Gino Tarozzi Philosopher of Physics

Studies in the philosophy of entanglement on his 60th birthday

Edited by
Vincenzo Fano

Epistemologia

FrancoAngeli

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Epistemologia, collana diretta da Evandro Agazzi

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La collana intende venire incontro a quellôesigenza, ormai generalizzata, di conoscenza epistemologica che si riscontra a livello di cultura medio-alta e che corrisponde, in senso lato, alla diffusa aspirazione a prender coscienza critica della complessa variet¨ della nostra civilt¨ scientifico-tecnologica. Aspirazione che si accompagna, altres³, al desiderio di venire in chiaro circa lo statuto epistemologico di molte discipline le quali solo di recente hanno rivendicato lôimpegnativa qualificazione di çscienzaè, pur riguardando ambiti di ricerca non inclusi nellôalveo delle discipline scientifiche tradizionali.
Rispetto ad analoghe collane gi¨ esistenti, questa si propone anche di allargare lôambito delle scuole e tradizioni epistemologiche finora pi½ correntemente conosciute in Italia, e che si ispirano in prevalenza al filone analitico anglosassone, portando lôattenzione su opere e autori afferenti ad altre aree culturali, come ad esempio quelle di lingua francese, tedesca, polacca.
Verranno quindi pubblicati, sia in traduzione che in opere originali, alcuni testi base di carattere istituzionale relativi allôepistemologia generale e alle diverse branche della filosofia della scienza. Per altro verso, verr¨ dato uno spazio pi½cospicuo del solito allôepistemologia delle scienze çumaneè, alla filosofia della logica, alle tematiche etiche che di recente si sono aperte nei riguardi della scienza. Pur senza rinunciare ad opere di carattere tecnico, lôaccento generale verr¨ posto piuttosto su quei tipi di trattazione epistemologica nei quali ¯ pi½presente un taglio specificamente filosofico.
La collana si propone di essere utilizzabile anche per corsi universitari: a tale scopo, oltre alle opere di carattere istituzionale cui si ¯ fatto cenno, annoverer¨ anche alcuni çreadingsè antologici, sia a carattere miscellaneo che monografico.

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Gino Tarozzi (on the left) with Franco Selleri in the fall of 1980 at the Institute of Theoretical Physics of the Vienna University, where they wrote their refutation of Clauser and Horne's probabilistic proof of Bell's theorem, which according to Karl Popper severely questioned the universality claim of this famous theorem (see Fano and Macchia contribution to the present volume)

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Alexander Afriat ï Evandro Agazzi ï Mario Alai ï
Gennaro Auletta ï Claudio Calosi ï Maria Luisa Dalla Chiara ï
Vincenzo Fano ï Roberto Giuntini ï Pierluigi Graziani ï
Rossella Lupacchini ï Giovanni Macchia ï Flavia Marcacci ï
William Shea ï Gino Tarozzi ï Isabella Tassani

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Introduction

Vincenzo Fano

It is said that young physicists crowded around the old von Neumann during the breaks in the conference to ask for advice on their research. The great mathematician listened attentively, then said or wrote something. It seems that only after months of hard work would postgraduate students completely realize the full meaning of the words of the Hungarian scientist! Something similar happened to me with Gino Tarozzi; that is, I understood what he was telling me when we first met in the Eighties only after some decades had passed. It is unclear whether this depends either on the inexperience of the student, or the long gestation peculiar to deep philosophical thoughts or else on the overwhelming depth of the thoughts of the teacher. Probably all three factors played their part. The fact remains that for many involved in the Italian philosophy of science, Gino was a teacher of inestimable value, as is also evident from the contributions collected in this volume.

Gino studied Philosophy at Bologna in the Seventies, when the cultural hegemony of logical positivism in Italy had been questioned only in part by the so-called "new philosophy of science". He graduated with Alberto Pasquinelli, one of the most authoritative representatives of that way of thinking. However, in those days the Master Degree in Philosophy was very flexible, allowing him to acquire extensive skills in mathematics and physics. In the meantime, he met Franco Selleri[1], who teaches physics at Bari University; with him he established a long and fruitful collaboration focused primarily on the foundations of quantum mechanics. In the same period he followed Marisa Dalla Chiara's courses in Florence on Logic and Philosophy of Science.

