Redefining Heat and Work in the Right Perspective of Second-Law-of-Thermodynamics

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Abstract

There are some misnomers and misconceptions about what is heat and what is work; the recognition of heat and work is even more difficult when it comes to categorize energy as heat or work. Since both heat and work are energy the name-confusion does not make much difference from engineering point of view, but re-defining ‘heat’ and ‘work’ in the right-perspective of second-law-of-thermodynamics \(^[1]\) is necessary to revise our understanding at fundamental level. It is concluded that ‘heat is the energy carried by mass-less photons whereas work is energy carried by mass-ive material fermions’. Revised understanding of heat & work in this way has far reaching consequences in Physics \([2-4]\). The present paper lays emphasis on re-defining heat and work, removing the prevailing misconception, talks about single photon interaction and heat property of photon. Also, interestingly, it is noted that different fields of study such as ‘Thermodynamics’ and ‘Relativity’ are interlinked.

Key words: Thermodynamics, Heat, Work, Energy, Irreversibility, Relativity, Photon, Photoelectric-effect, Compton-effect.

1 Introduction

Laws of thermodynamics are universally valid. The first-law is about the ‘conservation of energy’ whereas the second-law is about ‘conversion of energy’.
Engineers give equal weightage to both these laws, but unfortunately the second-law has largely been ignored by physicists. The second-law of thermodynamics which basically tells about the ‘irreversibility’ of the energy (heat and work) conversion process, has far-reaching consequences [2-4]. Second law of thermodynamics [1] implies that ‘although work can be fully converted to heat, but heat can-not be fully converted to work’. Efficiency of ‘work to heat conversion’ could be = 100%, but efficiency of ‘heat to work conversion’ must be < 100%. The second law of thermodynamics can be used as best criterion to judge whether a certain form of energy is work or is heat. Judging from this angle, as it is mentioned [2] and elaborated in this paper that: it is very unfortunate that there are some misnomer and misconceptions which exists & prevails specially for the heat, right from the very beginning till now in our understanding, in books and literature. Though these misnomer and misconceptions do not make much difference from engineering point of view, re-defining ‘heat’ and ‘work’ in the right-perspective of second-law-of-thermodynamics is necessary to revise our understanding at fundamental level as it has far reaching consequences at deeper level in Physics [2-4].

It is further shown that: though heat is considered as a statistical (bulk) property/aspect, but thermodynamics-laws are equally applicable even for a single photon interaction such as photoelectric-effect and Compton-effect. It is also found that widely differing fields of study ‘thermodynamics’ and ‘special-relativity’ are inter-supportive to each other [5-12].

2 Misnomers & Misconceptions about Heat & Work and Re-defining Energy as either Work or as Heat in view of Second-Law of Thermodynamics

In thermodynamic-processes ‘Heat’ and ‘work’ are generally considered obvious, but there are some basic misconceptions too. The so-called ‘heat of a hot-body’, as per second law of thermodynamics, is in fact not ‘heat’ but ‘work’ as it is due to vibration/motion of atoms/molecules. In electronic and other processes where usually ‘energy’- transfer/transition/conversion takes place, recognition of heat & work is even more difficult. What is energy? Is energy ‘heat’ or ‘work’? Identification of different types of energies either as work or as heat is discussed in the next paragraphs and represented in Figure 1.

First consider the potential-energy, it is the work-done against a force and is stored as potential energy; so potential energy is ‘work’. It is well known that when a stone falls from height, the potential energy changes to kinetic-energy, hence kinetic energy too is ‘work’ i.e., energy of motion and vibration of molecules and atoms are work. Stored energy of an electron in atom is
sum of its potential energy and kinetic energy, is thus again the stored energy is ‘work’. With furthermore arguments, it can be shown that: all stored energies such as electrostatic energy, chemical energy, internal energy, nuclear energy/mass energy \( mc^2 \) etc. are in-fact ‘work’. Though all stored energies are ‘work’; the energy with moving particle is ‘work’ if the energy is kinetic-energy and it is ‘heat’ if the energy is radiation-energy. In-fact **heat** is the energy carried by mass-less particle such as photon, whereas all other form of energy carried by mass-ive material particle are ‘work’ (Figure 1). In other words, messenger-particles bosons (photons) carry the ‘heat’ as radiation, whereas material-particles fermions (or fermion-groups as atoms/molecules) carry ‘work’ as kinetic & stored energy in the particle/matter. To illustrate - which energy is ‘work’ and which one is ‘heat’ a ray-table is shown as follows (Figure 1). The conclusion that ‘heat is carried by massless-particle photon’ reminds/revives the old caloric-concept [13-15] of heat as ‘energy in transit’ by massless-fluid ‘caloric’.

