Transfer of Quantumness to Macroscopic States at Non-Equilibrium Condition

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ABSTRACT— **A quantum demon is a thought experiment in quantum mechanics that describes a hypothetical being that can manipulate individual quantum states, violating the second law of thermodynamics. It is shown how the interaction-free measurement of the observers on a macroscopic thermal field, can make a superposition of cat states even at high-temperature limits. The ability of Alice and Bob to reduce the entropy of the fields without disturbing it directly is surveyed. Then, they can act as quantum demons. Investigation of making cat states under non-equilibrium conditions and the change in the Heisenberg uncertainty relation has been surveyed. Finally, we have also introduced the temperature-dependent Bell's inequality and studied the change in the limit of violation according to the non-equilibrium character of the dynamics.**

KEYWORDS: Displaced Thermal States, Wigner's Function, Macroscopic Quantum Coherence, Non-Equilibrium effects.

I. INTRODUCTION

Explanation of the emergence of classical properties from flabby unstable inhabitants of the quantum world is at the heart of the unsolved dilemmas in the foundation of quantum mechanics. Quantum mechanics itself does not prevent macroscopic objects from being found in a superposition of being here and there simultaneously. The obscured reality was first mentioned by Schrodinger's notorious gedanken experiment known as the cat paradox [1]. There was an everlasting effort from the early days of quantum mechanics to decipher the so-called measurement problem as the main enigma of standard quantum mechanics. Von Neumann cleared the issue by insertion of the collapse postulate that claims reduction of the wave function happens while the microscopic objects interact with measuring apparatus [2]. When you ask standard quantum mechanics about the essence of the collapse of the wave function it likely suggests you to be silent and do calculation! However, various schools have proposed appealing approaches to tackle the problem. Collapse theories, introduce fundamental constants in a non-linear framework [3-6] to overcome the appearance of classical traits from quantum context. Other approaches insist that the effects of gravity oblige the cat to decide to be alive or dead [7-10]. Decoherence tries to extends the limits of applicability of quantum mechanics to macroscopic domain by taking the inevitable interaction of real open quantum systems with their environments [11-15]. Quantumness of the system transfers to myriad degrees of freedom of environment and becomes inaccessible at the level of the system. As a consequence, it effectively, resembles as a classical one. With all of these, hitherto, it is a non- circumvented challenge that what makes a quantum object to behave effectively as a classical system? Is there an explicit Heisenberg cut which defines a distinct separation between quantum and classical sides?

One of the intriguing solutions would be to probe in quantum area for the states that almost behave in a similar way of classical states. They should be effectively localized in phase space and have positive Wigner's function [16,17]. Also, should not be found in superposition. Then, probably, the classical features of quantum systems can be attributed to such states with the most degree of confidence.

It is usually said that coherent thermal states at high temperatures are most prone to be called as classical-like states of quantum mechanics [18, 19]. In comparison, coherent states with large amplitudes lie in the next place since their superposition can be generated and verified experimentally [20–23] and be used for confirmation of non-classical features [24]. At the other side, considering non-equilibrium effects in the interaction of microscopic systems with thermal baths has attracted intensive attention in recent years [25–27]. In our previously work, we have shown that interaction with non-equilibrium baths provides more chance for cat states surviving of decoherence effects [28].

In this work, I try to change the point of view taken so far for taking thermal coherent states as the classical counterpart of quantum states. I show that entanglement between two spin $\frac{1}{2}$ particles and two separated thermal fields at different temperatures can result to generation of superposition of macroscopic cat state being alive even at high temperature limits. It mediates with measurement of the observers on the spins in different directions. Since, their measurements decrease the entropy, they also are able to decrease it at the level of thermal states with such an interaction free measurement. Then, presumably Alice and Bob can act as demons. The role of Quantum demons has been discussed extensively in literature. In [29] by introducing the concept of information into the second law of thermodynamics, an operational thermodynamically notion of information transfer is presented by hiring the action of a Demon. Scully in his seminal book [30] has tried to shed light on the concept and possible realization of a quantum Demon by explaining neat examples. Various types of theoretical Demons and the impact of their interpretation in defining heat and work in quantum mechanics can be found in [31]. Shenker and Hemmo in [32] have advised an idealized setup for realization of a Demon in quantum mechanics with and without collapse postulate.

However, to the best of our knowledge, using them as the generator of superposition of macroscopic quantum states at high temperatures, has not been previously described. I also discuss how the limits of uncertainty relation can be changed when introducing non-classical effects by interaction with a qubit plays a role.

Based on what is presented in [18] by a different Hamiltonian, we propose a Demon role for the observer that enable him to change the entropy of the classical-like states without disturbing it directly and also prepare it in a superposition of cat-like states.

The paper is organized as follows: in Section II, I introduce the model. In Section III, the details of the mathematics are given. In the results Section, I have surveyed how the non-equilibrium nature of the dynamics may affect the uncertainty limit and the quantumness of the quasi-like displaced thermal states. Concluding remarks are summed up in conclusion Section.

II. Mathematics

Here, we examine the possibility of entanglement between two thermal-coherent states out of equilibrium when interacting with a microscopic object. We consider the interaction of two well-separated thermal coherent states in sufficiently high but different temperatures, with a pair of entangled spin $\frac{1}{2}$ particles (See Fig.1).

Each of the spins interacts with its own bath and eventually, its spin component in an arbitrary direction becomes detected in detectors D_1 and D_2. We search for the reduced state of thermal fields after the measurement on spins has been completed.

