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Relativistic thermodynamic state functions from a time dilation perspective

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Abstract:

To embrace the special theory of relativity with classical thermodynamics correct Lorentz transformations of thermodynamic state functions are formulated. All of these Lorentz transformations of state functions equally support the time dilation phenomenon which is experimentally verified fact. Relativistic Boltzmann constant proves entropy to be the Lorentz variant. Twin paradox thought experiments for heat engines prove heat flux to be Lorentz variant. Lorentz transformation of entropy and heat flux proves temperature Lorentz invariant. All thermodynamic state functions are proved to be Lorentz variant which is shown in accord with Lorentz transformation of thermodynamic work.

Keywords: Special theory of relativity; time dilation; thermodynamics; State functions; Lorentz transformations.

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1. INTRODUCTION:

The special theory of relativity is the physical theory of measurement in inertial frames of reference proposed in 1905 by Einstein in the paper "On the Electrodynamics of Moving Bodies" [1]. Einstein discerned two fundamental propositions that seemed to be the most assured, regardless of the exact validity of the known laws of either mechanics or electrodynamics. These propositions were; (i) the constancy of the speed of light that is, light in vacuum propagates with the speed c (a fixed constant, independent of direction) in at least one system of inertial coordinates, regardless of the state of motion of the light source. (ii) the independence of physical laws from the choice of the inertial system that is if a system of coordinates K_0 is chosen so that with it all physical laws hold good in their simplest form, the same laws hold good with any other system of coordinates K_u moving at a uniform speed relative to K_0.

2. THEORY:

The present theory is developed to show that laws of thermodynamic hold well in their simplest form in all inertial frames. Time dilation is the most important consequence of the special theory of relativity and is an experimentally verified fact [2-3]. Only those Lorentz transformations of thermodynamic quantities will be correct that would support experimentally verified time dilation phenomenon. In the present paper, all variables with subscript *0* refer to the inertial frame K_0 with the observer at rest, while variables with subscript *u* refer to inertial frame K_u with the observer moving at relative speed *u***.** Where the Lorentz factor used in all equations is $\gamma = \left(1-u^2/c^2\right)^{\frac{-1}{2}}$.

3. Lorentz transformation of entropy:

Entropy is a measure of disorderness of the system. It is mathematically defined in terms of number of possible arrangements of the system as [4],

$$S_u = \left(k_B\right)_u \ln W \tag{1}$$

Since Boltzmann constant has already been quantum-mechanically proved Lorentz variant i.e. [5]. So substituting Lorentz transformation of Boltzmann constant in Eq. (1) gives,

$$S_u = \gamma^{-1} S_0 \tag{2}$$

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The decrease in entropy for moving observers had also been reported [6,7]. This Lorentz transformation of entropy supports time dilation. [5]

4. Lorentz transformations of Heat and Temperature:

Plank and Einstein proposed following Lorentz transformation for heat flux and temperature [8-9].

$$Q_u = \gamma^{-1} Q_0 \tag{2}$$

$$T_u = \gamma^{-1} T_0 \tag{3}$$

Ott proposed opposite Lorentz transformation for heat flux and temperature [9].

$$Q_u = \gamma Q_0 \tag{4}$$

$$T_u = \gamma T_0 \tag{5}$$

Only those Lorentz transformations will be valid that would support time the dilation phenomenon.

As entropy is mathematically defined as,

$$S_u = Q_u / T_u \tag{6}$$

From Eq. (2) entropy is observed to decrease for moving observer which supports the time dilation phenomenon. So then either heat flux is Lorentz variant given by Eq. (2) or temperature is Lorentz variant given by Eq. (5). Therefore both of the other Lorentz transformations for heat and temperature are given by Eq. (3) and Eq. (4) respectively are wrong. The second law of thermodynamics is a general principle that places constraints upon the direction of heat transfer and the attainable efficiencies of heat engines. According to the second law of thermodynamics, it is impossible to extract an amount of heat Q_H from a hot reservoir and use it all to do work W without exhausting some amount Q_C to a cold reservoir [10]. Let's carry out twin paradox thought experiment for two identical heat engines working between same temperatures; one is kept in rest-frame while other is sent on a journey at fractions of the speed of light. Heat engine sent on a journey should have a longer lifetime than the heat engine kept at a state of rest. Lorentz transformations for heat flux and temperature given by Eq. (4) and Eq. (5) do not support twin paradox thought experiments for two identical heat engines, so both of these transformations are wrong. Therefore only heat flux is Lorentz variant and Lorentz transformation given by Eq. (2) is correct. Heat flux would be observed to decrease for

