Quantum inertia stops superposition: Scan Quantum Mechanics

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Abstract. Scan Quantum Mechanics is a novel interpretation of some aspects of quantum mechanics in which the superposition of states is only an approximate effective concept. Quantum systems scan all possible states in the superposition and switch randomly and very rapidly among them. A crucial property that we postulate is quantum inertia, that increases whenever a constituent is added, or the system is perturbed with all kinds of interactions. Once the quantum inertia $I_q$ reaches a critical value $I_{cr}$ for an observable, the switching among its different eigenvalues stops and the corresponding superposition comes to an end, leaving behind a system with a well defined value of that observable. Consequently, increasing the mass, temperature, gravitational strength, etc. of a quantum system increases its quantum inertia until the superposition of states disappears for all the observables and the system transmutes into a classical one. Moreover, the process could be reversible. Entanglement can only occur between quantum systems because an exact synchronization between the switchings of the systems involved must be established in the first place and classical systems do not have any switchings to start with. Future experiments might determine the critical inertia $I_{cr}$ corresponding to different observables, which translates into a critical mass $M_{cr}$ for fixed environmental conditions as well as critical temperatures, critical electric and magnetic fields, etc. In addition, this proposal implies a new radiation mechanism from astrophysical objects with strong gravitational fields, giving rise to non-thermal synchrotron emission, that could contribute to neutron star formation. Superconductivity, superfluidity, Bose-Einstein condensates, and any other physical phenomena at very low temperatures must be reanalyzed in the light of this interpretation, as well as mesoscopic systems in general.

1. Introduction

Since its formulation in the 1920s and 1930s, the foundations of quantum mechanics have provided an endless source of intense and passionate debate and inspiration. The conventional Copenhagen interpretation, widely accepted for practical purposes, leaves however too many questions unanswered. Measurements of the microscopic entities by classical devices are supposed to produce the collapse of the wave functions into one of the possible states. That is, from all possible states in the superposition only one is realized in the measurement process, whereas the others just evaporate, as if macroscopic classical devices have the magical power to collapse wave functions. Moreover, the dividing line between macroscopic classical and...
microscopic quantum objects is completely unknown, even though many experiments have been performed in the last years trying to approach this frontier. These and some other questions have given rise to a plethora of different interpretations of quantum mechanics over the years.

Recently we have presented a novel interpretation of some aspects of quantum mechanics [1]. Our proposal, Scan Quantum Mechanics (SQM), is not radically different from conventional quantum mechanics since we let the mathematical formalism unmodified, as an effective correct description of the quantum systems. However, we put forward a mechanism underlying the superposition of quantum states, and a criterion for deciding the validity of the quantum description versus the classical description of the physical systems. To be precise, we postulate a property of all systems, quantum and classical alike, quantum inertia $I_q$, in such a way that quantum behaviour only manifests itself for values of $I_q$ below some critical ones $I_{cr}$ (one critical value for each observable). As a result, quantum inertia with its critical values marks the dividing line between the quantum and the classical worlds.

In the light of this interpretation, the answers to several long-standing crucial questions and paradoxes are most intuitive. This applies especially to the questions related to: the measurement problem, the superposition of quantum states, the elements of reality, the lack of entanglement between quantum systems and macroscopic objects, and the dividing line between quantum and classical behaviour, as we just mentioned. Other less intuitive but unavoidable features of this interpretation, like in conventional quantum mechanics, are the lack of well defined physical properties for quantum systems, randomness in the output of measurements and nonlocality, not only for quantum correlations but also for positions in space (i.e. quantum jumps instead of classical continuous trajectories).

Nevertheless, SQM can be tested with a number of laboratory experiments and by astrophysical observation, since it implies a new radiation mechanism in strong gravitational fields. This mechanism could contribute to neutron star formation and gives rise to non-thermal emission, especially $\gamma$-ray synchrotron radiation.

In what follows, as the purpose of this presentation is to emphasize the physical concepts of SQM, we will consider only pure states keeping the mathematical formalism to a minimum.