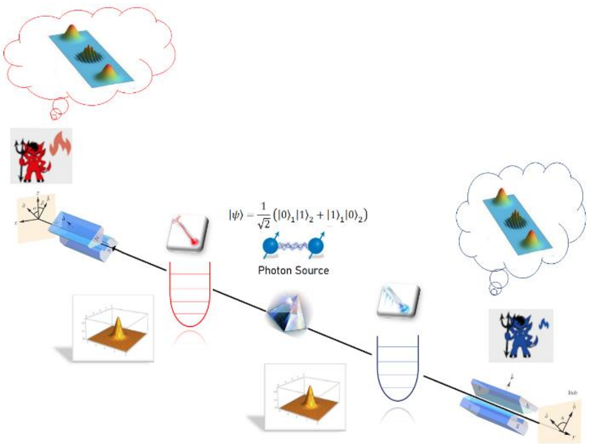

Fig. 1. The observer's measurement on entangled spins generates coherent thermal fields at superposition even at high-temperature conditions. Since Alice and Bon indirectly affect the state of macroscopic fields and can change their entropy, they also can act as quantum Demons.

We assume that the interaction of the spin-thermal field mediated by a Janes-Cummings kind Hamiltonian with large detuning where dispersive interaction between the particle and the thermal field will occur due to the following effective Hamiltonian:

$$\hat{\mathbf{H}}_{eff} = \hbar\chi\left(\hat{\boldsymbol{\sigma}}_+\hat{\boldsymbol{\sigma}}_- + \hat{\mathbf{a}}^\dagger\hat{\mathbf{a}}\hat{\boldsymbol{\sigma}}_z\right) \tag{1}$$

where $\hat{\boldsymbol{\sigma}}_+\left(\hat{\boldsymbol{\sigma}}_-\right)$ and $\hat{\mathbf{a}}^\dagger\left(\mathbf{a}\right)$ are raising and lowering operators of spin and creation and annihilation operators of the thermal field. $\hat{\boldsymbol{\sigma}}_z$ is the z component of Pauli operators. χ stands for the coupling constant. The full Hamiltonian containing related terms of both modes are given as:

$$\hat{H}_{\text{int}} = \hbar\chi_1\left(\hat{\boldsymbol{\sigma}}_+^{(1)}\hat{\boldsymbol{\sigma}}_-^{(1)} + \hat{\mathbf{a}}^{(1)\dagger}\hat{\mathbf{a}}^{(1)}\hat{\boldsymbol{\sigma}}_z^{(1)}\right) + \\ +\hbar\chi_2\left(\hat{\boldsymbol{\sigma}}_+^{(2)}\hat{\boldsymbol{\sigma}}_-^{(2)} + \hat{\mathbf{a}}^{(2)\dagger}\hat{\mathbf{a}}^{(2)}\hat{\boldsymbol{\sigma}}_z^{(2)}\right) \tag{2}$$

Displaced thermal states are prepared in $\boldsymbol{\rho}_{th} = \int d^2\alpha P^{th}\left(V,d\right)\left|\boldsymbol{\alpha}\right\rangle\left\langle\boldsymbol{\alpha}\right|$, where:

$$P^{th}\left(V,d\right) = \frac{2}{\pi\left(V-1\right)}\exp\left(-\frac{2\left|\alpha-d\right|^2}{V-1}\right) \tag{3}$$

where V and d are variance and displacement parameter respectively. Temperature varies with variance by $V = \coth\hbar\omega/2k_BT$ in which k_B, ω, and T are Boltzmann constant, angular frequency of oscillation, and the absolute temperature, respectively. At the middle, a spontaneous parametric down conversion is used to generate a pair of entangled particles in the state $\left|\boldsymbol{\psi}_\mathbf{0}\right\rangle = \frac{1}{\sqrt{2}}\left(\left|\mathbf{1}\right\rangle_1\left|\mathbf{0}\right\rangle_2 + \left|\mathbf{0}\right\rangle_1\left|\mathbf{1}\right\rangle_2\right)$. Then, the initial state of coupled thermal-spin state is given by:

$$\begin{aligned}\boldsymbol{\rho}_0 = \iint d^2\alpha d^2\beta P^{th}\left(V_H,d_H\right)P^{th}\left(V_C,d_C\right) \\ \left|\boldsymbol{\alpha}^{(1)}\right\rangle\left\langle\boldsymbol{\alpha}^{(1)}\right|\otimes\left|\boldsymbol{\beta}^{(2)}\right\rangle\left\langle\boldsymbol{\beta}^{(2)}\right|\otimes \\ \frac{1}{2}\begin{pmatrix}\left|\mathbf{0}^{(1)}\right\rangle\left\langle\mathbf{1}^{(1)}\right|\otimes\left|\mathbf{1}^{(2)}\right\rangle\left\langle\mathbf{0}^{(2)}\right| + \\ \left|\mathbf{1}^{(1)}\right\rangle\left\langle\mathbf{0}^{(1)}\right|\otimes\left|\mathbf{0}^{(2)}\right\rangle\left\langle\mathbf{1}^{(2)}\right| + \\ \left|\mathbf{0}^{(1)}\right\rangle\left\langle\mathbf{0}^{(1)}\right|\otimes\left|\mathbf{1}^{(2)}\right\rangle\left\langle\mathbf{1}^{(2)}\right| + \\ \left|\mathbf{1}^{(1)}\right\rangle\left\langle\mathbf{1}^{(1)}\right|\otimes\left|\mathbf{0}^{(2)}\right\rangle\left\langle\mathbf{0}^{(2)}\right|\end{pmatrix}\end{aligned} \tag{4}$$

