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Clausius’ thermodynamics, a theory of motive power from disorganized energy

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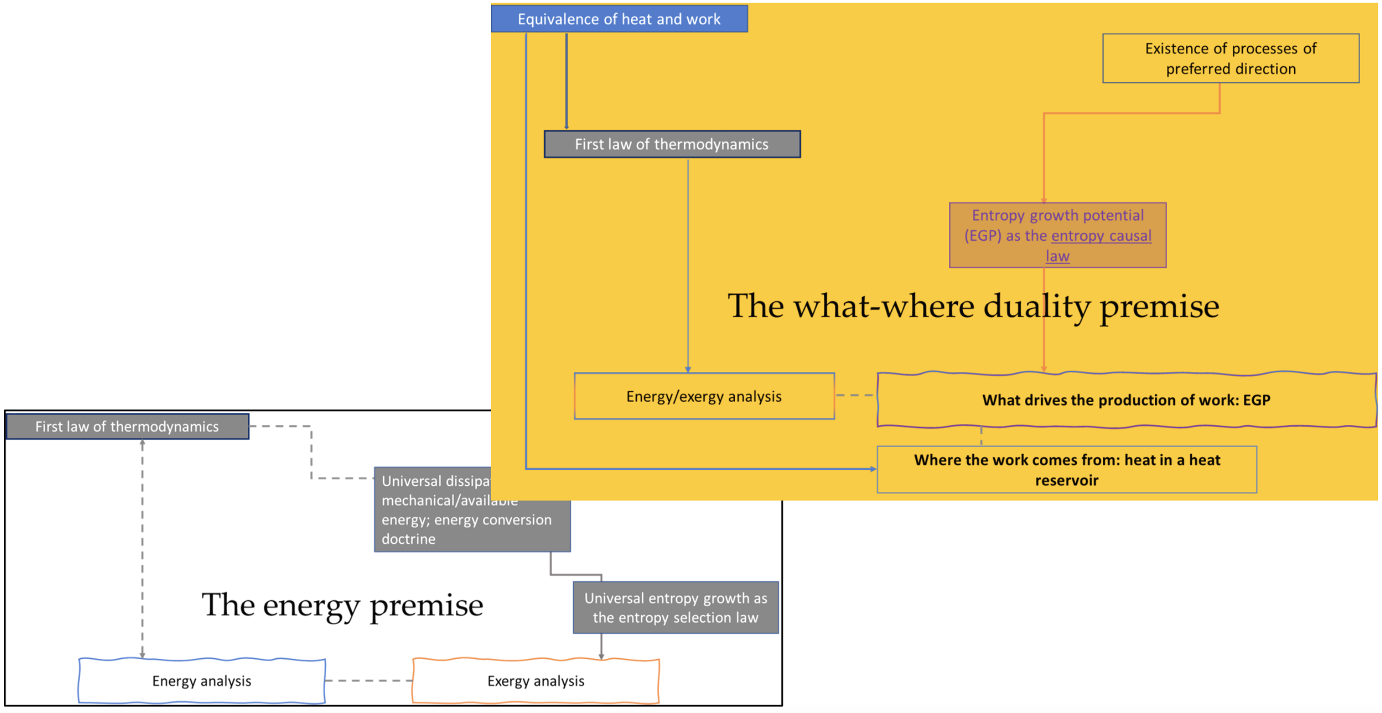
Abstract

Thermodynamics is the theory of energy resulting from the conceptual differentiation of caloric, circa 1850-1865, into energy (including both organized and disorganized energies), entropy, and heat (a disorganized form of energy)—one key part of the conceptual differentiation is the relation between organized energy and disorganized energy. The theory is often referred to as the Clausius-Kelvin theory as a single theoretical system. In actual fact, it is a blend of Kelvin’s contribution and Clausius’ contribution. Clausius’ version of the theory was transformed by Gibbs into Gibbsian thermodynamics, which is the result of a successful conceptual differentiation but one that does not involve the key part of the differentiation. Orthodox engineering thermodynamics is instead an update of energy physics formulated by Kelvin circa 1850-55 based on the *energy premise*, which errs on the “relation between two energies.” As a result, engineering thermodynamics is a defective theoretical system. This paper makes the case that Clausius’ theorem of entropy can be developed for reforming ET into a coherent system by rejecting the energy premise, which is to be supplanted with a what-where duality premise. Getting the relationship between two energies correctly, we shall have a completely different take on the connection between the “consumption of energy” and the surrounding “heat reservoirs.”

Keywords: Carnot’s theorem, equivalence of heat and work, energy physics, organized and disorganized energies, “compensation” and “equivalence” of transformations

Graphical Abstract



1. Introduction

Newcomen (1712) and Watt (1776) invented steam engines. In 1824, Carnot formulated a theory of steam engine in terms of the motive power of fire and Joule, following Black's introduction of heat as one measure of fire (the other is its temperature), empirically established (1843-45) the equivalence of heat and work, or power. Joule's finding may be referred to as the discovery that heat is a disorganized form of energy. We may refer to their contribution collectively as the NWCJ discovery of the motive power of *heat*, i.e., *disorganized energy*. The discovery gave rise to a new branch of physics, thermodynamics. Whereas mechanics is the physical theory of organized energy, thermodynamics is the physical theory of organized and disorganized energies.

In an address to the British Association in 1854, Thomson declared that Joule's discovery of the conversion of heat into work had 'led to the greatest reform that physical science had experienced since the days of Newton', the development of energy physics. This declaration of thermodynamics being a theory of energy represented one of the greatest advances leading to the expedient applications of energy of the last one-and-a-half century and, at the same time, resulted in a fateful energy-interpretation of the NWCJ discovery of disorganized energy. The energy-interpretation of the discovery highlighted the idea of "energy" in the phrase "disorganized energy" and stressed the idea of the conservation of total energy in all processes. The implication of this, especially the former highlight, is the adoption of the standard definition of energy as *the capacity for doing work*[1] and that "the adoption of the standard definition…perpetuated the view that energy, like mechanical energy [i.e., organized energy] had been, was the monolithic driver" for the production of work.[2] I shall call the view/doctrine that *energy is the monolithic driver for the production of work*the energy premise.

An argument against the *energy premise* has been made that there is no logical reason to conflate the two questions, what drives the production of *work* and where the *work* comes from.[2] I shall call this alternative premise the *what-where duality premise*. Note that mechanical energy, i.e., organized energy, *is* the capacity for doing work; for such cases, organised energy (in a waterwheel, e.g.) drives the production of work as well as that the work comes from the same organized energy. Both the energy definition and the conflation of the *what-where work questions*, which the energy premise does, applied to organized energy, an understanding that belonged to the preindustrial mechanical science. The NWCJ discovery of disorganized energy and the Thomson epiphany of energy physics, however, should have decisively broken away from this energy-premise understanding—which is a relic of the prediscovery age.

This paper explains why that did not happen with a review of the historical development of engineering thermodynamics that began as energy physics with its subtle inference of a limitation in the conversion of heat into work (i.e., heat cannot be 100% converted into work); the limitation inference may be referred to as an energy-premise inference; the paper then points out that energy-premise inference preempted the later formulation of the entropy principle from assuming its rightful power of explicating disorganized energy leading to awry of the true meaning of both energy and entropy; the limitation inference has been refuted in the 2022 paper[2] and the refutation strengthens the argument for supplanting the energy premise with the what-where duality premise; the substance of the paper is that we can incorporate the new premise into the framework of Clausius' theorem of entropy for a reformed engineering thermodynamics.

1.1. An introductory history of thermodynamics and introductory remarks

Before it became the theory of energy, the precursor of thermodynamics had been theories of heat or caloric, the study of heat/caloric and work and their interconversion. There had been mainly two theories, Carnot's theory, and Joule's theory. Coppersmith described the state of the scientific study of heat and work in the mid-nineteenth century, "While developing the absolute scale of temperature, Thomson still (in 1849) hadn't come round to accepting that heat could be converted into work. He thought that Carnot's conclusions would come crashing down if the axiom of the conservation of heat/caloric was abandoned. But he couldn't reconcile this axiom with Joule's experiments, which showed that heat and work were interconvertible, and that heat was actually consumed or generated in the process … It seemed as if both Carnot's and Joule's opposing theories were becoming more and more confirmed and entrenched. Thomson couldn't resolve this conflict: nor could he explain the conundrum of workless heat conduction; or the fact that Joule appeared to have shown conversions of work to heat, but not of heat into work"[3].

Thomson had the intuition that the creation of a useful theory of heat depended on the reconciliation of the conflict between Carnot's theory and Joule's theory, or the equivalence theorem, the theorem of the equivalence of heat and work. This has been sometime called Thomson's problem. [[3]:284, [4]:4] Both Thomson and Clausius carried out their versions of the synthesis of the equivalence theorem and Carnot's theory. A historical study of how Thomson carried out the synthesis is given by Smith in *William Thomson and the Creation of Thermodynamics: 1840-1855*[5]. How Clausius carried out his version of synthesis can be found in the book *Energy, the Subtle Concept*[[3]: 281-285 and 288-291] by Coppersmith, and in the article *A History of Thermodynamics: The Missing Manual* by Saslow[6].

Thermodynamics was the outcome of this synthesis project. Smith wrote, "What was emerging by the early 1850s, then, was classical thermodynamics as a science based on two axioms or laws"[[5][:278]. Today, the two laws are known as the law of energy and the law of entropy. In Sect. 2, the case that thermodynamics began its formative years as energy physics, or the energy physics synthesis circa 1850-1855[5], is presented. In this version of the synthesis, the second of the two laws as formulated by Thomson was not a law of entropy but the law of universal dissipation of mechanical energy or available energy. On the other hand, Tisza identified the key advance made in the synthesis project to be the conceptual differentiation (or bifurcation or splitting) of caloric, circa 1850-1865, into energy, entropy, and heat (a disorganized form of energy).[[7]; [8]: 22, 30-36] Energy physics, therefore, did not fit into this notion of conceptual differentiation being the DNA of the thermodynamic theory.

Sect. 3 introduces Clausius' 1854 Fourth Memoir *On a modified form of the second fundamental theorem in the mechanical theory of heat*[9][10], in which he called the equivalence of heat and work the first fundamental theorem and proposed a second fundamental theorem. In the Memoir,[9] Clausius chose "the analytical expression of the second fundamental theorem [for reversible processes]" equation *Eqn. (II)*. The entropy law resulted from Eqn. (II) has been referred to as the entropy selection law[11][12]. The law was then transformed and developed by Gibbs, which is referred to as the Clausius-Gibbs synthesis, into the theoretical system of Gibbsian thermodynamics. It is emphasized here that this is a theory based on both fundamental theorems, the first fundamental theorem, and the second fundamental theorem. That is, the foundation of equilibrium thermodynamics is different from that of energy physics: unlike energy physics which did not formulate a second law as a law of entropy, equilibrium thermodynamics was the result of the conceptual differentiation, explicitly, of caloric into energy and entropy. Section 3.2 also contains a review of how Tisza introduced an axiomatic form for Gibbsian thermodynamics, he called which *macroscopic thermodynamics of equilibrium* (MTE).

