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Impossibility of the continuous persistent-current in a superconductor

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Presence of *"persistent"*, *"directional-current"* in a superconducting states is a direct *"threat"* to the 2^{nd} law of thermodynamics. In this paper we will show that there will never be a *directional, (either clockwise, or anti-clockwise) "persistent-current"* for *"infinite-time"* in any superconductor (or in any material at any pressure or temperature), otherwise 2^{nd} law of thermodynamics will break down! We will show that the presence of very small, *non-zero*, finite, electrical resistance below the critical temperature and critical magnetic field in a superconductor is the clear *"signature"* of finite life-time of circulating-current, and thus, direct experimental *"validation"* of 2^{nd} law of thermodynamics at quantum-mechanical level.

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I. INTRODUCTION

Materials can be classified into insulators, semiconductors, conductors and superconductors based on their electrical response to the applied voltage. First time superconductivity has been discovered by Heike Kamerlingh Onnes in 1911, when he was working with solid mercury wire at 4.2K[1,2]. He found that resistivity of solid mercy wire drops $\sim 10^{-5}$ ohm at 4.2K[1,2]. For this discovery, he was awarded the Nobel prize in physics in 1913[1,2]. After that, a number of attempt has been made to realize superconductivity at room temperature. There is general belief in scientific community that, *"once the material reaches into superconducting states, then no further power is required to maintain the electrical current in superconducting material"*. And, thus, one can use superconducting material electrical property and can run in principle any electrical circuit which made from superconducting material without any electrical cost persistently. Many research group[3,4,5,6] claimed that continuation of persist current in experiments breaks essence of the 2^{nd} law of thermodynamics. They claim that 2^{nd} law of thermodynamics require serious modification atleast at quantum mechanical level. In this paper we will resolve this controversy and will show that the 2^{nd} law of thermodynamics still valid in superconducting materials at quantum mechanical level.

II. SUPERCONDUCTING $YBa_2Cu_3O_{7-\delta}$, I-V DATA[7]

Superconducting material transform into a superconducting states at a very precise temperature known as critical temperature, and below very precise magnetic field known as critical magnetic field. There are three type of superconductor namely: type-I, type-II, and type-1.5, depending upon whether material reject/allows the magnetic lines to pass through it, or whether there is any static/moving, attractive/repelling magnetic vortices's[2,8] under the presence of external magnetic field. We will not cover this topic in great details, because, our purpose is not to write another review article on superconductor, but, our main purpose in this paper is to analyze the persistent current which present in superconducting states, and whether this persistent current violates the 2^{nd} law of thermodynamics or not. We will use $YBa_2Cu_3O_{7-\delta}$

superconductor as our test case, without losing any generality. One can use another superconductor for analysis, but, conclusion will remain the *"same"*. If one see (see in Figure 11) $YBa_2Cu_3O_{7-\delta}$ film resistance versus temperature curve at zero external magnetic field, then one notice that there is transition in resistance from 20 ohm to nearly 0 ohm between 92-90K. Key point here is that $YBa_2Cu_3O_{7-\delta}$ film behaves like normal material above 92K, while turns into superconducting states below the 90K with effectively zero resistance. Why we are saying *"effectively- zero-resistance"*, because if one plot the same resistance versus temperature curve on logarithmic plot, then one notice that resistance is not *"exactly"* zero below the 90K. There is *"non-zero"*, finite resistance at any temperature, even at 0-K. The origin of this resistance is due to pure quantum mechanical effect (for more detail, read[9]). It has nothing to do phonon scattering with electrons. However, phonon does contribute in finite resistivity or finite conductivity at any non-zero temperature. The net resistance at any temperature will be the sum of resistance arises due to quantum mechanical effect, resistance due to phonon scattering, and contribution due to other impurity scattering mechanism. The net resistance will never be zero at any temperature or pressure. Only net resistance value can be minimized, but this value will never become *"absolute-zero"*. If one see $YBa_2Cu_3O_{7-\delta}$ film $\mathrm{I-V}$ curve (see in Figure 2), then, one notice that there is finite voltage drop at any current value, below the transition temperature (90K). Finite *"potential-drop"* (see in Figure 2) below the transition temperature at any applied current suggest that there is *"finite-resistance"* during superconducting-state in $YBa_2Cu_3O_{7-\delta}$ films. This resistance is the sum of quantum mechanical resistance plus the resistance arises due to temperature (phonon contribution). Value of this resistance can be minimized but this net value will *"never"* become *" absolute-zero"*. The reason that net resistance will never become absolute-zero at any temperature (even at 0K), because resistance arises due to quantum mechanical effect will always contribute. This quantum part of resistance is immortal at any temperature (for more details, read[9]). Presence of very small, non-zero, finite resistance during superconducting states will guarantee that no current in superconducting material will survive till infinite time. This current will *never* become *"immortal"* in the presence of very small, finite, non-zero resistance. Thus we are concluding that circulating current in superconducting states will *"vanish"* in finite time. Finite time may be one second, one minute, one hour, one day, one year, 100 year, or 10,000 year. 10,000 year is also a finite time. If current persistent long, then there is a great chance and greater certainty that some electronic device can be made based on the superconducting material, which can be used to improve living standard. Existence of very small, non-zero, finite-resistance at any temperature (even at 0-K) below the transition temperature will *"guarantee"* that superconducting-current will *"die"* its own natural death in a finite time, and thus, 2^{nd} law of thermodynamics will *"win"* this battle with full certainty.

