via forced interaction) with other system by imparting work (forced directional displacement) or heat (forced chaotic displacement/motion of a system molecular or related structures).* Energy exists in many forms: electromagnetic (including light), electrical, magnetic, nuclear, chemical, thermal and mechanical (including kinetic, elastic, gravitational, and sound), where, for example, electro-mechanical energy may be kinetic or potential, while thermal energy represents overall potential and chaotic motion energy of molecules and/or related micro structure.

References/Bibliography

NOTE: This paper is mostly written as reflection of author's understanding (including logical hypothesis) of the related phenomena over many years, including recent publications [6-8], while the other sources [1-5] are listed as "Bibliography," where the well-known facts cited in this paper are presented.

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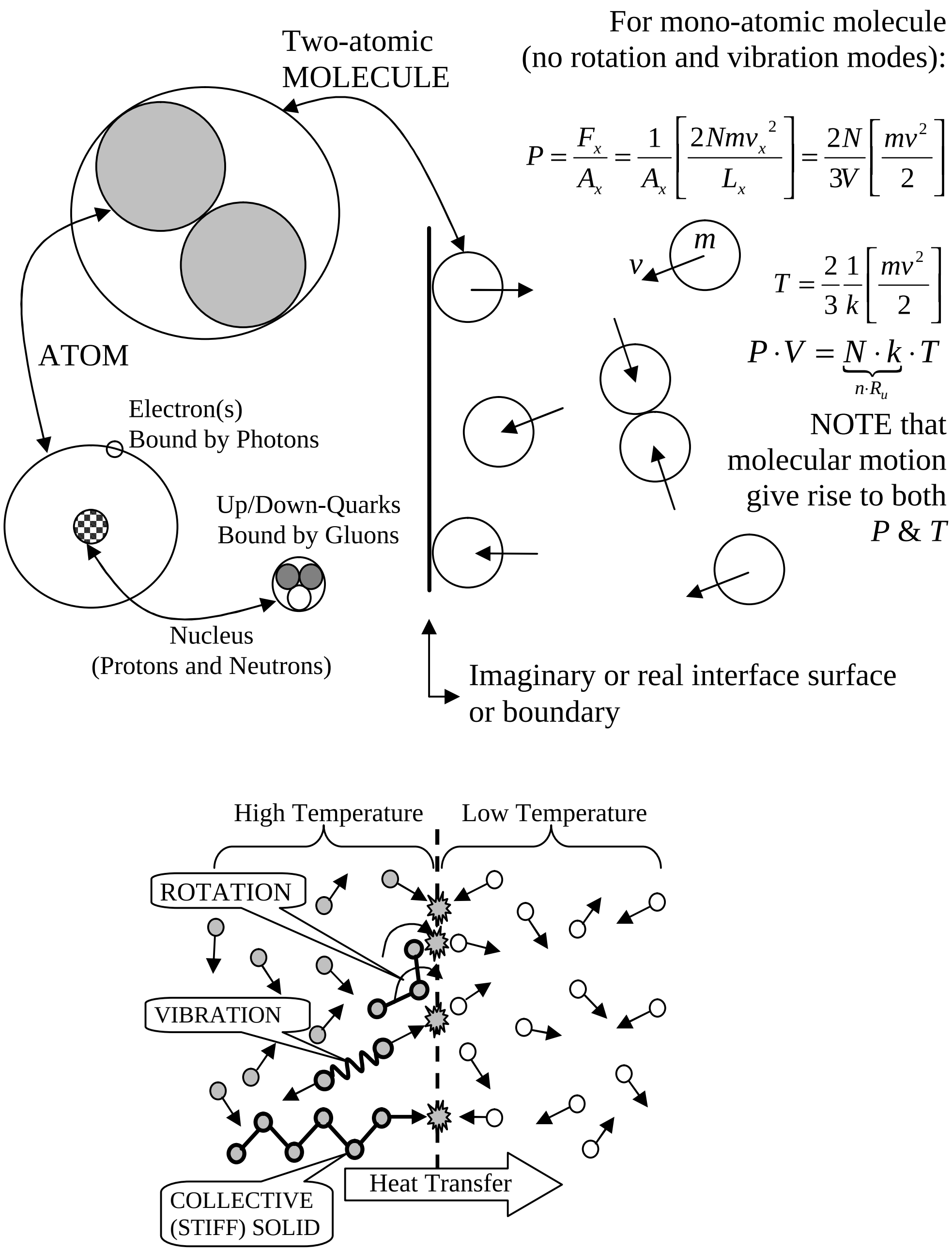
FIGURES (13) and TABLES (3) follow below:



Complications: rotation, vibration, and collective (stiff) solid behavior could contribute to the kinetic energy during particle interaction, i.e. temperature.