His dissertation is a demonstration of the inadequacy of a formal solution to the paradoxes of quantum mechanics, and the part containing a

1. Franco Selleri was preparing a contribution for this volume when after a long illness died November 2013.

criticism of the quantum logical approach to the double slit experiment and the discussion of an alternative realist interpretation published in a joint paper with Selleri in *Il Nuovo Cimento,* was considered "*tres interessant*" by Louis de Broglie. Gino continued his high standard scientific work, always in international volumes and journals, while working at the Institute for Cultural Heritage of Bologna. His career would be short and bright: associate professor at the University of Urbino in 1988, and already in 1994 full professor at the same university, where he still teaches; from 1996 to 1999 he was the youngest president of the Italian Society for Logic and Philosophy of Sciences (SILFS).

The main critique of the New Philosophy of Science against Neo-positivism focused on the impossibility to distinguish adequately between context of research and context of justification. This criticism, in particular in the works of Kuhn and Feyerabend, resulted in partially relativist positions, which bring into question the cognitive value of natural sciences. In contrast to the above perspective, Tarozzi proposes again the cognitive value of some philosophical hypotheses, which must be adequately confronted with scientific theories, that neo-empiricism had instead considered devoid of cognitive meaning. In this sense, Tarozzi, as well as the new philosophers of science, is influenced by Popper's thinking, especially where the latter says that metaphysics plays an important role in the natural sciences. However metaphysics[2] is not only a conceptual framework that influences the work of the scientist, as many have argued with Popper, nor simply the precipitate of scientific theories, as many today understand it, but rather an activity that produces statements with empirical sense, which, although not falsifiable, can nevertheless be controlled through a comparison with our best scientific theories.

It is a strange irony that in the Eighties when Tarozzi proposed his empirical realism and the possibility to discuss the ontology of physics from a philosophical point of view, there was considerable hostility, based on different forms of anti-realism, either from idealism, or from positivism, or based on an ill-concealed relativism. Today, however, ontology and metaphysics have largely caught on again, thanks also to the efforts of the generation of philosophers of science to which Tarozzi belongs. However, it has moved above and beyond, so that, on the one hand many people think of metaphysics as a simple extrapolation of the ontology of our best

2. It should be said that Gino is inextricably linked to the negative nature of the term "metaphysics", so he tends to use it as little as possible. However, the name has now returned to common usage, so we will stick to the latter use. It is also remarkable that between Popper and Tarozzi a remarkable dialogue developed about the foundations of quantum mechanics, which I will outline in my contribution to this volume.

physical theories (e.g. James Ladyman), whereas others believe that you can do metaphysics while basically ignoring physics (e.g. Jonathan Lowe). Unfortunately, now, as then, the idea of a relationship and dialogue on a par between philosophy and science, is anything but fashionable. As always, walking on the ridge between two slopes is difficult, so it is easy to fall back either into a metaphysical delirium, or into an arrogant scientism.

The last two decades of the 20th century were very important for the Italian philosophy of science, which, thanks to the efforts of an entire generation of scholars, among whom Tarozzi has played a significant role, has partially recovered the gap with the Anglo-Saxon school. Today, fortunately, the most sophisticated discussions on the foundations of mathematics, biology, physics and psychology are current in our universities and many Italian scholars actively contribute to these important philosophical discussions.

