The Real Mechanics of Quantum Entanglement

About realism and locality

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Revision 1.0

Can we understand nature on a quantum scale in terms of classical mechanics and explain its specific phenomena through the prism of local realism?

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1. Granular paradigm

In order to understand and explain what happens in the quantum world and to justify all its specific laws and phenomena, a perfectly rational approach would be to go down to smaller dimensional scales until we find the tiniest things, those primordial 'bits' that could make up all quantum structures and that should interact in the simplest way. Following this natural path, a minimal model was designed [1, Ch. 3.2] for the special medium they form, describing its functionality with a set of basic norms: *the granular postulates and laws* [1, Ch. 3.1 and 4]. The quantum universe is now coherently seen as the reflection of a minimal mechanics that works on extremely small (subquantum) scales, where the minimum spatial resolution in nature is reached. The granular level, as this model introduced it, has a series of special properties [1, Ch. 3] given by a *perfect fluid* that permeates all space, filling it completely. This perfect fluid is made up of a practically infinite number of identical components, the infinitesimal *granules*, and thus can be considered *homogeneous* and *isotropic* from a certain scale upward. The granular fluid is the source of all the rules governing the motion, interaction and transformation of quantum objects, as well as the propagation medium for all known fields. As any quantum structure (both particles and fields) is made of spatial granules, some questions immediately arise: 'Does the perfect homogeneity of the spatial fluid change in regions with high concentrations of ordinary matter?' or 'Are its physical parameters remaining the same in those regions?'. The answers were formulated in [2, Ch. 11.4], and they show how the granular medium reconfigures itself [2, Ch. 11.5] in the presence of dense matter (celestial bodies for example) and how one of its important properties - *the local absolute* - changes with the intensity of local granular fluxes. Both dimensional scales, quantum and macroscopic, are implicitly affected by the fluctuations and unevenness of these gravitational granular fluxes [2, Ch. 2.4.1]; thus, these changes generate an intermediate level of granularity within the local spatial fluid. Placed between the granular and quantum dimensions, this supra-granular level will actually determine all the particularities of the mechanics in that region.

The granular fluid ensures the continuous transfer of mechanical momentum (both through its fluxes and through the propagated fields) to all quantum objects, ensuring their full stability over time. Due to this continuous transfer of elementary impulse, all compact quantum objects acquire a permanent intrinsic rotational motion (in addition to their translational one [1, Ch. 6.1]); viewed on the quantum scale, these motions determine a special behavior for all quantum particles (both elementary and composite), namely *the wave-particle duality*. Once we have established these major features of the quantum world, the difficult problems of how we can interact with it, how we can observe it and finally measure its strange characteristics immediately arise. At the principle level, all physicists agree that probing and measuring the microscopic universe can be done using quantum objects and field-based systems, even if they are embedded in macroscopic devices and apparatuses. Consequently, beyond the technical aspects, two types of limitations arise along with this approach:

1. If we take into account the non-zero dimensions of all particles and their intrinsic undulatory motions, we can estimate a limited accuracy for the results of some position measurements. Moreover, if we narrow the position of a particle down, the uncertainty of a paired quantity – its momentum – will increase in the same ratio. This balance of *uncertainty* that exists for certain pairs of physical properties (Heisenberg's Uncertainty Principle) is a direct consequence of the wave-corpuscle duality in the quantum domain and ultimately determines a type of limitation in our knowledge for these phenomena.
2. Any measurement we would perform, even if its outcome is probabilistic, it requires an *interaction* with the quantum objects or systems being measured. The result will be an accurate reflection of the state those quantum objects had before the measurement started, but that state will be disturbed, it will change after this event.
   Remark. The duality of particles is a permanent feature; however, the exact type of property chosen for measurement - and implicitly the concrete configuration of the measuring device - will determine which side of this duality will be revealed after the interaction.

As long as the origin of the intrinsic motions of particles is at the granular level, the internal and external rotational speeds can have luminal or superluminal values – but they all remain below the maximum limit *C*. Any type of measurement, that is, any interaction with such a particle takes a certain amount of time; for example, the energy exchange carried out in some measurements cannot be instantaneous. Even in the case of quantized physical quantities, the results of any measurement can only be temporal averaged values; as the respective parameters have continuously varied, their instantaneous values are integrated until the interaction ends. Let's consider as an example the particle spin, the intrinsic angular momentum for which the granular paradigm [1, Ch. 3] assumes a *real* rotational motion, specific to the respective type of quantum structure. We are not able to find out what the particle's *current position* or *instantaneous orientation* is on its own orbit; however, if the particle has an electric charge, a certain type of interaction can tell us the direction of angular velocity, a global parameter of its intrinsic rotational motion. If an additional precession overlaps the particle's proper motion, it would not increase the spin uncertainty due to the temporal averaging we have already talked about. The permanent transfer of granular mechanical momentum establishes all the fundamental physical constants at the quantum level [2, Ch. 9]; this is why the quantum objects have some *strange properties*, and this is why some physical quantities are *quantized* in this microuniverse. A new question can now be asked, namely whether we could have better knowledge about the quantum realm by remodeling certain parameters, removing their probabilistic features and integrating them into pseudo-deterministic constructions; these new parameters should allow a different interpretation, maybe based on realism, of several experimental results we gathered.

2. The 'averaged spin' model

Seen at the granular level, an elementary particle can have, in addition to its own rotational motion, a secondary precession; this is caused by the surrounding fields or quantum noise [1, Ch. 6] and possesses an angular momentum (similar to the orbital one). Given this dual mechanical motion, of the *classical* type, can we formulate a simplified model for spin that goes beyond the wavy aspect of quantum objects and gets closer to an intrinsic characteristic reflected in their interactions? Meaning, once we *integrate* the primary and secondary precessions into a classical spin parameter, couldn't we add predictability to the motion of the particles and eventually bring realism and locality [11] to the quantum universe? And couldn't we incorporate some hidden variables into the average value of such properties, and thus come to a better interpretation and understanding of quantum phenomena? Moreover, couldn't we move the description of quantum states from *superposition* to *distribution,* from discrete to continuous, so the collapse of the wave function after interactions would no longer be the choice of a certain quantum state, but the revelation of a *threshold* exceeded by a certain average value?

To this end, a simpler model was designed for spin: $\tilde{\mathbf{s}}$, *the averaged spin*, i.e. a classic spin whose direction would be observed and averaged over a certain period of time. Both the actual attributes of granular motion and its specific quantization were taken into account. Two particular cases will be analyzed now: the rotation of a fermion – *the electron* – and a boson – *the photon*, and the entanglement of these particles will be explained from a mechanistic, granular perspective.

3. Entanglement of electrons

3.1. Electron spin

This type of discoidal particle [1] actually performs an orbital rotational motion, as in Figure 1a, apart from that around its own axis ($\overline{\omega}$). Two full rotations (720°) are required for the electron to come back to its initial orientation, hence the half-integer spin, or $\hbar/2$, assigned by the QM. Spatial symmetry makes it possible for that small orbital motion to be described by the angular momentum of a *single* rotation, by vector $\overline{s}$. We can simply observe that the projection of spin on the direction of momentum $\overline{p}$ (the so-called helicity) can only have two directions – as the particle can rotate only *clockwise* or *counterclockwise* about its moving direction. Therefore it makes perfect sense to quantize the projections of this vector on the axes of a frame of reference, +1/2 and -1/2 respectively. But the instantaneous spin vector, which is perpendicular to the plane of rotation, has a variable direction in time; given its *constant* magnitude, its tip can be anywhere on the surface of a sphere whose center is located on the axial trajectory. The orbital plane changes in orientation during the revolution of the particle, being traveled either clockwise or counterclockwise; even if a secondary precessional motion (wobble) exists, the global rotation does not change its direction. If we associate this complex rotation (a double spiral as a trajectory) with the instantaneous spin vector, the spatial region it can be located in would be *at most a hemisphere*. This is the exact reason we introduced a spin averaged over several primary revolutions, the spin denoted by $\tilde{\mathbf{s}}$. Over that period, the average direction of this spin will thus have a constant orientation, which does not depend on the concrete rotation of the particle (this is quite similar to the motion of a spinning top that starts precessing when external forces are applied). Therefore, the averaged spin of electrons:

- has an orientation given by averaging the *hemispherical spatial distribution* of the instantaneous angular momentum vectors (they are inside a solid angle subtended by the hemisphere at its center of value $\Omega = 2\pi$ sr)

- its origin is the center of a sphere of radius $r = s$ and its tip is on the surface

- has a magnitude of constant value, $s = +1/2$, dimensionless

- has continuous projections on the axes of a reference frame

Remark 1. Due to the particle's intrinsic rotation and its additional oscillations, the parameters that characterize its motion have variable instantaneous values; for an interaction, however, only their average value matters - and this actually validates this spin model.