The same $YBa_2Cu_3O_{7-\delta}$ superconducting film can be modeled using inductance and resistance elements, whose value will be equal to the superconducting inductance and resistance value (see in Figure 3). Total quantized magnetic flux associated with inductor with inductance L when supper current I flow in it is equal to $L \times I$. Since supper conducting film has very small, non-zero, finite resistance (see in Figure 2), therefore, current in the inductor will decrease as a function of time, following the mathematical relation, $I = I_0 e^{\frac{-Rt}{L}}$, where I_0 is the maximum amplitude of the superconducting current that will exist in superconducting states of the superconductor. As time progress, this superconducting current will start decreasing, and after 5-6 time constant, (time constant $= \frac{L}{R}$), this super-current will decrease very significantly. However, in principle, infinite time will elapse to turn it perfectly *"zero"*. If one see the time constant equation, $\frac{L}{R}$, then one notice that it is inversely proportional to magnitude of the superconducting film resistance. So, if resistance is small (as in superconducting case), then time constant will be large. Still, current will be almost dead within the 5-6 time constant. If one know the total magnetic flux associated with superconductor in superconducting state, then one can get inductance (L) of the film after dividing it by superconducting current(I). In other words $L = \frac{\Phi}{I}$, where Φ is the total magnetic flux associated with superconductor during superconducting states.

Alexey Nikulov and Daniel Sheehan in their editorial paper[10] at page 4, vehemently argued and wrote: *"Circular arguments about impossibility of second law violation abound. For a modern case in point, consider the quantum mesoscopic phenomenon of persistent current, i.e. direct current observed under equilibrium conditions investigated by one of the editorial authors (A.N.). It has been known for over forty years that persistent currents can be observed at non-zero resistance. Based on quantum theory and as corroborated in numerous experiments, a direct current in the equilibrium state can be maintained at non-zero power dissipation [15]. This is a clear threat to the second law, however, when confronted with this persistent current observed at non-zero resistance, the author found that most scientists simply stated that such an equilibrium phenomenon could not threaten the second law since no work can be extracted from the equilibrium state (see Discussion in [16]). Clearly, the defending statement is itself a formulation of the second law, rendering the argument circular".*

The first key argument in above statement is that Alexey Nikulov has measured persistent *direct-current* under equilibrium condition! Question arise that in what direction? Clockwise or anticlockwise? Who provide this unique direction to current in equilibrium condition? Is this not *contradicting* itself that there is a *net* directional process under *equilibrium* condition? How can system has attained equilibrium if directional process is still operating and dragging the system forward? Also, Alexey Nikulov should show his experimental set-up and experimented current data as a function of time to the whole world, because we want to know each and every details about his experiment that whether there is any small, non-zero, finite resistance exist in his $I-V$ data or not. Second key point in their statement is that *persistent current has observed nearly 40 year at non-zero resistance.* Alexey Nikulov and Daniel Sheehan should have provided the clear, unambiguous information about the *amplitude* of the persistent current, that, whether this amplitude has been decreases as a function of time or not! We have absolutely no doubt that amplitude of persistent-current has been decreases. It must decreases and follows the relation $I = I_0 e^{\frac{-Rt}{L}}$, where R is the small, non-zero, finite resistance that exist in superconductor during superconducting state and can be inferred from $I-V$ data at any temperature (see for example figure 2). Also, one can get inductance L of the superconductor once total magnetic flux Φ, and superconducting current I, is known after using the relation, $L = \frac{\Phi}{I}$. Also, one should not surprise at all that current persistent 40 year. It can persist even longer, or even less! Because, how long current will persist is depend on the time constant ($\frac{L}{R}$) of the electrical circuit made from superconductor under superconducting condition. Generally, current does persist till 4-5 time-constant with decreasing amplitude in any L-R circuit (we have discussed it in our previous section).