In this context Urbino plays a remarkable role, above all in philosophy and foundations of physics, as was recently pointed out by Evandro Agazzi:

> My contacts with Urbino were further consolidated after the arrival in this University of Gino Tarozzi, a philosopher of science who carried out important studies in the field of philosophy of physics and who, in particular, shares with me a realist conception of science. [...] On these occasions I also had the opportunity to know and appreciate some of his valuable collaborators and disciples, which ensure a continuity in this University in the field of philosophy of science that, despite appearances, it is not easy to achieve in most Italian universities. (Agazzi 2009, p. 20)

In what follows I will present and discuss the essays in this volume on the philosophical work of Tarozzi. First, though, I will try to summarize his major contributions in an arid but compendious and certainly incomplete list: Gino proposed experiments to detect the existence of quantum waves; questioned the ability of effectively representing non-locality by non-factorizability; developed a probabilistic version of the EPR argument; supported the unavoidability of reality principle in every formulation of the EPR argument; maintained the inability of non-distributive logic to solve the foundational problems of quantum mechanics; supported the empirical relevance of realism in a neo-empiricist framework; maintained and investigated the importance of measurement instruments in the formation of physical theories; discussed the empirical relevance of the causality principle when compared with quantum mechanics; used in many different ways Renninger negative measurement experiments to formulate quantum paradoxes; supported the reality of quantum waves, together with that of the corpuscles; argued that all the theories of quantum measurement

developed to date do not solve the problem of the disappearance of superposition; supported the incompleteness of quantum mechanics on the basis of the EPR argument; criticized the subjectivism of Wigner, London and Bauer and von Neumann; criticized micro-realistic interpretations of quantum mechanics, such as GRW; argued that property realism and not object realism could be empirically investigated.

Alexander Afriat teaches philosophy at the University of Brest. For several years he worked in Urbino next to Tarozzi, with whom he published several works (Afriat, Tarozzi, 2004 and 2006). In fact, in his contribution Afriat resumes and deepens the themes of those items. If we consider an entangled state, one can show that there is a relationship between the phases of the two products that has physical significance in the results of a possible measurement. From this Afriat concludes that both products must be real. For example, for an electron that is in a state of superposition between two eigenvalues of the observable position, both possibilities should be somehow real. This argument, which infers from the statistical significance of the difference in phase the reality of both possible states is, to my knowledge, partly new in the literature. After that Afriat resumes the argument already proposed with Tarozzi: if we measure in one of the two positions without finding the electron, automatically it is certain that it is in the other position. This means that, if we assume that before the measurement there is nothing at the point where we measured, we are forced to violate the metaphysical principle that from nothing nothing comes, since the standard quantum mechanics says that the transition from superposition to the location is not only epistemic. Therefore if we maintain that there is nothing before measurement we are led to very counterintuitive metaphysical conclusions.

Evandro Agazzi, a world-renowned philosopher, who needs no introduction, although not professor in Bologna, where Gino studied, immediately grasped the value of Tarozzi's work on quantum mechanics and realism, promoting and encouraging his studies. Evandro must therefore be counted among Gino Tarozzi's teachers. Agazzi's contribution to this volume is developed as a kind of integration of Tarozzi's "property realism". First of all Agazzi prefers the term "attributes", which also includes relations; secondly he proposes a realism of the object, intended as a structured set of properties. The object can be either abstract and therefore subjective, that is in fact a concept by which we represent the reality, or concrete, that is immanent to the thing. The latter would be reality in all its complexity, while the concrete object would include only those attributes

identified by the abstract object. Agazzi is also a promoter of a kind of scientific realism that bypasses the objection of the so-called pessimistic meta-induction by Laudan (1981), based on the fact that the truth and falsity of a theory must be evaluated with respect to a restricted range of objects. In this sense, for example, the Newtonian representation of the motion of the planets in the solar system remains true even after the advent of general relativity. To true theories correspond real unobservable entities, that is, to abstract objects of true theories correspond real concrete objects.