Sect. 4 considers orthodox thermodynamics, as an update of energy physics. When the MIT School of thermodynamics updated energy physics with its formulation of exergy analysis, it had the full benefits of Gibbsian equilibrium thermodynamics. The entropy law was incorporated in the update as a selection law, as it was mentioned in the above, and is still the standard view of the law. Sect. 4 of the paper makes the point that orthodox engineering thermodynamics, the Dresden/MIT-School update of energy physics, despite its incorporation of the entropy selection law, is still within the framework of energy physics with its energy conversion doctrine. While Tisza referred to the Clausius-Kelvin theory as a single theoretical structure system,[[8]: 104] this paper and the analysis of Sections 3 and 4 emphasize that the "Clausius-Kelvin theory" is in fact a blend of Thomson's (Kelvin's) contribution and Clausius' contribution: Clausius' has its lasting impact through Gibbs leading to MTE. Whereas, though MTE have been incorporated into an element of orthodox thermodynamics, Kelvin's energy physics still exerts a controlling role in orthodox thermodynamics; that is, the single, monolithic view of energy (the energy premise), not the conceptual differentiation of caloric into energy and entropy, remains to be the DNA of orthodox thermodynamics. Falling short of the conceptual differentiation leads to the questionable independency-status of the two laws of thermodynamics; the treatment of the relationship between disorganized energy and organized energy remains deficient in orthodox thermodynamics.

For overcoming the shortcoming, this paper makes its main point that there are two parts of the second fundamental theorem: “equivalence” of transformations and “compensation” of transformations. I shall relabel in Sect. 5 *Eqn. (II)*, Clausius’ first part of the second fundamental theorem, as *Eqn. (**II.1**)*, correspondingly, designating a proposed second part as *Eqn. (**II.2**)*. The first part led, in the 1865 paper by Clausius,[[10]:327-365] to the introduction of entropy—with the inequality for general processes, allied with equality *Eqn. (II.1)* for reversible processes, to the entropy law. Sect. 5 of the paper proposes a new synthesis of thermodynamics, a new Clausius synthesis, based on the first fundamental theorem and *both* parts of the second fundamental theorem. In the Clausius-Gibbs synthesis, it did not involve the second part of the second fundamental theorem, *Eqn. (**II.2**)*, because equilibrium thermodynamics did not need the second part (it did not involve dealing with details of the relation between organized energy and disorganized energy). In contrast, engineering thermodynamics needs something like the second part as causal agency. However, the orthodox engineering thermodynamics, in Sect. 4, did not invoke the second part because of its energy conversion doctrine, or the energy premise, which assigned energy the role of causal agency as well as that of conservation constraint. What this choice by engineering thermodynamics of the energy premise over the second part really means is that in the revolutionary discovery of heat energy, Joule and Thomson kept one traditionalist “previous habit”[13][14] of the single, monolithic drive thinking[2] of the pre-discovery mechanical world. In Fig. 5 and Fig. 6, it suggested the implication of this monolithic drive thinking to be the *absorption* of the entropy law by the premise/doctrine depriving the entropy law of its independent status. The principal objective of Sect. 5 is to show that the *what-where* duality premise is consistent with the second part of the second fundamental theorem. The new premise and the second fundamental theorem, therefore, can serve as a basis for reforming engineering thermodynamics by discarding the energy premise.

Sect. 6 shows that the *what-where* duality premise is consistent with the first fundamental theorem. Namely, of the what-where two questions of the new premise, the former question belongs to the purview of the second law or the second fundamental theorem while the latter to that of the first law or the first fundamental theorem. Tisza characterized the conceptual differentiation to be the origin of the two laws. Here, I suggest that the conceptual differentiation may be paraphrased in terms of the *what-where work questions* duality premise: the independence problem can be directly resolved with the what-where duality premise. In answering the latter *where* question, a consequential understanding is gained of the connection between the human drive for power and its impact on the surrounding environment.

2. Energy Physics Synthesis

Humankind had relied on fire for heat and light and on human power and animal power for power since antiquity. In the last two millenniums, humans learnt how to harness natural mechanical power in the forms of waterpower and wind power for food processing, manufacturing, and transportation. Then, from 1712 to 1824, Newcomen, Watt, and Carnot, collectively, (Newcomen invented the atmospheric steam engine in 1712, Watt made significant improvements in steam engine efficiency, and Carnot formulated a theory of heat engine in 1824) discovered the "motive power from fire." That is, fire, the erstwhile source for heat and light, was discovered to be a source, much more reliable and of abundant supply than animal sources and natural mechanical ones, for mechanical power as well.

Following Black's introduction of heat as one measure of fire (the other is its temperature), Joule established empirically that when work is transformed into heat, the ratio of the amount of disappeared work to the amount of produced heat is a universal constant. Joule posited that for the opposite change or transformation, the same ratio held. Although Thomson initially held against the latter claim of Joule, he came to accept the claim. Today, the idea of equivalence of heat and work in both directions, the *equivalence theorem*, as a cornerstone of energy physics as shown in the blue block in Fig.1, is universally accepted. I shall refer to these advances collectively (Newcomen invented the atmospheric steam engine in 1712, Watt (1776) made significant improvements in steam engine efficiency, Carnot formulated a theory of heat engine in 1824, and Joule (1843-45) established the equivalence of heat energy and work, i.e., mechanical energy) as the NWCJ discovery of motive power from heat. The discovery of the "motive power from heat" has proven to be a watershed event in human history.

The equivalence theorem led to the introduction of a new state function, the internal energy. In modern reconstruction, the concept of "adiabatic work" can be used to show the existence of the state function. With the introduction of internal energy, the equivalence theorem led directly to the first law of thermodynamics as shown in Fig. 1.

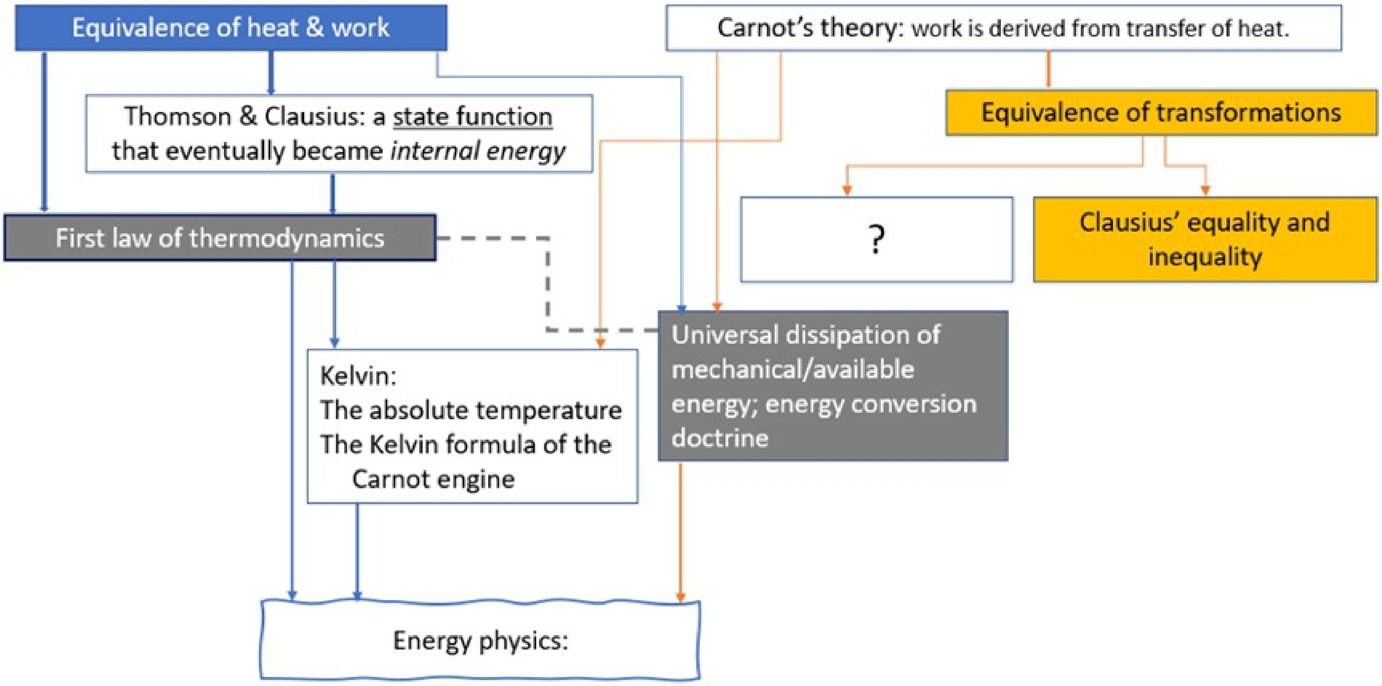


Figure 1. *Energy physics, circa 1854-55*

With the equivalence theorem and the first law firmly in place, both Thomson (later, Lord Kelvin) and Clausius saw that the key to a new branch of physics was how to reconcile the equivalence theorem that work is derived from the consumption of heat with Carnot's theory of heat engine that work is derived from the transfer of heat from a hot body to a cold body (in this transfer, heat is a conserved quantity). As Tisza noted, "classical thermodynamics was born out of the reconciliation of two apparently contradictory ingredients. The striking unification of the most diverse phenomena by the Mayer-Joule principle is to be contrasted with a peculiar new duality implicit in Carnot's principle: We have to draw the line between reversible and irreversible processes, a distinctive characteristic of thermodynamics that is not predicted, or even allowed, by the fundamental equation of mechanics or electrodynamics. The precise and detailed description of this dichotomy is a most difficult problem, one of the central themes of this book"[[8]: 30]. It, a detailed description of the reconciliation of this dichotomy through "splitting the concept of caloric into heat quantity, energy, and entropy"[[8]: 22], is also one of the central themes of this paper.

Both Kelvin and Clausius realized that the application of Carnot's idea to heat engines did not have to assume heat is conserved. Clausius approached the reconciliation project methodologically taking a giant step in 1850 and painstakingly between 1854 and 1865 taking several steps on "the road to entropy"[15]. This will be described in Section 3. In contrast, Kelvin in 1854 was able to, by reconciling Carnot's idea with the requirement of energy conservation instead of heat conservation without having to introduce the concept of entropy, derive the formula for the Carnot engine (see Fig. 1, [[16], [17]: Sects. 4.4 and 4.5]),

$$W = Q_1\left(1 - \frac{T_2}{T_1}\right)$$

where T_1 is the temperature of the hot heat source and T_2 the temperature of cold heat sink, and Q_1 the heat supplied to the engine from the hot heat source. The derivation was a tour de force as a first step towards reconciliation.

The reconciliation was completed in terms of the conceptualization of energy physics: Kelvin came to see that energy cannot be destroyed nor created (the first law) but energy is dissipated all the time. By that, he meant that available energy is dissipated spontaneously. He finally was able to explain the conundrum of workless heat conduction that while no energy can be destroyed available energy is dissipated/degraded in the process of workless heat conduction. In 1852, he published a short paper[[18]:511-514] proclaiming, without proof, that mechanical energy and available energy dissipate spontaneously and universally. His claim of universal dissipation of available energy has been universally accepted as a truism by everyone—except Planck, see below in Sect. 4.