Remark 2. The electron can be viewed from 'above', ignoring its intrinsic motions and attributing physical properties to a so-called point-like entity - as QM does. Anyway, it is still necessary to establish the source of these properties and use appropriate descriptions for them, so that the quantum world starts to make sense and we can approach it in a uniform way.

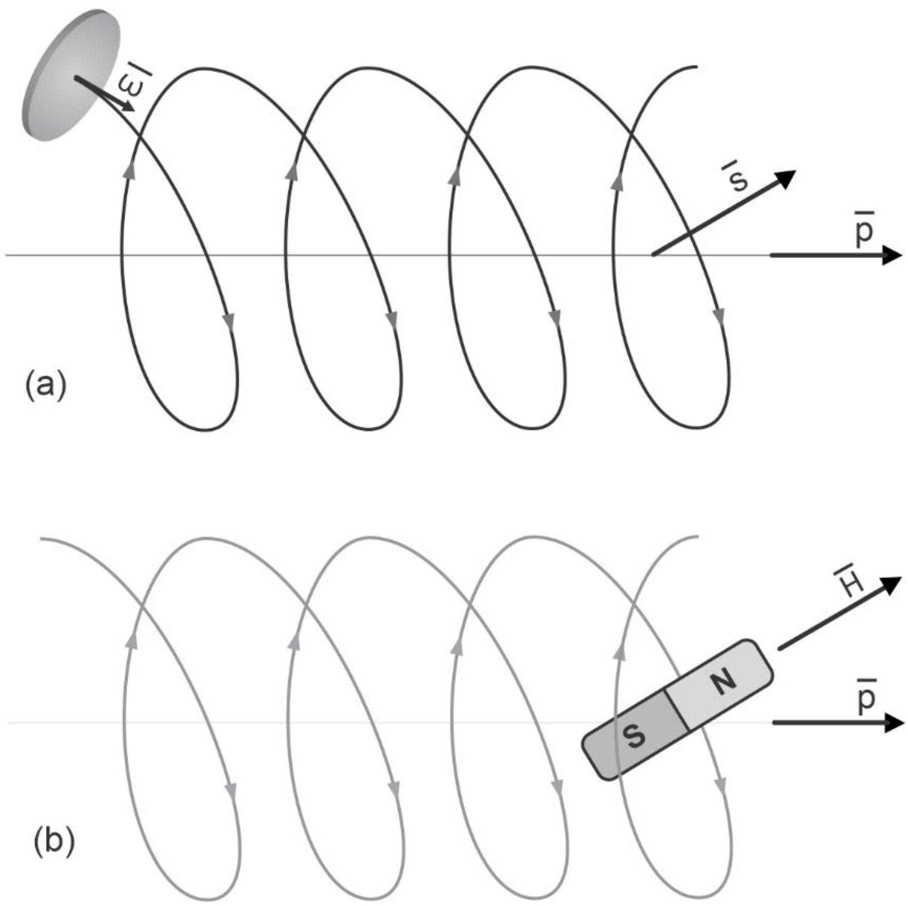

Figure 1

3.2. Entangled electrons

The granular interpretation for electric charge [1, Ch. 6.3] allows us to state that the intrinsic magnetic moment of an electron is caused by its intrinsic rotation – a phenomenon similar to the magnetic field generated by the electric current passing through a coil (the electrophotons emitted from distinct orbital positions have influence on other charged particles, by bending their trajectory in the same way as the whole particle in relative motion does). As we can have only two possible directions of rotation with respect to the overall direction of travel, the magnetic moment can also have only two discrete values (Figure 1b). This magnetic field varies during rotations, but it has a time-averaged direction almost identical to the averaged spin described above (there is a coupling between them). This is the reason why we can 'measure' the electron's spin direction by placing it in an inhomogeneous magnetic field, as in the Stern-Gerlach experiment [6]. This simple experiment only proves that the angular momentum of electrons is *quantized*; the interaction between the charged particles and an inhomogeneous magnetic field over a given spatial direction is not a real spin measurement, it is a process that tells us that their spin exists and its magnitude is discrete, having only one of two possible values (*up* and *down* for example) in any direction we choose. Spin, although it has a well-defined direction at any time, cannot be measured in this way on any of the axes of a reference frame.

Considering all these things above and keeping our analysis within the granular perspective, we can summarize the most important aspects that result from the intrinsic properties of electrons:

- Electrons have their own magnetic moment, with two discrete values, whose time-averaged orientation is fixed.
- Their mechanical spin has the same direction as the magnetic moment, and thus it can be somehow 'identified' by SG measurements.
- Once measured in one direction, the particle's spin has *changed*
- Spin 1/2 means that a 720-degree rotation is required to bring the electron back to its original orientation.

What exactly happens while we measure the spin in this experiment? It should be noted that the interaction between electrons and magnetic fields differs from the macroscopic, classical equivalent to which we may surely compare to now.

If we place a small bar magnet in a strong magnetic field, it will align in the direction of the field lines - like a compass needle orienting itself in the Earth's magnetic field.

At the quantum level, however, an electron in a *homogenous magnetic field* will experience a double interaction. Globally, its trajectory will curve due to the Lorentz force; locally, since the value of its magnetic spin cannot change, the electron will respond with a secondary precessional motion. In fact, the new electron spin will align parallel or antiparallel to the field lines, as average direction. You can see in Figures 2 and 3 the 'front' and the 'top' sides of two ideal electrons whose spin vector $\bar{s}$ is vertical and respectively inclined at an angle α. The magnetic spin of these two electrons is parallel to $\bar{s}$, and the magnetic regions 'North' and 'South' have different colors, light gray and dark gray respectively. Electrons are moving along the Y axis and their linear momentum is denoted by $\bar{p}$.