Using $\boldsymbol{\rho}\left(t\right) = \hat{\mathbf{U}}_I\left(t\right)\boldsymbol{\rho}_0\hat{\mathbf{U}}^\dagger\left(t\right)$ with the following evolution:

$$\hat{U}_I\left(t\right) = \exp\left[-it\chi_1\left(\hat{\boldsymbol{\sigma}}_+^{(1)}\hat{\boldsymbol{\sigma}}_-^{(1)} + \hat{\mathbf{a}}^{(1)\dagger}\hat{\mathbf{a}}^{(1)}\hat{\boldsymbol{\sigma}}_z^{(1)}\right)\right] \\ \exp\left[-it\chi_2\left(\hat{\boldsymbol{\sigma}}_+^{(2)}\hat{\boldsymbol{\sigma}}_-^{(2)} + \hat{\mathbf{a}}^{(2)\dagger}\hat{\mathbf{a}}^{(2)}\hat{\boldsymbol{\sigma}}_z^{(2)}\right)\right] \tag{5}$$

Final state of the combined system reduces to:

$$\boldsymbol{\rho}(t)=\frac{1}{2}\iint d^2\alpha d^2\beta P^{th}(V_H,d_H)P^{th}(V_C,d_C)$$
$$\left|\boldsymbol{\alpha}\mathbf{e}^{\mathbf{i}\chi_1 t\,(1)}\right\rangle\left\langle\boldsymbol{\alpha}\mathbf{e}^{\mathbf{i}\chi_1 t\,(1)}\right|\otimes\left|\boldsymbol{\beta}\mathbf{e}^{-\mathbf{i}\chi_2 t\,(2)}\right\rangle\left\langle\boldsymbol{\beta}\mathbf{e}^{-\mathbf{i}\chi_2 t\,(2)}\right|$$
$$\otimes\left|\mathbf{0}^{(1)}\right\rangle\left\langle\mathbf{0}^{(1)}\right|\otimes\left|\mathbf{1}^{(2)}\right\rangle\left\langle\mathbf{1}^{(2)}\right|+\left|\boldsymbol{\alpha}\mathbf{e}^{-\mathbf{i}\chi_1 t\,(1)}\right\rangle\left\langle\boldsymbol{\alpha}\mathbf{e}^{-\mathbf{i}\chi_1 t\,(1)}\right|$$
$$\otimes\left|\boldsymbol{\beta}\mathbf{e}^{\mathbf{i}\chi_2 t\,(2)}\right\rangle\left\langle\boldsymbol{\beta}\mathbf{e}^{\mathbf{i}\chi_2 t\,(2)}\right|\otimes\left|\mathbf{1}^{(1)}\right\rangle\left\langle\mathbf{1}^{(1)}\right|\otimes\left|\mathbf{0}^{(2)}\right\rangle\left\langle\mathbf{0}^{(2)}\right|$$
$$+e^{it(\chi_1-\chi_2)}\left|\boldsymbol{\alpha}\mathbf{e}^{\mathbf{i}\chi_1 t\,(1)}\right\rangle\left\langle\boldsymbol{\alpha}\mathbf{e}^{-\mathbf{i}\chi_1 t\,(1)}\right|$$
$$\otimes\left|\boldsymbol{\beta}\mathbf{e}^{-\mathbf{i}\chi_2 t\,(2)}\right\rangle\left\langle\boldsymbol{\beta}\mathbf{e}^{\mathbf{i}\chi_2 t\,(2)}\right|\otimes\left|\mathbf{0}^{(1)}\right\rangle\left\langle\mathbf{1}^{(1)}\right|\otimes\left|\mathbf{1}^{(2)}\right\rangle\left\langle\mathbf{0}^{(2)}\right|$$
$$+h.c \tag{6}$$

where *h.c* stands for hermit conjugate of the last term. To obtain (6) we have used:

$$\exp\left[-it\chi\left(\hat{\boldsymbol{\sigma}}_+\hat{\boldsymbol{\sigma}}_-+\hat{\mathbf{a}}^\dagger\hat{\mathbf{a}}\,\hat{\boldsymbol{\sigma}}_z\right)\right]\left|\mathbf{0}\right\rangle=e^{it\chi\hat{\mathbf{a}}^\dagger\hat{\mathbf{a}}}\left|\mathbf{0}\right\rangle \tag{7}$$

$$\exp\left[-it\chi\left(\hat{\boldsymbol{\sigma}}_+\hat{\boldsymbol{\sigma}}_-+\hat{\mathbf{a}}^\dagger\hat{\mathbf{a}}\,\hat{\boldsymbol{\sigma}}_z\right)\right]\left|\mathbf{1}\right\rangle=e^{-it\chi\left(\hat{\mathbf{a}}^\dagger\hat{\mathbf{a}}+1\right)}\left|\mathbf{1}\right\rangle \tag{8}$$

Confirmation of quantum coherence in thermal fields can be followed according various measures. Negativity of Wigner's function is conventional. Position and momentum distribution of the Wigner's function is given in Fig. 2.

For $\chi_1 t=\chi_2 t=\pi/2$ measurement of spin in x^+ direction on both particles, leaves the thermal fields in:

$$\boldsymbol{\rho}(t)=\frac{1}{8}\iint d^2\alpha d^2\beta P^{th}(V_H,d_H)P^{th}(V_C,d_C)$$
$$\left|i\boldsymbol{\alpha}^{(1)}\right\rangle\left\langle i\boldsymbol{\alpha}^{(1)}\right|\otimes\left|-i\boldsymbol{\beta}^{(2)}\right\rangle\left\langle -i\boldsymbol{\beta}^{(2)}\right|+$$
$$\left|-i\boldsymbol{\alpha}^{(1)}\right\rangle\left\langle -i\boldsymbol{\alpha}^{(1)}\right|\otimes\left|i\boldsymbol{\beta}^{(2)}\right\rangle\left\langle i\boldsymbol{\beta}^{(2)}\right|-$$
$$\left|-i\boldsymbol{\alpha}^{(1)}\right\rangle\left\langle i\boldsymbol{\alpha}^{(1)}\right|\otimes\left|-i\boldsymbol{\beta}^{(2)}\right\rangle\left\langle i\boldsymbol{\beta}^{(2)}\right|-$$
$$\left|i\boldsymbol{\alpha}^{(1)}\right\rangle\left\langle -i\boldsymbol{\alpha}^{(1)}\right|\otimes\left|i\boldsymbol{\beta}^{(2)}\right\rangle\left\langle -i\boldsymbol{\beta}^{(2)}\right| \tag{9}$$