Mario Alai, like Gino Tarozzi, is a pupil of Alberto Pasquinelli, though a few years older. He is a highly regarded scholar of realism and has worked with Gino on this issue (Auletta, Alai, Tarozzi 2009 and Alai, Tarozzi, 2006). In his contribution to this volume, he first tells briefly the evolution of the thinking of neo-positivist philosophers on the issue of realism and the criterion of meaning; after which he presents very clearly Tarozzi's proposal on the topic and then criticizes latter's point view. Alai notes that we must distinguish between a verificationist and a realist interpretation of statements like "if all sentient beings disappeared, then the planets would continue in their course." From the verificationist point of view this statement is equivalent to the counterfactual implication stated in a world devoid of minds, "if there are sentient beings, then they would observe the planets in their places in accordance with the laws of Newton." In this sense, after the liberalization of the meaning criterion, the logical positivists would accept this type of utterance. However, from a realist point of view, that statement would claim more than a mere prediction about the possible observations, that is it would establish the independence of the external world from the perceptions of sentient beings. In this sense, the neo-positivists would maintain that this kind of statement does not make sense even in the final stage of their thinking. Alai also notes that Tarozzi's thesis according to which philosophical statements would be confirmable, but not falsifiable, and those scientific would be both confirmable and falsifiable, and the metaphysical (meaningless) neither confirmable nor falsifiable, presupposes that there are confirmable but not falsifiable statements. But if a statement can be confirmed by experience, why can it not also be falsified? Finally Alai favors not only property realism, such as Tarozzi's, but that of objects too.

Gennaro Auletta teaches Logic and Philosophy of Science at the University of Cassino and worked for several years at the University of Urbino, side by side with Gino Tarozzi, as testified by the numerous articles that the two together have published (Auletta, Tarozzi, 2004a,

2004b and 2006, Auletta, Alai, Tarozzi, 2009). Tarozzi believes that there is no possible realist interpretation of quantum mechanics. Auletta, however, tries to show the compatibility of these two instances. To achieve this it is necessary to renounce the *omnimoda determinatio* School principle, according to which everything that is is determined according to all respects. Auletta shows that already in classical physics there exist real dispositions, such as potentials. He then recalls the notion of "power" introduced by Heisenberg, arguing that the wave function can be interpreted realistically as potential information. Auletta notes that Tarozzi's attempts to find an ontology for quantum mechanics by means of the notion of quantum wave turned out to be empirically false; so just following Tarozzi's idea that the metaphysical principles should be compared with scientific theories, he states that quantum mechanics falsifies a certain type of classical realism, while confirming a weaker form of it.

Claudio Calosi has for three years been postdoc in Urbino, where, after his important studies on the ontology of relativity, he has addressed the problem of the ontology of quantum mechanics, working in several essays with Tarozzi (Calosi, Tarozzi, 2013, 2014, Calosi, Fano, Tarozzi, 2012 and 2011). Calosi examines two important claims made by Tarozzi: first that an ingredient of each required argument of the Einstein-Podolsky-Rosen paradox is realism, and secondly that there are metaphysical theses, such as realism itself, which have empirical meaning. Calosi, following Harrigan and Spekkens (2010), distinguishes between an ontic plane and a quantum one. After that he defines physical states as those quantum states that have only one corresponding ontic state, while it is possible that two ontic elements correspond to the same quantum state. Realism would be the claim that in the ontic states corresponding to physical states there are no hidden variables. After that he shows that for the EPR argument weak Realism is enough, that is the thesis that each quantum state is a physical state, i.e. it has a different corresponding ontic state. Calosi goes on to suggest that, based on Pusey, Barrett and Rudolph, 2012, weak Realism is confirmed by quantum mechanics, while Realism is falsified. This argument is a further confirmation that Tarozzi's intuition according to which metaphysics can regain empirical meaning by a comparison with our best scientific theories is extremely fruitful.

Marisa Dalla Chiara, a well-known logician, as I said, played an important role in Gino Tarozzi's formation. Marisa, in her contribution with her pupil and collaborator Roberto Giuntini, outlines the non-

distributive logic of quantum events up to contemporary applications in quantum computing. She also shows how quantum superposition can be an extremely powerful tool to represent the complexity of the notion of meaning, especially in the case of musical languages.

