Fast and accurate control of gates for quantum hypercomputation based on coherent domains of water

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Abstract. Quantum electrodynamics (QED) predicts that, under suitable conditions for temperature and density, liquid water can be described as a two-phases system composed by a coherent and a non-coherent phase. The first one is characterized by the formation of macroscopic regions, called “coherent domains” (CDs), in which all the molecules are phase-correlated among them and with a self-trapped electromagnetic field that leaks out from the CDs in the form of an evanescent tail. This feature, along with the possibility for the CDs to have an excited energy spectrum, allow them to interact each other through quantum tunneling of virtual photons. We have already shown how to exploit this dynamics to realize quantum hypercomputation by using a set of universal quantum gates made of interacting water CDs. In this paper we discuss how to accurately and fast control the macroscopic quantum states of such water coherent domains, by using electromagnetic potentials to modify the phase of their wavefunctions. Finally, a possible experimental set-up designed to this aim, based on the electric version of the Aharonov-Bohm effect, is discussed.

1. Introduction

As known, quantum computation manipulates quantum information represented by quantum bits (qubits) to perform logical operations. Besides the theoretical interest behind the study of quantum computation, one of its most fascinating feature is its alleged “supremacy” with respect classical computation making use of bits and its promises in respect to its technological applications in emerging and strategical fields as, for example, computer science, cryptography and cybersecurity, simulation of very complex physical systems, quantum communication, finance, and so on. So far, many systems and arrangements has been proposed as candidates to realize “physical” qubits, namely the physical implementation of the logical quantum bits of information.

Generically, any quantum two-levels system could be considered to this aim and many proposals has been advanced among which, for example, trapped ions, superconductors, quantum dots, optical cavities, molecular spins and so on [1-4].

Nevertheless, due to the very special features required for a physical system to allow a good implementation of a logical qubit [5], all the quantum computational architectures considered so far are characterized by specific strengths as well as weaknesses [2-4]. Apart from the requirement to ensure the long-term stability of the system against environmental decoherence, one of the
most challenging issues of the actual quantum computing systems concerns the precise and fast setting up of the quantum states involved in computation and their control.

As pointed out by Di Vincenzo [5], the actual realization of any quantum computing scheme must satisfy, in particular, the following requirements:

- the physical realization of well-defined qubits;
- the initialization of the quantum system in a well-defined initial state, such, for example, the qubit \( |0\rangle \);
- the set-up and “programming” of a set of universal quantum gates;

As already shown in previous papers [4,6-12], the coupling between excited states of “coherent domains” (CDs) of water, due to the exchange of virtual photons through tunneling effect, can be exploited to construct a set of universal quantum gates for quantum computation, including, in particular, the three one-qubit T-gate, S-gate and Hadamard gate as well as the two-qubits CNOT gate [4,10].

More specifically, such coupling is due to the interaction between the excited coherent quantum states of water enclosed in tubular structures made of metamaterials (MTMs).

In fact, according to the theory of QED coherence in condensed matter [13], liquid water is a two-phases system, composed by a coherent and a non-coherent fraction of molecules. The former is composed by arrays of CDs, namely quantum macroscopic spatial domains in which all the molecules oscillate in phase with each other and with a self-trapped electromagnetic field at a common frequency \( \omega_{coh} \). On the contrary, the non-coherent phase is made by an ensemble of uncorrelated molecules (vapor phase) filling the interstices between coherent domains.

A fundamental consequence of such coherent dynamics is the emergence of a phase-locking between the matter and e.m. quantum fields so that the phase relationship between them keeps a constant value inside CDs. Moreover, the coherent e.m. field spreads across the CD boundaries in the form of evanescent field whose tail can overlap the analogous evanescent fields produced by the other CDs in the surroundings [4,6-13].

In the case of liquid water, it has been shown [14] the coherent oscillations of matter and e.m. field involve the excited state 5d of the water molecule at 12.06 eV, that is just below the ionization threshold, with a weight of 0.13 so that every water CD is a source of a plasma of quasi-free electrons (i.e. 0.13 electrons per water molecule, meaning about more than \( 10^4 \) quasi-free electrons per CD).