Surveying position-momentum uncertainty confirms that quantum properties can be effectively transferred to the classical-like thermal fields through interaction introduced above. When the spin of the particle 1 and 2 has been measured, the position-momentum uncertainty for the thermal field with lower temperature takes the following form:

$$\begin{pmatrix} V_C\Xi\left(F_1+F_3\right) \\ -2\dfrac{\Xi F_2\left(V_C-4d_C^2\right)e^{-2\left(\frac{d_C^2}{V_C}+\frac{d_H^2}{V_H}\right)}}{V_H V_C^3}\end{pmatrix}^{0.5}\times$$
$$\times\begin{pmatrix}\left(V_C+4d_C^2\right)\left(F_1+F_3\right)\Xi \\ -2d_C^2\Xi^2\left(F_1-F_3\right)^2 \\ -2\dfrac{\Xi F_2 e^{-2\left(\frac{d_C^2}{V_C}+\frac{d_H^2}{V_H}\right)}}{V_H V_C^2}\end{pmatrix}^{0.5}\geq 1 \tag{10}$$

where $\Xi, F_{1,2,3}$ are defined in Appendix B. Since the same inequality holds for a thermal coherent state without interaction with entangled state or the other field at a different temperature, by $V\geq 1$, Eq. (10) provides us with a measure to approximate the extend in which we can transfer quantumness to classical like cat stats with interaction free measurement on spins. Figure 3 demonstrates that how the limits of uncertainty principle can be changed according to the interaction with spins. It also provides us a framework to represent thermodynamically interpretation of uncertainty relations according to the temperature dependency of expectation values.

In Fig. 4 we have discussed how the famous Bell's inequality can be modified when entangled particles meet thermal baths while flew towards the detectors. For a simple form of Bell's inequality as:

$$p\left(a_+;b_+\right)\leq p\left(a_+;c_+\right)+p\left(b_+;c_+\right) \tag{11}$$

where *a*, *b*, and *c* stand for the vectors specify three non-orthogonal co-planer directions the observers agree to make measurement along them and $a(b,c)_\pm$ represents measurement along *a* results in $\pm\hbar/2$.

The new form of inequality when the interaction with thermal coherent states are involved has the following form:

$$\frac{1}{2}\sin^2\frac{\theta_{ab}}{2} \le \frac{1}{2}\sin^2\frac{\theta_{ac}}{2} + \frac{1}{4}\sin^2\frac{\theta_{bc}}{2}\left(1-\frac{e^{-2\left(\frac{d_C^2}{V_C}+\frac{d_H^2}{V_H}\right)}}{V_H V_C}\right) \qquad (12)$$

where θ_{ij} is the angle between corresponding vectors. Considering $\theta_{ab}=2\Theta$, and $\theta_{ac}=\theta_{bc}=\Theta$ (12) transforms to:

$$\sin^2\Theta \le \sin^2\frac{\Theta}{2} + \left(1+0.5\left(1-\frac{e^{-2\left(\frac{d_C^2}{V_C}+\frac{d_H^2}{V_H}\right)}}{V_H V_C}\right)\right) \qquad (13)$$

Which explicitly confirms that interaction with a classical-like states makes region of violation narrower.