FIG. 1: Active (energetic) and particulate structure of material system: sub-molecular, sub-atomic and sub-nucleus structures (top-left); gas kinetic structure including simple ideal-gas relations for pressure and temperature (top-right); and random kinetic interactions (collisions) between more and less energetic (high and low temperature) molecules, including complications due to more complex sub-structures (rotations, vibrations, etc.).

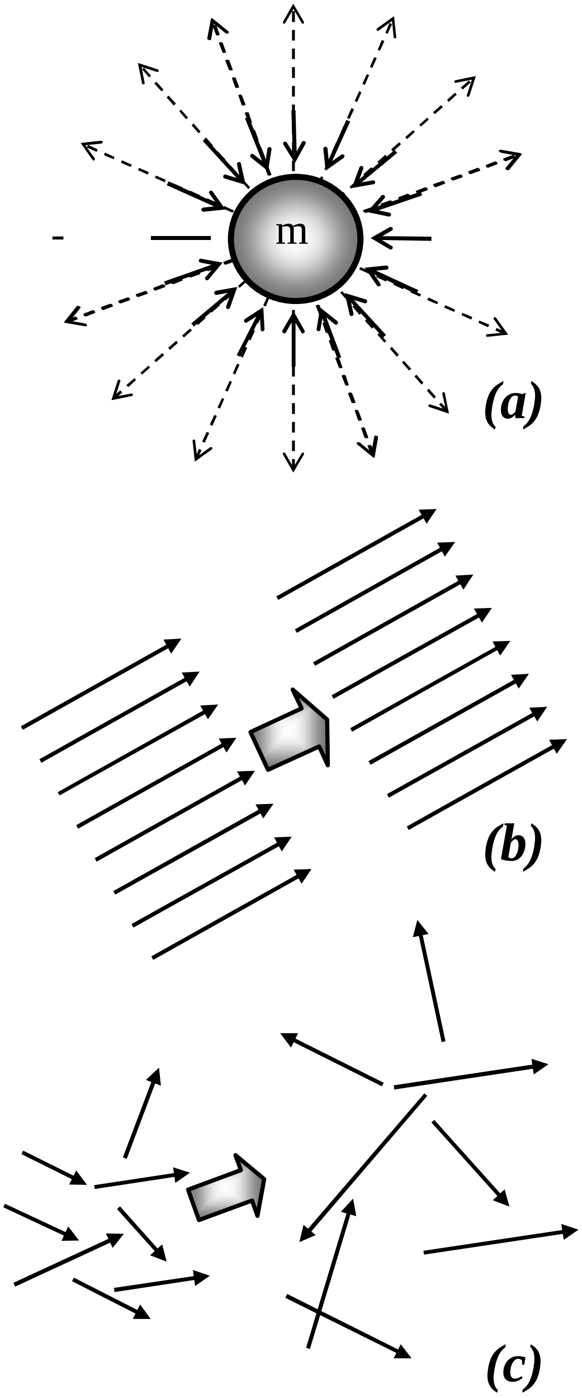


FIG. 2: Different types of energy (a) potential gravitational and electromagnetic radiation; (b) organized energy as work transfer; (c) disorganized thermal energy as heat transfer.

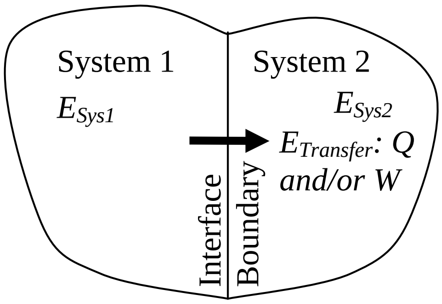


FIG. 3: Energy as material system property and energy transfer from one system to another

$$W = \vec{F}\cdot\vec{d} = \underbrace{\left(F\cdot\cos a\right)}_{\substack{F_d = \text{force} \\ \text{in d-direction}}}\cdot d = F\cdot\underbrace{\left(d\cdot\cos a\right)}_{\substack{d_F = \text{displacement} \\ \text{in F-direction}}}$$