This conceptualization is basically the energy conversion doctrine conceptualization. This doctrine, see the "universal dissipation…energy conversion…" block in Fig. 1, as well as the real meaning of "conversion" and that of "equivalence" (of heat and work) will be the investigative focus of this paper. In the paper, “conversion” is used in a different sense from “transformation,” which is used in the same general sense as process (as Clausius did in his Fourth Memoir, see below). Although Fig. 1 includes the block of the “equivalence of transformations,” it should be noted that “energy physics, circa 1854-55” represents the understanding achieved by Kelvin in terms of energy conservation and available energy dissipation without incorporating the “equivalence of transformations.” That role is assumed by the “universal dissipation of mechanical/available energy; energy conversion doctrine” block in Fig. 1. At this stage, the ideas of “equivalence of transformations” and “equivalence values” (or “entropy”) were afoot but not yet at the center stage. The way Kelvin achieved the reconciliation of the equivalence theorem and Carnot’s theory is not by “splitting the concept of caloric into heat quantity, energy, and entropy” in the exact sense—unless one accepts the notion of energy degradation as the synonym of entropy growth, as many erroneously do.

The tour de force derivation and the truism of energy degradation as the synonym of entropy growth are evidence that Kelvin's theory of energy physics has succeeded too well that this success made hidden of “the precise and detailed description of this dichotomy being a most difficult problem” as well as “details of the relation between organized energy and disorganized energy.”

3. The Second Fundamental Theorem

Clausius began in his 1854 Fourth Memoir[9] “rebuilding” Carnot’s idea into the equivalence of transformations, which is sometimes called the second equivalence theorem or the second fundamental theorem. This rebuilding is a major move by Clausius to “move beyond” Carnot’s theory. In the case of the first equivalence theorem, the equivalence of heat and work, which both Thomson (Kelvin) and Clausius were able to apply to develop the concept of a new state function, internal energy *U*—thus, arrived at the formulation of the first law, the energy law. Unlike that case, Carnot’s theory did not lead directly to the concept of entropy as a new state function. The road to entropy had to go through Clausius’ second equivalence theorem, the equivalence of transformations.

Clausius adopted the terms “Carnot’s theorem” and, for the first equivalence theorem, “first fundamental theorem.” He expressed analytically the first fundamental theorem (“the first fundamental theorem will be expressed by the equation”[[9]:113]) as *Eqn. (**I**)*, which is here slightly modified into the modern form,

$$Q_{1-2} = (U_2 - U_1) + W_{1-2} \qquad (I)$$

With regard to Carnot’s theorem, he wrote in the Fourth Memoir, “Carnot’s theorem, when brought into agreement with the first fundamental theorem, expresses a **relation** [bold added] between two kinds of transformations, the transformation of heat into work, and the passage of heat from a warmer to a colder body … In deducing this theorem, however, a process is contemplated which is of too simple a character; for only two bodies losing or receiving heat are employed, and it is tacitly assumed that one of the bodies between which the transmission of heat takes place is the source of the heat which is converted into work. Now by previously assuming, in this manner, a particular temperature for the heat converted into work, the influence which a change of this temperature has upon the relation between the two quantities of heat remains concealed, and therefore the theorem in the above form is incomplete"[[9]:116-117].

Carnot introduced for the first time in physics the idea of unidirectionality in the physical processes of heat transmission and proposed that the production of work can be derived from managing these unidirectional processes. Carnot had demonstrated these ideas in the four steps Carnot cycle, in which there is no separate account of heat transmission transformation and the production of work transformation. Clausius saw a crucial improvement to be made in describing the Carnot engine with a modified cyclical process to talk about these transformations distinctively.

3.1. Clausius' two types of transformations and the Aequivalenzwerth of a transformation

"With Carnot, he [Clausius] postulated that heat could drop from a high temperature to a low temperature in what we shall call a 'transmission transformation.' Contrary to Carnot, however, he also assumed that heat could be converted to work in a 'conversion transformation.' Clausius was impressed by the fact that both kinds of transformations had two possible directions, one 'natural' and the other 'unnatural' [these were not Clausius' terminology; instead, he called them 'positive transformations' and 'negative transformations' respectively]. In the natural direction, a transformation could proceed by itself, spontaneously and unaided, while the unnatural direction was not possible at all unless forced by some outside influence**"** [[15]:1068]. Clausius himself put the last point this way, "*an uncompensated transmission of heat from a colder to a warmer body can never occur.* The term 'uncompensated' here expresses the same idea as that which was intended to be conveyed by the words 'by itself' "[[9]:118].

That is, Clausius generalized Carnot's ideas into

(i) the notion that there are processes or transformations of preferred direction; these are new kinds of processes different from mechanical processes;
(ii) one difference is that each type of the new kind of processes, to adopt the terms of Cropper[15], can be divided into "processes or transformations of natural direction" and "processes or transformations of unnatural direction";
(iii) another is the notion of "compensation" or "compensated," and that an uncompensated process of the unnatural direction of the new kind of processes can never occur; furthermore,

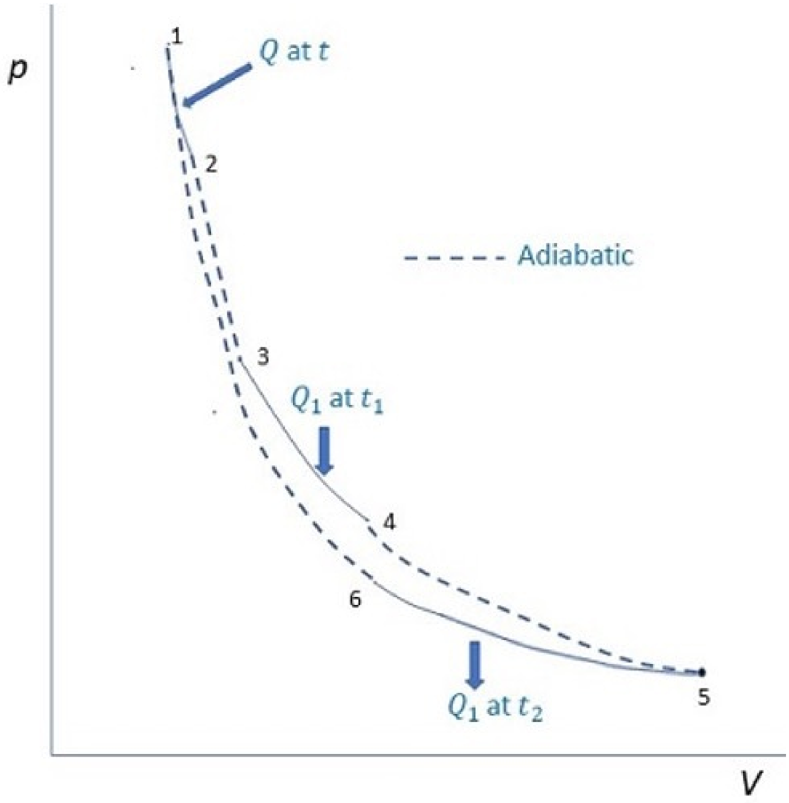


Figure 2. *The six stage Clausius cycle*

(iv) that compensation of heat transmission of natural direction and heat into work process/transformation of unnatural direction can be demonstrated with a six-stage Clausius cycle (following Cropper[15], see Fig. 2) in which Steps 2 (2→3), 4 (4→5), and 6 (6→1) are adiabatic steps; while, at Step 1 (1→2), a quantity Q is supplied to the cycle's working fluid **in communication with a body** K at temperature t; between Step 3 (3→4) and Step 5 (5→6), a quantity Q_1 is supplied to the cycle **in communication with a source body** K_1 at temperature t_1 at Step 3 and the same quantity is discharged by the cycle **in communication with a sink body** K_2 at temperature t_2 at Step 5 representing heat transmission of Q_1 from t_1 to t_2; the consideration of the first fundamental theorem leads to the conclusion that the supplied Q at Step 1 is transformed through the cyclic process completely into work; and

(v) that compensation of a transformation, e.g., a heat transmission of natural direction or a heat into work process of unnatural direction, can be *quantitatively* expressed in terms of the *equivalence value (Aequivalenzwerth)* of the transformation.

Clausius introduced the concepts of *equivalence-value* and *equivalence.* Transformations are characterized by equivalence-value (Aequivalenzwerth) of positive sign of natural direction or negative sign of unnatural direction. In the Fourth Memoir[9] and in Cropper's paper[15] and Saslow's paper[6], details of the mathematical argument of Clausius' reasoning are given. A brief summary of the initial steps with regards to the forms of equivalence values and the condition of reversible compensation (which Cropper called the condition of balance[[15]: 1070]) are reproduced here.

It is assumed that the equivalence value for one kind of transformation, the transformation of work to heat appears in the form $Q\,f(t)$ as a positive transformation and conversely, for heat to work transformation, $-\,Q\,f(t)$. In the other kind of transformation, the positive heat transmission transformation from t_1 (higher temperature) to t_2 (lower temperature), its equivalence value appears in the form of $\bar{Q}\,f(t_1, t_2)$ and conversely, the negative heat transmission transformation from t_2 (lower temperature) to t_1 (higher temperature) to be $\bar{Q}\,f(t_2, t_1)$. Therefore, $\bar{Q}\,f(t_2, t_1) = -\,\bar{Q}\,f(t_1, t_2)$.

Clausius now considers the reversible compensation of two transformations, one positive (heat transmission from t_1 to t_2) and one negative (transformation of heat to work). He suggests the condition of reversible compensation *equivalence of transformations* to be a criterion in terms of the equivalence values of the two transformations. The criterion is a vanishing algebraical sum of the two equivalence-values ("…in every reversible cyclical process of the above kind, the two transformations which are involved must be equal in magnitude, but opposite in sign, so that their algebraical sum must be zero"[[9]: 123]). As $\bar{Q}$ in Fig. 2 is Q_1, we have

$$-\,Qf(t) + Q_1\,f(t_1, t_2) = 0 \qquad (1)$$

I now paraphrase the steps of Clausius, Cropper, and Saslow. Note that the same equivalence of transformations holds for a six-stage Clausius cycle in Fig. 2 with a different t, e.g., t', as long as the "compensation" of the positive heat transmission, $Q_1 f(t_1, t_2)$, remains the same. In such cases, t' can be any temperature: whereas Clausius considered $t' > t > t_1$, we may consider a t'' to include t_1 or t_2. That is, by repetitive application of (1), we have,

$$Q\,f(t) = Q'\,f(t') = Q''\,f(t'') = Q^{t_1} f\left(t_1\right) = Q^{t_2} f\left(t_2\right) \qquad (2)$$

At this point, Clausius considered a simple heat-pump Carnot cycle operating between t' and t. In view of (2), instead, we consider a five-stage Clausius cycle operating between t_1 (T_1) and t_2 (T_2): as shown in Fig. 3, a cycle receives $Q^{t_1} + Q_1$ from a K_1 heat source-body and discharges Q_1 to a K_2 heat reservoir.