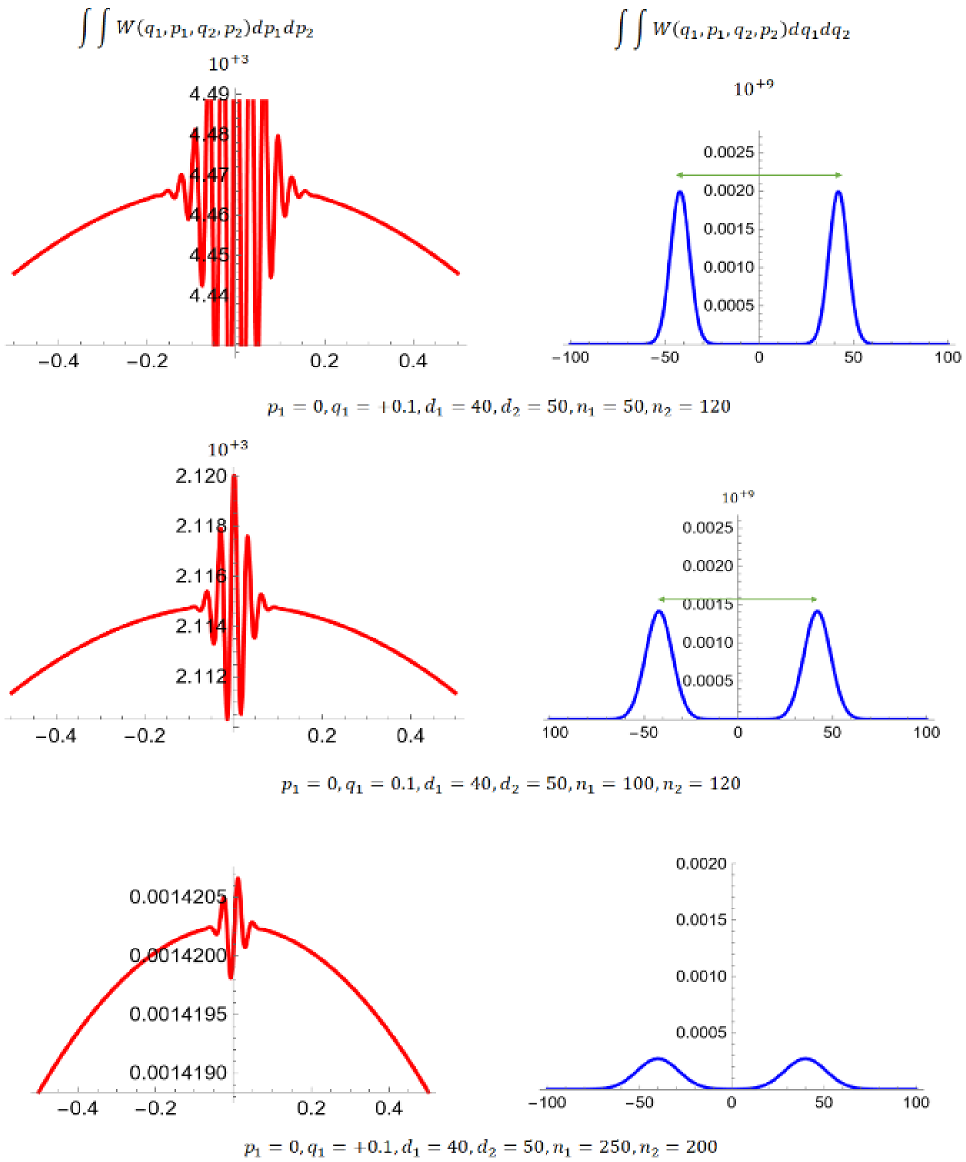

Fig. 2. Momentum (Red) and Position (Blue) distribution of the Wigner function of thermal fields depicted against different *d* and *V* parameters. Quantum coherence can be preserved even at high temperatures limit for the cat states. Increase in difference between temperature of the two fields makes room for perseveres of quantum coherence at non-equilibrium condition.

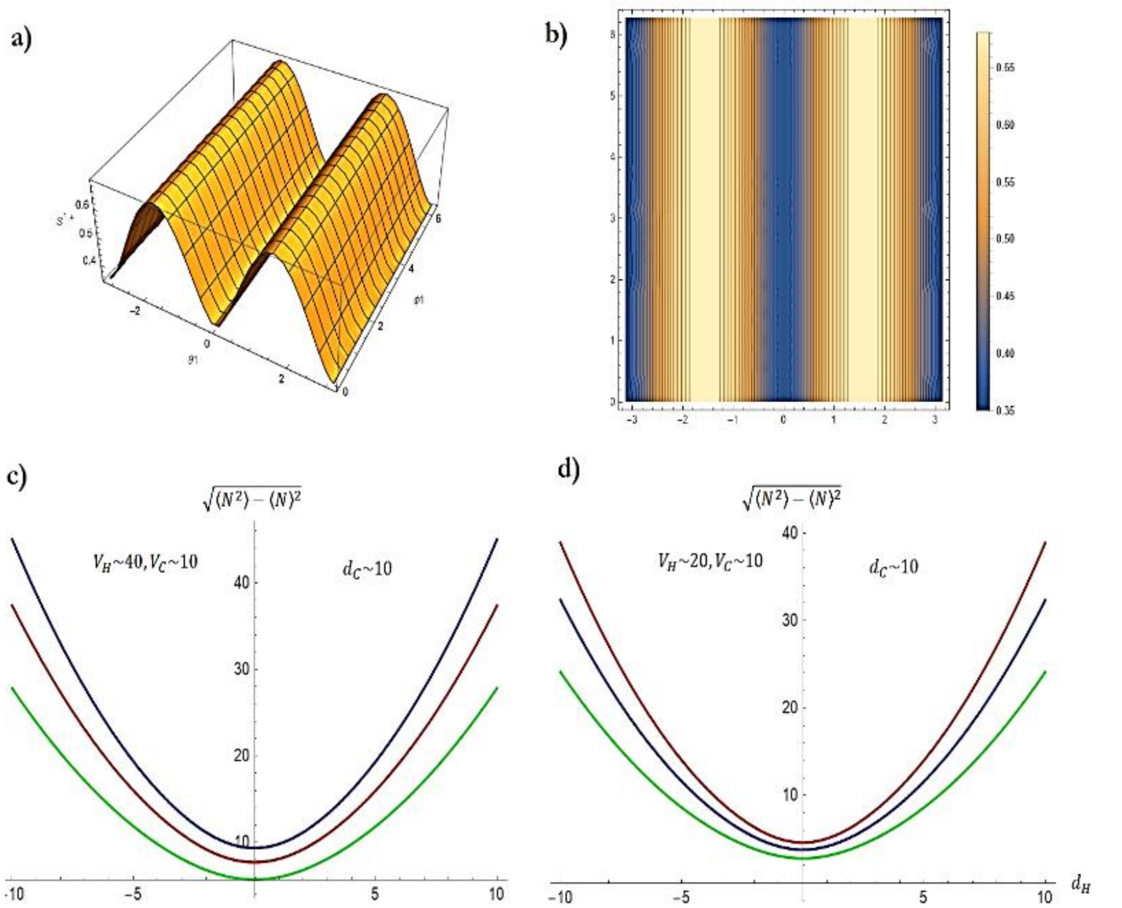

Fig. 3. von Neumann entropy (Up) for $S^{1,-}$ (left) and its contour (Right) is depicted for different angle of spin measurement (θ_1,ϕ_1) (Bottom). Population analysis of coherent field for $V_C/V_H = 4$ (Left) and $V_C/V_H = 2$ (Right) in a fixed value of displacement parameter of the colder field. The action of observers can change the entropy of thermal fields without disturbing them directly.