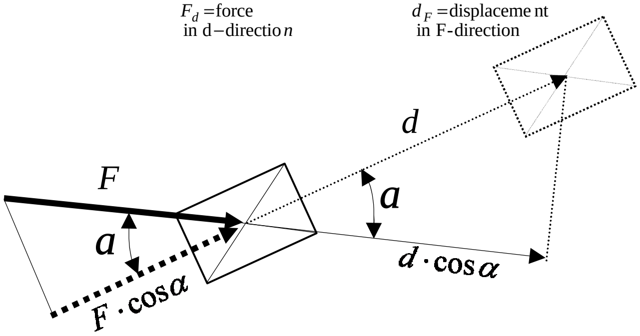


FIG**. 4**: **Work, force and displacement**

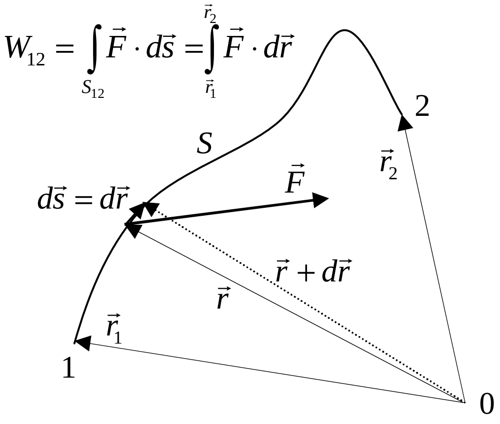


FIG. **5**: **Work along arbitrary path**

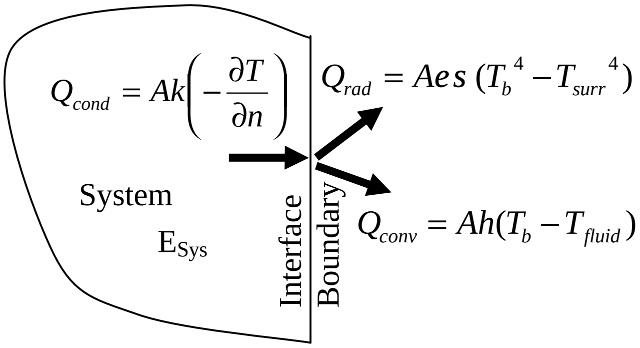
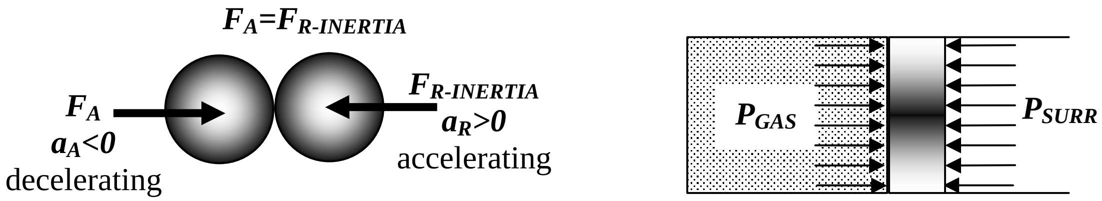


FIG. 6: Heat as energy-transfer by (a) conduction, (b) convection, and (c) radiation is due to difference in temperature

Unrestricted object-A motion:
Object energy stays the same.

Unrestricted gas expansion:
Gas energy stays the same.



Object-A motion restricted by Object-R:
Object-A energy reduced, i.e.
transferred to Object-R.

Restricted gas expansion by
surroundings:
Gas energy reduced, i.e.
transferred to surroundings.

FIG. 7: Energy of an unrestricted particle, object or material system, like gas etc., stays the same (unchanged) and is transferred during forced-displacement-interaction from acting or source system to reacting or sink system and thus conserved within the interacting objects or systems.