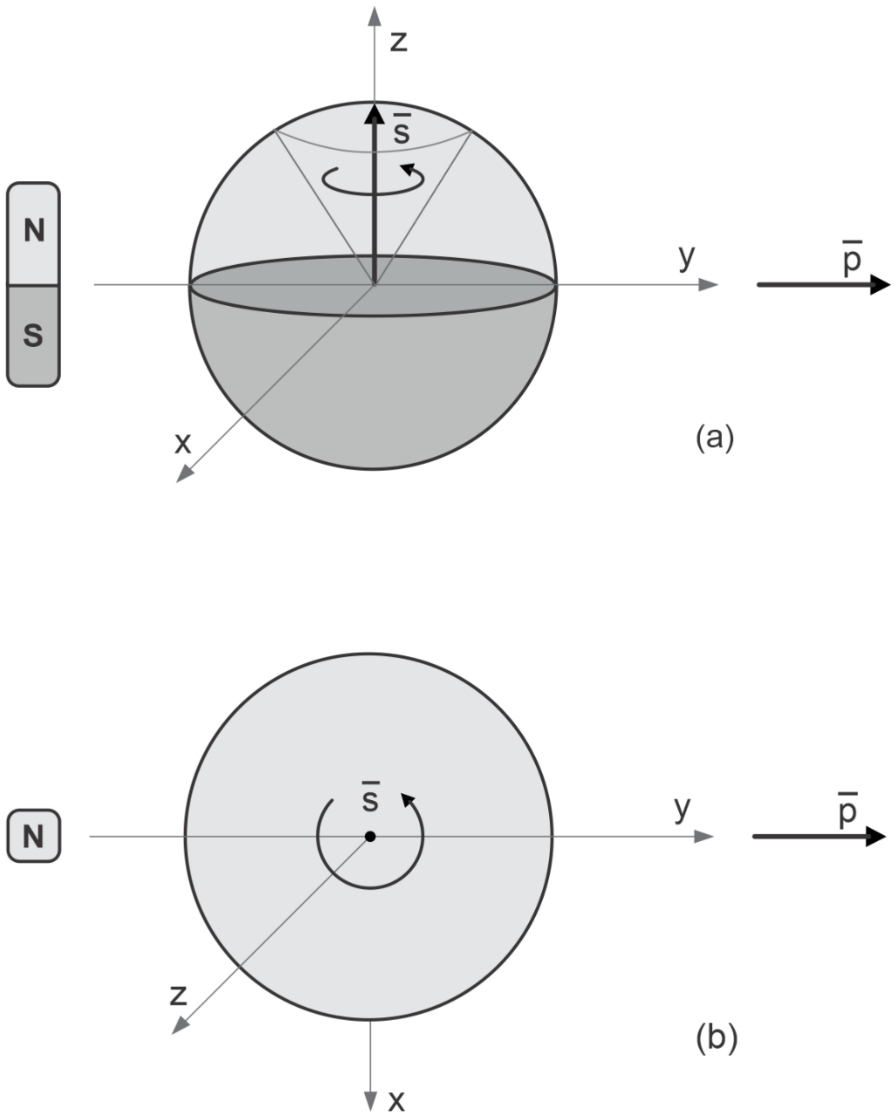

Figure 2

An electron in an *inhomogeneous magnetic field* will experience similar interactions, but there is a torque that tends to align its spin with the gradient of the external magnetic field. A small force F_z (the Z-axis component of the Lorentz force) will act on the particle, as shown in Figures 4a and 4b. Thus, the electron will be slightly deflected by this force, up or down, and these two trajectories depend on the initial orientation of the particle's spin. The upward and downward deviations are fixed because the F_z forces are constant - they do not depend on the initial inclination of the spin.

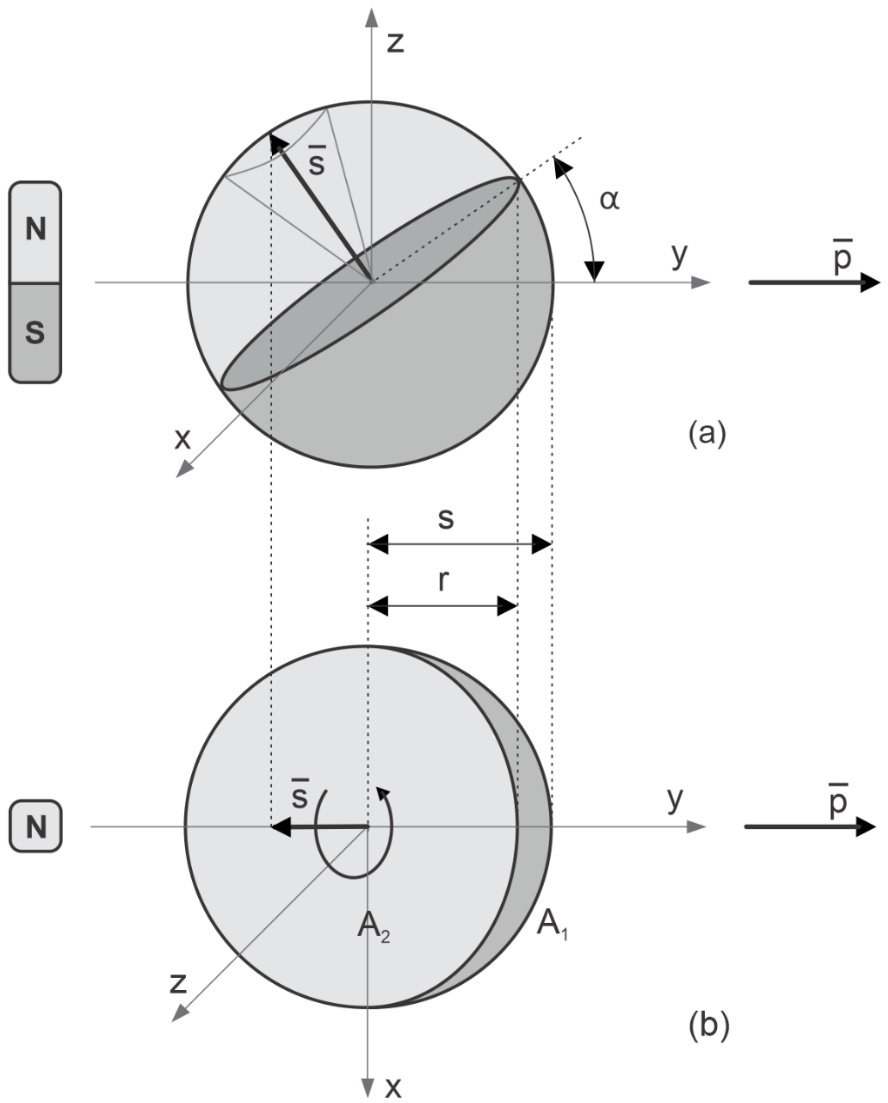

Figure 3

We assume that both the instantaneous and the averaged spin have defined orientations before measurement; also, during the interaction, a time-averaged orientation is decisive. The binary decision for the particle's spin state being 'up' or 'down' is thus determined by the projection of the averaged spin on the plane formed by the field lines. While precession adjusts itself to the magnetic field intensity, the averaged spin aligns along the vertical field lines; the instantaneous spin vector (its components on the X and Y axes) will have a primordial uncertainty in position, specific to a wavy quantum object. After measurement, however, the instantaneous spin will be bound to rotate inside a *hemisphere*, the upper one for the spin up state and the lower one for the spin down state, respectively.

If a beam of thermally generated electrons (they have random angular momentum orientations) enters the SG device, we will see two equal groups coming out from the filter: 50% spin-up and 50% spin-down of the incident number; the probability of each possible orientation is, as expected since the new definition of spin in the MG context, 50 percent. But let’s examine now a few other configurations of SG filters (see Figure 5) and then interpret the particular statistics shown by measurements. This analysis will be of the classical type, specific to granular mechanics, and it assumes random, but *defined spin directions* for the particles emerging from the electron gun. Moreover, all the experiments were performed with a very large number of electrons, so their statistics must be significant. To make things very clear, we used smaller numbers (starting from 100) in order to easily calculate the final percentages.

a) We can simply infer that those 50 electrons are still spin-up oriented after the first measurement, as they all passed through the second filter (which is also vertical). Has anything changed after this series of measurements?

1. The electrons that passed through the first filter had the averaged spin oriented upwards (inclined or not), being included in the upper hemisphere.

2. As they passed through the first filter, those 50 electrons acquired a secondary precessional motion around the measurement direction. Their instant spin will rotate continuously, but it will always be included in the upper hemisphere and its average tilt to the vertical will be maintained. This means a new orientation for their *averaged spin*, namely the measurement direction.