The presence of such plasma of electrons makes it possible for the CDs to have excited coherent states produced by electron coherent “vortices” [14] that can be easily excited by external, even weak, energy source so originating metastable coherent excited states. Due to the coherence, the energy is absorbed by the CD as a whole. Moreover, the coherent vortices, being coherent, are characterized by a very long lifetime (they cannot be excited nor decay thermally) and have a quantized magnetic moment that allows them to align to an external static magnetic field.

The particularly long lifetime of unperturbed excited coherent states is due to the energy gap \( \Delta E < 0 \) that characterizes the energy of the coherent state with respect the non-coherent one. The situation is quite similar to that occurring in the superconductor state in which to break a Cooper’s pair (so reverting the superconductor to a usual conductor) it is needed to supply energy to the system.

The energy of an excited coherent vortex, associated to a single CD, is given by [14]

\[
E_n = \frac{\tilde{L}_n^2}{2K} - g\tilde{L}_n \cdot \tilde{B} \tag{1}
\]

where \( \tilde{L}_n \) is the angular momentum, \( K \) is the momentum of inertia of the CD, \( g = e/2m \) the gyromagnetic ratio and \( \tilde{B} \) the external magnetic field. From equation (1) we see energy
depends on the quantized angular moment and, then, is related to the rotational frequency of the vortices.

The Hamiltonian of a system composed by \( N \) interacting excited CDs can be written, within our model \([4,9,10]\), as:

\[
H = \sum_{i=1}^{N} \varepsilon_i \vert i \rangle \langle i \vert + \sum_{i \neq j}^{N} \Gamma_{ij} \vert i \rangle \langle j \vert
\]  

(2)

where \( \vert i \rangle \) is the excited states of the i-th coherent tubular CD, \( \varepsilon_i \) its relative excitation energy and \( \Gamma_{ij} \) the “strength” of the tunneling interaction between the i-th and j-th CDs. The physical realization of quantum computation algorithms implies to map logical qubits to physical states of the considered quantum system, namely the “physical” qubits, and then to implement a suitable set of quantum gates to perform logical operations.

The possibility to exploit the interacting water CDs to perform practical quantum computation strongly depends on the ability to set and control the physical parameters and the quantum states appearing in the Hamiltonian (1). In particular, in order to use the above model of quantum hypercomputation to realize an actual computer architecture, we need a method to suitable change the quantum state of water CDs able to ensure:

- to “read” the quantum state associated to a given water CD;
- the precise control of the quantum states, namely the possibility to change the state vector describing water coherent domain from an initial state \( \vert \Psi_0 \rangle \) to to a desired new quantum state \( \vert \Psi_1 \rangle \);
- that the above operations will not put the quantum state out of coherence.

In the following we’ll show how to achieve these goals within the same framework of QED quantum coherence in condensed matter by considering the active role of e.m. potentials on the coherent states of liquid water.

2. Quantum coherent states of water as eigenstates of quantum phase operator

One of the most important results emerging from the above outlined framework is that the quantum state describing a water CD is a coherent state characterized by a well-defined value of matter and e.m. field common frequency of oscillation. This fact has a number of very important mathematical and physical consequences as we’ll briefly outline below.

First of all, a coherent domain in condensed matter can be described by a macroscopic wavefunction given by

\[
\Psi (\vec{x},t) = \Psi_0 (\vec{x},t) e^{i\Theta (\vec{x},t)}
\]  

(3)

where \( \Psi_0 (\vec{x},t) \) is the wavefunction amplitude and \( \Theta (\vec{x},t) \) its phase. In the case of water, the phase \( \Theta (\vec{x},t) \) also includes the rotational frequency of coherent vortices so that the wavefunction (3) is considered to give a complete description of the energy spectrum of a CD.

From a mathematical viewpoint, coherent states can be considered as eigenvectors of a suitable quantum phase operator \([14,15]\) which is fundamental for a quantum mechanical description of such states since the information about their physical structure is just contained in the phase.

In \([15]\) a detailed treatment concerning the definition and the properties of quantum phase operator has been carried out. We recall that in quantum optics, a coherent state \( \vert z \rangle \), with \( z = \vert z \vert e^{i\phi} (\phi \in \mathbb{R}) \), of quantized electromagnetic field, also called a “Glauber state”, is an eigenstate of the annihilation operator \( \hat{a} \), namely
\[ \hat{a} |z\rangle = z |z\rangle \quad (4) \]

and can be expanded, in terms of the occupation states \{ |n\rangle \} of Fock space, as \[15\]

\[ |z\rangle = \exp \left( -\frac{1}{2} |z|^2 \right) \sum_{n=0}^{\infty} \frac{z^n}{\sqrt{n!}} |n\rangle \quad (5) \]

whose mathematical properties are well-known.