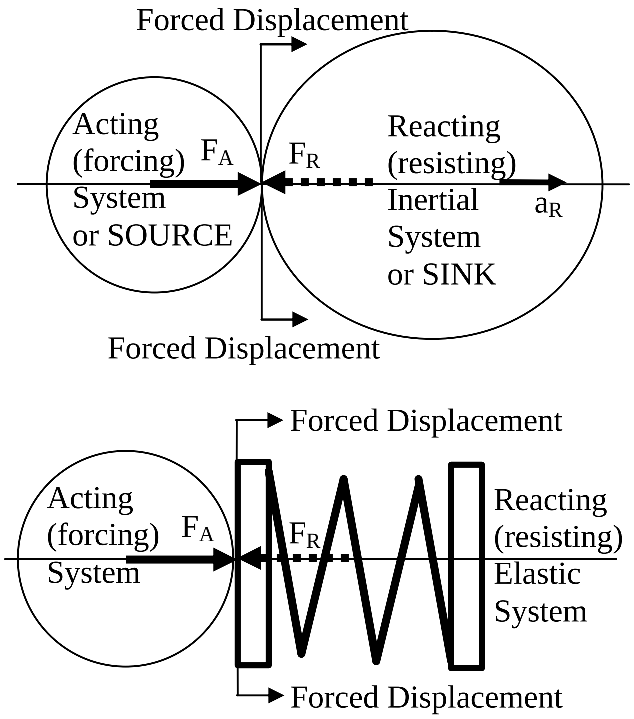


FIG. 8: Forced-displacement interactions between two inertial systems (top); and one inertial and one elastic system (bottom).

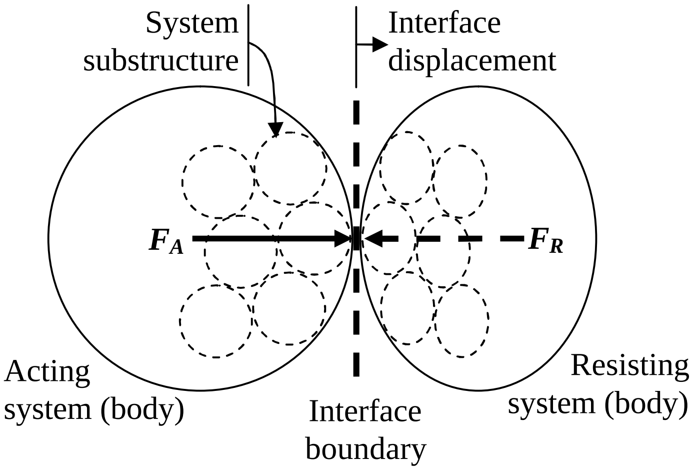


FIG. 9: Forced-displacement interaction between two material systems including sub-interactions and energy redistribution within their sub-structures.

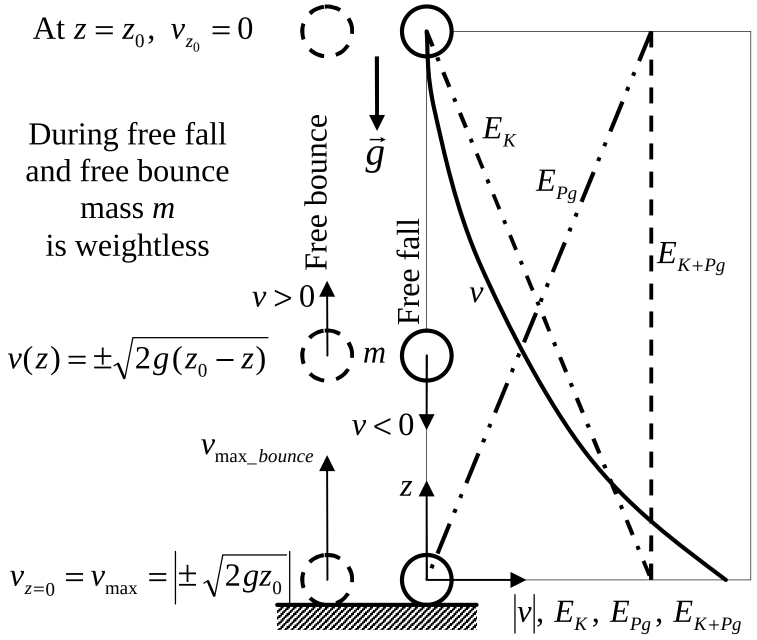
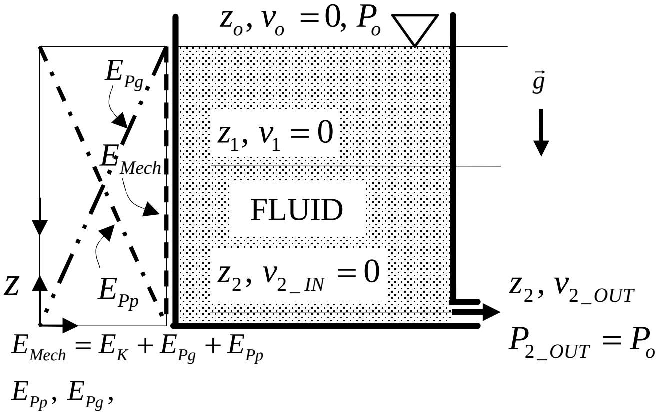