We have, from (1), for the five-stage Clausius cycle (with Q^{t_1} supplied in $1^{t_1} \rightarrow 2^{t_1}(3)$ step, and Q_1 transmitted between 3→4 and 5→6 steps),

$$-Q^{t_1}\,f(t_1) + Q_1\,f(t_1, t_2) = 0 \qquad (3)$$

And from (2) as applied to the cycle as a simple Carnot cycle (with $1_1^{t} \rightarrow 4$ as a single step),

$$(Q^{t_1} + Q_1)\,f(t_1) = Q_1\,f(t_2) \qquad (2a)$$

Substitution of $Q^{t_1}\,f(t_1)$ from the above into Eq. (3) yields,

$$f(t_1, t_2) = f(t_2) - f(t_1) \qquad (4)$$

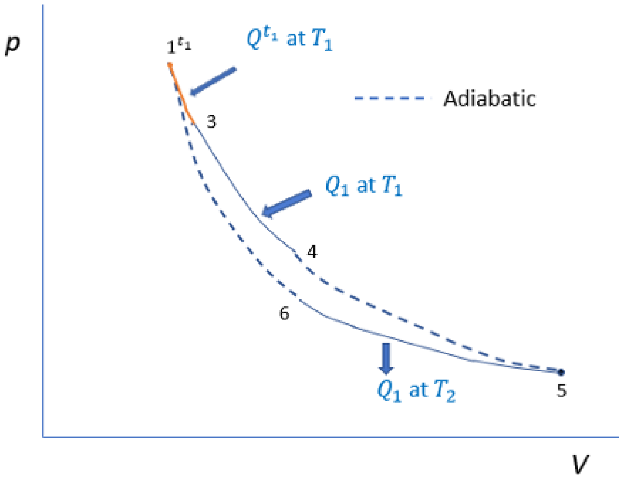


Figure 3. *A five-stage Clausius cycle as reduced from the six-*

stage Clausius cycle

“This was another cornerstone of Clausius’ transformation theory.

It showed that a *single* function, the still undetermined *f(t)*, sufficed for equivalence-value determinations” (Cropper [[15]:1071]). At this point, Clausius rewrote *f* in terms of a new but still unknown function,

$$f(t) = 1/T \qquad (5)$$

where $T(t)$ is a new, material-independent function of temperature *t* involved in the equivalence values. That is, the equivalence of transformations in Fig. 2, Eq. (1), takes the form,

$$Q_1/T_2 - Q_1/T_1 - Q/T = 0 \qquad (6)$$

Clausius, at this point, stated the *theorem of the equivalence of transformations*, his statement of which is reproduced here,

> *If two transformations that, without necessitating any other permanent change, can mutually replace one another, can be called equivalent, then the generation of the quantity of heat Q of the temperature t from work [the first kind], has the equivalence-value*
>
> $$Q/T$$
>
> *and the passage of the quantity of heat Q from the temperature* T_1 *to the temperature* T_2 *[the second kind], has the equivalence-value*
>
> $$Q[(1/T_2) - (1/T_1)]$$
>
> *wherein T is a function of the temperature, independent of the nature of the process by which the transformation is effected.*[[9]:125-126]

Here, Clausius used the term, equivalence, as “replacement” of one transformation with another. But throughout the Fourth Memoir he also used the term in another sense, which is as stated by Libb Thims as follows:

> *In all cases where a quantity of heat [Q] is converted into work, and where the body affecting*

> *this transformation ultimately returns to its original condition, another quantity of heat [Q_1] must necessarily be transferred from a warmer to a colder body; and the* ***magnitude*** *of the last quantity of heat, in relation to the first, depends only upon the temperatures of the bodies between which heat passes [and the temperature of the body where Q is converted], and not upon the nature of the body affecting the transformation.*[19]

We may surmise a definition of equivalence:

> *Equivalence is the quantitative relationship between two transformations in terms of their equivalence values; the relationship in two senses: as replacement of one with another if the two transformations involved are equal in magnitude and of the same sign, and as condition-of-balance in reversible existence when the two transformations involved are equal in magnitude but opposite in sign (or, when the transformations which occur exactly cancel each other so that their algebraical sum is zero).*

From equivalence as replacement, Clausius was able to argue that every transmission of heat of the second kind can be considered as a combination of two opposite transformations of the first kind, i.e., the conversion-transformation of work into heat and the transformation of heat into work.

From equivalence as condition-of-balance, Clausius was able to prove that any reversible cycle can be broken down into an infinite number of steps so that the overall cyclic equivalent “compensation” (i.e., reversible compensation) can be represented by a vanishing sum of equivalence values. Thereby, the “analytical expression for all reversible processes of the second fundamental theorem” is the equation,

$$\oint dQ/T = 0 \qquad (II)$$

With *(II)*, Clausius was on the way to, in his 1862 Sixth Memoir[[10]:215-250], the concept of “disgregation” and, finally, in the 1865 Ninth Memoir[[10]:327-365], the concept of entropy and, with the inequality version of *(II)*, i.e., ***(II.2**.2)* as given in Sect. 5.1. below, the formulation of the entropy law.

Before he arrived at that final goal, he in Fourth Memoir proceeded, by noting that dQ/T is a perfect differential and Joule’s law of ideal gases, to prove that

$$T = a + t \qquad (7)$$

where a is 273° C and t is in Celsius, so T is the ideal gas scale T_g. As Saslow noted, “Clausius’s work is still not fully appreciated as forming the basis for both entropy and temperature. The unit of temperature is indeed the Kelvin, and to Kelvin we owe a great debt for early thermometry. However, it was Clausius who rigorously established that the ideal gas, or Kelvin scale, is the unique thermodynamic temperature"[[6]:40].

3.2. The Clausius-Gibbs synthesis

In assessing Clausius' scientific body of work, Cropper noted, "… his place in the beautifully clear line of development of thermodynamics between 1824 and 1875—from Carnot to Clausius, and then to Clausius' greatest successor, Willard Gibbs. Clausius' role in this was pivotal. He knew exactly how to interpret and rebuild Carnot's message, and then to express his own conclusions so they could be used by another genius, Gibbs"[[15]:1073]. Eqn. (II) and its allied inequality led directly to Gibbs' starting point of the *maximum entropy principle of thermodynamic equilibrium* (see Fig. 4).

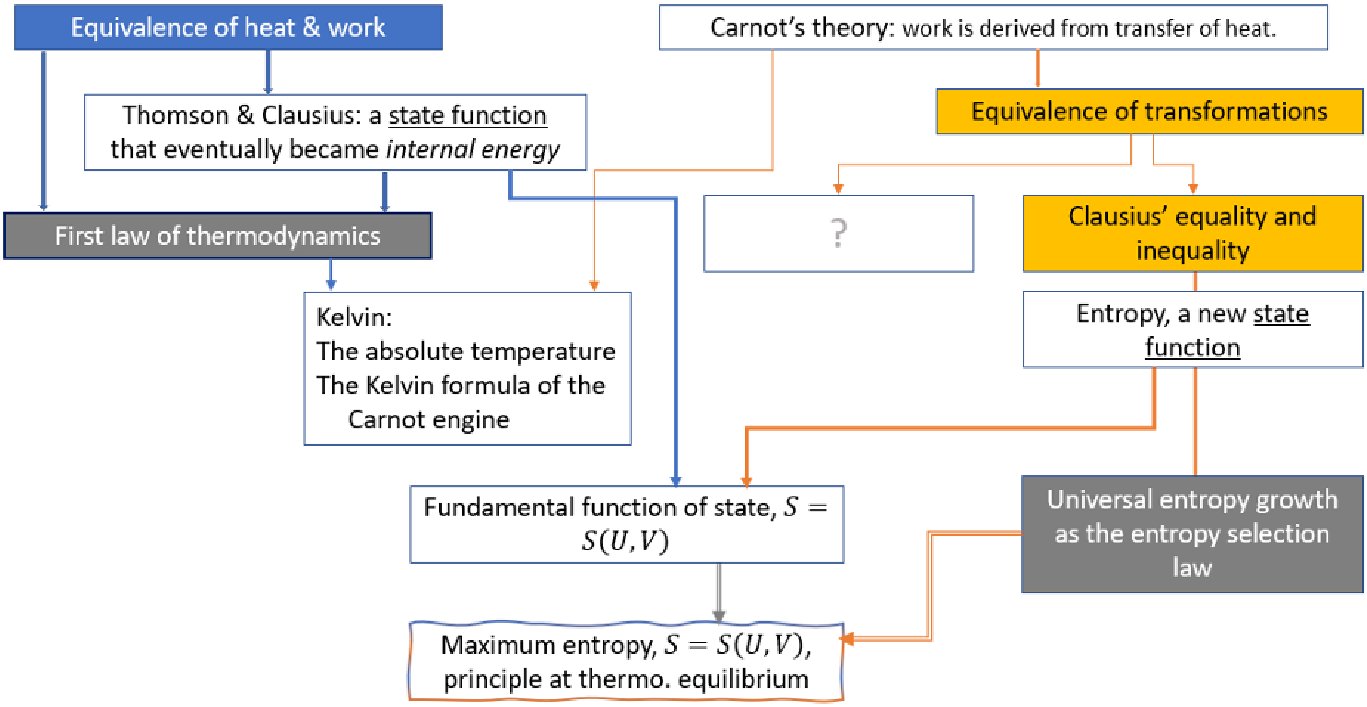


Figure 4. *Gibbsian equilibrium thermodynamics, a branch of physics resulted from the conceptual differentiation of caloric into energy and entropy. NOTE the independency status of the two equivalence theorems.*

Between 1873 and 1878, Gibbs single-handedly developed the theory of equilibrium thermodynamics, a shining example of building an edifice of thermodynamics on the cornerstone of the first fundamental theorem and the second fundamental theorem.

Gibbsian thermodynamics was given an axiomatic treatment by Tisza[[8]: 104; [20]] and Callen[[21]]. Tisza spoke of "the classical theory of equilibrium is a blend of two essentially different logical structures: we shall distinguish the theory of Clausius and Kelvin, on the one hand, from that of Gibbs, on the other." Furthermore, Tisza pointed out that the Clausius-Kelvin theory received the axiomatic investigation of Caratheodory and he suggested to refer to it as the CKC theory. That "no comparable axiomatic investigation of the Gibbs theory has been performed thus far. Accordingly, in the existing texts, the CKC and the Gibbsian thermodynamics are intricately interwoven…The first objective of the paper is to formulate a postulational basis from which a theory, almost identical to that of Gibbs, is derived as a self-contained logical structure. We shall call this theory thermostatics, or alternatively the macroscopic thermodynamic of equilibrium (MTE)”[[8]: 104-105]. The goal of Tisza’s axiomatic project is to formulate the Gibbs theory “as an autonomous logical structure”[[8]: 106].

Caratheodory made the concept of *quasistatic processes* the central feature of his formalism, which is referred to as classical formalism in [17]. An investigation on that issue was made in[17], with the following conclusion: “A reversible machine remains the best or natural approach to start the consideration of the concept of entropy. Once the introduction is made, classical formalism is correct in pointing out that reversibility is a too restrictive condition for defining entropy. Classical formalism is mistaken, however, in replacing reversibility with quasi-staticity. The modern formalism shows that quasi-staticity in the classical formalism is *in fact* internal reversibility, which is the necessary and sufficient condition for the definition of entropy” [[17]: 152]. Leaving aside the CKC theory, this paper focuses on the intricately interwoven relation between the classical CK theory and Gibbsian thermodynamics. The analysis taken here suggests that the CK theory is not a coherent single system but a blend of two systems: the energy physics theory, in Section 2, and Clausius’ second fundamental theorem-based theory, in this section, which by extension includes Gibbsian thermodynamics. We do not have a logical structure of the CK theory to speak of and surely have no such structure of “Gibbsian thermodynamics embedded in the CK theory” to speak of. What Tisza realized was that Gibbsian thermodynamics could be investigated to discover its own autonomous logical structure free from the CK theory. Transforming it into MTE, therefore, is an improvement both logically and pedagogically. Generations of students of thermodynamics learning thermodynamics using Callen’s excellent text can attest to it.