Such coherent states involve a linear combination of an infinite number of eigenvectors of the number operator \[ \hat{N} = \hat{a}^{\dagger} \hat{a} \] and consequently an infinite number of quanta. As discussed in \[15\], an effective quantum phase operator should act on a coherent state by changing its phase, so we consider the so-called “phase shifting” operator, defined as

\[ \hat{P}(\phi_0) \equiv \exp \left( -i \hat{N} \phi_0 \right) \quad (6) \]

whose effect on a coherent state of the type (5) is just to generate a phase shift \[ \phi_0 \] namely

\[ \hat{P}(\phi_0) |z\rangle = |e^{-i\phi_0} z\rangle \quad (7) \]

The operator \[ \hat{P} \] is a function of \[ \hat{N} \] only, (i.e. the number operator itself generates a phase shift of the quantum state) so the phase is a quantity canonically conjugated to the number of quanta, namely, in the phase representation \[15\]

\[ \hat{N} = -\frac{\partial}{\partial \phi} \quad (8) \]

and we can define a quantum phase operator \[ \hat{\Theta} \], satisfying the commutation relation

\[ [\hat{N}, \hat{\Theta}] = -i \quad (9) \]

that leads to the following uncertainty relation

\[ (\Delta \hat{\Theta}) (\Delta \hat{N}) \geq \frac{1}{2} \quad (10) \]

For a very high number of quanta \( (N \rightarrow \infty) \), as occurs in the coherent states, relation (10) implies the value of phase is always well-defined since \( \Delta \Theta \rightarrow 0 \). This characterizing feature of coherent states demonstrates the consistency of a quantum “phase” operator of which coherent states are eigenvectors and that could be used to define macroscopic quantum state associated to water CDs and to their time-evolution. The latter, in fact, is described by the unitary time-evolution operator

\[ U(\tau) = \exp \left( -i \hat{H} \tau \right) \quad (11) \]

where \( \hat{H} \) is the Hamiltonian operator applied for a time interval \( \tau \). As discussed above, we need to control such Hamiltonian in a precise way in order to act on specific qubits and to implement the desired quantum gates \[4\]. More specifically, within our model of quantum computation, this means to control the physical state of the water CDs and their dynamical evolution that, in turn, implies the ability to set, “measure” and modify the quantum phase \( \Theta(\vec{x}, t) \) in equation (3) through the action of a suitable Hamiltonian. The Schrödinger equation implies the quantum state \( |\psi(t_2)\rangle \) at a given time \( t_2 \) is obtained from the state at a previous time \( t_1 \) through the equation
\[ |\psi(t_2)\rangle = U(t_1, t_2) |\psi(t_2)\rangle \]  

(12)

where \( U(t_1, t_2) \) is the unitary time-evolution operator (11) given by

\[
U(t_1, t_2) \equiv \exp\left[-i\frac{\hat{H}}{\hbar}(t_2 - t_1)\right]
\]

(13)

By comparing equations (13) and (6) we argue [15] the time-evolution operator is formally identical to the phase-shift operator, provided that we assume

\[ \hat{H} = \hbar \omega_0 \hat{N} \]  

(14)

with \( \omega_0 \equiv \phi_0/\tau \) and \( \tau \equiv t_2 - t_1 \) so we can write

\[ \hat{P}(\tau) \equiv \exp\left(-i\frac{\hat{H}}{\hbar}\tau\right) \]  

(15)

and, finally

\[
\exp\left(-i\omega_0 \tau \hat{N}\right) |\phi\rangle = \exp\left(-i\frac{\hat{H}}{\hbar}\tau\right) |\phi(t_0)\rangle = |\phi + \phi_0\rangle = |\phi(t_0 + \tau)\rangle
\]

(16)

Equation (16) clearly means the time evolution of a coherent domain coincides with a change of the value of its overall phase.