3. All 50 electrons will pass through the second filter because their averaged spin is oriented vertically, upwards.

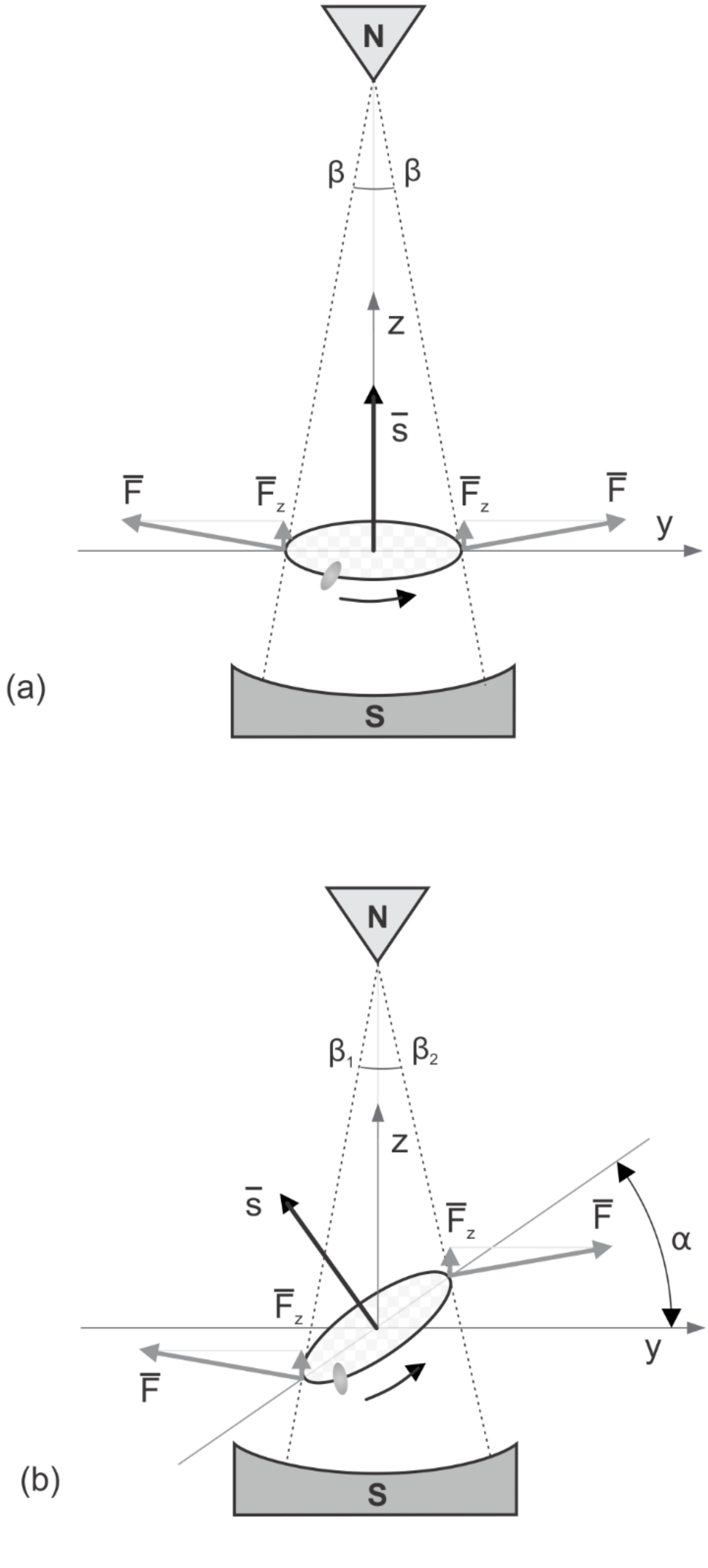

Figure 4

b) When the second filter is inclined in the opposite sense, we have additional confirmation that none of the 50 spin-up electrons has undergone a spin-flip.

c) From those 50 spin-up electrons, 25 passed through a second filter inclined at 90°. So, half of the spin-up electrons - which is normal statistically speaking - precessed more time in the right hemisphere (and less in the left one) during the measurement and thus they were pulled in this direction.

d) We can see how a filter inclined at 90° changes the instantaneous spin for all electrons passing through it, i.e. the spin of 25 electrons will now precess only in the right hemisphere; out of those 25, 12.5 will pass through the third filter and this confirms the above assumption.

e) Similarly to the measurement in case c), we would expect to see that 37.5 electrons will pass through a filter inclined at 45° - which is halfway between 25 and 50 if the orientations were linearly distributed. But the result is different, 42.5, and this significant deviation from the anticipated value requires a separate explanation!

f) Similarly to case e), we would expect to see 12 percent of electrons emerging from that spin-filter inclined at 135°, but the measurement yielded only 7.5 - so another significant deviation from the anticipated value!

g) After passing through a 45° spin-filter, 42.5 electrons will have their instantaneous spin distributed inside the upper-right hemisphere, so that another filter inclined at an angle of 90° will now allow a greater number of electrons to pass, more than those 25 observed in case c). The ratio of 50/42.5 shown in case e) is identical to 42.5/36 shown in case g), which means that the measurements performed at a certain angle cause similar spin distributions in space.

Possible conclusions:

- A SG measurement in any direction modifies the spin of the involved electrons and makes them precess with respect to that direction. Their new *averaged spin vector* will therefore align with that direction of measurement.

- The *instantaneous spin vector* of the electrons will thus be evenly distributed inside the hemisphere associated with the respective direction of measurement, and its precession will have a constant frequency that depends on the magnetic field intensity.

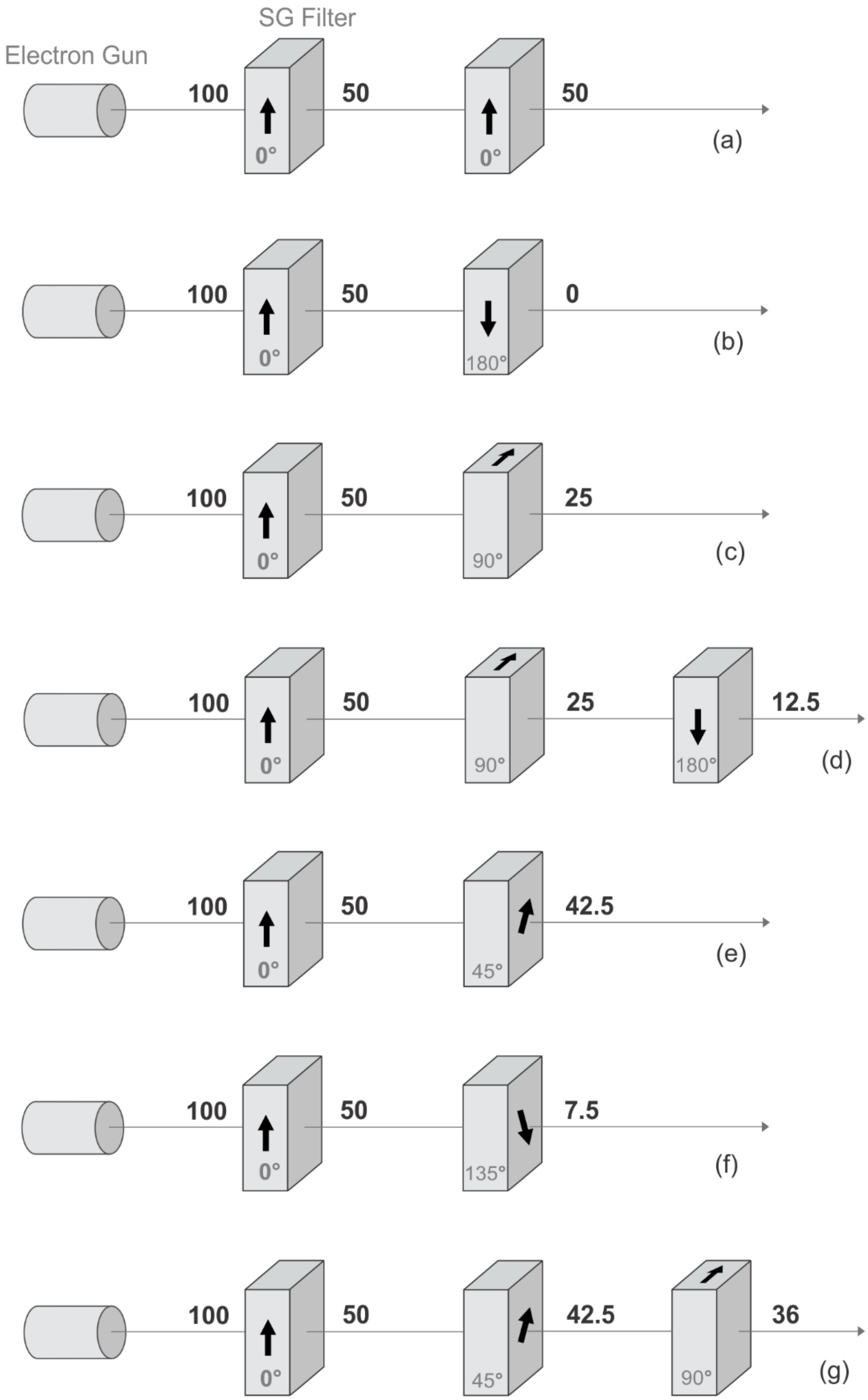
SG Filter
Electron Gun
100
50
0°
0°
50
(a)
100
50
0°
180°
0
(b)
100
50
0°
90°
25
(c)
100
50
0°
90°
25
180°
12.5
(d)
100
50
0°
45°
42.5
(e)
100
50
0°
135°
7.5
(f)
100
50
0°
45°
42.5
90°
36
(g)

Figure 5

- This secondary precession movement, regardless of the magnitude of the inhomogeneous magnetic field, cannot move the instantaneous spin outside the boundary of a hemisphere.