4. Orthodox Engineering Thermodynamics

The analysis in Section 3 places Gibbsian thermodynamics to be embedded in the Clausius’ second fundamental theorem-based theory, rather than in a single system of CK theory. The latter notion is the result of a misunderstanding of the CK theory by confusing it with orthodox thermodynamics as a seamless whole of Gibbsian thermodynamics and engineering thermodynamics.

The incorporation of the entropy selection law into engineering thermodynamics took the form of what I call the Dresden/MIT-School update of energy physics. Erstwhile, the engineering application of thermodynamics was initiated with the control-volume energy analysis first formulated by Zeuner of Dresden [22]. This was then followed by the introduction of two new elements: fundamental function of state for calculating thermodynamic relationships; control-volume formulation with exergy analysis.

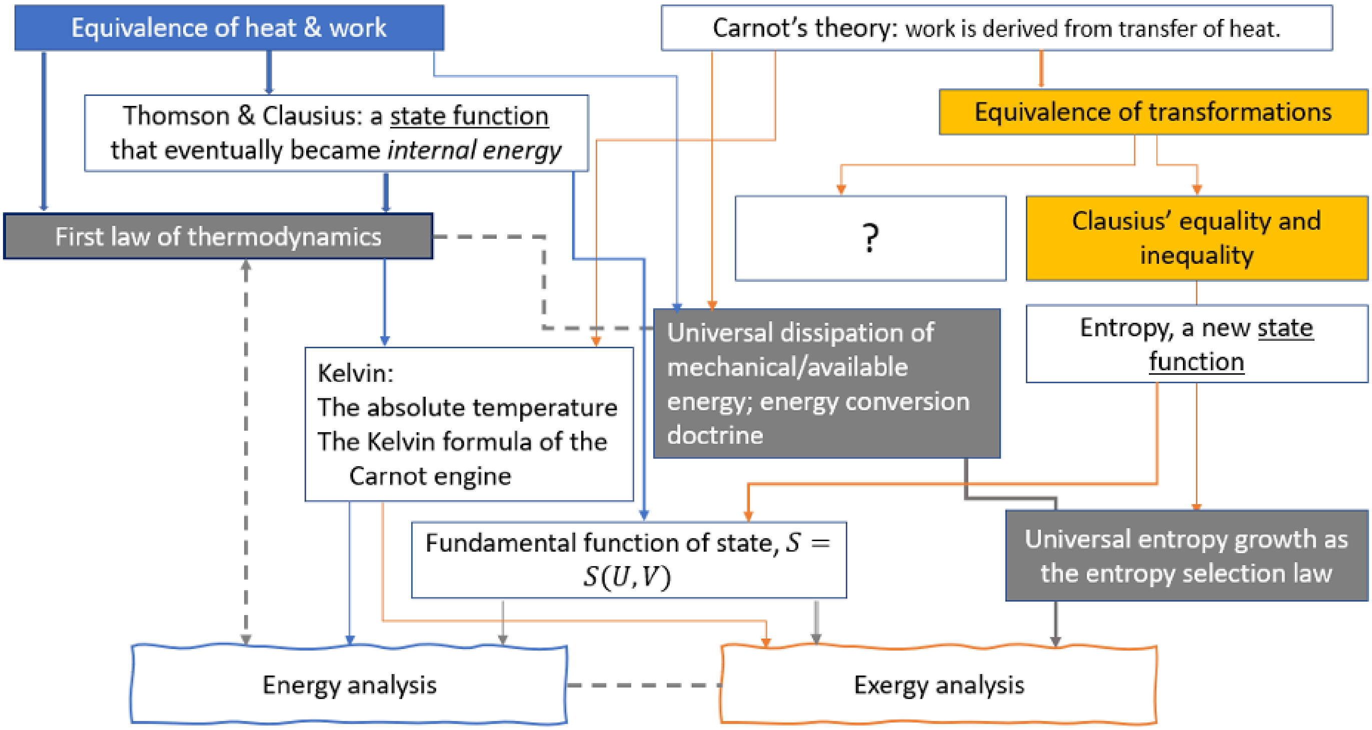


Figure 5. *Orthodox engineering thermodynamics, the Dresden/MIT-School update of energy physics. Contrary to Fig. 4, note the loss of the independency status of the two laws, i.e., two equivalence theorems, in this figure; this loss will be highlighted in Fig. 6.*

I call the Dresden/MIT-School update *orthodox engineering thermodynamics*, as shown in Fig. 5. With these updates, engineers have been able to apply orthodox thermodynamics, expediently, to using fossil fuels energy with improving efficiency. Improving efficiency, famously as discovered by the economist Jevon, rather than reducing the consumption of fuels which it does in individual applications, instead leads to an increase in *total* consumption of fuels. This has become known as the Jevon paradox or the rebound effect. The positive-feedback-loop of efficiency gain to increase in production/profit to rebound effect to exponential economic growth explains what has made possible the Anthropocene—the explosive industrialization and economic growth since the 1712-1843 NWCJ discovery of motive power from heat.

It is this orthodox thermodynamics, which is referred to as the CK theory based on two**independent** fundamental laws of nature, the first law and the second law. That would be a mistaking interpretation. Contrary to Gibbsian thermodynamics, the two laws lose independency status in orthodox engineering thermodynamics as shown in Fig. 5.

This loss is associated with the following implications. Both the energy definition, energy as the capacity for doing work, and the conflation of the *what-where work questions* applied to organized energy, an understanding that belonged to the preindustrial mechanical science. The NWCJ discovery of disorganized energy and the Thomson epiphany of energy physics, however, should have decisively broken away from this energy-premise understanding—which is a relic of the preindustrial age. That did not happen because in energy physics and orthodox thermodynamics the explanation of the difference between organized energy and disorganized energy was answered in terms of the 'dissipation' or 'degradation' of energy in lieu of an increase in entropy: Namely, while organized energy can be dissipated into heat or disorganized energy without limitation disorganized energy cannot be 100% converted into organized energy, which is referred to as the limitation inference as an energy-premise inference. There are some overlaps between the limitation inference and Kelvin's postulate (see Fermi's comment below) and, for this reason, it is often considered to be a statement of the second law itself. Such interpretation is not acceptable. It is important to note that Max Planck rejected this interpretation of the second law:

> *The real meaning of the second law has frequently been looked for in a "dissipation of energy." This view, proceeding, as it does, from the irreversible phenomena of conduction and radiation of heat, presents only one side of the question. There are irreversible processes in which the final and initial states show exactly the same form of energy, e.g., the diffusion of two perfect gases or further dilution of a dilute solution. Such processes are accompanied by no perceptible transference of heat, nor by external work, nor by any noticeable transformation of energy. They occur only for the reason that they lead to an appreciable increase in entropy.* ([[23]: 103–104])

Fermi also wrote:

> *An essential part of Lord Kelvin's postulate is that the transformation of the heat into work is the only final result of the process. Indeed, it is not impossible to transform into work heat taken from a source all at one temperature provided some other change in the state of the system is present at the end of the process.*[24]

"Some other change in the state of the system" is precisely "what drives the production of work." Despite Planck's analysis and Fermi's concurrence, the influence of energy physics has been persistent: As Daub, the history-of-science scholar, noted, "Entropy and the dissipation of energy are as inseparable as Siamese twins in the thought of every student of thermodynamics"[25]. That they are as inseparable as Siamese twins is Exhibit A of the loss of independency between the two laws.

In an important sense, the "Universal dissipation of mechanical/available energy" block, let us call it the "Energy-conversion doctrine" block, ***absorbed*** the entropy law as suggested in Fig. 5 manifested as the iron-chain circle. See also Fig. 6, in which the circle is referred to as the "energy premise circle"[2].

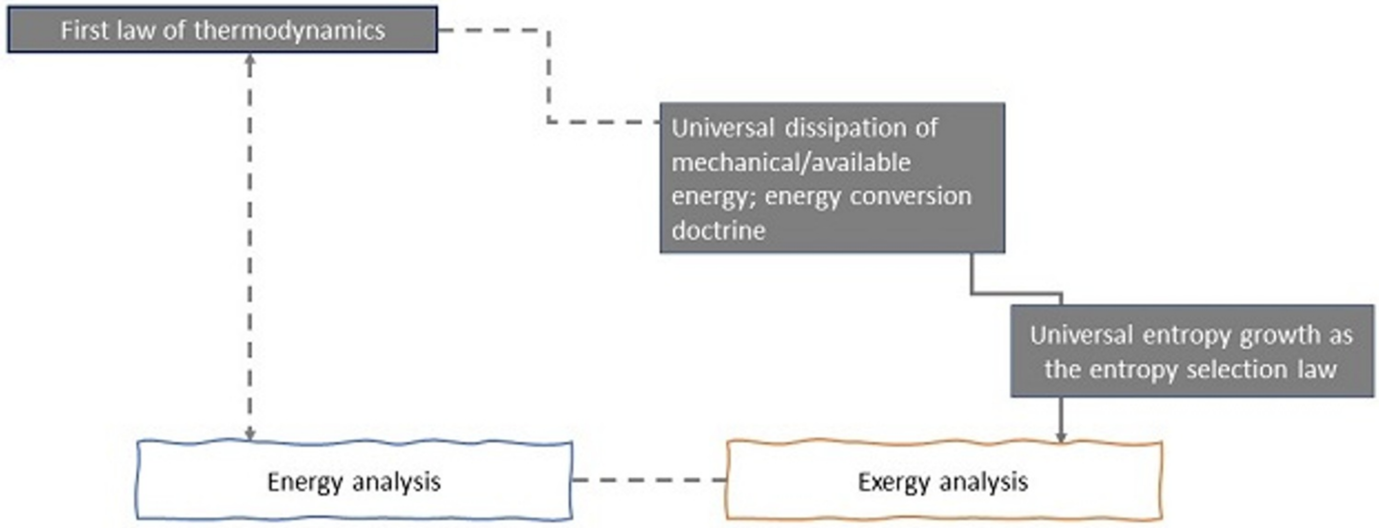


Figure 6. *The energy premise circle*

Uffink, the historian of science, in a detailed analysis of the second law literature, commented on the issue spot-on,

> *Planck puts the second law, the concepts of entropy and irreversibility at the very centre of thermodynamics. For him … Increase in entropy is, therefore, a necessary and sufficient criterion for irreversibility. Before Planck's work, there were also alternative views. We have seen that Kelvin attributed irreversibility to processes involving special forms of energy conversion. This view on irreversibility, which focuses on the 'dissipation' or 'degradation' of energy instead of an increase in entropy was still in use at the beginning of the century; see e.g., Bryan (1904). Planck's work extinguished these views, by pointing out that mixing processes are irreversible even though there is no energy being converted or degraded ([[26]:42-43]).*

There is a dichotomy between the Clausius-Gibbs synthesis (Fig. 4), which is free from the energy premise's grasp, and orthodox thermodynamics (Figs. 5 and 6) under the clutch of the energy premise. It is the latter energy-premise inference that preempted the (later) formulation of the entropy law from assuming its rightful power of explicating disorganized energy as an **independent** fundamental law of nature. Contrary to the common wisdom, this dichotomy prevented the CK reconciliation of the dichotomy between Carnot and Joule to its successful conclusion. In the second fundamental theorem, I shall argue in Sect. 5, we can find the tool that finally breaks the indissoluble energy premise circle of equating dissipation of energy with entropy growth.