Vincenzo Fano, a pupil and collaborator of Gino Tarozzi since the time of his thesis, argues, along with Giovanni Macchia, the importance of non-factorizability in the proof of probabilistic Bell's theorem. Gino was one of the first to grasp the importance of Suppes and Zanotti's theorem for the issue of non-locality. The theorem suggests that the experimental violation of Bell's inequality implies some form of non-separability only in a strictly deterministic world. Arthur Fine even tries to prove that the violation of Bell is nothing but a consequence of the incompatibility between observable typical of quantum mechanics. His project does not seem conclusive. On the other hand, many scholars believe that it is not correct to attribute holistic ontological consequences to the violation of Bell's inequality, because the common cause principle does not hold in an indeterministic context.

Pierluigi Graziani is a logician and for several years held a position at the University of Urbino, and thus worked closely with Gino Tarozzi (see, e.g. Graziani, Tarozzi, 2012). In his contribution, he examines the critique offered by Tarozzi to the possible solution of the quantum paradoxes through logic. Birkhoff and von Neumann in fact show that if we associate with each projector in the Hilbert space a statement that assigns a property to a physical system, the analysis of the double-slit experiment implies that the algebra of logic of these statements is not Boolean, but we must give up distributivity. Graziani shows how Tarozzi argues against this perspective not so much defending the a priori character of logic, but by showing that every formal system is in fact bearer of an ontology. In particular, by following the road proposed by von Neumann and Birkhoff one will accept a subjectivist perspective. Graziani, however, shows that Tarozzi implicitly assumes Hilbert's notion of "formal"; while other perspectives in the analysis of the topic could lead to different results.

Rossella Lupacchini teaches logic and philosophy of science in Bologna and studied with Gino Tarozzi on the foundations of quantum mechanics, in particular by developing the logical and epistemological aspects of quantum computing. Rossella outlines Tarozzi's reflection on the reality of quantum waves, from the suggested experiments proposed in the eighties to detect them, to the most recent reflections on a new form of

complementarity between wave correlations and path detections (Auletta, Tarozzi, 2004a and b). In particular, she develops a relational conception of quantum waves, rather than substantive, showing how this perspective fits in well with the elusive nature of quantum phenomena. So realism is not incompatible with quantum mechanics, if one accepts to introduce non-separable real relational properties into the ontology of the theory.

Flavia Marcacci is completing her PhD work with Gino Tarozzi in History of science. In her contribution she presents Gino's reflections on scientific instruments and their relation with theory. Thereafter she discusses briefly Gino's realistic attitude, in particular concerning quantum waves. Finally she reconsiders Gino's attempt to credit Tonomura's movie with epistemological value. Indeed in the film it is possible to see at the same time a corpuscular and wavelike character of particles. Flavia evaluates in which sense it is possible to judge movie as a scientific instrument.

As I said, Gino worked for many years at the Institute for Cultural Heritage of the Emilia Romagna Region. And there too he was able to seize the opportunity to create a fruitful field of investigation. He edited three books on the importance of measurement instruments for the conceptual understanding of science, one of which is in two volumes (Tarozzi 1983, 1985a and 1985b, and Tarozzi van Vloten, 1989). In those years among his teachers and cultural landmarks there was the great historian of science William Shea, now Galileo Professor Emeritus of the History of Science at the University of Padua. In his contribution to this volume Bill takes up Tarozzi's reflections on the importance of measurement instruments in the formation of the concepts of natural sciences. In particular, Shea, following Paolo Rossi, shows how at the base of scientific revolution there is also a re-evaluation of technology and how images of machines have influenced the scientific representation of the world. Until recently, in fact, the scientific view of the world seems to have embraced the idea that the universe is like a machine and not a body. This is perhaps one of the most profound breaks with the Aristotelian picture of the world. This type of representation was undoubtedly influenced by the connection between mathematics and technology that was established during the Renaissance from Descartes mechanistic world view.