2. Scan Quantum Mechanics

Scan Quantum Mechanics consists basically of an interpretation of the wave function in which the superposition of the quantum states, at any instant, is only an approximate effective concept. The mathematical formalism is the same as in conventional quantum mechanics because there is no need to propose any modifications. For simplicity, let us consider a quantum system with only one observable. To be precise, we assume that the system is in a normalized superposition $\psi = \sum_k c_k |a_k\rangle$ of orthonormal eigenvectors $|a_k\rangle$ of an hermitian operator $A$, with eigenvalues $a_k$, that represents the observable. Then, the measurement is supposed to collapse the initial state, or wave function $\psi$, of the system to a unique well defined state, say $|a_m\rangle$, with the particular value $a_m$ of the observable, the probability of encountering this value being given by the Born rule, i.e. $|c_m|^2$. Our proposal differs from conventional quantum mechanics in essentially two postulates:

1. The quantum systems scan the eigenstates of the observables, described by the wave function $\psi$, and switch among them randomly at very high speed so that, effectively, due to insufficient time resolution, the systems appear to be in a superposition of the different eigenstates $|a_k\rangle$, with eigenvalues $a_k$, at any instant. The relative time the quantum system spends in a particular state $|a_m\rangle$ coincides with the probability $|c_m|^2$ of finding that state during a measurement.
2. The quantum switching depends on a crucial property shared by all physical systems, quantum inertia $I_q$, that increases whenever a constituent is added, or the system is perturbed with all kinds of interactions and energies. If the value of $I_q$ is below the critical one for the observable, $I_q < I_{cr}$, then the quantum switching among the available states is at work and the wave function $\psi$ describes the system exactly as in conventional quantum mechanics. If, on the contrary, the value of $I_q$ reaches the critical one, $I_q \geq I_{cr}$, then the system is unable to switch among the different eigenvalues of the observable, the quantum switching freezes and the superposition of states disappears leaving behind a classical system with a well defined value of the observable. As a consequence, the system’s wave function $\psi$ stops providing the correct description of the system. Thus for SQM the origin of classicality, the dividing line between quantum and classical behaviour, is simply described by the relation $I_q \geq I_{cr}$.

The generalization of postulate 2 for quantum systems with more than one observable, $A, B, C, \ldots$, is straightforward. Obviously, once the quantum inertia $I_q$ reaches the critical values $I_{cr}^A, I_{cr}^B, I_{cr}^C, \ldots$, for all the observables, the quantum superpositions stop and the system becomes classical, with well defined values of all the observables. The situation in between, when $I_q \geq I_{cr}$ for some observables but not for all, leads to hybrid systems where quantum and classical behaviour should co-exist. These hybrid systems should exist, especially at very low temperatures and weak gravitational fields, as it actually happens in mesoscopic systems.

Notice that, as long as $I_q < I_{cr}$ for a system, SQM is indistinguishable from conventional quantum mechanics for all practical purposes although, in principle, it provides a more accurate description of the quantum systems at very small time scales for which we lack experimental resolution. Moreover, since the quantum systems are also evolving unitarily with time, as dictated by the Schrödinger equation, the rôle of time in SQM is twice as prominent as it is in conventional quantum mechanics. This is no obstacle, however, in order to transfer the essential concepts of our proposal to relativistic Quantum Field Theory.

For $I_q \geq I_{cr}$, however, the wave function $\psi$ rather than collapsing goes ‘out of order’, in the sense that it does not provide the correct description of the physical systems once the switching among the quantum states has stopped. In other words, we regard the wave function as only a mathematical description of the system, in agreement with conventional quantum mechanics, in the same way that a parabolic trajectory is a description of the motion of a bullet, without further physical substance.

A different issue is whether Schrödinger’s equation should be modified, by adding a nonlinear term in the Hamiltonian, in order to account for the effect of the quantum inertia on the quantum systems, eventually leading to the end of the superposition of states. For us this is not at all obvious because our impression is that there are two levels of physical reality: the quantum level and the spacetime level, the former being more fundamental than the latter. In our views quantum inertia stays deep inside the quantum level, not showing up in the spacetime dynamics explicitly, and its major (or unique) rôle is to affect the ability of the system to switch among the available quantum states, providing as a consequence a criterion for the validity of the wave function and the applicability of the Schrödinger equation.