5. A New Clausius Synthesis: *Reversible-like compensation of transformations*

Available energy (i.e., free energy) was a great insight of Kelvin,[[17]: 168] the insight that enabled the presupposition of the energy premise making the Anthropocene possible. At the same time, the premise made the essence of disorganized energy hidden and preempted engineering thermodynamics from achieving the conceptual differentiation of caloric explicitly. It has been proposed in a 2022 paper [[2]: 11] that the energy premise is to be supplanted with the what-where duality premise. As a continuation of this project, this paper shows that the what-where duality premise is consistent with the second fundamental theorem, in this section, which provides the explication of the *what* question. And, in Sect. 6, that the duality premise is consistent with the first fundamental theorem which provides the explication to the where question. The what-where duality premise together with the first and second fundamental theorems, therefore, will lead to a successful goal of discarding the energy premise—as a necessary step of Planck's project of placing "the second law and irreversibility at the very centre of thermodynamics" [[26]: 42].

5.1. The two parts of the second fundamental theorem

The above Sect. 3 summary of Clausius' arrival at the result*(II)* is well-known and hugely important, but it represents only one slice of his generalization of Carnot's ideas as given in **(i) to (v).** Let us revisit the statement of the**fundamental theorem** itself, which was repeated by him in the Ninth Memoir "to show the general importance of the magnitudes which I have introduced…":

> *The second fundamental theorem asserts that all transformations occurring in nature may take place in a certain direction, which I have assumed as positive, by themselves, that is, without compensation; but that in the opposite, and consequently negative direction, they can only take place in such a manner as to be compensated by simultaneously occurring positive transformation" [[10]: 364].*

Rather than emphasizing *the quantitative equivalent relationships* between/among transformations as the theorem of the equivalence of transformations does, here Clausius reasserted the ideas underlying replacement and condition-of-balance to be the three *qualitative ideas* of (i) existence of processes of preferred direction, (ii) the fact that for each preferred direction there are positive (natural) and negative (unnatural) directions, and (iii) the idea of compensation. The basic problem remains "a relation between two kinds of transformations, [e.g.,] the transformation of heat into work, and the passage of heat from a warmer to a colder body" [[9]: 116]. Compensation is the general term for describing this relation. When the relations between the two kinds are reversible, the relations are called equivalent compensation (i.e., reversible compensation) with the algebraical sum of equivalence values being zero. For each idealization of reversible compensation, there are an infinite number of "reversible-like compensated transformations." Focus on equivalence, correspondingly on the definition of entropy, is clearly only one slice of Clausius' innovation.

There is a good reason for such a narrower focus of students of thermodynamics as it is evident in Gibbs' influential obituary article on Clausius, "Rudolf Julius Emanuel Clausius" in the *Proceedings of the American Academy* (new series, vol. XVI, pp. 458–465, 1889)[27], and the volume on *The Second Law of Thermodynamics* edited by J. Kestin[28]. In both such widely accessible and influential sources on Clausius' body of work, the selected papers by Clausius are First Memoir, which Gibbs called "an epoch in the history of physics," in which "the science of thermodynamics came into existence," and Sixth Memoir and Ninth Memoir, in which the significance of the second fundamental theorem is linked with the introduction of *entropy*. Both sources did not select the Fourth Memoir, the importance of which has been made only in relatively recent time by Cropper[15], Zwier[29], and Saslow[6].

Going back to Clausius' Fourth Memoir, we find Eqn. (11), $N = \oint \frac{\delta Q}{T}$ ([9]: 127). It is at this point that Clausius wrote, "If the process is *reversible*, then, … , we can prove …*that the transformations which occur must exactly cancel each other, so that their algebraical sum is zero.*" Which is, for the case of two transformations in reversible relation, the equivalence of transformations (6) relabeled as *(II.1.1)*,

$$Q_1[(1/T_2) - (1/T_1)] - Q/T = 0 \qquad (II.1.1)$$

For the case of an arbitrary reversible cycle that can be broken down to an infinite number of steps,

$$\oint dQ/T = 0 \qquad (II.1.2)$$

That is, if the processes are **approximately reversible** (i.e., reversible-like), the condition of compensation of the six-stage cycle is

$$Q < T \cdot Q_1[(1/T_2) - (1/T_1)] \qquad (II.2.1)$$

That of a cycle of an infinite number of steps is,

$$\oint dQ/T > 0 \qquad (II.2.2)$$

Which are referred to as the "second fundamental theorem of reversible-like compensation" (see Fig. 8 in Sect. 5.3 below). I use the term here to mean the inclusion of reversible-like compensated transformations: while in its reversible idealization it becomes the **single event** of compensated transformations in equivalence characterized by equality of Q/T and $Q_1(1/T_2) - (1/T_1)]$, compensation in general or reversible-like compensation comprises **all events** within a Poincare range (see Sect. 5.2 for the meaning of which).

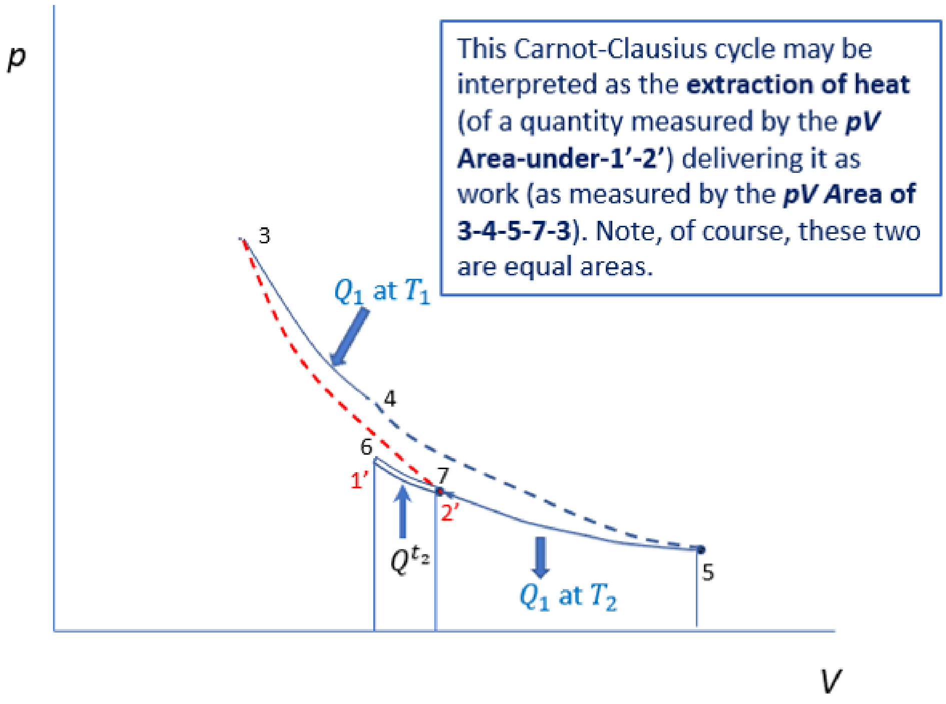
Consider another five-stage Clausius cycle (alternative to Fig. 3 in which a converted heat Q^{t_1} is supplied at T_1), in this version a converted heat Q^{t_2} is supplied at T_2. That is, the original $1 \to 2$ step is now $1^{t_2} \to 2^{t_2}$. For this case, *(II.1.1)* and *(II.2.1)* reduce to, respectively,

$$Wrev = Q = Q_1 T_2[(1/T_2) - (1/T_1)] = Q_1[1 - (T_2/T_1)] \qquad (8)$$

which is the Kelvin formula of the Carnot engine, and

$$Wrev - like = Q < Q_1[1 - (T_2/T_1)] \qquad (9)$$

In the Kelvin formula, (8), a partial amount of supplied heat Q_1, $Q_1\left[1 - \left(\frac{T_2}{T_1}\right)\right]$, is converted into work with the rest, $Q_1\left(\frac{T_2}{T_1}\right)$, discharged into a T_2 heat sink. Note that the same physical interpretation can apply to the five-stage cycle in Fig. 3 interpreted as a simple Carnot cycle with the amount of heat supplied being $Q_1 + Q^{t_1}$. In this case, the converted heat and discharged heat according to (8), $\left(Q_1 + Q^{t_1}\right)\left[1 - \left(\frac{T_2}{T_1}\right)\right]$ and $\left(Q_1 + Q^{t_1}\right)\left(\frac{T_2}{T_1}\right)$, can be shown by using (6) to be Q^{t_1} and Q_1, respectively. However, such conventional interpretation in accordance with a simple Carnot cycle is that based on the single, monolithic drive perspective, which, while correctly representing the Carnot engine as a specific "heat to work transformation," distorts the true nature of generalized "heat to work transformation" making the essence of reversible or reversible-like compensation hidden.



This Carnot-Clausius cycle may be interpreted as the **extraction of heat** (of a quantity measured by the ***pV* Area-under-1'-2'**) delivering it as work (as measured by the ***pV* Area of 3-4-5-7-3**). Note, of course, these two are equal areas.

Figure 7. *The Carnot-Clausius cycle of the Carnot engine*

For unmasking that, we need to consider this new five-stage Clausius cycle by adjusting the

$1^{t_2} \rightarrow 2^{t_2}$ step to be 1’→2’ at a temperature infinitesimally lower than T_2 as shown in Fig. 7. In *(II.1.1)*, as Clausius intended, the heat transmission of natural direction is separated from the transformation of heat into work of unnatural direction. The Clausius formula of the Carnot engine, in accordance with Fig. 7, is

$$W_{rev} = Q = T_2 \cdot Q_1 \left[\frac{1}{T_2} - \frac{1}{T_1} \right] \qquad (10)$$

In which, an amount of $Q = Q^{t_2}$ corresponding with **the area under curve 1’ -2’ is extracted from the t_2 (T_2) heat reservoir** (as suggested by the arrow direction in Fig. 7) having it delivered as work of **the area enclosed by 3-4-5-7-3 to a work reservoir**. We shall refer to the cycle as interpreted in Fig. 7 as the Carnot-Clausius cycle of the Carnot engine.

Once the step 1’→2’ in Fig. 7 is identified to be a heat extraction process, as a matter of operational steps we see no difference among the “step $1^{t_1} \rightarrow 2(3)$ in Fig. 3,” the “step 1→2 in Fig. 2,” and the “step 1’→2’ in Fig. 7.” All three require temperature differences maintaining the necessary heat transmission processes. Operationally, the so-called conversion-of-heat transformations are all identifiable to be extraction-of-heat transformations. The question is then, “is to name them conversion or extraction simply a semantic question?” In the following, reasons why the naming is a substantive matter are made. This being the case, of the three figures, Fig. 2, Fig. 3, and Fig. 7, graphically speaking Fig. 3 can be easily interpreted as a single Carnot cycle leading to the interpretation of conversion. For this reason, it is advisable to think of the Carnot engine as a five-stage cycle such as Fig. 7. When one does think of the Carnot engine in terms of Fig. 3, it should be as a five-stage cycle in terms of $W_{rev} = Q^{t_1} = T_1 \cdot Q_1 \left[\frac{1}{T_2} - \frac{1}{T_1} \right]$, not as a four-stage simple Carnot cycle in terms of the Kelvin formula, $\left(Q_1 + Q^{t_1} \right) \left[1 - \left(\frac{T_2}{T_1} \right) \right]$. Even though the two expressions yield the same value.