Isabella Tassani concluded her PhD program with Gino Tarozzi and now she teaches history of science in Urbino. Therefore she is a direct student of Gino's, so much so that she has written several works with him

(Tarozzi, Tassani, 2001, 2007, and 2013). Tassani, in her contribution to this volume, takes into account the notion of causality, focusing in particular on the utopia of a causal explanation of the world since the advent of quantum mechanics. She traces the origins in the Renaissance of this ideal, particularly in the thought of Thomas More and Francis Bacon; then she outlines the modern critique of this concept from Hume to Russell and Norton, based on the empirical irrelevance of the concept. Eventually she shows how Tarozzi has proven that causality can be empirically meaningful, by setting up an empirical dialogue between different forms of the principle of causality and quantum mechanics, which is substantially either a trivialization or a refutation of the first. Lastly, according to Tarozzi the dream of a causal explanation of microphysical phenomena should not be abandoned.

I thank the *Scuola di filosofia della conoscenza* of Urbino University, who contributed for the publication of the volume and my daughter Francesca, who prepared scrupulously the camera ready of the book. All papers except one use for reference the Author-data system. Shea's paper puts references directly in footnotes, since it is a detailed historical analysis.

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An oudenepistemological paradox revisited

Alexander Afriat

It does not seem unsuitable, in a volume dedicated to Gino Tarozzi, to revisit ideas from Afriat & Tarozzi (2004, 2006).

Suppose we have an appropriate particle which could be *here* ¦ or *there* ¯ (since it cannot be split, leaving it partly here *and* there); if it's here $\left(\left|1^{¦}\right\rangle\right)$ it isn't there $\left(\left|0^{¯}\right\rangle\right)$, and the other way around[1] $\left(\left|0^{¦}\right\rangle\left|1^{¯}\right\rangle\right)$. The trouble is that (provided certain conditions are satisfied) the two possibilities are *superposed* $\sim\left|1^{¦}\right\rangle\left|0^{¯}\right\rangle+\left|0^{¦}\right\rangle\left|1^{¯}\right\rangle$ with physically significant phase factors arg α and arg β. We can choose a phase difference of π = arg (–1) = arg β – arg α, and suppose that the moduli of α and β are the same (and equal to $1/\sqrt{2}$, for normalization):

$$\left|\cdot\right\rangle=\frac{1}{\sqrt{2}}\left(\left|10\right\rangle-\left|01\right\rangle\right).$$

The statistical significance of the phase relation means that the two products are physically related, and communicate with one another. How could there be genuine, effective physical interaction (interference) between a real product and a merely fictitious one? The physical significance of the relation $R\left(\left|10\right\rangle,\left|01\right\rangle\right)$ suggests that *both* of the relata $\left|10\right\rangle\,\&\,\left|01\right\rangle$ related by *R* are really there, not just one of them; neither one can be entirely discarded.

In a sense Gleason's theorem, which tells us that different states are statistically distinguishable, already tells us that phase – without which the state cannot be fully characterized – is bound to be significant. The statistical significance has to be revealed by an appropriate observable,

1. I'll sometimes just write $\left|01\right\rangle$ or $\left|10\right\rangle$, without the superscripts.

which is *sensitive*[2] to coherence in the tensor product space $\mathfrak{H} = \mathfrak{H}^{\dagger} \otimes \mathfrak{H}^{-}$. We know that if the observable $A : \mathfrak{H} \to \mathfrak{H}$ is the product $A^{\dagger} \otimes A^{-}$ of an observable $A^{\dagger} : \mathfrak{H}^{\dagger} \to \mathfrak{H}^{\dagger}$ here and an observable $A^{-} : \mathfrak{H}^{-} \to \mathfrak{H}^{-}$ there it will be indifferent to the phase relation, in the sense that a mixture (namely $\circ = \left(|10\rangle\langle 10| + |01\rangle\langle 01|\right)/2$ of products can be found with the same average tr(ρA) =tr(P_{ψ}A) as $|\cdot\rangle$, where the operator P_{ψ} projects onto the ray determined by $|\cdot\rangle$. So the observable itself will have to entangle observables in $\mathfrak{H}^{\dagger}$ and $\mathfrak{H}^{-}$ for it to be sensitive to entangled states, in other words to coherence in the product space $\mathfrak{H}$.