- The SG filter does not measure a spin orientation in fact, it only shows whether the momentary projection of this vector on certain axis is positive or negative. After the measurement, we can say that the averaged magnetic spin will be 'polarized' in that new direction.

But let's move on and analyze the pairs of particles generated in quantum processes where both linear and angular momentum are conserved; these correlated pairs - entangled particles - have a total zero spin and a maximum coherence of their spin states. Therefore, prior to any measurement, the spins of two perfectly correlated electrons are aligned in *opposite directions*, i.e., at an angle of 180°. We hope that the experimental results will confirm these suppositions and be in agreement with:

- the idea of *fixed, real spin orientations* that all entangled particles have before interactions
- the idea of *fully independent* measurements for each particle, meaning the result of one measurement does not depend on the result of the other, or on the order of events.
- the uncertainty of some pairs of physical properties (Heisenberg) [9]. Once we have measured a particle in Z direction, i.e. the orientation of its instantaneous spin is more certain, the components along the X and Y axes are less certain – and this allowed me to actually introduce the concept of averaged spin. As the measurement tries to restrict the particle's 'freedom' of rotation on Z-axis, its 'freedom' along the X and Y axes will automatically increase, leading to a maximum vector distribution throughout the associated hemisphere.

1. Using a SG filter to measure the first electron in each pair, the results show the spin-up state for half of them.
2. Now we are using another SG filter, inclined at 180° (the results will be in the same direction, easier to compare). The results for the second electron in those pairs will show a spin-up state each time, which corresponds perfectly to the theoretical predictions.
3. Now let's tilt the second filter at different angles and make a statistic on the cases in which the result is spin-up. The graph of the measured percentage as a function of angle is shown in Figure 6, the black curve. In light gray is drawn the line that represents a normal distribution, as expected for a classic phenomenon.

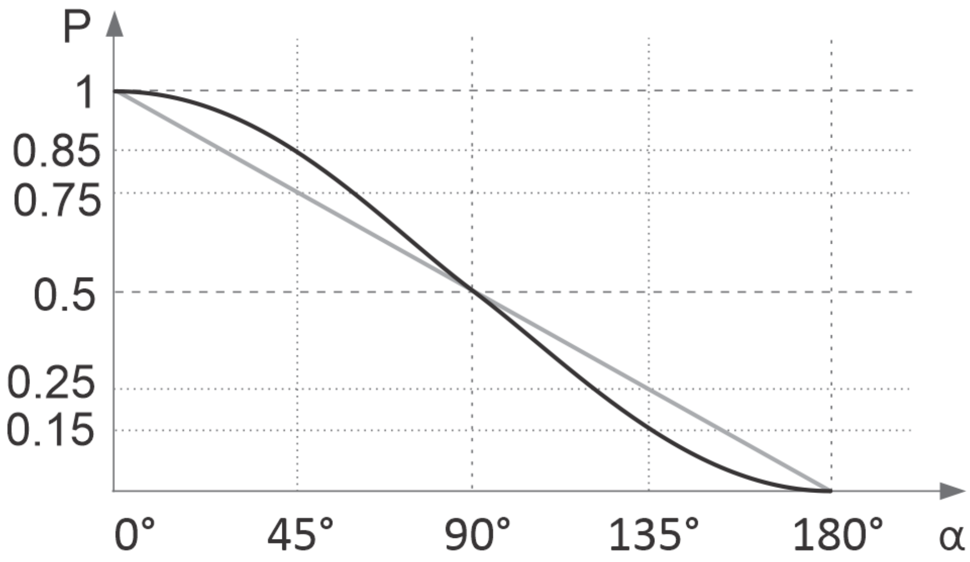

Figure 6

When the SG filters are inclined at 0°, 90° and 180° (as in the cases described above, see Figure 5), the resulted percentages match the expectations, respectively 100%, 50% and 0%. However, the other values do not coincide with the normal statistics and this mismatch should be explained classically, if possible. For example, for the 45° inclination, a percentage of 75% was expected, but the measurement yielded more, 85% !

We have learned so far that the successive measurements of the two electrons in an entangled pair yield the same results as the measurement of a single electron that successively passes through two SG filters. To understand their strange spin distribution of spin, we have to analyze in more detail what happens when the up-down separation occurs in a SG filter. Figure 2 shows the averaged spin of an electron that just emerged from a SG filter, spin that has aligned along the N-S direction of this device; as we have stated above, the tip of its instantaneous spin can now be anywhere on the surface of the upper hemisphere, the light gray one, due to the precession movement it has acquired in SG's magnetic field. We will now use another SG filter, which has a certain angle of inclination α about the first one's direction. In Figure 3 the same electron is shown before entering the apparatus, and you can observe the α inclination of its averaged spin about the SG's filtering direction and the light gray area where its instantaneous spin can oscillate.

An instantaneous spin that rotates for a longer time in the upper hemisphere leads to an upward deflection of the electron, i.e. its state will be detected as spin-up, while a longer period in the lower hemisphere will lead to a spin-down state. Geometrically, the tip of the instantaneous spin on the gray hemisphere's surface means spin-up – when it is located in the upper hemisphere - and spin-down - if it is located in the lower hemisphere. Therefore, A2 can be identified as a plane area for spin-up and respectively A1 (as a numerical size) for spin-down. Now we can write the probability of spin-up detection as a function of those two areas:

$$P_{up} = A2 / (A1+A2)$$

where A1+A2 is the area of the circle with radius s and A2 is the area of the semicircle with radius s plus the area of the semiellipse with the small axis r. The expression becomes:

$$P_{up} = (\pi\, s^2/2 + (\pi\, s^2 \cos \alpha)/2)/\ \pi\, s^2 = (1 + \cos \alpha)/2 = \cos^2 (\alpha/2)$$

whose graphical representation exactly matches the black curve in Figure 6.

All explanations and hypotheses we have put forward so far are thus confirmed by this formula. The electron is a special particle; its particular rotations, reflected by a spin vector that moves in three-dimensions, can be evaluated probabilistically if we project this vector onto a plane oriented in a certain direction. Two entangled electrons have opposite angular momenta, but the exact direction in which they are aligned cannot be revealed. However, we can 'measure' the probability of their direction being inside a given hemisphere. Once this measurement is performed, the electron will start to precess; its spin continuously changes, but it remains inside the hemisphere associated with the chosen direction. We conclude, therefore, that *the measurement does not choose a spin state* from a mix of states; the spin state has been established since the creation of the electron pair, and the so-called measurement cannot give us this exact information – it only shows if the pre-existing spin vector falls within a hemisphere drawn around the measurement direction. In addition, after measurement, the averaged spin became aligned along this new Z direction and the instantaneous spin is now distributed everywhere within the associated hemisphere; a new measurement, in another direction, can only give us the probability for a spin located inside the new hemisphere.

All these strange things are a consequence of the quantum world's peculiar features and its special mechanics, but they still obey the fundamental principles and laws of physics. Moreover, the new interpretations bring realism to this world, as well as locality. We do not necessarily need a superposition of the up and down states to describe the spin of the entangled particles, nor do we need the hypothesis of a spin state being chosen at the time of measurement - even if they lead to good mathematical results. The fact that current physics accepts models in which causality is greatly distorted and locality is violated seems unacceptable.