Let us look at the question ‘what is work’ from a different angle. Work is the energy spent against a force, and this is either stored as potential-energy or delivered as kinetic-energy. Kinetic-energy is a ‘kinetic’ manifestation of the ‘static’ potential-energy, and both are interchangeable to each other. Next question may be ‘what are the forces against which work could be done’. There are four fundamental forces of Nature: Gravitational, Electromagnetic and Nuclear (Weak & Strong). The other forces such as muscle-force, hammer-force, explosive-force etc. are all basically electromagnetic force. So, all the energies, except radiation-energy, are ‘work’.

Now let us examine what we mean by ‘heat of a hot body’. The word ‘heat’ here is a misnomer, ‘heat of the hot body’ is due to motion and vibration of molecules and atoms and thus what we say as ‘heat’ is actually due to kinetic and internal energy which are really in the category of ‘work’.

In thermodynamics, conventionally it is said that disordered motion is heat whereas ordered motion is work, this too is a misconception. Both disordered and ordered motion energy are work, we may say it disordered work and ordered work. We cannot distinguish energy of a crowd as heat and energy of a military-platoon as work; similarly, we cannot distinguish that energy of ordinary light as heat and energy of laser beam as work. The energy of crowd or platoon both are work, whereas energy of light or laser both are heat; since in the former example energy is carried by mass-ive material body whereas in the later example energy is carried by mass-less particle (photon).

Now let us consider the conventionally called ‘heat-transfer’ [16]; it is said that the transfer is through (i) Conduction, (ii) Convection and (iii) Radiation. But a careful re-examination of the fact would reveal that the literally real ‘heat-transfer’ is only through radiation only where the heat (radiation energy) is transferred from one place to the other. The transfer of energy in conduction
Figure 1: 'What is Energy?': In fact all forms of energies are 'work' except the radiation-energy which is 'heat'. 
and convection in in-fact the kinetic-energy transfer from one atom/molecule to the other, so it should be called ‘work-transfer’. Thus in place of ‘heat-transfer’ name, ‘energy-transfer’ name would be a better name because this includes all the three modes of energy transfer through conduction, convection and radiation; ‘heat and mass transfer’ name is also acceptable because mass in itself implies energy too.

Now let us consider how energy is emitted and is absorbed. Energy emission can be viewed as the release of energy when say electron/atom/molecule goes from a higher energy level to a lower energy level, releasing full energy change $\Delta E$ (work) in full to heat ($h\nu$). However, when heat ($h\nu$) falls on an opaque body, a part of it may be reflected from surface-atoms and the remaining is absorbed. This remaining energy goes to impart kinetic energy & internal energy to molecules & atoms; only part of ‘the absorbed part of heat’ converts into ‘work’, some energy must go as waste (reflected/radiated from inside atoms). So, as per second law of thermodynamics even the blackest of black-body can not have 100% absorptivity of heat i.e., $\alpha$ can-not be equal to 1 but must be very slightly less than 1.

When it comes to the meaning of temperature of a hot body; conventionally it is thought that it is a measure of the level of heat but truly speaking it is measure of level of energy (work) contained in it. Also, we speak that internal energy is due to vibration of atoms/molecules viz. $\frac{1}{2}mv^2 = 3kT$ for solid [17], which means that temperature (T) is a measure of kinetic energy (work).

Energy-wise heat (Q) and work (W) are equivalent by the Joule’s relationship $W = JQ$. Though W & Q are equivalent by the above relation, but the transformation-processes of ‘work to heat’ and ‘heat to work’ are different (efficiency-wise) from the point of view of second law of thermodynamics. First law of thermodynamics (energy conservation) states equivalence of $W$ & $Q$ energy-wise, whereas the second law of thermodynamics (entropy increase) implies the non-equivalence or irreversibility in its conversion.