A sensitive observable can be constructed as follows. There will be an orthonormal basis $|0^{\dagger}\rangle, |1^{\dagger}\rangle$ here, and a similar one there. We will need states[3]

$$|\pm\rangle = \frac{1}{\sqrt{2}}\left(|0^{\dagger}\rangle \pm |1^{\dagger}\rangle\right)$$

here and states

$$|\theta, \pm\rangle = \frac{1}{\sqrt{2}}\left(\cos\frac{\theta}{2}|0^{-}\rangle \pm \sin\frac{\theta}{2}|1^{-}\rangle\right)$$

there, and self-adjoint operators

$$\pm^{\dagger} = |1^{\dagger}\rangle\langle 1^{\dagger}| - |0^{\dagger}\rangle\langle 0^{\dagger}|$$

$$\pm = |+\rangle\langle +| - |-\rangle\langle -|$$

here and

$$\theta_{\pm} = |\pm, +\rangle\langle \pm, +| - |\pm, -\rangle\langle \pm, -|$$

there, to define the operator

$$S_{\theta} = \pm^{\dagger} \otimes \theta_{+} - \pm^{\dagger} \otimes \theta_{-} + \pm \otimes \theta_{+} + \pm \otimes \theta_{-}.$$

Since tr($P_{\psi}S_{\pi/4}$) = $2\sqrt{2}$ is note equal to tr($\rho\ S_{\pi/4}$) = 2 the operator $S_{\pi/4}$ represents a sensitive observable, which can 'see' coherence by telling $|\cdot\rangle$ and ρ apart. The observable $\pm^{-} = |1^{-}\rangle\langle 1^{-}| - |0^{-}\rangle\langle 0^{-}|$ represents the

2. Capasso *et al*. (1973), Fortunato & Selleri (1976).
3. The presence or absence of superscripts will henceforth be more important.

presence or absence of the particle *there*. Its average $\sim = \langle \cdot \,| I \otimes \pm^{-} | \cdot \rangle$ for state $|\cdot\rangle$ vanishes, unlike the averages

$$\sim_0 = \langle 10 | I \otimes \pm^{-} | 10 \rangle = -1$$

$$\sim_1 = \langle 01 | I \otimes \pm^{-} | 01 \rangle = +1$$

for the two terms superposed in $|\cdot\rangle$. If we look for the particle here without finding it, the superposition will be reduced to its second term $|01\rangle$, while the average of σ^{θ} jumps from 0 to +1. Everything here will turn on this jump, and how to interpret it. The trouble is that in standard quantum mechancs this average has real – ontic, not just epistemic – meaning; so the jump in σ^{θ} will be correspondingly real, and more than just an acquisition of knowledge, an information jump, a mere update. For it may be thought that the following happens: first we are in a state of balanced ignorance, expressed by α, in which we have no idea where the particle is. Once we discover that the particle is there, by looking for it here, we overcome that ignorance, and to update our previously imperfect knowledge replace α by the certainty expressed by α^1. So only one of the two terms in $|\cdot\rangle$ is really present in nature, only we do not know which one until we look. But how can a fictitious, physically absent possibility be statistically relevant? Both terms must therefore be present in nature, which means that the average α, the quantity σ^{θ}, and the jump are all real and not just epistemic.

The jump takes place once we have found out that the particle is not here. One can wonder about the nature of this 'discovery'. Physically it would appear that very little need be involved; for only an *absence* is being established, a void or vacuum is being found. The jump is temporally circumscribed, in fact we can say that it takes place at a certain time τ, when the discovery is made here. But what does the discovery involve? What is it that happens at time τ here, that causes the jump there? Is it an *awareness* of the absence? A *perception* of the void? A *realization* or *understanding* that there's nothing here? Do we have to *take down* the null result? *Register* it? *Tell a friend*?[4] *Poison a cat*?[5]

Three possibilities come to mind. The effect could be due to

1. the physics of measurement
2. the neurophysiology of knowledge acquisition
3. the (nonphysiological) mysteries of knowledge and the soul.

4. Wigner (1962).
5. Schrödinger (1935).