Einstein formulated the EPR paradox [10] and that analogy with a pair of gloves to illustrate what happens in the case of quantum entanglement, but he was only partly right. Here is a better version of that analogy, closer to reality, if we are allowed to make some changes:

Each box contains a pair of gloves, and the two gloves of each pair are placed on top of each other in a different order. Moreover, those boxes can be opened on several sides and we have agreed upon which side will be used. An observer moves one of the boxes at a great distance and opens it; he discovers which of the gloves (the right-handed or left-handed one) is on top and, at the same time, instantly knows that the opposite glove is on top in the other box.

Reality contains a hidden variable that indicates the direction of spin, but we cannot access it, and this is equivalent to what QM claims - that piece of information does not exist. However, we can access partial, quantized information that shows whether a particle is spinning clockwise or anticlockwise in a certain direction; simultaneously we know what another observer would see if he measures the entangled particle in the same direction (the spin will be inverted). It is obvious that these results depend on direction, but they are the reflection of a pre-defined, fixed, real state that existed before any interaction. The result of the second measurement is not determined by the first measurement, there is no physical connection between the two events. Even if the measurements show a nonlinear correlation between the spins of these particles, the phenomenon is perfectly justified by their mechanical movements in a three-dimensional space. As the granular model provides a good picture of the quantum world and ensures better interpretations, all we have to do is to correctly apply the rules of classical mechanics to this kind of phenomenon.

Note: The setup of Bell's experiment, in which three detectors inclined at 120° are used for each entangled particle, gives statistical results that can be easily extrapolated from the above analysis (see Figure 6) and for which the explanations are absolutely similar.

4. Entanglement of photons

4.1. Photon spin

As we know that the *ideal photon* is a complex, three-dimensional granular structure [2, Ch. 13.2] with a specific shape (an accurate replica of the path taken by the electron when emitted it) and that *the real photon* is extensively described by the tree model [2, Ch. 13.3], we may wonder if an averaged spin-like parameter can be used to describe the state of these particles, in the same way we previously associated this vector to electrons. But first, a few granular considerations must be formulated for a single photon (not a light beam) in order to find the correct answer:

- The spin of this 'rigid', wavy shaped particle has an integer value (s = 1), i.e., a hypothetical full rotation (of 360°) would bring the particle back to its initial orientation.

- We can assimilate, ideally, the wave generated by a photon with *a full oscillation* of its granular mass, and thus the envelope of its structure can have a sinusoidal projection on an axial plane; this internal structure remains unchanged while the particle moves rectilinearly (at the speed of light) along the OY axis (as seen in Figure 7).

- From any inertial frame of reference (but not the ones in which the photon is at rest), an observer can see how its granular distribution – the so-called electric field component of the wave – changes over time. We will thus see a sinusoidal waveform of the electric field $\overline{\mathrm{E}}$ in a plane perpendicular to the direction of travel (XOZ). During a wave period, this vector can oscillate in a fixed direction or it can rotate and have a spiral-shaped path. This direction of oscillation, which can thus be fixed or variable for a particular photon, is called *polarization.* The two possible types of polarization are: *linear* (e.g. horizontal as in Figure 7b or vertical as in Figure 7a) and *elliptical* (circular) respectively. Considering the degrees of freedom of the photon, the QM makes the association between circular polarization and spin, allowing two discrete values for the projections of this vector in the direction of propagation (+1 and -1). These two integer values would thus correspond to the rotation of the electric field in time, +1 to *the right* and -1 to *the left* along the direction of propagation. It should be mentioned here that linear polarization is mathematically treated by QM as a superposition of two circularly polarized waves (right and left), with equal amplitudes and phases.

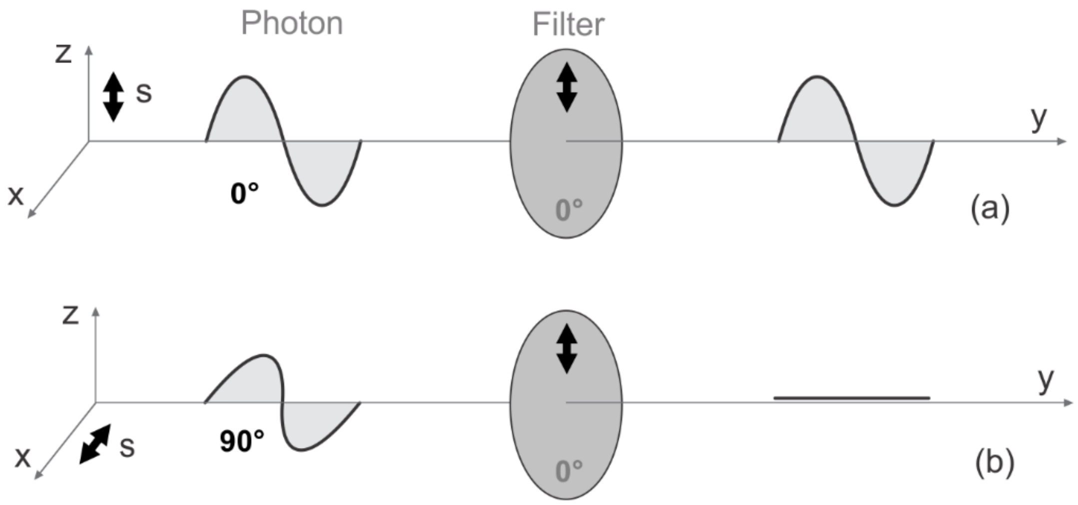

Figure 7

Considering all of the above features of photons, we can simply associate the direction in which their 'electric' field oscillates with an instantaneous spin and thus come near the concept of averaged spin for photons. As it was previously shown [2, Ch. 13.2], photons are not perfect constructions, and the oscillations of their electrical component can vary along the entire length of their structure. How their electric field rotated would thus give us the spin component along the direction of propagation (positive would mean clockwise rotation) and how their amplitude varied would give us the projection on the XOZ plane.

The component of spin in a transverse plane (perpendicular to the linear momentum vector) can consequently be found using polarizing filters. In the case of photons that travel horizontally, this spin could indicate, for example, their polarization in the vertical direction. But their 'electrical' granular component does not vary in a single plane, there is also a rotational component (its envelope actually looks like a spiral – a 'frozen' replica of the secondary spiral path followed by the electron during emission). If we add the granular clones that accompany all photons after they pass through transparent materials, the spin vector becomes more complex: its instantaneous direction is variable (as the instantaneous spin of the electron) and its vertical projection is actually a *plane distribution* of a certain angle. Thus, over the entire wave period, the spin vector varies along all the axes; as the photon rotates in the same direction as the electron that generated it, the projection of the global spin vector onto linear momentum will always have a non zero amplitude.

The averaged spin is therefore perfectly associated with *the real rotation* of compact particles and with *the virtual rotation* of photons. If a photon that 'rotates' clockwise (+1) meets an electron that rotates in the opposite direction (-1/2), there will be an interaction, a transfer of momentum. This quantum process ends when this transfer of momentum (and energy) to the electron is complete (+1-1/2=1/2) and the charged particle starts rotating clockwise. The quantum nature of this transfer is a simple consequence of a binary state: any compact particle has an intrinsic motion, it can only rotate clockwise or anticlockwise about its linear momentum! As a result of rotational symmetry, the property called total spin *is conserved* in a quantum system.

4.2. Correlated photons

The passage of photons through a linear vertical polarizer (Figure 8) is well-known in Quantum Mechanics: how a photon behaves depends on its spin, on which direction points the spin component in a vertical plane. All photons that emerge from an incandescent bulb have randomly oriented spins and therefore the percentage of photons that pass through this filter is 50%. But what is the exact mechanism that explains the passage of a single photon through the polarizing filter?

Here are four logical observations that could help me better understand how the polarization of light works in a few experiments:

1. A vertically polarized photon will definitely pass through the filter.
2. If the projection of its averaged spin on the transverse plane is inclined to the vertical direction at a maximum of 45°, the photon has a chance to pass.
3. The photons that passed through the polarizing filter have a new averaged spin (and a new distribution of the instantaneous one) - whose component in the vertical plane is now aligned along the vertical direction.
4. Due to the 180° symmetry of a filter, all vertically polarized photons (with positive or negative spin components in that direction) will be equivalent.