The masses of the particles, the interactions among them and many other perturbations and interactions coming from the environment (temperature, gravitation, electric and magnetic fields, collisions,...) all must contribute to the load of quantum inertia of a system $I_q$, apart from their contributions to the system’s Hamiltonian, either to the kinetic or to the potential energy. Consequently, if due to these contributions $I_q$ reaches the critical value $I_{cr}$, then the system stabilizes to only one state, say $|a_m\rangle$ with eigenvalue $a_m$. This state will be observed as a well defined physical state with value $a_m$ by the measuring devices of the classical world.

An important feature of the quantum switching versus quantum inertia is its plausible
reversibility. That is, if the load of quantum inertia $I_q$ of a quantum system is pushed up until or above the critical value $I_{cr}$ but it can be decreased back below $I_{cr}$, by lowering the temperature, the magnetic field, the gravitational strength, or by any other means, then as soon as $I_q < I_{cr}$ the quantum switching resumes activity leading to the apparent superposition of states again, and the wave function $\psi$ comes back to work giving a correct effective description of the system, as a result. For the purpose of visualization, one could regard the quantum available states as located at degenerate minima of a potential, the quantum system oscillating very rapidly among these minima, like a special type of quantum tunneling. The load of quantum inertia $I_q$ raises the barriers among the different states until the switching finally stops, when $I_q \geq I_{cr}$, and the system gets trapped in one of the minima as a consequence. The other way around, lowering the potential barriers below $I_{cr}$, by decreasing $I_q$, will immediately resume the frantic oscillations of the system among the minima of the potential.

One may wonder whether the quantum switching is really random or it follows a specific pattern. However, there is no reason a priori for the quantum switching to follow a specific pattern because the only requirement is that the times spent in the different states must be proportional to their probabilities as given by the corresponding coefficients in $|\psi|^2$. Moreover, a specific pattern for the quantum switching would require the existence of hidden variables that SQM does not need otherwise and that, in addition, could conflict with experimental results, namely with the violation of the Leggett inequalities [2] that discard many interpretations of quantum mechanics that make use of nonlocal hidden variables\(^4\). Consequently, we postulate that the patterns followed by the quantum switchings must be random.

Positions in space and momenta are treated as any other observable. Namely, we propose that quantum systems will be switching among available positions in space, without passing through intermediate points, as long as $I_q < I_{cr}$, where $I_{cr}$ is the critical quantum inertia that stops the quantum jumps. Therefore, as soon as $I_q \geq I_{cr}$, the systems will stop the quantum switching among positions and will follow classical continuous trajectories like a tiny bullets. Quantum jumps are therefore the rule in SQM, and the possibility that they become continuous classical trajectories, whenever $I_q \geq I_{cr}$, opens up a world of new effects that have to be taken into account for the study of many physical phenomena. For example, if this happens to electrons in atoms due to, for example, the action of very strong gravitational fields, then the atoms will look like tiny planetary systems, with the electrons emitting $\gamma$-ray synchrotron radiation while falling into the nuclei. This non-thermal emission from astrophysical objects with strong gravitational fields, like neutron stars or black holes, should also be taken into account as an efficient mechanism for the conversion of atoms into neutrons in neutron stars and in accretion discs of some black holes, producing sudden explosions of gamma rays in all directions (less intense, however, than the ‘canonical’ gamma ray bursts). Since the gravitational strength of white dwarfs is not enough to produce this mechanism, as these stars would turn very quickly into neutron stars otherwise, it provides a lower bound for the critical gravitational strength necessary to ignite this mechanism. That is, $G_{cr} > G_{wd}$, where $G_{wd}$ stands for the gravitational strength of white dwarfs.

The foregoing discussion is most helpful in order to understand what is going on when the position of a particle is given by a superposition of two trajectories, like in interferometry experiments, either by means of a double slit or a beam splitter. The particle then has 50% probability to follow one route or the other. In conventional quantum mechanics, due to particle-wave duality the particle follows both routes, showing its wave-like nature, until it is detected. Then magically the wave-like nature transmutes into a particle-like nature because in the measurement devices nobody sees a wave but just an impact of a particle. In contrast, for SQM the particle is a wave-like corpuscle equipped with some wave-like behaviour, which bears

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\(^4\) We remind the reader that the experimental violation of the Bell inequalities discards only the local hidden variable interpretations of quantum mechanics, i.e. it does not discard the nonlocal ones.
little resemblance with classical corpuscles and even less resemblance with classical waves, and follows the two routes jumping very fast between them, without passing through intermediate positions. If there is a double-slit setting, the particle actually passes through the two slits unless the thickness of the double-slit screen is extremely thin, as the particle will be able to switch many times trajectories while crossing through the slits. If one or two detectors are placed just behind the two slits, in order to determine which slit the particle came across, then obviously the particle will impact on only one of the detectors since it will stop switching trajectories (and often even existing) afterwards.