Alexey Nikulov and Daniel Sheehan further wrote[10] *"Clearly, the defending statement is itself a formulation of the second law, rendering the argument circular. The free energy $F = E - ST$ has minimum value in the equilibrium state and it is impossible to decrease in value below its minimum. But the internal energy E can be decrease without any decrease of the free energy at non- zero temperature $T > 0$ if the entropy S decreases at the same time. As this anecdote shows, in defending the second law, one must be careful not to implicitly assume it, but this is often not as easy at it looks. As recounted by Callender, even luminaries such as Szilard-in his analysis of* *a mechanical Maxwell demon-fell prey to such circular reasoning"*

There are two free energy exist in thermodynamics. One is Gibb's free energy and other is Helmholtz free energy. We guess that they are talking about Gibb's free energy. Take any thermodynamics system, which has total free energy or total maximum available energy for reversible work is equal to $E-ST$. Question is whether $E-ST$ is the maximum amount of *"non-expansion work"* that can be extracted from a thermodynamically closed system, or one can extract even more? Alexey Nikulov and Daniel Sheehan are arguing that they can extract even more than $E-ST$! Let critically analyze this problem. If we take Gibb's free energy $F=E-ST$, then first term corresponds to the total internal energy (H) equal to chemical energy(U) plus pressure-volume energy(PV), whereas second term ST correspond the thermal energy. Lets take an exothermic reaction in which total chemical energy decreases after reaction. Thus E term decreases, because we are dealing *"non-expansion work"*, so no expansion allowed. Now look the second term ST. If process is exothermic, then temperature of the system will increase, which indirectly increase entropy, S. Or, other possibility is that entropy S, increases at the constant temperature T through expansion of the volume, but expansion of volume is not allowed! So, only first scenario can happen. In first scenario first term E decreases, whereas second ST increases. Net $\delta E-\delta(ST)$ term decreases and turns negative, which contradict the essence of *"thermodynamics equilibrium"* that the change in Gibb's free energy at equilibrium must be zero. And thus this process is *"impossible"*. If one analyses the endothermic case, then total change in Gibb's free energy at equilibrium will turn positive, which again contradict the essence of thermodynamic equilibrium that change in Gibb's free energy at thermodynamic equilibrium must be zero. So, endothermic process is also not allowed. So, neither exothermic nor endothermic process is allowed for extracting further reversible work. Let see if process is neither exothermic nor endothermic. If process is neither exothermic nor endothermic, then δE will be zero, and thus change in second term will also be zero, because their is no shuffling of energy can take place. What we can conclude now is that, we don't know on what *"fundamental-ground"*, Alexey Nikulov and Daniel Sheehan have argued to extract further reversible work more than the $E-TS$. Alexey Nikulov and Daniel Sheehan should have explained their unique process through which they will extract maximum amount of non-expansion work more than $E-TS$, without breaking any thermodynamics fundamentals. What seems to author is that if one define F=$E+TS$ instead of F= $E-TS$, only then Alexey Nikulov and Daniel Sheehan thought process can work. But then whole thermodynamics rule and fundamentals will break down!

Both further wrote[10] *"In the second paper The deep physics behind the second law: Information and energy as independent forms of bookkeeping by T. L. Duncan and J. S. Semura discuss the possibility that the foundation of the second law may lie the finite capacity of nature to store information about its own state"*

If one read T.L.Duncan "The deep physics behind the second law" paper, then one notice that T.L.Duncan has not given any clear, unambiguous justification that *"why"* energy and information should be treated independently. He tries to hide his logic under first law of thermodynamics. In nature, both information and energy are perfectly connected. In-fact the flow of information is directly dictated by 2^{nd} law of thermodynamics. Information can only flow if 2^{nd} law of thermodynamics allow it after consulting with the first law of thermodynamics. So, any bit of information can only flow, when both first and second law of thermodynamics agree unequivocally.