Here is the respective number of photons that passed through the series of filters shown in Figure 8:

a) If the secondary filter is also vertically polarized, all 50 photons that have passed through the first filter will also pass through the second.
b) If the secondary filter is rotated at 90°, not a single photon of those 50 will pass through it.

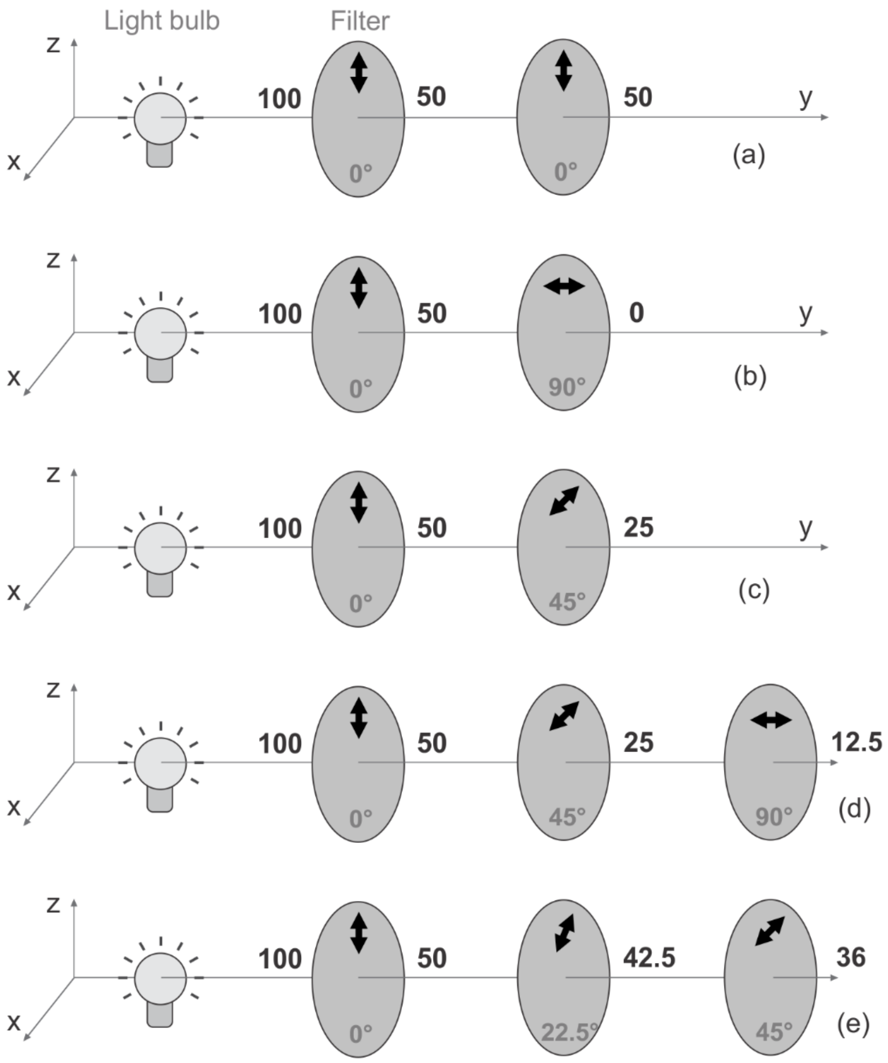

Figure 8

c) When the secondary filter is rotated at ±45°, only half (25) of those 50 will pass through the second filter.
d) This is the same configuration as in case b), except for the filter inclined at ±45°; its presence leads to 12.5 photons (as percentage) emerging from the last filter.
e) A filter rotated at 22.5° that is followed by another at 45° leads to 36 photons emerging from the last filter.

In cases a), b) and c) we observe a normal results statistics, the number of photons decreases proportionally to the angle of 0..90°. Case d) confirms that the averaged spin was changed by the polarizing filter, and case e) shows a small deviation from the expected linearity (37.5 photons were expected after the second filter, measured 42.5) – which now needs to be explained classically.

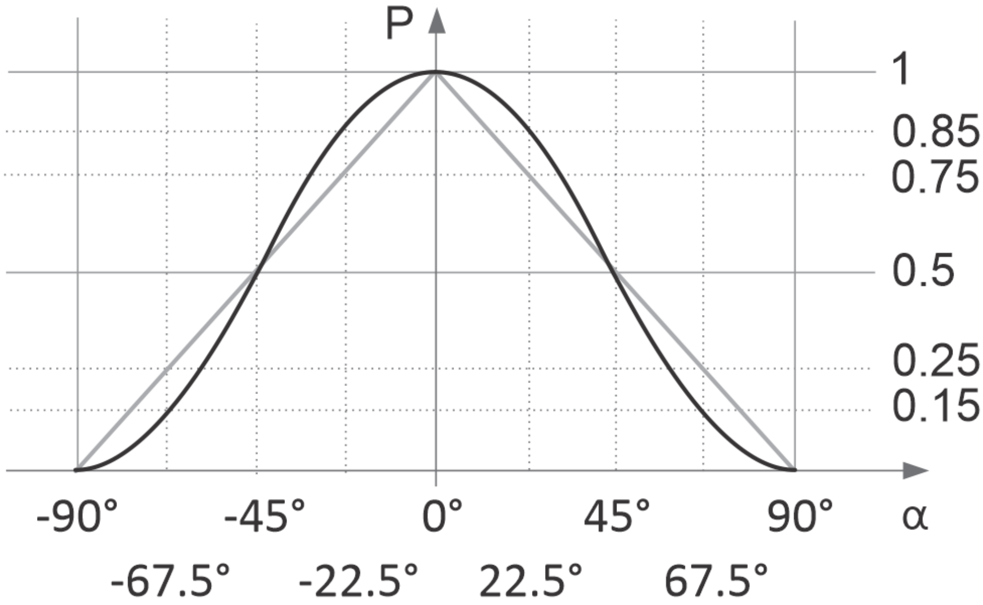

Figure 9

The gray line in Figure 9 represents the expected statistics, while the black curve shows the real percentage of photons that passed through the second filter. If we are experimenting with pairs of 'entangled photons' (their averaged spins are perpendicular), where the first photon passes through a polarizing filter and the other one through a filter rotated at 90°+α, the final results will be the same.

What we can easily observe is a perfect similarity between the entanglement of photons (and its type of statistical deviations) and the entanglement of electrons (and its deviations); there is one single thing that differs, the angular range, which is 180° for electrons and 90° for photons. Moreover, the explanations that we can formulate for these apparently strange quantum behaviors are also similar.

A vertically polarized photon will pass through the polarizing filter. The plane area (see Figure 10a, the light gray filled zone) in which the projection of its averaged spin can be located has an angular range of 90°. The spherical sector that corresponds to the full rotation (one revolution) of this surface around the Y-axis is shown in Figure 10b; its volume is half the volume of the sphere of s radius, and it represents the space where the averaged spin vectors of the respective photons can be located.