Due to its relationship with the quantum probabilities, the time spent by the systems in each available state must be quantized in terms of a time unit, that we call *quantum switching time* \( t_S \). To be consistent, \( t_S \) must depend on the quantum inertia \( I_q \). The simplest guess is:

\[
t_S = C \frac{h}{I_q - I_c}, \quad I_q < I_c,
\]

where \( h \) is the Planck constant and \( C \) is just a dimensionless proportionality constant. In this expression the quantum inertia has dimensions of energy or mass, as we set \( c = 1 \). The classical world corresponds to \( I_q \geq I_c \) where \( t_S \to \infty \). Observe that the minimum value of \( t_S \), given by \( t_{S\text{min}} = C \frac{h}{I_c} \) is obtained when the quantum inertia vanishes, unless the latter can reach negative values, \( I_q < 0 \), a possibility that we do not consider. Let us remark that a true superposition corresponds to \( t_S = 0 \), since then the system would be in all the states simultaneously, but this can only occur in the limit \( I_c \to \infty \).

In the spirit of conventional quantum mechanics, it is tempting to propose as well a lower bound relating the indeterminacy on the quantum inertia \( \Delta I_q \) with the corresponding indeterminacy on the switching time \( \Delta t_S \), such as:

\[
\Delta I_q \Delta t_S \geq \frac{h}{4\pi}.
\]

Notice that if different observables have different values of the critical quantum inertia \( I_c \), these result in different values of the quantum switching time \( t_S \). This we find most natural since, for example, switching among positions in space is a very different process than switching among spin states, or photon polarizations.

The relation \( I_c = C \frac{h}{t_{S\text{min}}} \) provides interesting insight into the values of \( I_c \) as function of the minimum switching time \( t_{S\text{min}} \). For example, if we set \( C = 1 \), for \( t_{S\text{min}} \) equal to the Planck time \( t_{Pl} = 5.39 \times 10^{-44} \) s, one gets for the critical quantum inertia \( I_c = 7.67 \times 10^{19} \) GeV = \( 1.367 \times 10^{-7} \) kg. This value is far too large for a critical mass \( M_c \) in order to mark the dividing line between the quantum and classical worlds, and therefore should be discarded.

In Table 1 some other values of \( I_c \) are given as function of \( t_{S\text{min}} \), setting \( C = 1 \). We can compare those values with the masses of molecules currently used in interferometry experiments aiming to find the dividing line with respect to the mass and size [3]. For this it is useful to keep in mind that the proton mass is \( m_p = 0.938272 \) GeV while the value of an atomic mass unit, used in atomic and molecular physics, is: 1 amu = 0.931494 GeV. At present, the largest molecules for which quantum mechanical behaviour has been confirmed are in the mass range of \( 10^{-22} \) kg (\( 10^5 \) amu), whereas the smallest objects known to behave according to classical mechanics have a mass of order \( 10^{-9} \) kg (\( 10^{18} \) amu). As a result, there are 12 orders of magnitude to search for a critical mass \( M_c \), the corresponding values of \( t_{S\text{min}} \) ranging from \( 10^{-41} \) to \( 10^{-30} \) s, as follows from \( t_{S\text{min}} = h/I_c \). This means 12 orders of magnitude to find the dividing line where the center of mass motion of an object obeys quantum mechanics or classical mechanics instead.