FIG. **10**: **Energy and work due to conservative gravity force**

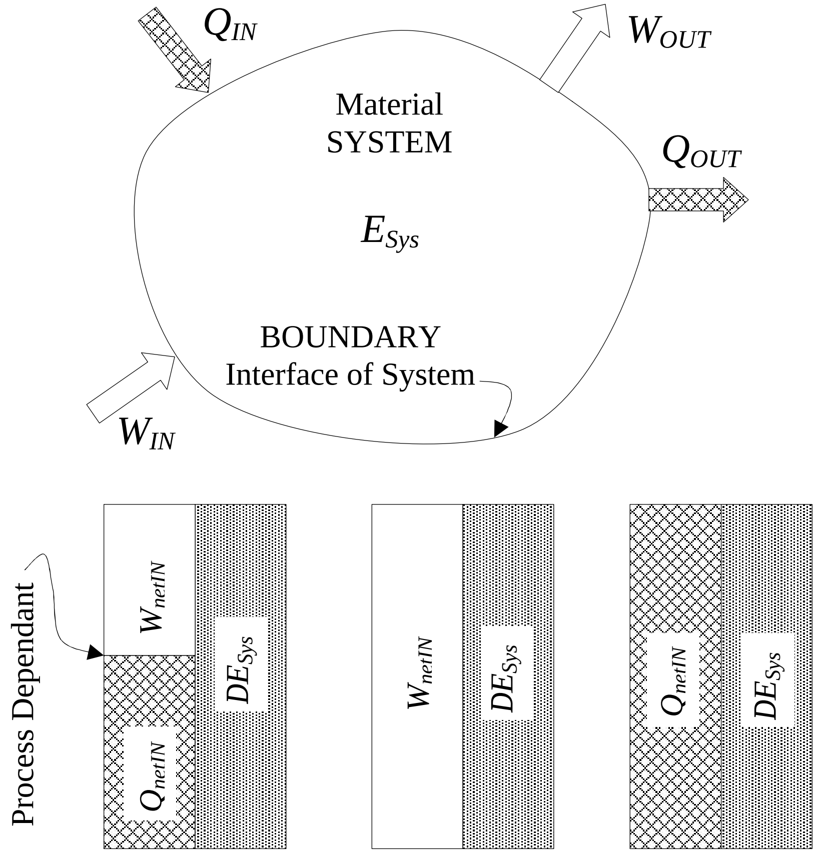


$$E_{Mech,0} = E_{Mech,1} = E_{Mech,2\_IN} = E_{Mech,2\_OUT}$$

$$\left[\underbrace{\frac{v^2}{2}}_{=0} + \underbrace{\left(\frac{P}{r}\right)}_{=0} + \underbrace{gz}_{\substack{PE_g= \\ =E_{Pg}}}\right]_0 = \left[\underbrace{\left(\frac{v^2}{2}\right)}_{=0} + \underbrace{\left(\frac{P}{r}\right)}_{E_{Pp}} + \underbrace{gz}_{0}\right]_{2\_IN} = \left[\underbrace{\left(\frac{v^2}{2}\right)}_{KE=E_K} + \underbrace{\left(\frac{P}{r}\right)}_{=o} + \underbrace{gz}_{0}\right]_{2\_OUT}$$

$P_{2\_IN} = rg(z_o - z_2)$ and $v_{2\_OUT} = \sqrt{2g(z_o - z_2)}$

FIG. 11: Conservation of fluid mechanical energy: Bernoulli equation, hydrostatic equation, and Torricelli's orifice velocity.