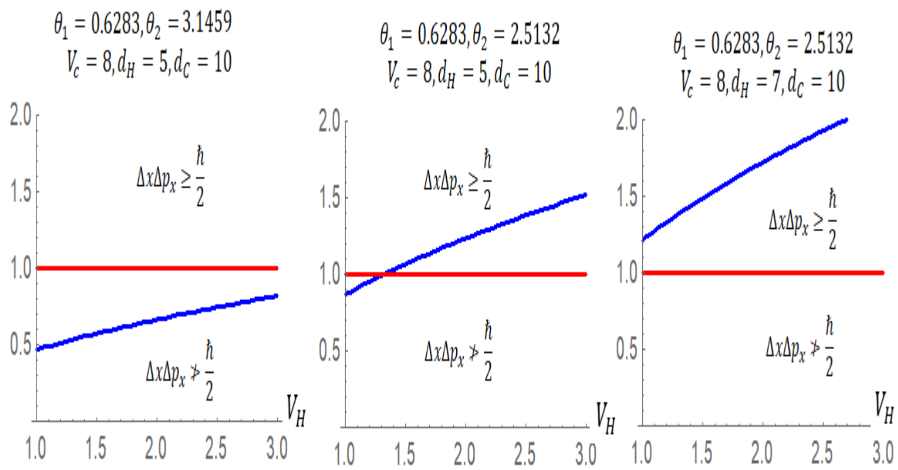

Fig. 4. The left side of uncertainty relation introduced in Eq. 8 (Blue) is depicted against the temperature of the warmer field. The range of *d* and *V* in which violation of Heisenberg inequality becomes augmented can be followed. It is in correspondence with imposing quantum characteristics more and more on a quasi-classical state.

At last, we have surveyed how measurement on spins can change the entropy of the joint thermal state without disturbing them directly. In this way, observer role as quantum Demons that can alter the entropy of the system without disturbing it. Von Neumann's entropy for a mixed state with general form of

$\hat{\boldsymbol{\rho}} = -\sum_k \psi_k |\boldsymbol{\psi}_\mathbf{k}\rangle\langle\boldsymbol{\psi}_\mathbf{k}|$ can be given by $S = -\sum_k \psi_k \ln \psi_k$ where ψ_k is the eigen-value of $\hat{\boldsymbol{\rho}}$. To calculate S for thermal states, we need the reduced density matrix after

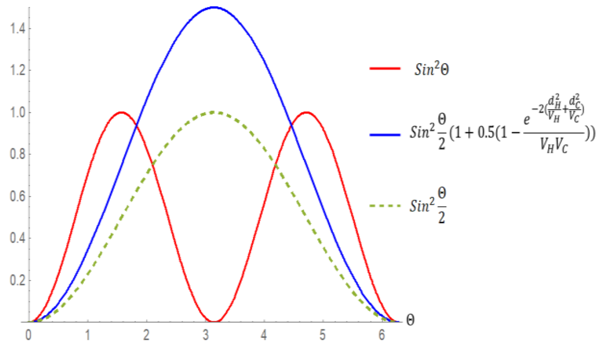

Fig. 5. Testing Bell's inequality for the entangled particles when they interact with thermal fields. Dashed line shows the r.h.s of inequality (11). Interacts with a classical-like system limits the region of violation of Bell's inequality in comparison with conventional form of Bell's inequality represented by blue and red plots.

measurement on spin $1/2$ particles is done. Measurement of spin in arbitrary direction (θ_1, ϕ_1) for particle 1 and (θ_2, ϕ_2) for 2 can be realized with projection operators $|\mathbf{n}^{\pm}\rangle\langle\mathbf{n}^{\pm}|$ with the definitions:

$$|\mathbf{n}^{+}\rangle = \cos\frac{\theta}{2}|\mathbf{0}\rangle + e^{i\phi}\sin\frac{\theta}{2}|\mathbf{1}\rangle$$
$$|\mathbf{n}^{-}\rangle = e^{-i\phi}\sin\frac{\theta}{2}|\mathbf{0}\rangle - \cos\frac{\theta}{2}|\mathbf{1}\rangle \tag{14}$$

Reduced states of thermal fields results by $\langle\mathbf{n}^{\pm(1(2))}|\boldsymbol{\rho}(t)|\mathbf{n}^{\pm(1(2))}\rangle$ for different possible outcomes. Then, von Neumann entropy of thermal states can be obtained according to what is extended in [34]. (See Appendix B).

III. Results

Transfer of quantumness of entangled particles to macroscopic thermal fields can be realized through the quasi-probability distribution in position-momentum space obtained by integration on Wigner function of the joint thermal states is displayed in Fig. 2. As seen, interference pattern survives even at high temperature limit. Comparison between a) and b) plots admits that interference pattern becomes augmented where the difference between T_H and T_C is larger. In other words, when non-equilibrium character of the dynamics becomes more significant. Henceforth, non-equilibrium effects improve the ability of Schrodinger cat to revel of being alive *and* dead simultaneously. However, the temperature difference cannot be raised arbitrary. At sufficiently high temperature, represented in c panel, interference is going to be disappeared and classical-like behavior, expected thermal coherent states, becomes revived.

Figure 3, Up, shows that how the change in entropy of the thermal field is affected by the type of measurement selected by the observers. Since, they directly probe the stat of the entangled spins, reduction in entropy of classical-like fields deserves them to be considered as Maxwell's Demon acting in quantum world. Variation in population, Figs. 3(c-d}, is another symptom of spooky action of demons on the state of classical-like cat state. Again, larger difference in temperatures results in major amounts of change in σ_n^2.