Observe also in Table 1 that the values of \( t_{S\text{min}} \) in unambiguous quantum territory, like \( 10^{-27} \) s corresponding to 4407 protons (4439 amu) are orders of magnitude smaller than the smallest
Table 1. Some values of the critical quantum inertia $I_r$, expressed in GeV and kg, as function of the minimum switching time $t_{S\text{min}}$ in seconds, using the relation $I_r = \hbar/t_{S\text{min}}$.

| $t_{S\text{min}}$ (s) | $I_r$ (GeV) | $I_r$ (kg) |
|----------------------|-------------|------------|
| $10^{-42}$           | $4.135 \times 10^{18}$ | $7.37 \times 10^{-9}$ |
| $10^{-40}$           | $4.135 \times 10^{16}$ | $7.37 \times 10^{-11}$ |
| $10^{-38}$           | $4.135 \times 10^{14}$ | $7.37 \times 10^{-13}$ |
| $10^{-36}$           | $4.135 \times 10^{12}$ | $7.37 \times 10^{-15}$ |
| $10^{-34}$           | $4.135 \times 10^{10}$ | $7.37 \times 10^{-17}$ |
| $10^{-32}$           | $4.135 \times 10^{8}$ | $7.37 \times 10^{-19}$ |
| $10^{-31}$           | $4.135 \times 10^{7}$ | $7.37 \times 10^{-20}$ |
| $10^{-29}$           | $4.135 \times 10^{5}$ | $7.37 \times 10^{-22}$ |
| $10^{-27}$           | $4.135 \times 10^{3}$ | $7.37 \times 10^{-24}$ |

lifetime of particle decay. This provides a consistency check for our proposal since values of $t_{S\text{min}}$ larger than the lifetime of particles could lead to conflict.

As regards quantum entanglement, SQM requires exact synchronization between the switchings of the quantum subsystems involved with respect to the quantum time in the Hilbert space. Once one partner stops switching, for example due to a measurement, the switching stops instantly for all the entangled partners, without the need of any signals. The reason is that the resulting quantum system acts as a whole, independently of the physical locations of its parts in spacetime. In other words, the gain of quantum inertia $I_q$ by any of the subsystems adds to the total load of $I_q$ for the complete system. This produces the freezing of the entangled property for all the partners involved, but not forever, for as soon as they could release enough quantum inertia, the partners would resume the switching activity, liberating themselves from the entanglement bound.

A rather cumbersome aspect of quantum entanglement is its supposed proliferation and ubiquity, contrary to our daily experience of the world around, giving rise to very long Von Neumann chains. However, in SQM quantum systems cannot get entangled with classical systems by interacting with them, unless the quantum inertia $I_q$ of the latter is very close to the critical value and, somehow, it can be lowered even more through the contact with the quantum system. Therefore we conclude that in SQM the Von Neumann chains are very short, as generically they only involve quantum systems that were already in superpositions before the interactions took place. For example, the minimal version of the Schrödinger’s cat chain: quantum system $\langle \text{alive} \rangle$ $\rightarrow$ poison bottle $\langle \text{broken} \rangle$ $\rightarrow$ cat, reduces to only the quantum system, and neither the poison bottle nor the cat are in superpositions of any kind, as they are macroscopic classical objects. In other words, neither the bottle is in the superposition of $|\text{broken}\rangle$ and $|\text{unbroken}\rangle$ states, nor the cat is in the superposition of $|\text{alive}\rangle$ and $|\text{dead}\rangle$ states, in agreement with the conventional interpretation of quantum mechanics.

3. Experiments to probe Scan Quantum Mechanics
In [1] we reviewed, in the light of the more intuitive description offered by SQM, the most relevant past and present experiments that have been performed in order to test the conventional quantum mechanics. Apart from the classical interferometry and entanglement experiments, we also considered the behaviour of polarized light passing through a tourmaline crystal, as described by Dirac [4]. This provides another beautiful example where SQM improves our intuition and understanding about what is actually going on in quantum mechanical experiments. Let us say a few words about it.
Tourmaline crystals have the property of letting through only light plane-polarized perpendicular to its optic axis. As a result, if the incident light is polarized perpendicular to the optic axis, it will all go through; if parallel to the axis, none of it will go through; while if polarized at an angle $\alpha$ to the axis, a fraction $\sin^2\alpha$ will go through. The description offered by SQM to the passing of light through a tourmaline crystal differs substantially from the picture held by conventional quantum mechanics. First of all, when a photon passes through a crystal its quantum inertia will necessarily increase, the exact increment depending on a number of factors such as the crystal structure and pattern, crystal chemical composition, temperature, incident angle of the photon and its polarization. Second, if the polarization of the incident photon split into a superposition of two perpendicular polarization states then SQM predicts that the photon will switch very fast and randomly between the two, increasing its quantum inertia $I_q$ in the process, until it eventually reaches a critical value $I_{cr}$. At that instant the switching between polarization states stops and the photon continues its way in a well defined polarization state. If the photon is polarized parallel to the optic axis, then the crystal absorbs the photon and nothing is observed on the back side, whereas if the switching stops when the photon is polarized perpendicular to the optic axis, then the photon reaches the back side of the crystal.