(a) Both *Q* & *W*
Work-Heat interaction
(*process dependant*)

(b) *W* only (No *Q*)
Work interaction
(*adiabatic process*)

(c) *Q* only (No *W*)
Heat interaction
(*caloric process*)

FIG. 12: System energy and energy boundary interactions (heat and work transfers) for (a) arbitrary, (b) adiabatic, and (c) caloric processes

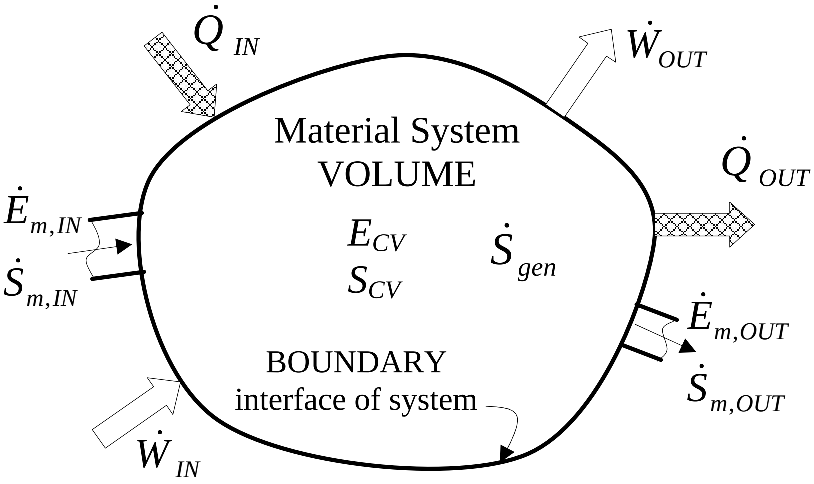


FIG. 13: Control-volume (CV) energy and entropy, and energy and entropy flows through the boundary interface of the control volume

TABLE 1: Material system structure and related forces and energies		
Particles	*Forces*	*Energies*
Atom nucleus	Strong and weak	Nuclear
Electron shell	electromagnetic	Electrical, magnetic, electromagnetic
Molecules	Inter-atomic/molecular	chemical
Molecules	Random collision and inertial, Potential inter-molecular	Sensible thermal
Molecules	Potential inter-molecular	Latent thermal
Molecules	Potential inter-molecular	Mechanical elastic
System mass	Inertial and gravitational	Mechanical kinetic and gravitational potential

TABLE 2: Typical energy units with conversion factors

Energy units	*J*	*kWh*	*Btu*
1 Joule (*J*)	1	2.78×10^{-7}	9.49×10^{-4}
1 kilowatt hour (*kWh*)	3.6×10^{6}	1	3.412×10^{3}
1 kilocalorie (*kcal*=*Cal*=1000 *cal*)	4187	1.19×10^{-3}	3.968
1 British thermal unit (*Btu*)	1055	2.93×10^{-4}	1
1 pound-force foot ($lb_f \cdot ft$)	1.36	$3.78\ 10^{-7}$	1.29×10^{-3}
1 electron volt (eV)	1.6×10^{-19}	4.45×10^{-26}	1.52×10^{-22}
1 Horse Power×second (*HP·sec*)	745.7	2.071×10^{-4}	0.707

TABLE 3: Energy forms and classifications

ENERGY									
Scale		*Energy Form (Energy Storage)*		*Energy Process*	*Type*			*Transfer* (release)	
						KINETIC (motion)		**KINETIC** (motion)	
MACRO/external (mass-based)	MICRO/internal (structure-based)				**POTENTIAL** (state or field)	Directional(#)	Chaotic dissipative	**WORK**(*) directional(#)	**HEAT** dissipative
		MECHANICAL							
X		• kinetic	$mV^2/2$	Acceleration		X		X	
X		• gravitational(+)	mgz	Elevation	X			X	
X		• elastic	$kx^2/2$ or $PV=mP/r$	Deformation	X			X	
		THERMAL	U_{th}						
	X	• sensible	$U_{th}=mc_{avg}T$	Heating			X		X
	X	• latent	$U_{th}=H_{latent}$	Melting Evaporation	X				X
	X	CHEMICAL	U_{ch}	Chemical Reaction	X				X
	X	NUCLEAR	U_{nucl}	Nuclear Reaction	X				X
		ELECTRICAL	E_{el}						
	X	• electro-kinetic	$V(It)$ or $LI^2/2$	Electro-current flow		X		X	
	X	• electrostatic	$(It)^2/(2C)$	Electro-charging	X			X	
		MAGNETIC	E_{magn}	Magnetization					
	X(&)	ELECTROMAGNETIC	E_{el_mag}	Radiation		X(&)		X	

(#)Electro-mechanical kinetic energy type (directional/organized, the highest energy quality) is preferable since it may be converted to any other energy form/type with high efficiency.

(*) All processes (involve energy transfer) are to some degree irreversible (i.e. dissipative or chaotic/disorganized).

(+) Due to mass position in a gravitational field.

(&) Electromagnetic form of energy is the smallest known scale of energy.