Though he was not always consistent, that both step 1→2 in Fig. 2 and step 1’→2’ in Fig. 7 should not be called “conversion of heat into work” is in line with Clausius’ true thinking as he noted in Eighth Memoir:

> *The starting point of my treatment of the second fundamental theorem in the mechanical theory of heat, was the difference that exists between the transfer of heat from a warmer to a colder body, and that from a colder to a warmer one; the former may, but the latter cannot, take place of itself. This difference between the two kinds of transmission being assumed from the commencement, it can be proved that an exactly corresponding difference must exist between the conversion of work into heat, and the transformation of heat into work; that heat, in fact, cannot simply transform itself into work (another simultaneous change, serving as a compensation, being always necessary thereto), whereas the opposite transformation of work into heat may occur without compensation.*

A clear difference was made by Clausius in this paragraph between “conversion” and “transformation” rejecting symmetry between the two directions. One may surmise that “conversion” is used for a particular kind of transformation that may occur uncompensated or like mechanical transformations in accordance with efficient causation. This identification of “conversion” with “transform itself” of efficient causation has been made in another paper[14]. A discussion of the meaning of causations, including the difference between efficient causation and efficacious causation, can also be found in papers[14][29]. The first reason that name matters is that “conversion” carries the baggage of efficient causation of mechanical science with the implication of false symmetry of transformation of heat into work and transformation of work into heat.

With the drive-force (the equivalence value of heat transmission) in Figs. 2 and 7 a given fixed value, the amount of transformed heat into work is proportional to the temperature of the heat reservoir T, i.e., a lower amount of extracted heat with a lower reservoir temperature. Whereas a widely shared idea of students of thermodynamics is that a heat engine output becomes greater (of a higher amount) with lower reservoir temperature in accordance with the Kelvin formula (8). This is explained by noting that in this case when the drive-force, the equivalence-value of the transformation of natural direction, $Q_1\left[\frac{1}{T_2}-\frac{1}{T_1}\right]$, is not a fixed value, instead, being a strongly dependent function of T_2. So that the product of a lower T_2 and an even higher $Q_1\left[\frac{1}{T_2}-\frac{1}{T_1}\right]$ becomes higher with lower reservoir temperature T_2. This happens when **the heat reservoir** in the Kelvin formula **doubles** as a “sink” for the source-sink drive and as a “reservoir” for heat supply to the cycle. The second reason that name matters is that “conversion” fails to decipher the role of heat reservoir, the true roles of which become clear only when we look at the problem as extraction of heat (see Sect. 6 for more on the role of heat reservoir).

5.2 A common property, entropy growth potential

In recent years, I, before a close reading of Fourth Memoir to appreciate the implication of Clausius’ second fundamental theorem as articulated in the above, have arrived at a result,

> *For a given initial state of a system-surroundings arrangement and its defined final state for the system that the system will proceed to under spontaneous conditions, a change in the entropy of the universe(system + surroundings) for this spontaneous event has a special meaning: Following an insight of Poincare that this “spontaneous change in total entropy” is a common property (“property common to all possibilities”) shared by all events (as defined by the pair of initial state and final state) falling within the range delineated by the bookends of spontaneous event and reversible event.*[12][17]

I called this common property *entropy growth potential (EGP).* That is, EGP is the drive-force, or the equivalence-value of the transformation of natural direction, that compensates the process for work production of unnatural direction; every event within the Poincare range is compensated by the same common equivalence-value with specific resulting entropy growth corresponding with the specific-event work-output.

The analytical expressions of which are, for the case of system-surroundings with EGP being a function of surroundings' temperature, T_0,

$W_{rev} = Q = T_0 \cdot EGP\left(T_0\right)$, correspondingly,

$$W_{rev-like} \leq T_0 \cdot EGP\left(T_0\right) \qquad (\mathbf{II.2}.3)$$

For the case of isolated composite systems with their EGP to be independent of surroundings,[30][17][12][2]

$W_{rev} = Q = T_{Reservoir} \cdot EGP$, correspondingly,

$$W_{rev-like} \leq T_{Reservoir} \cdot EGP \qquad (\mathbf{II.2}.4)$$

Where $T_{Reservoir}$, like T in *(**II.2**.1)*, can be the temperature of any available reservoir.

This independently arrived result in [12][17] is consistent with the second fundamental theorem: For cyclic processes involving two transformations, EGP is interchangeable with the equivalence values of the transformations of natural direction that compensate for the other transformations; for generalized processes, EGPs represent their driving forces as equivalence values of transformations of natural direction do for cyclic processes; another innovation in the concept of EGPs is the explicit reference to the Poincare range in its application and that of calling a specific event in the range a reversible-like event/process.

5.3. A new Clausius synthesis

I call the second part of the second fundamental theorem the *second fundamental theorem of reversible-like compensation.* The incorporation of the "second fundamental theorem of reversible-like compensation" is shown in purple color in Fig. 8. The two parts of the second fundamental theorem are "equivalence of transformations," the first part, and "*reversible-like* compensation of transformations," the second part. In the figure, the first fundamental theorem is shown in blue, the first part of the second fundamental theorem in brown-yellow, and the second part of the second fundamental theorem in purple.

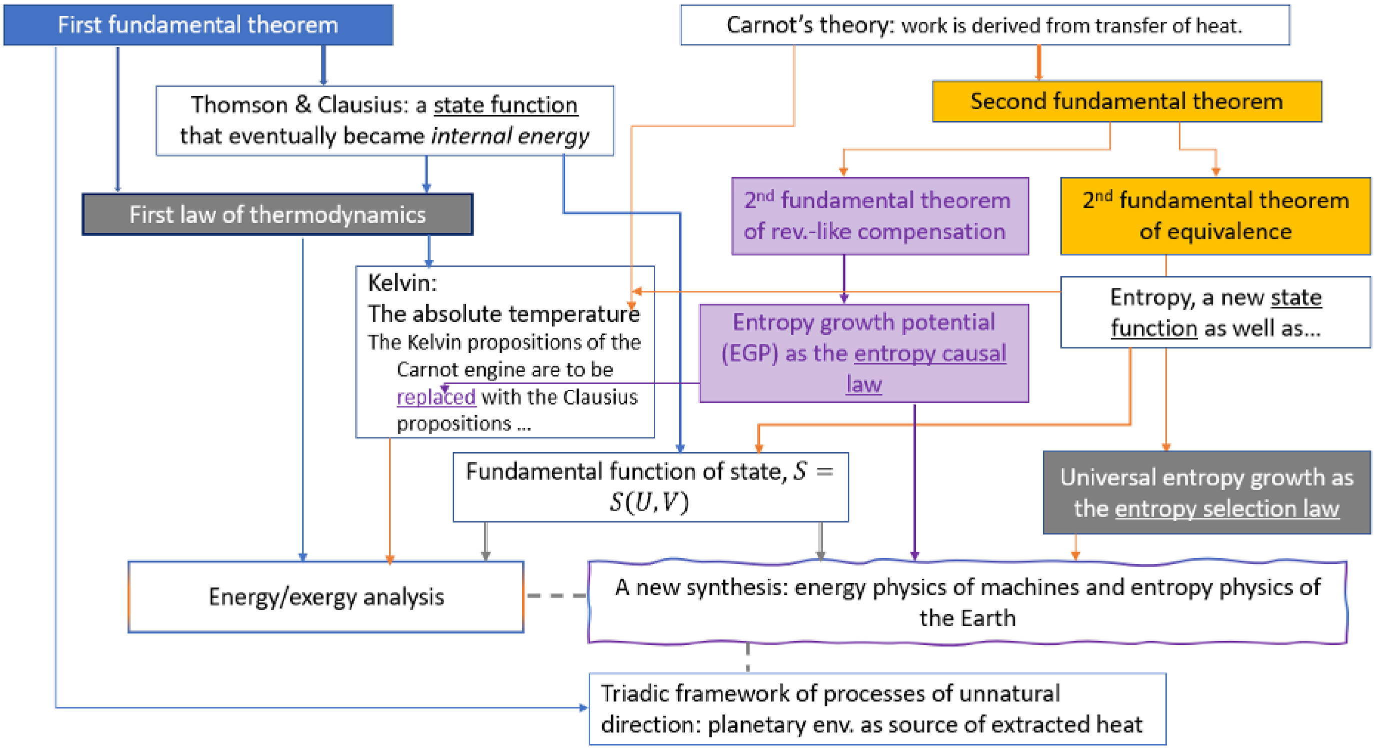


Figure 8. ***A new Clausius synthesis****, a theory resulted from the conceptual differentiation of caloric into energy/mechanical-energy, entropy, and heat as based on two fundamental laws: the first law which is stripped of its causal agency and the second law which has two parts, as a selection law and a causal law.*

The NWCJ discovery of the motive power from heat energy discovered that the erstwhile source for heat and light, fire, can also be a source for mechanical power. Sadi Carnot pointed out that mechanical power is derived from the unidirectional transfer of heat though he assumed that heat is "conserved" during the process (Carnot's theorem). James Prescott Joule demonstrated that in the production of work heat is consumed, instead, energy is conserved. William Thomson erected the energy physics edifice by the synthesis of the first fundamental theorem and Carnot's theorem, which he transformed into the energy premise of universal-dissipation-of-available-energy/energy-conversion-doctrine. The "consumption" of heat energy became the defining notion in energy physics in Fig. 1 and orthodox thermodynamics in Fig. 5. And the definition of energy was and still is [1][31][32][33] the "capacity for doing work." The definition of energy applies to organized energy perfectly but its adoption inflicts total confusion on the meaning of disorganized energy, the great NWCJ discovery, and shakes the first law and the second law their independency status.

Rudolf Clausius, "by his restatement of Sadi Carnot's principle known as the Carnot cycle, he gave the theory of heat a truer and sounder basis" (from a Wikipedia page). His restatement includes the above-stated five points of (i) to (v). Clausius' original notion of compensation (iii) was eventually developed into the "*equivalence* of transformations," which, the first part of the theorem as *Eqn. (**II**.1.2)*, is widely known. In the new Clausius synthesis as shown in Fig. 8, the above (iii) is restated as,

> *“Compensation of two transformations, a transformation of natural direction and a “heat into work” transformation of unnatural direction, is quantitatively expressed in terms of reversible-like-compensation of transformations.”*

This is shown in Fig. 8 as the second part of the second fundamental theorem, which results in the EGP principle as the entropy causal law. Fig. 8 is further reduced to its core content in terms of the what-where duality premise as Fig. 9. The thesis of the paper is twofold: that the what-where duality premise is consistent with the second part of the second fundamental theorem and the first fundamental theorem, as it will be discussed in Sect. 6 and that, as shown in the Graphical Abstract, the energy premise is supplanted with the what-where duality premise.