This is perfectly consistent with the picture of a water CD as a macroscopic quantum object whose components have lost their individuality and share among each other only their common oscillation frequency \( \omega_{\text{coh}} \). If we assume the Hamiltonian in (15) fully describes the interaction between a CD and its surrounding environment, equation (16) tells us that such interaction results in phase shift due, as we’ll show in the following, to the action of the electromagnetic vector and scalar potentials.

3. The physical meaning of macroscopic quantum coherent state and the role of phase

The coherent states of water so far considered are similar to those defined in quantum optics where they describe, for example, the states associated to coherent e.m. radiation field of a laser beam. More precisely, coherent states have properties similar to those characterizing “classical” coherent light and, in fact, they can be considered as the most closely quantum mechanical approximation of these classical states. Consequently, as laser light can be represented, under certain conditions, as idealized classical coherent light, in the same way, laser light can be quantum-mechanically described by quantum coherent states.

The connection between coherent states and light appears also natural since, as well as different states of light are distinguished by intensity and phase, a coherent state, being defined by a complex number, is determined by its amplitude and phase. Analogously to the case of quantum optics, such coherent states represent the most closely quantum mechanical approximation of classical states in the limit where the number of quanta tends to infinite.

In order to better understand the physical meaning of the macroscopic quantum wavefunction associated to coherent states of water we recall, from the above discussion, that the concept of coherent state has been firstly introduced to correctly get macroscopic radiation waves from quantum electrodynamics, basing on the idea that these macroscopic radiations, whose overall behavior is characterized by classical-like properties expressed in terms of average field values, may be formed by the condensation of a large number of photons.
As we have also seen, these states, being characterized by a well-defined value of quantum phase, are not eigenstates of number operator $\hat{N}$, since they are characterized by large uncertainty in particle numbers. This is just what happens in condensed matter when the conditions for the occurrence of a coherent quantum macroscopic state are verified, namely when a large ensemble of interacting matter and e.m. quanta (considered as elementary quantum oscillators) perform a runaway towards the more stable coherent state leading to the formation of CDs [6,9,13]. These states correspond to the evolution of the system of interacting matter and e.m. field around classical paths, whose stationary solution show a space-structure composed by an array of CDs, macroscopic quantum structures resulting by the condensation of many quanta (belonging to the matter and e.m. fields coherently interacting each other).

It has been shown [13] the true vacuum state of a coherent systems in condensed matter is that in which a very high number of elementary quantum components oscillate in phase (named “coherent ground state” or CGS).

Formally, we consider a state representing a macroscopic quantum field which contains a very high number of quanta with a specific phase, whose vacuum (the CGS in our case) is not the state $|0\rangle$ of the Fock space, defined by $\hat{a}|0\rangle = 0$, but a new vacuum in which many bosons (the quasiparticles composing the system) are condensed.

In this case, if we indicate as $|0(z)\rangle$ the vacuum associated to $\hat{a}$, namely

$$\hat{a}|0\rangle = 0$$

and consider the Bogoliubov transformation

$$\hat{a} \rightarrow \hat{\alpha}(z) + z$$

where $z$ is a c-number, the vacuum state $|0(z)\rangle$ for $\hat{\alpha}(z)$, satisfying

$$\hat{\alpha}(z)|0(z)\rangle = 0$$

is the coherent state of $\hat{a}$ with eigenvalue $-z$ [15] that is

$$\hat{a}|0(z)\rangle = -z|0(z)\rangle$$

and it can be obtained from $|0\rangle$ by the transformation

$$|0(z)\rangle = \exp \left(-\frac{1}{2}|z|^2\right) \exp (-z\hat{a}^\dagger) \exp (-z^*\hat{a}) |0\rangle$$

Equation (21) shows the vacuum state $|0(z)\rangle$ of $\hat{\alpha}$ is a superposition of states characterized by many $\hat{a}$-particles and can be considered as a condensation of them. From the above discussion, we argue the coherent state of matter and e.m. fields, including a very high number of quanta oscillating in phase and giving rise to the CDs arrays in condensed matter, is conceptually analogous to the coherent state $|z\rangle$ above considered, namely the vacuum state with particle condensation. This result further confirms that the quantum state describing coherent domains of water must be an eigenstate of the phase operator $\hat{\Theta}$ since it is characterized by a well-defined common oscillation frequency of matter and e.m. field.