3 Single Photon Interactions (such as Photoelectric-Effect & Compton-Effect) and Heat Property of the Photon

Conventionally, heat is considered to be an averaged quantity, so questions arise ‘whether a single photon has heat property and that whether applying second-law-of-thermodynamics to single photon interaction such as Photoelectric-effect and Compton-effect are reasonable or not?’ The authors answer both these questions as yes and yes, and firmly states that indeed it is reasonable because: (i) Average of a single data is also a quantity i.e., the data itself, a photon of energy ($h\nu$) has its average energy too as ($h\nu$), (ii) Though from the very
beginning (much before the birth of photon-concept) it has been considered (in view of kinetic theory of gases) that heat is statistical (bulk) property; but no-one established this or no-law dictates that the second-law-of-thermodynamics can not be applied to a single photon interaction. This means that nothing forbids/prohibits and is therefore permissible; in fact single photon interactions (such as Photoelectric and Compton effects) are neat examples of applicability of both the first and second law of thermodynamics, (iii) It is shown [2] (and will be reproduced again for charity & completeness) that not only the applicability holds good very well but also shows new light (understanding) i.e., it leads to conclusion that the second-law-of-thermodynamics is in accordance with the basic idea of special-relativity, (iv) The theory of relativity is applicable well to single-particle therefore the second law of thermodynamics too should be applicable, since both are shown to be interlinked [5-12].

3.1 Photoelectric Effect

The photoelectric-effect [17] equation for a single photon interaction $h\nu - h\nu_0 = \frac{1}{2}m_0v^2$ is indeed in accordance with the second law of thermodynamics $Q_1 - Q_2 = W$, which means that the work-function ($h\nu_0$) corresponding to $Q_2$ can never be zero (and that is true). The thermodynamic-efficiency of the process is therefore $\eta = \frac{(\nu - \nu_0)}{\nu} < 1$.

3.2 Compton Effect

The Compton-effect [17] equation for energy conversion (first law of thermodynamics) $h\nu - h\nu' = \frac{1}{2}m_0v^2$ or more precisely (with relativistic consideration)

$$h\nu - h\nu' = \frac{m_0c^2}{(1 - \frac{v^2}{c^2})^2} - m_0c^2$$

is also in accordance with the second law of thermodynamics $Q_1 - Q_2 = W$, which means that $\nu'$ can never be zero (and that is true). The thermodynamic-efficiency of the process is, similar to that of photoelectric effect, therefore $\eta = \frac{(\nu - \nu')}{\nu} < 1$.

3.3 Temperature of a Photon

For a rough estimate of temperature of a photon coming out from its source, the photon’s energy (\(\frac{hc}{\lambda}\)) is equated to the internal energy $3kT$ of the source. This yields $T = \frac{hc}{(3k\lambda)}$ which is quite similar to the source-temperature estimate by Wein’s law [17] $T = \frac{hc}{(4.96k\lambda)}$. However, the single photon temperature is usually high, but its effect is not appreciably felt physically unless a large number of photons fall upon and absorbed fully. Moreover, only a part of photon’s energy is absorbed on the receiver body and that too further radiates-back as high-wavelength radiation.
Assigning a temperature to photon(s) is not something that is completely new: cosmologist often ascribe a temperature of 2.70 K to Cosmic-Microwave-Background (CMB) radiation (photons)\cite{18-22}. Usually a ‘color’ is linked to ‘temperature’, and whole range of VIBGYOR spectrum are linked to its corresponding temperatures.

Photon do has heat property; heat of thermal-photon can be physically felt, it is the photons which heats the food in the microwave-oven or solar-cooker. Our sensory-organs too are made of materials-atoms (fermions), part of the photon’s energy is first taken-up by the organ and the energy-transfer communicated to the brain-matter. Even the instruments (material) absorb the energy and the expansion (of say, Hg material) calibrated. Though photon’s heat is measured with the intervention of some material (sensory organ or measuring-instrument), but it is true that photon do has heat property and has a temperature too. If we are unable to see something, that doesn’t mean that it doesn’t exist; we do not see atoms but atoms do exist, and we have indirect evidences for its presence. Ironically, everything which we see around us is visible only due to presence of apparently-invisible photon. Presence of photon and its heat, however, can be sensed as solar-radiation, viewed as chemical-reaction taking place on photographic-plate or can be heard as radio-song and so on. Even the absence-of-photon as shadow indicates its existence. Photon is essential for photosynthesis, and it can be further argued that the essence of life is photon and its heat. Whole range of electromagnetic radiation is heat; though our-sensory organs (hearing, seeing and feeling-heat) may be more receptive only to certain range of frequencies.