In Fig. 4, the change in the limits of $x-p$ uncertainty relation has been followed for one of the thermal fields when the measurement on the spins has been completed. Larger limits of the l.h.s of inequality (8) corresponds with increase in the quantum properties of the classical-like thermal fields. Comparison between left and the middle shows that for the same V and d parameters the decision of Alice and Bob to perform measurement in their own basis can induce the change in the limit of allegiance of the uncertainty relation. It is novelty of this work where the form of the uncertainty relation depends on the kind of the measurement of the observer in addition of the nature of quantum state. For a thermal coherent field, the position-momentum uncertainty relation reduces to $V \geq 1$ which means that quantum traits attributed to coherent thermal fields according to uncertainty relation at most varies linearly with *V*. Under non-equilibrium condition, measurement on spin by demons, relates the limits of uncertainty in a complicated way to the *V* parameter of both fields. Then, it would be possible to enlarge the region of $x-p$ Heisenberg inequality besides the constant value of *V*. Comparison between the middle panel and the left, also shows that for a same temperature of one field V_C smaller values of the ratio of displacement parameters d_C/d_H results in more values of l.h.s of (12) that accompanies with increase in quantum nature of quasi-classical like coherent thermal fields.

In Fig. 5 the limits of Bell's inequality have surveyed when the entangled particles confront with a classical-like state in their way to the detectors of Alice and Bob. As may expected, interaction with a thermal mode tries to destroy the entanglement between the two particles in comparison with the conventional Bell's type experiment, red plot, in absence of a source of coherent field. Despite that the scheme sketched above can results to preparation of cat states from a classical-like state, the limits of violation of the Bell's inequality becomes narrower.

It should be declared that, when the interaction Hamiltonian of a bipartite system commutes with the free Hamiltonians of each part, as the case in the presented model, it can be verified that the net change in exchanged heat and work on both systems will be zero [35]. Then, reduction in the von Neumann entropy accompanies with no exchange of heat and work between two parts of the system. Accordingly, the role of the observer as a quantum Demon makes more sense in the presented model.

IV. Experimental Feasibility

For making an experimental realization of the problem, one can use a source of entangled electrons [36]. The two mode thermal states can be tackled by using two cavities and atomic state detector [37]. An all-optical scheme with free traveling fields and a cross-Kerr medium equipped with parametric down conversion crystal as a source of entangled photon is another experimental setup proposed for empirical realization of the model [38,39]. The observation of interference fringes can be performed hiring homodyne detection.

It is also worth noting that a quantum demon can be realized in experience as microwave cavity that convert information to work by powering up a propagating microwave pulse by stimulated emission [40].

V. Conclusion

The possibility of observing a macroscopic cat state is hindered in experience according to fragility of such states against interaction with their hot environments. In this work we examined the ability of overcome on this impediment by hiring a non-equilibrium interaction even at high temperature limit. The presented interaction free measurement scheme, is a novel way for producing cat states by the change in the entropy of thermal field. As a consequence, reviving cat states is mediated by the action of a quantum demon. Elaborated works can be done in future by including quantum models of the environments in the framework of decoherence models and master equations as a powerful dynamical map with more details.

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A. *Appendix A: Position-Momentum Uncertainty relation under non-Equilibrium Condition*

For analysis of Heisenberg Uncertainty relations at the level of thermal fields, we trace over the other field where a specific pair of measurement has been accomplished on spins. Then the expectation values can be calculated for examining Heisenberg inequality. Suppose that spin measurements resulted to $+\hbar/2$ for particle 1 and $-\hbar/2$ for particle 2. The reduced state of the thermal field at lower temperature obtains as:

$$\boldsymbol{\rho}_C = Tr_H \left\langle \mathbf{n}_+^{(1)}\mathbf{n}_-^{(2)} \middle| \boldsymbol{\rho}(t) \middle| \mathbf{n}_+^{(1)}\mathbf{n}_-^{(2)} \right\rangle \tag{A.1}$$

where $\boldsymbol{\rho}(t)$ is defined in (5) and Tr_H means trace over the thermal field at higher temperature. For $\chi_1 t = \chi_2 t = \pi/2$ reduced state of the colder thermal field obtains as:

$$\boldsymbol{\rho}_c = \Xi \int d^2\alpha P^{th}(V_C, d_C)\big(F_1 |\mathbf{i\alpha}\rangle\langle \mathbf{i\alpha}|$$
$$-\frac{F_2}{V_H} e^{\frac{-2_H^2}{V_H}} \left(|-\mathbf{i\alpha}\rangle\langle \mathbf{i\alpha}| + |\mathbf{i\alpha}\rangle\langle \mathbf{-i\alpha}|\right) + F_3 |-\mathbf{i\alpha}\rangle\langle -\mathbf{i\alpha}|\big)$$
$$\boldsymbol{\rho}_c = \Xi \int d^2\alpha P^{th}(V_C, d_C)\big(F_1 |\mathbf{i\alpha}\rangle\langle \mathbf{i\alpha}| -$$
$$- F_2 \frac{1}{V_H} e^{\frac{-2_H^2}{V_H}} \left(|-\mathbf{i\alpha}\rangle\langle \mathbf{i\alpha}| + |\mathbf{i\alpha}\rangle\langle \mathbf{-i\alpha}|\right) +$$
$$+ F_3 |-\mathbf{i\alpha}\rangle\langle -\mathbf{i\alpha}|\big) \tag{A.2}$$

with the following definitions:

$$F_1 = \cos^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2}$$
$$F_2 = -\frac{1}{4}\sin 2\theta_1 \sin 2\theta_2$$
$$F_3 = \sin^2\frac{\theta_1}{2}\sin^2\frac{\theta_2}{2} \tag{A.3}$$

