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ON QUANTUM PROPENSITIES: TWO ARGUMENTS REVISITED

ABSTRACT. Peter Milne and Neal Grossman have argued against Popper's propensity interpretation of quantum mechanics, by appeal to the two-slit experiment and to the distinction between mixtures and superpositions, respectively. In this paper I show that a different propensity interpretation successfully meets their objections. According to this interpretation, the possession of a quantum propensity by a quantum system is independent of the experimental set-ups designed to test it, even though its manifestations are not.

1. POPPER'S PROPENSITY INTERPRETATION

Karl Popper's propensity interpretation of quantum mechanics is arguably his most important contribution to the philosophy of physics. It is clear that Popper conceived the propensity interpretation of quantum mechanics as both a milestone of his philosophical career, and a key to his philosophical system. He defended it in a large number of his writings, and over a very long period of time (Popper 1957; 1959; 1963; 1967 and 1982). It was a milestone since it was a consideration of the nature of quantum phenomena that led him to abandon the frequency theory of probability, and adopt instead a propensity interpretation for objective probabilities in general. As he wrote:

> The interpretation of the two-slit experiment ... ultimately led me to the propensity theory: it convinced me that probabilities must be "physically real" – that they must be physical propensities, abstract relational properties of the physical situation, like Newtonian forces, and "real", not only in the sense that they could influence the experimental results, but also in the sense that they could, under certain circumstances (coherence) interfere, i.e., interact, with one another. (Popper 1959, p. 28)

The propensity interpretation was supposed to be a key to Popper's philosophical system since it (i) resolved the paradoxes of quantum mechanics; (ii) re-established the possibility of a thoroughly realist interpretation of the quantum theory, of physics, and of science in general; and (iii) provided strong empirical confirmation in

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favour of the propensity interpretation of the calculus of probability. The following passages illustrate some of these convictions:

> The main argument in favour of the propensity interpretation is to be found in its power to eliminate from quantum theory certain disturbing elements of an irrational and subjectivist character ... it is by its success or failure in this field of application that the propensity interpretation will have to be judged. (Popper, *op.cit.*, p. 31).

> A statement about propensity may be compared with a statement about the strength of an electric field ... And just as we can consider the field as physically real, so we can consider the propensities as physically real. They are *relational* properties of the experimental set-up. For example, the propensity 1/4 *is not a property of our loaded die*. This can be seen at once if we consider that in a very weak gravitational field, the load will have very little effect – the propensity of throwing a 6 may decrease from 1/4 to very nearly 1/6. In a strong gravitational field, the load will be more effective and the same die will exhibit a propensity of 1/3 or 1/2. (Popper 1957, p. 68).

> The main thing about the propensity interpretation is that it takes the mystery out of quantum mechanics... It does so by pointing out that all the apparent mysteries would also involve thrown dice, or tossed pennies ... exactly as they do electrons. In other words, it shows that quantum theory is a probability theory just as any other game of chance. (Popper, *op.cit.*, p. 68).

> ...it seems to me that ... these probabilities (propensities) whose amplitudes can interfere should be conjectured to be *physically real, and not merely a mathematical device* ... [...] The laws of superposition express real probabilistic dependence. I therefore think that the way quantum mechanics differs fundamentally from classical physics – that is, in the interference of the propensity waves – shows that the propensity waves can interact and are therefore real. This is a powerful argument for the existence of propensity fields. (Popper 1967, pp. 83–84).

From these passages we can extract the following five theses which, I believe, constitute the heart of Popper's propensity interpretation:

(Thesis 1) Propensities are real properties instantiated in the quantum world.

(Thesis 2) Propensities are not monadic properties of quantum systems, but relational properties of the entire experimental set-ups that test them. A one-electron universe would lack any propensities: these can only be ascribed to particles in conjunction with whole experimental set-ups, including measurement devices, designed to test them.

(Thesis 3) Quantum theory is essentially a probabilistic theory, in the sense that it is a theory about the probabilities that certain outcomes obtain in certain experimental set-ups.

(Thesis 4) The quantum wave-function, or quantum state, is a description of a *propensity wave* over the outcomes of an experimental set-up.

(Thesis 5) Providing an objective interpretation of the probabilities in quantum mechanics in terms of propensities is sufficient to solve the philosophical puzzles concerning quantum mechanics.

My main claim in this paper is the following: Popper's five theses are not independent of what *type* of propensity interpretation one may give to quantum theory: it is possible to provide propensity interpretations for quantum mechanics that do not satisfy some or even all these theses. I explain the basic elements of one such interpretation, in terms of *quantum selections*, in Sections 4 and 5 of this paper. In the next two sections, I explain the kind of criticisms that Popper's interpretation has been subjected to. I focus on two in particular – due to Peter Milne and Neal Grossman respectively – because they capture what I take to be the essential objections. Then, in Sections 4 and 5, I go on to develop an alternative propensity interpretation that, I argue, can overcome Milne's and Grossman's objections.