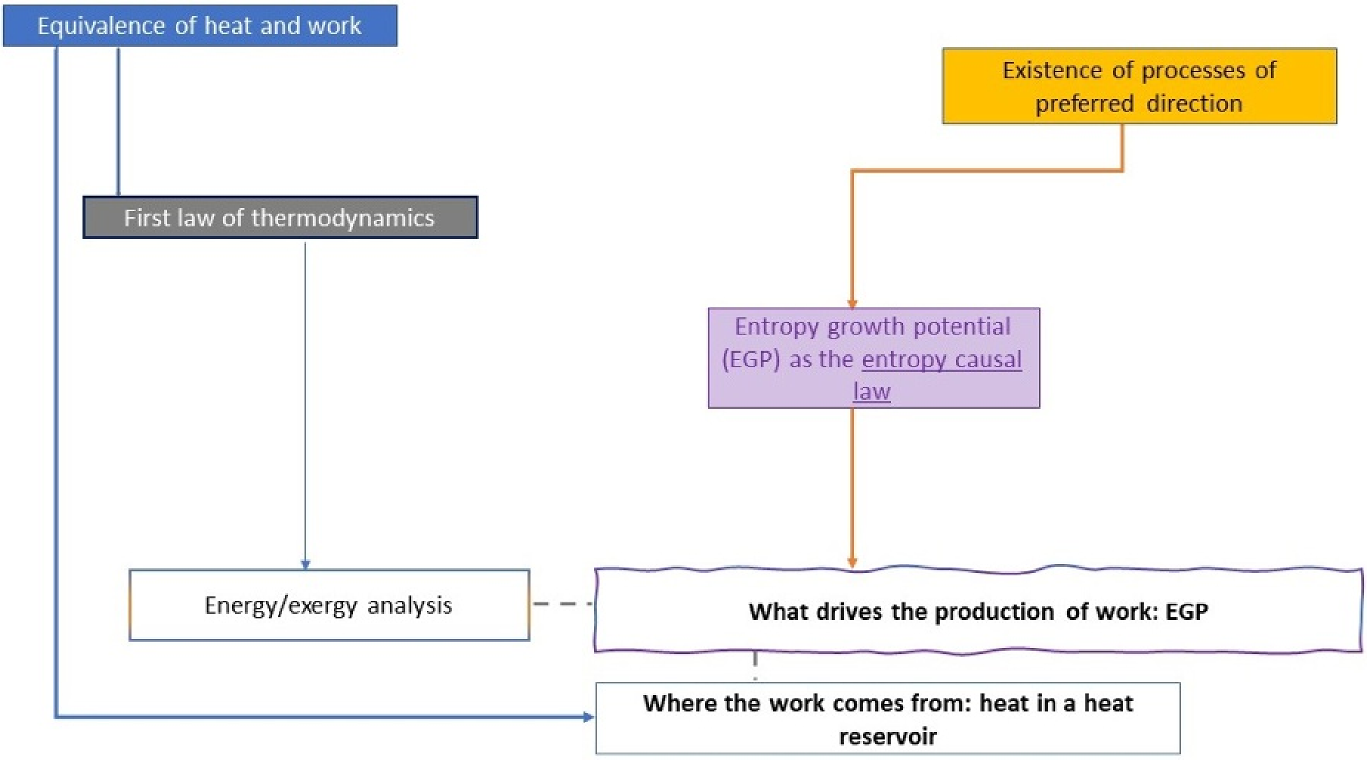


Figure 9. ***The what-where duality premise***, *the core questions it poses and how it fits into the theoretical structure of thermodynamics*

Note that *(**II.2**.2)* is of course an integrated part of the second fundamental theorem of equivalence but its use is in the sense of the entropy law as an entropy selection law, whereas *(**II.2**.1)*, *(**II.2**.3)*, and *(**II.2**.4)* collectively represent an entropy law as an entropy causal law. The entropy causal law is the law that a transformation of natural direction enables the extraction of heat from a heat reservoir delivering it into work. That is, the concept of reversible-like compensation of Clausius’ synthesis cuts the Gordian knot of the energy premise, the “circle” of Fig. 6, finally succeeding in reconciling the dichotomy between Carnot and Joule to its logical conclusion.

Hicks noted, “The definition of energy as the capacity to do work is generally presented in the same chapter as the definitions of kinetic energy, potential energy, and mechanical energy. Since mechanical energy can be fully used to do work, no problem arises in that context" [[33]:530]. Mechanical energy indeed is the capacity for doing work. But the newly discovered disorganized energy (the NWCJ discovery) cannot be fully used to do work. Energy physics and orthodox thermodynamics, therefore, "have been applying thermodynamics in the context of the pre-industrial mechanical sciences"[2]. That means: the common "energy" view inherited from the equivalence of heat and work is a mischaracterization of the NWCJ discovery. The real discovery is the discovery—in accordance with the concept of reversible-like compensation—of the production of work to be derived/compensated from "transformations of natural direction" found in fuels and in renewables, not of the production of work to be derived from energy found in fuels. Namely, the discovery of disorganized energy is the discovery of the unidirectional "transformations of natural direction" in disorganized energy not the energy in disorganized energy.

6. Discussion

A crucial advantage exists in separating what drives the production of work from where the work comes from, the former is the purview of the second law or the second fundamental theorem while the latter is that of the first law or the first fundamental theorem. Separating the what-where work questions should have been a logical follow-up to the formulation of two laws. Orthodox thermodynamics and the simple Carnot cycle have failed to take the logical step, which was the source of all the puzzlement.

More than that, the industrialization based on orthodox thermodynamics' understanding of heat and energy was a Faustian bargain: There is a school of thought by the name of entropy pessimism. Entropy pessimists believe that human use of energy intrinsically degrades our ecosystem because the entropy law asserts the inevitable entropy growth and with that the inevitable accumulation of waste heat. But, with what drives the production of work to be EGP as one part of the what-where duality premise, a new insight emerges from the realization that EGP in itself does not automatically lead to the production of work as a process of efficient causation does. Instead, in the EGP framework the real meaning of equivalence of heat and work is found—once heat is relieved of "a schizophrenic double role that it cannot fulfill"[[34]: 179-180]— in the requirement of a heat reservoir so that the EGP can enable the extraction of heat delivering the heat in the form of work, i.e., mechanical energy, to a mechanical-energy reservoir—i.e., a triadic framework of EGP, heat reservoir, and mechanical-energy reservoir[2]. That is, heat of a heat reservoir is where the work comes from. In orthodox thermodynamics and the simple Carnot cycle, however, with the conflation of the two questions, the same heat reservoir is used as a heat reservoir source from which heat is obtained and as a heat sink for what drives the production of mechanical energy. When the heat reservoir serves a double role, which is the case with the usage of fossil fuels, activities in the production of work and power always result in the production of waste heat. Humankind acquired the power of "unlimited" supply in fossil fuels but with the bargain of inevitable accumulation of waste heat.

As a practical and social-consideration matter, a simple Carnot cycle and orthodox thermodynamics represented the *philosophical/scientific accord* of the Anthropocene, the accord that has enabled incredible economic growth. The bargain is that the economic growth is unsustainable as a result of the accumulation of waste heat.

Entropy does grow inevitably. But the accumulation of waste heat is not inevitable. Accumulation of waste heat is the result of fossil fuel usage which necessitates the planetary environment to serve as both heat reservoir and heat sink. The latter is not an intrinsic role of heat reservoir thermodynamically speaking but the consequence of the fossil-fuel energy regime, the consequence that entropy growth potential (EGP) in that regime requires a heat sink. The fact that physics and thermodynamics do not require “transformations of unnatural direction” to have a heat sink has been demonstrated with the examples of isolated composited systems in References[[30] 2014], [[17] 2019], and [[2] 2022]. For isolated composite systems, their EGPs are independent of any heat reservoir temperature since no heat sink is required. Unlike fossil fuel energy its burning requires a heat sink, the transformation of isolated composite systems into work requires only a heat reservoir for heat source. Instead of producing waste heat, such activities of production of work lead to the extraction of heat from the environmental heat reservoir. The last point applies to the application of renewables as well.

The use of renewables does not require a planetary environment as a heat sink; the radiative interactions occur among the Sun, the Earth, and space; the planetary environment is not a part of the equation for EGP (the planetary environment is energy-neutral in this radiative heat exchange). The environmental heat reservoir in the case of renewables-EGP serves only as a heat reservoir source. In the fossil fuel energy regime, we have been blinded to such possibility of freedom from energy-powered economic activities leading to the inevitable production of waste heat. This has been sometime referred to as entropy pessimism. Moving forward to the renewables-powered regime, we can see the compelling advantage of renewables not only for the benefit that their energy forms are renewed diurnally but also for the fundamentally changed nature of the footprint of their usage. That is, the more we apply renewables-EGP the more heat is extracted from the planetary heat-reservoir-source. The third reason that name matters is, therefore, rejection of the term is a part of cutting the Gordian knot, which (the separation of the what-where work questions) unfolds the true meaning of the NWCJ discovery, thus resolving the dilemma facing the Anthropocene of entropy pessimism vs. economic growth.

Unfoldment of the true meaning of the NWCJ discovery will serve as a philosophical accord for Anthropocene 2.0.[35] This results in the possibility of an incremental decrease in the entropy of the planet, a Gaia-like[36] processes/transformations for the planet Earth.[35] It is noteworthy that William James Sidis cited, in his 1925*The Animate and the Inanimate*[37], Lord Kelvin,

> *It is conceivable that animal life might have the attribute of using the heat of surrounding matter, at its natural temperature, as a source of energy for mechanical effect . . . .The influence of animal or vegetable life on matter is infinitely beyond the range of any scientific inquiry hitherto entered on. Its power of directing the motions of moving particles, in the demonstrated daily miracle of our human free will, and in the growth of generation after generation of plants from a single seed, are infinitely different from any possible result of the fortuitous concurrence of atoms.*

The miracle Kelvin alluded to has a perfectly rational account in Clausius' thermodynamics. Animals and vegetable life can do it, and so can a planetary-wide Anthropocene 2.0.

7. Conclusion

Available energy (i.e., free energy) was a great insight of Kelvin, the insight that enabled the presupposition of the energy premise making the Anthropocene possible. At the same time, the premise made the essence of disorganized energy hidden and preempted engineering thermodynamics from achieving the conceptual differentiation of caloric explicitly. It has been proposed in a 2022 paper, *Triadic relations in thermodynamics*, that the energy premise is to be supplanted with the what-where duality premise. This paper shows that the what-where duality premise is consistent with the first fundamental theorem and the second fundamental theorem. The what-where duality premise together with the first and second fundamental theorems, therefore, will lead to a successful goal of discarding the energy premise and unfolding the essence of disorganized energy. The real discovery of the NWCJ discovery is the discovery of the production of work to be derived from *spontaneous transformations* found in fuels and in renewables, not of work to be derived from *energy* found in fuels. There can never be "consumption" of energy; the relation between disorganized energy and organized energy is to be sought in terms of the relation between the "transformations of natural direction" of disorganized energy and mechanical energy. Once this relation is expressed this way, the connection between "transformations of natural direction" and the surrounding heat reservoir is completely different from the conventional entropy-pessimist take. Contrary to entropy pessimism, Anthropocene 2.0 is the idea that the "industrial scale" consumption of spontaneous transformations, aka entropy growth potential, in the renewables regime is sustainable. A group of philosophers from Oxford has been making the moral case for "longtermism". The principal inference of the paper is that in the renewables regime the planetary environment serves as a heat reservoir rather than doubles as a heat reservoir/heat sink provides a necessary condition for sustainability in the sense of longtermism.

The existential threat facing the Earth is greenhouse-gas emissions in the short term but in the long run the Earth faces global entropic disorder, sometimes referred to as the existential threat of entropy pessimism. We may call the former the proximate threat and the latter the ultimate threat. Nuclear energy is being promoted by some since it does not emit greenhouse gas. That is true but it is noted that nuclear energy is not a long-term solution to the ultimate threat while renewables are the solution to both threats based on the thermodynamic analysis of this paper.

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NOTE: Kelvin used the same kind of terms as quoted here in "On the Miracle of Life": Excerpt from an address at the annual meeting of the Christian Evidence Society, May 23, 1889, as quoted in Heros of the Telegraph by J. Munro.

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