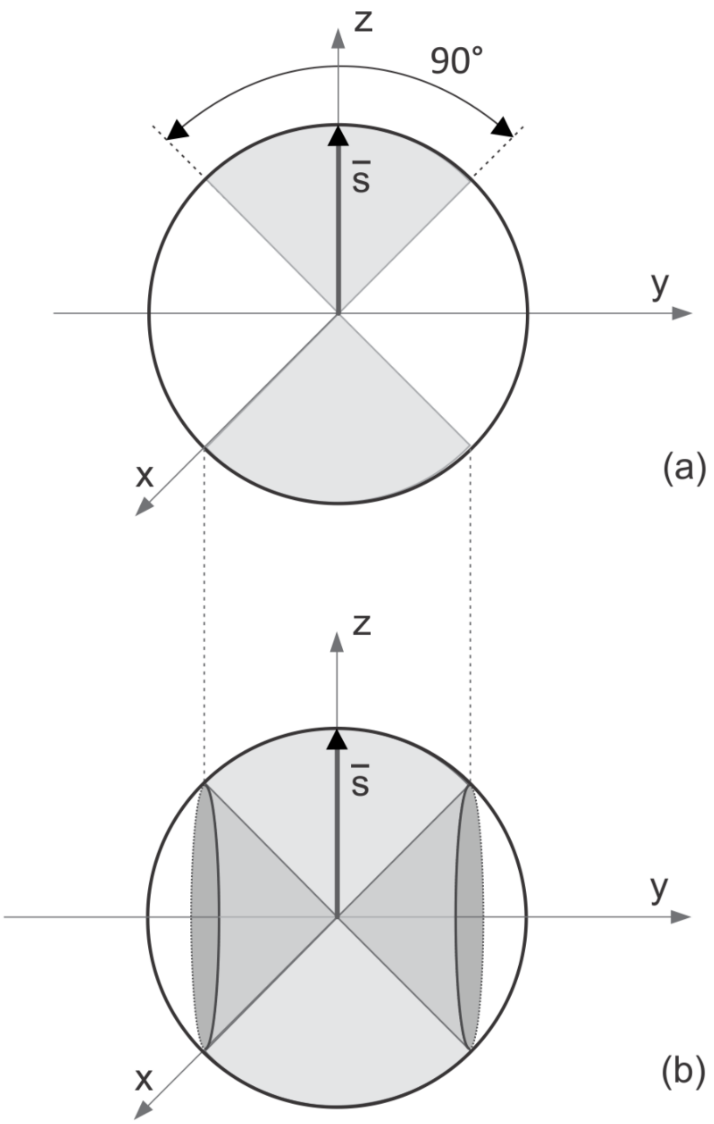

Figure 10

Let's imagine now that we have rotated the polarizing filter at the α angle clockwise, as drawn in Figure 11a. A photon of spin s_1 has passed through the light gray area (which is associated with the initial vertical position of the filter); a photon of spin s_2 could pass through the dark gray area (which is associated with the inclined position of the filter) with a certain probability.

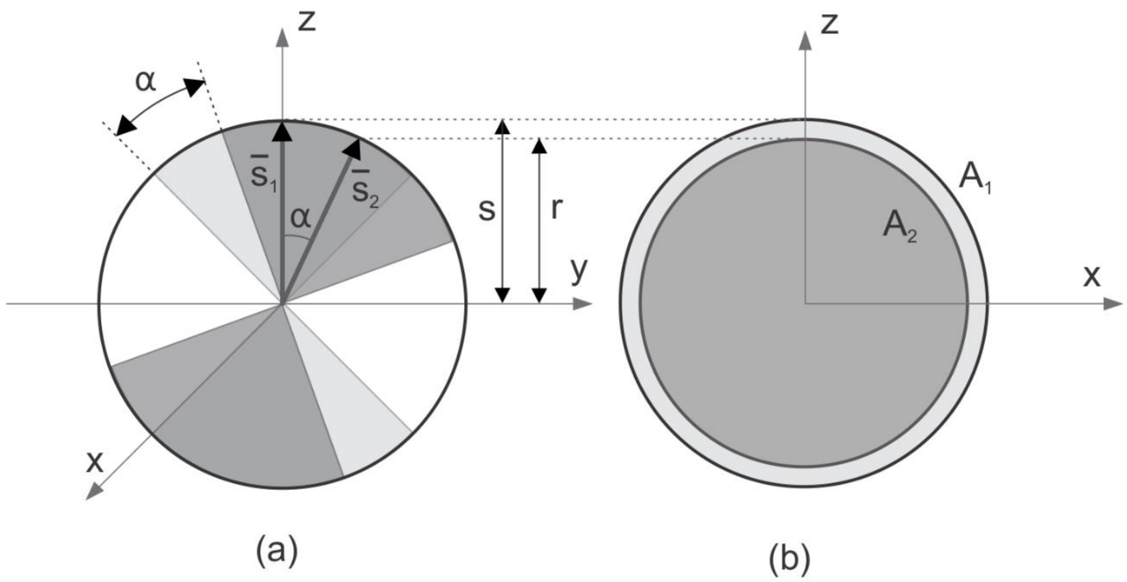

Figure 11

If we look at the lateral projections of these areas onto the XOZ plane (Figure 11b), it is easy to understand why the second photon of the entangled pair has a lower probability of passing and how this decrease is proportional to the ratio of the areas projected on a vertical plane that is parallel to the direction of travel, A1 and A2.

$$P_2 = A2 / A1$$

A1 and A2 represent the two circular areas of radius s and r respectively. It results:

$$P_2 = (\pi\ r^2)/(\ \pi\ s^2) = (\pi\ (s \cos \alpha)^2)/(\pi\ s^2) = \cos^2 (\alpha)$$

i.e. a function that shows a degree of correlation in polarization identical to the one depicted before (the black curve in Figure 9).

A classical, mechanistic approach led us to theoretical results that correspond to the experimental data; however, this does not mean that all the previously stated assumptions are implicitly correct. It is up to each reader to choose the most appropriate premises and interpretations for entanglement.

5. Conclusions

Our microuniverse seems to be very well described by the actual QM's standard model (wave functions, superposition, probabilities), and the theoretical results it yields are a perfect match for the experimental data. But is this standard model complete and free of contradictions? Are the conclusions of non-locality and non-realism to which it leads us in the case of quantum entanglement all correct? Do they constitute a scientific truth to be added to the current model of the quantum realm and will it continue to be coherent?

Or could things be different, and, as it was already explained in this article's introduction, some fundamental quantities can have another theoretical model? One in which all quantum objects have internal structures and intrinsic motions that we must take into account. What if this new model, which at the most elementary level is only based on the simple laws of classical mechanics, allows us a correct interpretation of microscopic reality – where both locality and realism can occupy the right place alongside the principles of relativity?

The quantum world is a special universe that can only be reached by means that it makes available to us. The closer we come to its objects, the more imprecise are the measurements of their properties. Thus, chance plays a fundamental role at this level, and a probability is the maximum amount of information we can get about some quantum quantities or states. However, our theoretical models must maximize this information so that we can learn as much as possible about objective reality and better interpret its inner mechanisms. Once we have established a minimum set of laws and principles underlying these mechanisms, exceptions must no longer be accepted at any dimensional level.

There are two divergent positions in this article, both describing the state of the particles before we measure their quantum spin parameter: *a superposition of states* in Quantum Mechanics' formalism and *pre-defined states* in Granular Mechanics' new formalism. These two hypotheses lead to correct results, but only the first one involves a contradiction in principle.

After measurements, in all the above cases, the averaged spin aligns along the direction of measurement and the instantaneous spin distributes over a certain solid angle (electrons start precessing and photons get adjacent clones). This is the granular-classical effect of measurement, which is equivalent to the collapse of the wave function in QM. The particle is constrained by the external fields to limit its degrees of freedom and will therefore respond with a change of state – the spatial distribution of its angular momentum expands; in essence, this is a Heinsenbergtype *uncertainty* transfer: the more we restrict a quantum parameter, the more inaccurate another paired quantity becomes.

But how is a measurement described by the two formalisms?

1. QM case: it is a collapse of the wave function, and one of the quantum states in superposition is probabilistically chosen.
   Superposition of states -> lack of realism, lack of causality and locality
2. GM case: it is a probabilistic exposure of a pre-defined state that is associated with a specific spatial distribution.
   Pre-defined states - > realism, causality and locality

We can also talk about quantum-scale determinism: it is based on processes that take place at the granular scale and have time-averaged effects, so it is practically impossible to observe and evaluate. We could name it *elementary*, as its reflection in measurements is only probabilistic. For the same reason we cannot see quantum realism either, so it is also *elementary.* Moreover, the fact that we cannot measure a certain quality of a quantum object does not mean that it does not exist. It simply follows that the two formalisms described here can coexist together, as they lead to the same results, but the first one does not allow rational and coherent interpretations.

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7. Acronyms and conventions

SG - Stern-Gerlach

QM - Quantum Mechanics

GM - Granular Mechanics

AFR - Absolute Frame of Reference

IFR - Inertial Frame of Reference

RF - Reference Frame

TR - Theory of Relativity

TGR - Theory of General Relativity

TA - Theory of the Absolute

PT - Prime Theory

'**abc**' - Figurative text