2. MILNE'S ARGUMENT

I have emphasised above that Popper ascribes special importance to the two-slit experiment. It was this experiment that led him to the propensity interpretation in the first place. However, as Peter Milne has argued (Milne 1985, p. 66): "... the propensity interpretation of the probability calculus, as expounded by Popper, cannot shed any light on the two-slit experiment". Milne's argument is effective against a propensity interpretation which, like Popper's, takes propensities to be relational properties of whole experimental arrangements. The argument is surprisingly compact so we can review it in detail.

In a two-slit experiment quantum particles are allowed to pass through a screen with two slits a and b on it, and registered on a final scintillating screen. The experiment can be performed with slit b closed (experimental arrangement "A"), with slit a closed (experimental arrangement "B"), or with both slits open (experimental arrangement "C"). Unexpectedly from a classical point of view, the distribution of registered position measurements on the further screen in experimental arrangement C does not correspond statistically to the sum of the distributions observed in experiments A and B; instead, a typical interference pattern is observed. And quantum theory predicts accurately each of these three probability distributions, P_a, P_b, P_c including, crucially, the interference distribution P_c observed in experimental arrangement "C". Figures 1, 2, 3 represent arrangements A, B, C respectively.

Now according to Popper's theses (1–5), the probability distributions P_a, P_b and P_c are to be thought of as real propensity waves – each being a relational property of experimental arrangements A, B and C respectively. The interference distribution P_c is to be explained as the result of the physical interaction between the real propensities corresponding to P_a and P_b. This is precisely what will "take the mystery out of quantum mechanics". However, since Popper asserts

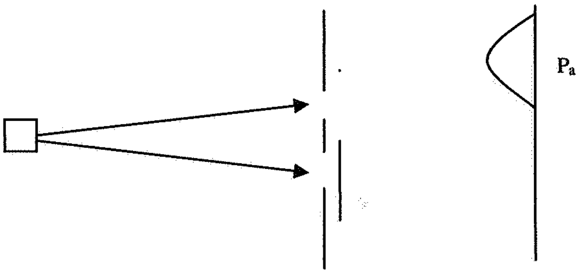

Fig. 1. Experimental arrangement "A".

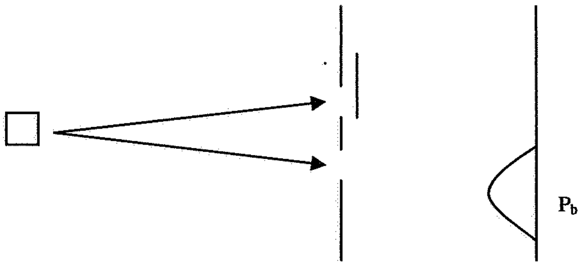

Fig. 2. Experimental arrangement "B".

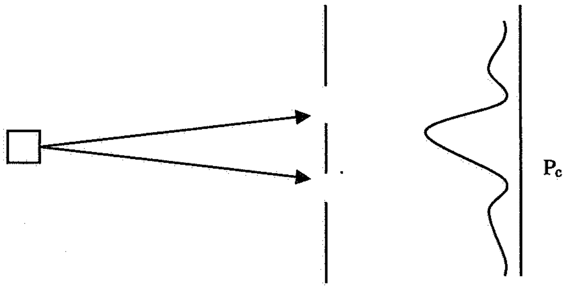

Fig. 3. Experimental arrangement "C".

that propensities are properties of whole experimental arrangements, this amounts to the requirement that the experimental arrangements A and B be co-present in experimental arrangement C. Since A and B cannot be co-present in C as *whole* experimental arrangements, they must be partial specifications – i.e., descriptions of *parts* of C. Milne argues persuasively (Milne, *op. cit.*, pp. 68–69) that this is impossible, since A, B and C are contradictory. A and C contradict each other on whether slit *b* is closed or open; B and C contradict each other on whether slit *a* is closed or open, and A and B contradict each other regarding both slits *a* and *b*.

The alternative, which Milne considers and quickly rejects, is to think of P_c as the result of the interference of two compatible arrangements A′ and B′, each giving rise to P_a and P_b *in the experimental arrangement C*. For instance, A′ could be the arrangement that specifies that slit *a* is to be open but remains silent about slit *b*; while B′ could be the arrangement that specifies that slit *b* is open, but remains silent about slit *a*. The problem with this response is that there is no reason to suppose that P_a, P_b would be the observed distributions in the rather different arrangements A′ and B′. These arrangements are not equivalent to A and B. Thus, according to Milne, we can not make sense of the statement that P_a, P_b are real properties of distinct whole experimental arrangements that physically interfere in experimental arrangement C in order to generate P_c. This seems to undercut Popper's argument in favour of the propensity interpretation, in precisely the context that motivated and gave rise to it.

