Quantization of thermal conductance and quantum thermodynamics

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The finnish research group led by Mikko Möttönen working at Aalto University has made several highly interesting contributions to condensed matter physics during last years (see http://www.sciencedaily.com/releases/2015/04/150430141602.htm about condensed matter magnetic monopoles and http://tinyurl.com/jd26rhy about tying quantum knots: both contributions are interesting also from TGD point of view). This morning I read about a new contribution published in Nature [D1] (see http://arxiv.org/pdf/1510.03981v1.pdf). One can find also a popular article telling about the finding (see http://phys.org/news/2016-02-revolutionizes.html).

What has been shown in the recent work is that quantal thermal conductivity is possible for wires of 1 meter when the heat is transferred by photons. This length is by a factor 10^4 longer than in the earlier experiments. The improvement is amazing and the popular article tells that it could mean a revolution in quantum computations since heat spoling the quantum coherence can be carried out very effectively and in controlled manner from the computer (see http://phys.org/news/2016-02-revolutionizes.html). Quantal thermal conductivity means that the transfer of energy along wire takes place without dissipation.

To understand what is involved consider first some basic definitions. Thermal conductivity k is defined by the formula $j = k\nabla T$, where j is the energy current per unit area and T the temperature. In practice it is convenient to use thermal power obtained by integrating the heat current over the transversal area of the wire to get the heat current dQ/dt as analog of electric current I. The thermal conductance g for a wire allowing approximation as 1-D structure is given by conductivity divided by the length of the wire: the power transmitted is $P = g\Delta T$, $g = k/L$.

One can deduce a formula for the conductance at the the limit when the wire is ballistic meaning that no dissipation occurs. For instance, superconducting wire is a good candidate for this kind of channel and is used in the measurement. The conductance at the limit of quantum limited heat conduction (see https://en.wikipedia.org/wiki/Thermal_conductance_quantum) is an integer multiple of conductance quantum $g_0 = k_B^2\pi^2T/3h$: $g = ng_0$. Here the sum is over parallel channels. What is remarkable is quantization and independence on the length of the wire. Once the heat carriers are in wire, the heat is transferred since dissipation is not present.

A completely analogous formula holds true for electric conductance along ballistic wire (see https://en.wikipedia.org/wiki/Conductance_quantum): now g would be integer multiple of $g_0 = \sigma/L = 2e^2/h$. Note that in 2-D system quantum Hall conductance (not conductivity) is integer (more generally some rational) multiple of $\sigma_0 = e^2/h$. The formula in the case of conductance can be "derived" heuristically from Uncertainty Principle $\Delta E\Delta t = h$ plus putting $\Delta E = e\Delta V$ as difference of Coulomb energy and $\Delta t = q/I = qL/\Delta V = e/g_0$.

The essential prerequisite for quantal conduction is that the length of the wire is much shorter than the wavelength assignable to the carrier of heat or of thermal energy: $\lambda \gg L$. It is interesting to find how well this condition is satisfied in the recent case.

The wavelength of the photons involved with the transfer should be much longer than 1 meter. An order of magnitude for the energy of photons involve and thus for the frequency and wavelength can be deduced from the thermal energy of photons in the system. The electron temperatures considered are in the range of 10-100 mK roughly. Kelvin corresponds to 10^{-4} eV (this is more or less all that I learned in thermodynamics course in student days) and eV corresponds to 1.24

microns. This temperature range roughly corresponds to energy range of $10^{-6} - 10^{-5}$ eV. The wave wavelength corresponding to maximal intensity of blackbody radiation is in the range of 2.3-23 centimeters. One can of course ask whether the condition $\lambda \gg L = 1$ m is consistent with this. A specialist would be needed to answer this question. Note that the gap energy .45 meV of superconductor defines energy scale for Josephson radiation generated by super-conductor: this energy would correspond to about 2 mm wavelength much below one 1 meter. This energy does not correspond to the energy scale of thermal photons.

I am of course unable to say anything interesting about the experiment itself but cannot avoid mentioning the hierarchy of Planck constants. If one has $E = h_{eff}f$, $h_{eff} = n \times h$ instead of $E = hf$, the condition $\lambda \gg L$ can be easily satisfied. For superconducting wire this would be true for superconducting magnetic flux tubes in TGD Universe and maybe it could be true also for photons, if they are dark and travel along them. One can even consider the possibility that quantal heat conductivity is possible over much longer wire lengths than 1 m. Showing this to be the case, would provide strong support for the hierarchy of Planck constants.

There are several interesting questions to be pondered in TGD framework. Could one identify classical space-time correlates for the quantization of conductance? Could one understand how classical thermodynamics differs from quantum thermodynamics? What quantum thermodynamics could actually mean? There are several rather obvious ideas.

1. Space-time surfaces are preferred extremals of Kähler action satisfying extremely powerful conditions boiling down to strong form of holography stating that string world sheets and partonic 2-surfaces basically dictate the classical space-time dynamics [K4, **?**, K3]. Fermions are localized to string world sheets from the condition that electromagnetic charge is well-defined for spinor modes (classical W fields must vanish at the support of spinor modes).

   This picture is blurred as one goes to GRT-standard model limit of TGD and space-time sheets are lumped together to form a region of Minkowski space with metric which deviates from Minkowski metric by the sum of the deviations of the induced metrics from Minkowski metric. Also gauge potentials are defined as sums of induced gauge potentials. Classical thermodynamics would naturally correspond to this limit. Obviously the extreme simplicity of single sheeted dynamics is lost.

2. Magnetic flux tubes to which one can assign space-like fermionic strings connecting partonic 2-surfaces are excellent candidates for the space-time correlates of wires and at the fundamental level the 1-dimensionality of wires is exact notion at the level of fermions. The quantization of conductance would be universal phenomenon blurred by the GRT-QFT approximation.

   The conductance for single magnetic flux tube would be the conductance quantum determined by preferred extremal property, by the boundary conditions coded by the electric voltage for electric conduction and by the temperatures for heat conduction. The quantization of conductances could be understood in terms of preferred extremal property. m-multiple of conductance would correspond to m flux tubes defining parallel wires. One should check whether also fractional conductances coming as rational m/n are possible as in the case of fractional quantum Hall effect and assignable to the hierarchy of Planck constants $h_{eff} = n \times h$ as the proportionality of quantum of conductance to $1/h$ suggests.

3. One can go even further and ask whether the notion of temperature could make sense at quantum level. Quantum TGD can be regarded formally as a "complex square root" of thermodynamics. Single particle wave functions in Zero Energy Ontology (ZEO) can be regarded formally as "complex square roots" of thermodynamical partition functions and the analog of thermodynamical ensemble is realized by modulus squared of single particle wave function.

   In particular, p-adic thermodynamics used for mass calculations can be replaced with its "complex square root" and the p-adic temperature associated with mass squared (rather than energy) is quantized and has spectrum $T_p = log(p)/n$ using suitable unit for mass squared [K1].

   Whether also ordinary thermodynamical ensembles have square roots at single particle level (this would mean thermodynamical holography with members of ensemble representing ensemble!) is not clear. I have considered the possibility that cell membrane as generalized Josephson junction is describable using square root of thermodynamics [L1]. In ZEO this would allow to describe as zero energy states transitions in which initial and final states of event corresponding to zero energy state have different temperatures.

Square root of thermodynamics might also allow to make sense about the idea of entropic gravity, which as such is in conflict with experimental facts [K2] .

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