Both further wrote[10] "Can order arise from disorder without an external influence? This is one of the deepest questions connecting Nature to the second law."

What we can say here is that this will "never" happen anytime. The day this happen, one can go back in past,

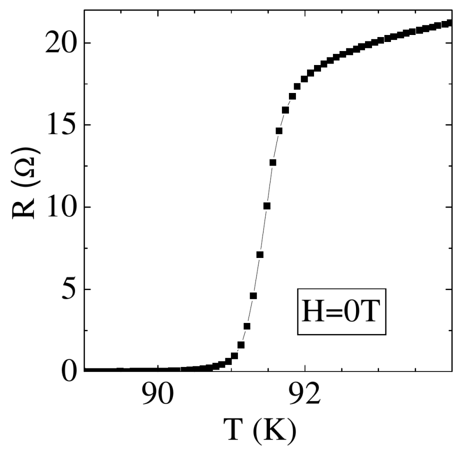

FIG. 1: Resistive transition under zero magnetic field for $YBa_2Cu_3O_{7-\delta}$ film[7].

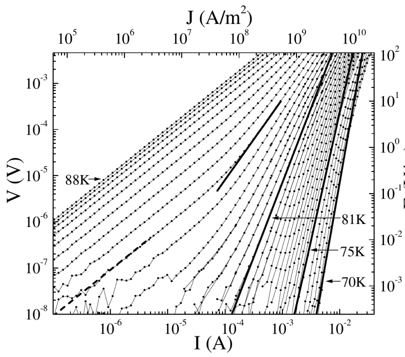

FIG. 2: I-V curves for $YBa_2Cu_3O_{7-\delta}$ film , at constant temperature on log-log plot[7].

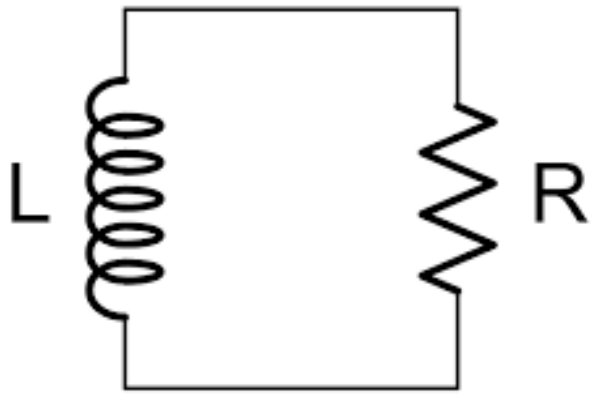

FIG. 3: $YBa_2Cu_3O_{7-\delta}$ superconducting film electrically equivalent to $\mathrm{L}-\mathrm{R}$ (inductance-resistance)circuit .

time can flow back, dead man can alive again, and many more weirdness that any one can think-of! This suggest that breaking of the second law of thermodynamics have very serious implication.

Now, we can quote Arthur Eddington again: *"The second law of thermodynamics holds, I think, the supreme position among the laws of Nature. If someone points out to you that your pet theory of the universe is in disagreement with Maxwell's equations then so much the worse for Maxwell's equations. If it is found to be contradicted by observation, well, these experimentalists do bungle things sometimes. But if your theory is found to be against the second law of thermodynamics I can give you no hope; there is nothing for it but to collapse in deepest humiliation"*[10].

III. CONCLUSION

In this paper we have tried to resolve the conflicting issue between 2^{nd} law of thermodynamics and persistent current during superconducting states in a superconductor. We have shown that the presence of very small, finite, non-zero, electrical resistance below the critical temperature and critical magnetic field is the clear evidence of finite life-time of circulating current in a superconductor. Since, according to laws of thermodynamics, every directional process in nature is irreversible (degree of irreversibility vary from process to process, but no directional process is 0% irreversible, or 100% reversible) and has finite lifetime, therefore, circulating current will not persistent continuously infinite time in a superconductor. We have shown that the presence of very-small, non-zero, finite resistance in superconducting states is the direct evidence of validation of the 2^{nd} law of thermodynamics at quantum mechanical level.

We hope that this paper will clear the controversy surrounding the 2^{nd} law of thermodynamics at quantum mechanical level, and will stimulate the scientific community to explore a new area with certain responsibility toward some very fundamental laws of nature, such as 2^{nd} law of thermodynamics.

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