More interestingly, such coherent states resemble, for example, the wavefunctions representing superfluid and superconductor physical systems.

As well as the macroscopic model of superconductivity is based on the hypothesis that there is a macroscopic wave function $\Psi(\vec{r},t)$ which describes the whole ensemble of superconducting electrons, the theory of QED coherence in matter predicts a macroscopic wavefunction associated to the coherent domains which describes the collective coherent behavior of matter (water
molecules in our case) and e.m. field whose quanta can be considered as a condensate of quasiparticles that can be observed at a macroscopic scale.

The assumption of a macroscopic quantum wavefunction describing the whole ensemble of matter-e.m. interacting fields has further consequences, apart from the role played by phase, concerning, first of all, the meaning of $|\Psi(\vec{x}, t)|^2$. For a single particle, this quantity represents the density probability to find the particle at point $\vec{x}$ at time $t$ and give rises to the normalization condition $\int |\Psi|^2 dV = 1$. Analogously, we assume the macroscopic wavefunction $\Psi(\vec{x}, t)$ representing the whole ensemble of coherently interacting matter+e.m. fields quanta, satisfies the normalization condition

$$\int \Psi^*(\vec{x}, t) \Psi(\vec{x}, t) dV = N$$  \hspace{1cm} (22)

$$|\Psi(\vec{x}, t)|^2 = n(\vec{x}, t)$$  \hspace{1cm} (23)

where $N$ is the total number of particle in the ensemble and $n(\vec{x}, t)$ its local density. In particular, when considering the equation (23), there must be a sufficiently large density of quanta in order to make the definition of local density meaningful.

Finally, the consideration of a macroscopic wavefunction describing the whole coherent ensemble (as the water CD in our case) has the advantage to allow the quantum dynamical characterization of the system irrespective of the detailed microscopic underlying dynamics.

4. Fast and precise control of coherent quantum state of water through e.m. potentials

4.1. The e.m. potentials in quantum mechanics

It is known that classical electrodynamics can be expressed either in terms of the “physical” electric and magnetic fields $\vec{E}(\vec{x}, t)$ and $\vec{B}(\vec{x}, t)$ either in terms of electromagnetic potentials $\phi$ and $\vec{A}$, respectively defined as the scalar and vector e.m. potentials being the components of the four-vector $A_\mu = (A_0, \vec{A})$ with $A_0 = \phi$. Differently from classical mechanics, in quantum theory, which is based on the Hamiltonian or Lagrangian formulation, the local electromagnetic fields disappear from the equation of motion leaving the place to scalar and vector potentials.

It is known from the general theory that the equation governing the motion of a particle of charge $q$ and mass $m$ in a region in which there is a e.m. field described by the four-potential $A_\mu$, is the Schrodinger equation:

$$i\hbar \frac{\partial}{\partial t} \Psi = \left[ \frac{1}{2m} \left( -i\hbar \nabla - \frac{q}{c} \vec{A} \right)^2 + q\phi \right] \Psi$$  \hspace{1cm} (24)

where the Hamiltonian of the system is

$$H = \frac{1}{2m} \left( -i\hbar \nabla - \frac{q}{c} \vec{A} \right)^2 + q\phi$$  \hspace{1cm} (25)

The e.m. potentials are defined so that the electric and magnetic fields expressed as

$$\vec{E} = -\frac{\partial \vec{A}}{\partial t} - \vec{\nabla} \phi \quad \vec{B} = \nabla \times \vec{A}$$  \hspace{1cm} (26)

are invariant under gauge transformation of potentials

$$\vec{A} \rightarrow \vec{A}' = \vec{A} + \vec{\nabla} \Lambda \quad \phi \rightarrow \phi' = \phi - \frac{\partial}{\partial t} \Lambda$$  \hspace{1cm} (27)
where $\Lambda$ is some scalar function and the Schrödinger equation (24) assumes the invariant form

$$i\hbar \frac{\partial}{\partial t} \Psi' = \left[ \frac{1}{2m} \left( -i\hbar \vec{\nabla} - \frac{q}{c} \vec{A} \right)^2 + q\phi' \right] \Psi'$$