4 Thermodynamics and Relativity Linked through Photon

Consider the Compton-effect again. ‘The outgoing photon ought to exist, i.e., $\nu'$ can never be zero (which is in accordance with the second law of thermodynamics)’ is re-studied further considering the two possibilities:

(i) If the incident photon ($\nu$) strikes the electron in x-direction and if after collision the electron is deflected-away from x-direction, the changed-photon ($\nu' > 0$) ought to come-out to balance the ‘momentum of electron in y-direction’.

(ii) If the incident photon ($\nu$) strikes the electron in x-direction and if after collision the electron too moves in x-direction, the changed-photon ($\nu' > 0$) after impact may come-out in x-direction. This possibility is further analyzed as follows.

The energy-equation of Compton-effect can be re-written using $\nu' > 0$ as follows,
\[ h\nu > \frac{m_0c^2}{(1-\frac{v^2}{c^2})^{\frac{1}{2}}} - m_0c^2 \]

and the conservation of momentum for possibility (ii) using \(\nu' > 0\) yields,

\[ \frac{h\nu}{c} > \frac{m_0}{(1-\frac{v^2}{c^2})^{\frac{1}{2}}}v \]

Putting the value of \(h\nu\) from one equation into the other and after simplification, the following interesting result is found to emerge-out as

\[ 0 < v < c \]

which is well in-accordance with the basic concept of the theory of Relativity.

This means that the result of second law of thermodynamics (\(\nu'\) is never zero, ‘heat to work’ conversion \(\eta = \frac{Q_1-Q_2}{Q_1} = \frac{W}{Q_1} < 1\)) is compatible with the essence of special-relativity (\(v < c\) i.e., no matter how energetic may be the incident photon, velocity of electron can not exceed velocity of light \(c\), implying \(\beta = \frac{v}{c} < 1\)). It is amazing that how two quite different fields of study - ‘Thermodynamics (\(\eta < 1\)’ and ‘Relativity (\(\beta < 1\)’ are inter-supportive and inter-linked to each other and appear to be the two faces of the same coin. The link of Thermodynamics and Relativity has been reported [5-12] earlier also.

5 **Heat and Work Revisited**

Probably the root-cause of the confusion about heat & work arises due to the fact that both (heat & work) can give rise to a feel of temperature to our senses. But if we widen our thought-horizon to encompass both heat and work as ingredients (as follows) for temperature, the confusion about heat and work diminishes. The confusion/misconception however can not be removed completely in one go, it needs time for our mind-set to adopt for the change/revision. Work and heat can be considered to be related to temperature (of say, solid) as follows:

For **work** ingredient as internal energy

\[ \frac{1}{2}m_0v^2 \approx 3kT, \quad T \approx \frac{m_0v^2}{6k} \]

For **heat** ingredient as radiation energy

\[ h\nu \approx 3kT, \quad T \approx \frac{h\nu}{3k} \]

Now, let us re-view heat and work in the popular equation of first law of thermodynamics (energy conservation) : \(dQ = dU + dW + Losses = dU + dW + dL_W + dL_Q\). Each terms are discussed in some details for clarification, as follows.

**dQ:** It is the input-energy (heat) to the system. It is usually the stored-energy (work) of the fuel which is released as heat \((h\nu)\) after ignition and which is then
transferred to atoms/molecules as kinetic-energy (work); part of this kinetic-energy \( \frac{1}{2}mv^2 \) goes as internal-energy \( (dU) \) to the gas & the container-body and part of which is used up to produce work \( (dW) \) through piston-motion. Some input energy goes as waste as radiation \( (dL_Q) \) as a necessity dictated by the second law of thermodynamics.

**\( dU \):** It is the kinetic-energy \( \frac{1}{2}mv^2 \) of the atoms & molecules of the exhaust gas & the container body. It is also called as internal or thermal-energy. As discussed (& tabulated) earlier, the kinetic-energy is like work but it gives a feel of temperature, so usually misunderstood as heat.

**\( dW \):** Part of the kinetic-energy of the combustion gases produces useful work \( (dW = p.dV) \) through piston motion. Part of this work is used for useful work (such as raising a load or moving a vehicle); whereas part of it goes as waste against, say, friction-resistance and goes as thermal-energy \( (dL_W) \) and finally goes off as radiation heat.

For constant-volume process or for heating solid \( dV = 0 \) hence for it \( dQ = dU + dL_Q \), similar to the second-law-of-thermodynamics equation \( Q_1 = W + Q_2 \), indicating that \( dU \) is like work.