Normalization coefficient Ξ results from $Tr\boldsymbol{\rho}_C = 1$ as:

$$\Xi = 2\left(F_1 + F_3 - 2F_2 e^{-2\left(\frac{d_C^2}{V_C} + \frac{d_H^2}{V_H}\right)}\right)^{-1} \tag{A.4}$$

where $\theta_{1,2}$ are the angles Alice and Bob aligning their analyzers. As a consequence, expectation values integrate as:

$$\langle a \rangle = i\Xi d_C (F_1 - F_4)$$
$$\langle a^\dagger \rangle = -i\Xi d_C (F_1 - F_4)$$
$$\langle a^2 \rangle = \Xi d_C^2 \left(\frac{2F_2 e^{-2\left(\frac{d_C^2}{V_C} + \frac{d_H^2}{V_H}\right)}}{V_H V_C^3} - (F_1 + F_4)\right)$$
$$\langle a^{\dagger 2} \rangle = \Xi d_C^2 \left(\frac{2F_2 e^{-2\left(\frac{d_C^2}{V_C} + \frac{d_H^2}{V_H}\right)}}{V_H V_C^3} - (F_1 + F_4)\right)$$
$$\langle a^\dagger a \rangle = \Xi\left(V_C + 2d_C^2 - 1\right)(F_1 + F_4)$$
$$+\Xi \frac{F_2\left(V_C + 2d_C^2 - 1\right)(F_1 + F_4)}{V_H V_C^3} \tag{A.5}$$

Which finally reduces to uncertainty relation given in Eq. (9).

B. *Appendix B: von Neumann Entropy Calculation for Coherent Thermal Fields*

Suppose that measurement on particle 1 is done with θ_1 and ϕ_1, and the result is $+$. Reduced state for remaining parts including thermal states and particle 2, will be $\left\langle \mathbf{n}^{+(1)} \middle| \boldsymbol{\rho}(t) \middle| \mathbf{n}^{+(1)} \right\rangle$ and its explicit form for $\chi_1 t = \chi_2 t = \frac{\pi}{2}$ can be represented by $\begin{pmatrix} A_1 & A_2 \\ A_3 & A_4 \end{pmatrix}$ with following elements:

$$A_1 = \frac{1}{2}\sin^2\frac{\theta_1}{2} \iint d^2\alpha d^2\beta$$
$$P^{th}(V_H, d_H) P^{th}(V_C, d_C)$$
$$|-i\alpha\rangle\langle -i\alpha| \otimes |i\beta\rangle\langle i\beta| \tag{B.1}$$

$$A_2 = \frac{1}{4}\sin\theta_1 \cos\theta_1 e^{-i\phi_1} \iint d^2\alpha d^2\beta$$
$$P^{th}(V_H, d_H) P^{th}(V_C, d_C)$$
$$|i\alpha\rangle\langle -i\alpha| \otimes |-i\beta\rangle\langle i\beta| \tag{B.2}$$

$$A_3 = \frac{1}{4}\sin\theta_1 \cos\theta_1 e^{i\phi_1} \iint d^2\alpha d^2\beta$$
$$P^{th}\left(V_H, d_H\right) P^{th}\left(V_C, d_C\right)$$
$$\left|-i\alpha\right\rangle\left\langle i\alpha\right| \otimes \left|i\beta\right\rangle\left\langle -i\beta\right| \qquad \text{(B.3)}$$

$$A_4 = \frac{1}{2}\cos^2\frac{\theta_1}{2} \iint d^2\alpha d^2\beta$$
$$P^{th}\left(V_H, d_H\right) P^{th}\left(V_C, d_C\right)$$
$$\left|i\alpha\right\rangle\left\langle i\alpha\right| \otimes \left|-i\beta\right\rangle\left\langle -i\beta\right| \qquad \text{(B.4)}$$

Then, the entropy S for the joint state of thermal coherent states can be given as:

$$S^{1,+} = -\lambda_1 \ln\lambda_1 - \lambda_2 \ln\lambda_2$$

where $\lambda_{1,2}$ are the eigen-values of $\begin{pmatrix} B_1 & B_2 \\ B_3 & B_4 \end{pmatrix}$ with:

$$B_1 = \frac{1}{2}\sin^2\frac{\theta_1}{2} \text{ and } B_4 = \frac{1}{2}\cos^2\frac{\theta_1}{2} \qquad \text{(B.5)}$$

And

$$B_2 = B_3^* = \frac{e^{-i\phi_1}\sin 2\theta_1}{8V_C V_H} e^{-\left(\frac{2d_H^2}{V_H}+\frac{2d_C^2}{V_C}\right)} \qquad \text{(B.6)}$$

For measurement on particle 1 and result -, corresponding b_i's coefficients are:

$$B_4 = \frac{1}{2}\sin^2\frac{\theta_1}{2} \text{ and } B_1 = \frac{1}{2}\cos^2\frac{\theta_1}{2} \qquad \text{(B.7)}$$

And b_2 is the same.

For $S^{2,-}$ one has:

$$B_1 = \frac{1}{2}\sin^2\frac{\theta_1}{2} \text{ and } B_4 = \frac{1}{2}\cos^2\frac{\theta_1}{2} \qquad \text{(B.8)}$$

$$B_2 = B_3^* = -\frac{e^{-i\phi_2}\sin 2\theta_2}{8V_C V_H} e^{-2\left(\frac{d_H^2}{V_H}+\frac{d_C^2}{V_C}\right)} \qquad \text{(B.9)}$$

Since entropy is an extensive property for separable thermal states, to obtain the entropy of the joint-thermal states, when for example, the measurement on spin of the particle 1 has resulted to + and 2 to -, the entropy will be $S^{1+,2-} = S^{1+} + S^{2-}$. In the same way, we can construct $S^{1+,2+}$, $S^{1-,2+}$, and $S^{1-,2-}$

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