Quantum Thermodynamics

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Density Matri
Formalism

Theorie

Typicalit

ovironment assisted variance

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Conclusion:

Statistical Mechanics from Quantum Thermodynamics

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Need for quantum foundations of statistical mechanics

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- Quantum probability amplitudes are not consistent with the axiom of a priori equal probability(at least not on first sight).
- Absence of unitarity in the evolution of thermodynamic systems.
- Further applications.

Density Matrix

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The definition:

$$\rho = \sum_{j} p_{j} |\psi_{j}\rangle \langle \psi_{j}| \tag{1}$$

Quantum Randomness vs Classical Randomness:

$$\sum p_j = 1 \tag{2}$$

The canonical state:

$$\Omega_S = (1 - p)^k \sum_s \exp\left(-\frac{|s|B}{k_B T}\right) |s\rangle\langle s| \propto \exp\left(-\frac{H_S}{k_B T}\right)$$
(3)

Assumptions

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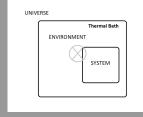
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 ${\sf Restricted\ Subspace\ } R$

$$\mathcal{H}_R \subseteq \mathcal{H}_S \otimes \mathcal{H}_E$$

(4)



Equiprobable:

$$\mathcal{E}_R = \frac{\mathbb{I}_R}{d_R}$$

(5)

State of the system:

$$\Omega_S = \operatorname{Tr}_E \left(\mathcal{E}_R \right) \tag{6}$$

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- We compare with a pure state of the Universe.
- Typicality is a naturally statistical equality of an observable in the two cases (i.e. pure or maximally mixed state of the universe):

$$\rho_S = \text{Tr}_E(|\psi\rangle \langle \psi|) \tag{7}$$

It has been proven that for sufficiently large dimensions of the environment(i.e. possible states):

$$||\rho_S - \Omega_S|| \approx 0 \tag{8}$$

Envariance

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- There are arguments that the symmetry of envariance can produce Born's rule and Thermal States.
- ψ_{SE} is called envariant under a unitary map $U_{\mathcal{S}} = u_S \otimes \mathbb{I}_E$ iff there exists another unitary $U_E = \mathbb{I}_E \otimes u_E$ such that:

$$U_{S} |\psi_{SE}\rangle = (u_{S} \otimes \mathbb{I}_{E}) |\psi_{SE}\rangle = |\eta_{SE}\rangle$$

$$U_{E} |\eta_{S\mathcal{E}}\rangle = (\mathbb{I}_{S} \otimes u_{E}) |\eta_{SE}\rangle = |\psi_{SE}\rangle$$
(9)

Envariance

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To illustrate the above we state a simple example. Let \mathcal{S} and E be two level systems and assume that $|\psi_{SE}\rangle \propto |\uparrow\rangle_S \otimes |\uparrow\rangle_E + |\downarrow\rangle_S \otimes |\downarrow\rangle_E$.

$$|\uparrow\rangle_{\mathcal{S}}\otimes|\uparrow\rangle_{E}+|\downarrow\rangle_{\mathcal{S}}\otimes|\downarrow\rangle_{E}\xrightarrow{U_{\mathcal{S}}}|\downarrow\rangle_{\mathcal{S}}\otimes|\uparrow\rangle_{E}+|\uparrow\rangle_{\mathcal{S}}\otimes|\downarrow\rangle_{E}$$
(10)

$$|\downarrow\rangle_{\mathcal{S}}\otimes|\uparrow\rangle_{E}+|\uparrow\rangle_{\mathcal{S}}\otimes|\downarrow\rangle_{E}\xrightarrow{U_{E}}|\downarrow\rangle_{\mathcal{S}}\otimes|\downarrow\rangle_{E}+|\uparrow\rangle_{\mathcal{S}}\otimes|\uparrow\rangle_{E}$$
 (11)

Conclusions

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- Quantum Thermodynamics promises a lot about the foundations of Statistical Mechanics.
- Information Theoretic Approaches are quite convincing and they obviously have something to do with Statistical Mechanics in general.
- Quantum Entanglement is of a vital importance in the production of Statistical Mechanics Formulas via Hilbert Spaces.

The end

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Thank you!!!!