(28)

provided that the wavefunction transforms as

$$\Psi' (\vec{x}, t) = \Psi (\vec{x}, t) \exp \left[ i \frac{q}{\hbar c} \Lambda (\vec{x}, t) \right]$$

(29)

In particular it can be shown [16] that the solution of the Schrödinger equation (24) can be written, in a covariant form, as

$$\Psi (\vec{x}, t) = \Psi_0 (\vec{x}, t) e^{i \frac{q}{\hbar} \left( \int_{\vec{x}_0}^{\vec{x}} \vec{A} (\vec{x}') d\vec{x}' - \int_{t_0}^{t} \phi (t') dt' \right)}$$

(30)

provided that

$$\frac{\partial \vec{A}}{\partial t} = \vec{\nabla} \phi = 0$$

(31)

where the points $(\vec{x}_0, t_0)$ and $(\vec{x}, t)$ define the path of the particles in the space-time region in which the e.m. field is present and $\Psi_0 (\vec{x}, t)$ is the solution of the (24) when $\phi = \vec{A} = 0$, namely in the absence of e.m. field.

Equation (30) shows that when a charged particle enters in a region in which a e.m. field is present it “accumulates” a phase given by

$$\Delta \Theta = q \frac{\hbar}{\vec{A}} \left( \int_{\vec{x}_0}^{\vec{x}} \vec{A} (\vec{x}') d\vec{x}' - \int_{t_0}^{t} \phi (t') dt' \right)$$

(32)

If we consider a situation in which only the vector potential $\vec{A} (\vec{x})$ or the scalar potential $\phi (t)$ is present, we can respectively write

$$\Delta \Theta_\vec{A} = \frac{q}{\hbar} \int_{\vec{x}_0}^{\vec{x}} \vec{A} (\vec{x}') d\vec{x}'$$

(33)

and

$$\Delta \Theta_\phi = -\frac{q}{\hbar} \int_{t_0}^{t} \phi (t') dt'$$

(34)

From equation (33) we obtain, if $\nabla \times \vec{A} = 0$

$$\nabla \Theta = \frac{q}{\hbar} \vec{A}$$

(35)

and, from equation (34)

$$\frac{d\Theta}{dt} = -\frac{q}{\hbar} \phi$$

(36)
4.2. The role of e.m. potentials in the dynamical evolution of a coherent system

As we have shown, when a charged particle enters a region in which a e.m. field is present it acquires a phase given by equation (32). If \( \Psi \) describes a non-coherent state of a system, then its phase-shift due to the e.m. potentials has no effect on its dynamical evolution and can be even eliminated through a global phase transformation. On the other hand, the presence of potentials (or their modification through the gauge \( \Lambda \)) affects only the phase of wavefunction and not its amplitude that depends by the "physical" fields (the amplitude, in fact, remains unaffected by gauge transformation).

The case is totally different if the wavefunction \( \Psi \) describes a macroscopic coherent quantum system in which the phase plays an essential role.

As we have seen, in the coherent quantum state of water, the wavefunction \( \Psi \) (both of particles and e.m. field) acquires a macroscopic meaning and a wave-like behavior, a situation quite similar to that occurring in laser or in superconductivity where the entire collection of microscopic objects (respectively photons and super-electrons) is described in terms of an electromagnetic field with a well-defined phase.

A simple picture of what happens in this case would be a stationary situation in which \( |\Psi (\vec{x},t)|^2 \) is approximately constant and the Hamiltonian \( H \) of the system can be replaced by the energy \( E \) of the particles. In this case the Schrödinger equation for the wavefunction (3) can be written as

\[
\hbar \frac{\partial \Theta}{\partial t} = -E 
\]  

that confirms the quantum features of the particles reduce to the phase of wavefunction. For a non-coherent system, the particles cannot have the same energy and the time-evolution of the phase of their respective wavefunctions differs for all the particles. This means the values of phase are, in general, uniformly distributed and they don’t contribute to the value of observable macroscopic quantities describing the system as a whole.

On the contrary, in a coherent system, as that composed by the water CDs, all the elementary components of the system are characterized by the same quantum state, just described by the macroscopic wavefunction (3), and by the same energy value caracterizing the CGS [9,13]. As a result, as already discussed above, all the elementary constituents of the system (water molecules and its associated coherent e.m. field in our case) form a phase-locked state in which they are all strongly-correlated. In these circumstances, the phases are not randomly distributed and sum up to a well-defined value affecting the macroscopic variables as described by the macroscopic wavefunction (3).