In SQM finding the dividing line between quantum and classical behaviour amounts to finding the values of the critical quantum inertia $I_{cr}$ for all the observables of a system. For this reason in [1] we also proposed some experiments to be performed in order to determine the critical values $I_{cr}$ for some observables, that translate into critical masses $M_{cr}$, critical temperatures $T_{cr}$, critical electric or magnetic fields, etc. The critical values are experimental input in SQM, like the masses of elementary particles in the Standard Model of Particle Physics (no theory has been able to predict them so far). In addition, those experiments can also test the reversibility of the dividing line between the quantum and the classical worlds whenever this is possible: adding or subtracting constituents to the system, increasing or decreasing the temperature, etc.

The contribution of the masses of the constituents to the quantum inertia $I_q$ is very intuitive and is the major reason behind the dividing line between quantum and classical systems, since carefully increasing the number of constituents of a quantum system will eventually lead to its transmutation into a classical one when reaching a critical mass $M_{cr}$. To be more precise, for fixed environmental conditions, adding constituents to a quantum system until $I_q$ reaches the corresponding critical value, $I_q \geq I_{cr}$, results in the cessation of the system’s quantum jumps between the two (or more) trajectories in interferometry experiments: the system has become classical and follows a well defined trajectory. As a consequence, no interference pattern can be created by repeating the experiment with a large number of identical systems, unless one or more of the external conditions change, for example a decrease in temperature. We conclude, therefore, that it should be technically possible to determine (or estimate at least) the critical quantum inertia $I_{cr}$ associated to the mass of physical systems, i.e. a critical mass $M_{cr}$ for given external conditions, by performing interferometry experiments probing large molecules, like nanoparticle interferometry with complex organic molecules and inorganic clusters, as reported in ref. [3], or probing nanocrystals to which the experimentalists could add or subtract atoms one by one.

Apart from the masses of the constituents, according to SQM the many perturbations and interactions coming from the environment must contribute as well to the quantum inertia $I_q$ of the physical systems. Thus one has to consider: temperature, gravitational forces, electric and magnetic fields and collisions with all kinds of matter and radiation. One has to take into account that these perturbations affect different observables in different ways and also that different observables have, in principle, different values for the critical inertia $I_{cr}$.

Once the dividing line had been found between quantum and classical behaviour regarding the mass of the physical systems, for fixed environmental conditions, the next interferometry experiments must be performed using borderline systems near the critical mass $M_{cr}$, varying
slightly one of those conditions.

To start, one has to perform experiments increasing and decreasing the system’s temperature to test its effect on the quantum inertia $I_q$, as well as testing the reversibility of the process, with the possibility of finding a critical temperature $T_{cr}$. A technical complication will always appear: the difficulty to distinguish between the influence of temperature on the quantum inertia and the thermal fluctuations, which also spoil quantum coherence. Although thermal noise is ubiquitous and some decoherence mechanisms might be at work to some extent, SQM offers a complementary explanation in order to understand what is its influence on physical systems. Namely, apart from the thermal noise, above certain critical temperature $T_{cr}$ the quantum inertia $I_q$ of the system surpasses the critical value $I_{cr}$ and, as a result, the system becomes purely classical (with no tunneling possible, for example). Below the critical temperature $T < T_{cr}$ the system recovers its quantum behaviour, such as the tunneling ability. For this reason, we are convinced that all known experimental effects and phenomena that make use of very low temperatures must be reanalyzed in the light of SQM, i.e., taking into account the possibility of a critical temperature $T_{cr}$ corresponding to a critical quantum inertia $I_q$.