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moving observer, this also supports time dilation phenomenon as a slow rate of exchange of heat flux would result in a prolonged lifetime of heat engine that was sent on a journey. Lorentz transformation for heat flux also relates time dilation phenomenon with zeroth law of thermodynamics which explains the attainment of thermal equilibrium between bodies at different temperatures. Time require to achieve thermal equilibrium between two bodies at a different temperature will be dilated because heat flux will be observed to decrease for observers moving at fractions of the speed of light. Thus Lorentz transformation for heat flux given by Eq. (2) embraces time dilation phenomenon with the second and zeroth laws of thermodynamics.

The temperature of the bodies will be observed the same in all frames independent of relative speeds of observers is now more widely accepted. Recently, Landsberg and Matsas, considering the Unruh–DeWitt detector, concluded that continuous Lorentz transformations of temperature cannot exist for black body radiation [11]

5. Lorentz transformations of Thermodynamic State Functions:

According to the First Law of Thermodynamics, internal energy for a moving observer is defined as, [4]

$$U_u = Q_u + PV_u \tag{6}$$

As it follows from the special theory of relativity volumes is Lorentz variant and pressure is Lorentz invariant, so thermodynamic work is Lorentz variant i.e. [6-7]

$$PV_u = \gamma^{-1} PV_0 \tag{7}$$

Substituting values of Lorentz transformed equations of thermodynamic work and heat from Eq. (7) and Eq. (2) respectively in Eq. (6), proves internal energy to be Lorentz invariant,

$$U_u = \gamma^{-1} U_0 \tag{8}$$

Since enthalpy is defined as, the sum of internal energy and Pressure volume work [4]. For moving observer it can be stated as,

$$H_u = U_u + PV_u \tag{9}$$

Substituting values of Lorentz transformed equations of thermodynamic work and internal energy from Eq. (7) and Eq. (8) respectively in Eq. (9), proves enthalpy to be Lorentz invariant,

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$$H_u = \gamma^{-1} H_0 \tag{10}$$

Gibb's free energy is defined as the difference between enthalpy and product of temperature and entropy. For moving observer it can be stated as [4],

$$G_u = H_u - TS_u \tag{11}$$

Substituting values of Lorentz transformed equations of enthalpy and entropy from Eq. (10) and Eq. (1) respectively in Eq. (11), proves Gibb's free energy to be Lorentz invariant,

$$G_u = \gamma^{-1} G_0 \tag{12}$$

Gibb's Helmholtz Energy is the difference between internal energy and the product of temperature and entropy [4]. For moving observer it can be stated as,

$$A_u = U_u - TS_u \tag{13}$$

Substituting values of Lorentz transformed equations of internal energy and entropy from Eq. (8) and Eq. (1) respectively in Eq. (13), proves Gibb's Helmholtz Energy to be Lorentz invariant,

$$A_u = \gamma^{-1} A_0 \tag{14}$$

Consider a gas container enclosing gas molecules within it. Let the container is moving at fractions of the speed of light. If a container is pumping against the speed of light, stuffing more and more energy but can never attain the speed of light. So where does energy going on which is being supplied to the container to make it achieve the speed of light. Energy eventually goes into the mass of the container. Walls of the container and molecules confined with it become heavy. Thus heavier molecules have a lesser tendency to do thermodynamic work so does internal energy also decreases. This results in thermodynamic work and internal energy to be Lorentz invariant. Since all thermodynamic state functions are related to thermodynamic work in some way or other, so this demands all thermodynamic state functions to be Lorentz variant. So all thermodynamic state functions decrease for moving observers as shown in Eq.s (8), (10), (12) and (14). Lorentz's transformations of all thermodynamic state functions, heat, and thermodynamic work are consistent with the Lorentz transformation of Boltzmann constant and Universal gas constant [5-7].

6. Conclusions:

Relativistic Boltzmann constant proves entropy to be the Lorentz variant. Twin paradox thought experiments for heat engines have ensured heat flux to be Lorentz variant and observed to decrease for moving observers. Lorentz transformations of entropy and heat flux render temperature to be Lorentz invariant. As thermodynamic work is the Lorentz variant this leads to all thermodynamic state functions and heat to be Lorentz variant and thus observed to decrease for moving observers. All laws of thermodynamics retain their form in all inertial frames. Only those Lorentz transformations are correct that support the experimentally verified time dilation phenomenon.

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