Another way to see this is to remember that coherent systems are generally characterized by non-linear dynamics (that originates the quantum phase transition to the non-coherent state to CGS) [9,13] in which the Hamiltonian (25) contains self-interaction terms as \( V = V (\Psi) \).

As already recognized [10,14], in such complex systems, the phase acquires an important physical meaning (so ceasing to be a pure mathematical entity as in classical electrodynamics) able to drive its dynamics since the electromagnetic potentials of the different components of the system determine their phase evolution that, in turn, drives the system evolution.

As regards as the microscopic physical mechanism underlying the action of e.m. potentials on the coherent evolution of the system, we remember the water CDs can be considered as an enormous reservoir of quasi-free coherent electrons that are involved in the CD oscillation. This means the e.m. potentials could act on each of them according to the Hamiltonian (25) modifying their frequency of oscillation and, consequently, the overall phase of the CD.

Furthermore, due to the coherence of the excited states of water CD, the coherent quasi-free electrons are not able to dissipate their energy thermally. This is conceptually similar to what happens in a superconductor where we have supercurrents composed by Copper pairs described
by coherent wavefunctions and for which the e.m. potentials are able to modify their quantum behavior at a macroscopic scale.

To be able to modify the macroscopic quantum phase of a coherent state means, within our model, to have the skill to control the quantum state of water CDs which are fully characterized, being macroscopically coherent, by their quantum phases. The precise tuning of this phase would allow us exactly controlling the quantum state of the system and its excited states (each of them is associated to a well-defined rotational frequency of coherent electron vortices), i.e. the physical parameters driving the evanescent tunneling interaction between CDs and then the quantum gates based on them [4,10].

A space-time modification of would determine a substantial change in the physical state and evolution of the water CD so that, more generally, the interaction among two or more CDs or between a CD and the surrounding “environment” can be considered as mediated by the action of the phase shift operator.

Then, by properly manipulate the space-time values of e.m. potentials, it could be possible to “program” and control the quantum gates using water CDs as physical substrate.

In this way we can easily satisfy the requirement needed for quantum computation about the control of states, by setting a correspondence between a given value of phase and the initial quantum state of computation, for example

\[ |\Phi_0\rangle \rightarrow |0\rangle \]  

(38)

and recalling that, since any coherent state corresponds to an eigenstate of quantum phase operator with a well-defined value of phase, we can always state a bijective correspondence between such value and the corresponding quantum state of CD, namely

\[ \Theta_i \rightarrow |\Theta_i\rangle \]  

(39)

Finally, a further very intriguing feature of phase tuning through e.m. potentials is its long-range as well as superfast propagation [6,10,14], since the interaction that determines the change of phase, in this case, is driven by a phase velocity and is able to propagate even faster than light without violating any fundamental principle since it involves only a local supply of energy arising from quantum vacuum fluctuations.

5. A possible experimental set-up to control quantum phase of water CDs

As we have seen, water CDs are macroscopic quantum objects described by the wavefunction (3). In [4,10] we have considered tubular structures whose walls are composed by metamaterials (MTMs) filled by coherent water so that the inner volume of such tubes could be considered as unique tube-shaped CD. We have also shown [4,6,10] how the interaction between such tubular CDs could be used to realize universal quantum gates for attaining a quantum hypercomputation systems, provided that the state of each of these CDs (i.e. their quantum phase) could be controlled with precision.

In the following we’ll discuss a possible conceptual experimental set-up able to achieve the control of quantum phase of water coherent domains. To this aim we’ll exploit the relationship between e.m. potentials and phase of the water CDs and, in particular, the equation (34), to show how to set-up a given phase difference between two water CDs.

The theoretical treatment we’ll based on is in somewhat similar to that considered in the study of the electric Aharonov-Bohm effect (see [17] for a good treatment). In our configuration we assume \( \vec{A} = 0 \) and \( \vec{\nabla} \phi = 0 \) locally and consider two close water CDs (each enclosed in a MTM-made container), placed on either side of a large plane capacitor as shown in figure 1.