Unfortunately we cannot follow the same procedure increasing and decreasing the gravitational strength. Gravitation has been considered already for a long time as a possible cause for the collapse of the wave function or for decoherence [5], [6], [7]. According to SQM, increasing gravitational fields must increase the load of $I_q$ with the corresponding increase in the switching time $t_S$. It is therefore possible that the quantum switching of a system stops altogether provided the gravitational strength reaches a strong enough value. This has very interesting implications for astrophysical objects with strong gravitational fields, providing an efficient mechanism for the capture of electrons by the protons in the nuclei, turning the atoms into neutrons, as we argued before.

The effect of magnetic and electric fields on $I_q$ should also be tested in interferometry experiments using borderline systems, and one can consider also other tests, like the Stern-Gerlach experiment.

As a matter of fact, many experiments have been performed, or proposed, in the last years by a number of groups in order to test the quantum-to-clasical transition [3], [8], [9], [10]. Although these experiments were designed to test decoherence theory or collapse models, they can be applied to test SQM too, i.e., to determine (or estimate) the values of the critical quantum inertia $I_{cr}$, via a critical mass $M_{cr}$ for fixed environmental conditions, or via critical temperatures $T_{cr}$, or critical values of other physical parameters.

To finish, an important observation about the possible effects of quantum inertia $I_q$ on experiments is that in some experimental settings the researchers involved do not plan to destroy the system, usually a particle, in the measurement process, but only to get some information about it, like the trace it leaves in a bubble chamber, for example. Some of these procedures are called weak measurements and the experiments usually involve a weak measurement for the momentum of the particle followed by a normal (strong) measurement for the position of the particle, crashing it against a screen or a detector (see for example [11]). In our opinion, the weak measurements could disrupt a quantum system much more than the experimenters are aware of via $I_q$, for example stopping the quantum jumps among the available positions, so that the system continues its way as a tiny bullet, following a continuous classical trajectory that can be confused with a bohmian trajectory (since this is also a continuous classical trajectory).

4. Conclusions and final remarks

SQM puts forward a mechanism underlying the superposition of quantum states, and postulates a property of all systems, quantum inertia $I_q$, such that quantum behaviour only manifests itself for values of $I_q$ below some critical ones $I_{cr}$. Therefore $I_q$ with its critical values marks the dividing line between the quantum and the classical worlds.
SQM is not radically different from conventional quantum mechanics, but it provides a more accurate description of the quantum systems at very small time scales for which we lack experimental resolution. As a matter of fact, as long as $I_q < I_{cr}$ for all the observables of a physical system, SQM is essentially indistinguishable from conventional quantum mechanics.

One may wonder what causes the quantum switching in SQM, in the first place. In our opinion, the switching among the available states is a natural fact of the quantum world, without the need for any specific cause, neither a quantum potential nor any other forces. It only stops when the quantum inertia $I_q$ reaches a critical value $I_{cr}$. More meaningful in this case is turning the question upside down: What causes the classical systems not to switch among different states? Not to have superpositions and present well defined properties instead? The answer given by SQM is quantum inertia $I_q$ surpassing a critical value $I_{cr}$ for each observable.

Regarding entanglement, observe that in principle it allows us to distinguish SQM from conventional quantum mechanics as SQM predicts the end of the entanglement bounds due to the release of $I_q$. In practice, however, to test this effect might be an impossible task if very long distances (interstellar or larger) were involved.

Let us stress again that mesoscopic systems in general as well as physical phenomena at very low temperatures, such as superconductivity, superfluidity, Bose-Einstein condensates, etc. must be reanalyzed in the light of SQM, i.e. taking into account the possibility of existence of quantum inertia $I_q$ with critical values $I_{cr}$ for the observables, giving rise to critical values for the mass, the temperature, electric and magnetic fields, etc. Similarly, non-thermal radiation by neutron stars and accretion discs of black holes must be reanalyzed taking into account the possibility of the emission of $\gamma$-ray synchrotron radiation, as described by SQM, turning atoms into neutrons.

Finally, it is interesting to notice also that, despite the asymmetry with respect to space and time, the essential ideas of SQM can be transferred straightforwardly to Quantum Field Theory, in which case the probabilities are implemented by switchings and quantum jumps of the particles, the quantum inertia giving rise to natural ultraviolet cutoffs. This brings about a very intriguing possibility: does quantum gravity really exist? For if strong enough gravitation disables quantum mechanics via quantum inertia, then there is no much room left for quantum gravity.

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