**Losses:** There are two types of losses viz., (1) \( dL_W \) and (2) \( dL_Q \), re-explained as follows.

(i) \( dL_W \) is the loss from the total work produced; the total work produced \( dW_t \) is equal to sum of useful work \( (dW) \) and loss due to friction etc. \( (dL_W) \). Thus as per ‘first law’ of thermodynamics \( dQ = dU + dW + dL_W \).

(ii) \( dL_Q \) is the loss dictated by the ‘second law’ of thermodynamics, some energy must go as waste radiation energy.

(iii) Taking into, account both the ‘first law’ and ‘second law’ of thermodynamics, the final equation is as follows: \( dQ = dU + dW + dL_W + dL_Q \).

### 6 Another Look on Question of ‘What is Energy’

Let us have another look (Figure 2) on the basic question - ‘what is energy, is it heat or work?’ To reconcile with the prevailing/conventional concept of heat-transfer; instead of categorizing energies into only heat and work, if we categorize (as follows (Figure 2)) energies into three categories namely - heat, work and therm (the term for the internal or thermal energy), the whole confusion seems to fade away. It may, however, be seen that the complex inter-conversion among work, therm (thermal-energy) and heat occurs. For example, the fuel’s
Figure 2: Another look on what is energy and its fate.
chemical energy is first released as heat (dQ) which converts to thermal-energy (dU) and work (dW) plus losses (Figure 2).

Work (dW) is work and heat (dQ) is heat, but the thermal energy (dU) i.e., therm (though actually being manifestation of stored work) is considered as heat; since heat (hν) and thermal-energy ($\frac{1}{2}mv^2$) both gives a feel of temperature T, as explained earlier.

So in the new light of work, therm, and heat; the modes of heat transfer conduction and convection is through therm-transfer whereas radiation is due to photon-transfer. You feel the heat of a coke-oven at a distance through photon-transfer, but if you touch the hot-coke the feel of heat (hotness) is due to therm transfer. If we consider the ‘therm and photon’ together as one word ‘caloric’, the confusion about heat transfer fades away in favor of caloric-transfer, but this reminds and revives the old ‘caloric theory’ [13-15] of heat-transfer.

7 Discussion

‘Law(s) of thermodynamics’ are not simply meant for engineers only. Its greatness goes much beyond [23, 24]. It is said [24] that the four laws of thermodynamics (Zeroth, First, Second and Third) drives the universe, and that not knowing (appreciating) the second-law of thermodynamics is like never having read a work of Shakespeare’! Physicists have great respect for special-relativity and other physical-laws, but in-general ignore the importance of the second-law of thermodynamics.

The first law of thermodynamics tells about equivalence of work and heat, energy-wise, indicating energy-conservation. But the second law of thermodynamics tells about non-equivalence of work-to-heat and heat-to-work conversion-processes indicating irreversibility (asymmetry); this asymmetry in the second-law could be due to not-so-obvious but hidden asymmetry in special-relativity.

The second law of thermodynamics is not simply a law of thermodynamics dealing with engines and refrigerators. It has much more significance at fundamental level especially in Physics as discussed in earlier-papers [2-4]. It is also seen as law of entropy-increase of the system. It also indicates and establish the fact of irreversibility. This thus points towards the thermodynamic arrow of time [25, 26] which differentiates past from future. The asymmetry hidden in it due to the irreversibility seems to be the cause of homo-chirality [27-31] in biological molecules. Thus the key to life and our existence (or anthropic-principle [32]) could be embedded in the second law of thermodynamics. If the second law of thermodynamics is so important fundamentally and that it differentiates between ‘work to heat’ or ‘heat to work’ conversion, it would be right-time to clearly elaborate and re-define heat and work in the right perspective to avoid/remove any misnomer/misconception unfortunately prevailing till
8 Conclusions

Heat and work both are energy, but it is not obvious what the different forms of energies are: work or heat. From the right-perspective of second-law-of-thermodynamics it is concluded that ‘heat is carried by mass-less messenger particles photons, whereas work is carried by mass-ive material particles fermions’. The prevailing misnomer/misconception about heat and heat-transfer is removed. Studies on ‘single photon interaction’ indicates that though in-general heat is a statistical-property but there exists heat property and temperature to single photon too. To reconcile with the present understanding of heat-transfer, a new term ‘therm’ is used for internal-energy, the ‘therm and photon together’ reminds of the old concept of ‘caloric’. Interestingly, the different fields of study ‘thermodynamics’ and ‘relativity’ are seen to be interlinked.

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