A voltage difference \( \Delta V \equiv V \) is induced between the two CDs in the regions in which \( \vec{E} = 0 \). If we indicate with \( V_1(t) \) the potential at the left face of the capacitor and with \( V_2(t) \) the
Figure 1. Two water coherent domains subject to an electric potential difference $V$. Positive potential is on the left, negative potential on the right. A charged capacitor is placed between the two CDs, generating the electric field directed from the left to the right.

Potential at the right face we can write the phase difference between the two CDs, by using the equation (34) on both the sides of the capacitor and taking the difference between the two terms

$$\delta \Theta = \frac{e}{\hbar} \int_{t_1}^{t_2} V(t) \, dt$$  \hspace{1cm} (40)$$

where $V(t) = V_2(t) - V_1(t)$, $\Delta t = t_2 - t_1$ is the time interval during which the potentials are active on both the faces of the capacitor and, in our case, $q = -e$. Equation (40) shows that by suitably adjusting the potential $V$ as well as the time interval $\Delta t$ we could, in principle, obtain a desired phase shift between the wavefunctions of the two water CDs. In this way it could be possible, by considering a “reference” isolated CD (namely whose phase doesn’t change with time), to set the value of phase of any other water CD through equation (40).

As regards as the last point, the phase difference so “stored” in the CDs can be measured by exploiting the Josephson effect that my occur between the two involved CDs. In fact, as we have discussed above, the energy of excited levels of CDs is “stored” in the quasi-free electrons coherent vortices who have an associated quantized angular momentum given (in absence of external magnetic field), through equation (1), by

$$L_n = \frac{K}{\hbar} E_n$$  \hspace{1cm} (41)$$

which creates a quantized magnetic flux $\Phi$ confined inside CDs, namely the necessary condition for the appearance of a supercurrent along the tubular CDs.

In order to obtain an observable supercurrent, a physical connection between the CDs should be realized by using, for example [18], superconducting wires originating from the two CDs connected through an insulating Josephson junction $J$, located far from the capacitor as represented in figure 2.

Measuring such a supercurrent would give an indirect measure of the phase shift $\delta \Theta$ by using the first Josephson equation

$$I = I_c \sin (\delta \Theta)$$  \hspace{1cm} (42)$$

where $I$ is the supercurrent and $I_c$ is the “critical” current that depends on the configuration of the junction $J$ [18].

Despite its conceptual simplicity, this measurement process could produce several systematic effects able to affect the measurements results as, for example, the interference of the electric field of the capacitor on the superconducting wires or the non-vanishing electrical fields produced by the thermal noise inside the metamaterial structures enclosing water CDs.

Furthermore, particular care must be taken in placing water CDs in a region from which the electric field is entirely excluded a condition that could be satisfied, for example, by putting tubular CDs inside suitable Faraday cages.
6. Conclusions and outlook

According to the theory of QED coherence in condensed matter, liquid water could be described as a two-phases systems in which one phase is “coherent” and characterized by the formation of macroscopic regions, called “coherent domains” (CDs), in which all the water molecules are phase - correlated among them and with a self-trapped electromagnetic field.

The CDs admit excited energy states due to the formation of coherent electron vortices that allow them to interact each other through quantum tunneling of virtual photons. We have already shown how to exploit this novel kind of quantum interaction to realize a set of universal quantum gates able to perform quantum hypercomputation, provided we are able to control and “program” the macroscopic quantum state of CDs to realize the required quantum gates and the logical operations.

Such quantum states are characterized by a well-defined value of phase, being eigenstates of quantum phase operator. So, manipulating these phases would allow us to set and control the associated quantum states of water CDs.

In this paper, basing on the physical significance of electromagnetic potential in quantum mechanics, we have discussed how to use e.m. scalar vector to modify the phase of water CDs. A conceptual experimental setup able to perform such phase control is finally discussed.

Despite its theoretical foundation, this scheme needs to be implemented to consider, for example, the design of a suitable method to measure the phase difference between the involved water CDs able to avoid the main issues previously described as well as the possibility to use the e.m. vector potential, apart the scalar potential, to generate the required phase field. All these issues will be carefully analyzed in forthcoming publications.

We think our proposal, although introductory at all, could represent a further strategical step towards the actual realization of quantum hypercomputer system using water molecules as physical and computational substrate.

7. References

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