3. GROSSMAN'S CRITIQUE

Neal Grossman presented a different argument against Popper's propensity interpretation (Grossman 1972). It is in particular directed against theses (3–5). Grossman argues that to take quantum theory to be about probabilities, and to understand the wavefunction as describing a propensity wave, is tantamount to equivocating superpositions with mixtures, which in turn means that the propensity interpretation can not help to solve the conceptual problems of quantum mechanics.

Grossman uses the example of a quantum particle in an infinite one-dimensional potential well with a state given by the wavefunction: $\psi=(1/\sqrt{2})\ U_1 + (1/\sqrt{2})\ U_2$; with $U_n=\sqrt{(2/L)}\ \sin(n\pi x)/L$, where L is the width of the potential well. What is then the probability of finding, on a measurement of position, the particle in the first quarter of the well? Grossman points out that there are two ways to approach this problem. We may:

> (a) … find the probability of finding the particle in the first quarter of the well for each U_n, multiply the two probabilities, and sum over all n; or (b) evaluate $\int_0^{L/4} \Psi\Psi^* dx$ directly. (Grossman 1972, p. 453).

If quantum theory is a theory about probability, it should make no difference which route we follow, as long as we employ properly the axiom of conditional probability. But note that route (a) entails the ignorance interpretation of ψ: what it means for a system to be in a pure superposition ψ is that the system is in either of the pure states that compose it with a certain probability. However, the ignorance interpretation of superpositions, unlike that of mixtures, has long been discarded.[1]

Suppose that we follow the former route. The probability that a particle in state Ψ is found in state U_1 is $\frac{1}{2}$, as is the probability that it be found in state U_2. What is then the probability that it be found in the first quarter of the potential well, given that it is found in U_1? That is, what is the value of $P(L_{1/4}/U_1)$? This is given by the integral:

$$\int_0^{L/4} U_1^* U_1 \, dx = \int_0^{L/4} 2/L \sin^2(\pi x/L) \, dx = 0.091.$$

Hence

$$P(U_1 \& L_{1/4}) = P(L_{1/4}/U_1)P(U_1) = 0.045$$

Similarly for:

$$P(U_2 \& L_{1/4}) = P(L_{1/4}/U_2)P(U_2) = 0.125$$

And hence, assuming U_1 and U_2 are mutually exclusive:

$$P(L_{1/4}) = P(U_1 \& L_{1/4}) + P(U_2 \& L_{1/4}) = 0.045 + 0.125 = 0.17$$

The direct route, on the other hand, gives the following result:

$$\begin{aligned} P(L_{1/4}) &= \int_0^{L/4} \Psi^* \Psi dx = \int_0^{L/4} 1/2(U_1 + U_2)^*(U_1 + U_2) dx \\ &= P(U_1 \& L_{1/4}) + P(U_2 \& L_{1/4}) + \int_0^{L/4} U_1 U_2 dx \\ &= 0.045 + 0.125 + 0.15 = 0.32. \end{aligned}$$

Thus routes (a) and (b) differ. Route (a) assumes that since the particle has a definite probability of being in either state U_1 or U_2, we must calculate all other probabilities conditional on the particle actually being in either of these states. The correct predictions, however, are given by route (b), which is the one recommended by quantum mechanics.

Grossman draws two lessons from this. He first writes that "quantum mechanics *cannot* be reduced to probability. For the latter is applicable to an ensemble if and only if the individuals of the ensemble have definite (albeit unknown) values." (Grossman, *op.cit.*, p. 454). Indeed, Grossman's example brings out an uncomfortable tension between Popper's thesis (3) and the other theses. For if the theory is just about probabilities, how can it in addition describe the propensities, or dispositional properties, that underlie and explain those probabilities? Or are these two (probabilities and propensities) not distinct? This is a thorny issue in the metaphysics of dispositional properties, and I will return to it; but the most satisfying answer by far is that they must be distinct: propensities are precisely meant to explain the occurrence of the probabilities that correspond to the observed frequencies.

The second lesson that Grossman rightly draws from the example above is that merely interpreting (as propensities or as anything else) the probabilities that appear in quantum mechanics will not suffice to solve the paradoxes of quantum mechanics. The source of the paradoxes of quantum mechanics is that the probabilities calculated by routes (a) and (b) differ; and no interpretation of these probabilities, whether objective or subjective, will see such differing predictions converge.

4. QUANTUM SELECTIONS: A NEW PROPENSITY INTERPRETATION

In this Section I sketch a formalism for interpreting quantum mechanics that refers to quantum dispositional properties, and in turn suggests a new propensity interpretation of quantum mechanics. The formalism is based on the notion of a quantum *selection.*[2] This is an interaction of the pointer position observable of a measurement apparatus with a dispositional property of a quantum system. Each physical observable of a system in a specific quantum state ψ defines a probability distribution relative to that state. Such a probability distribution exemplifies the propensity, or dispositional property, of the system. Among the dispositional properties I include those responsible for values of position, momentum, spin and angular momentum. We can represent such dispositional properties by means of what Fine calls the *standard representative*. Consider the following definition of the equivalence class of states relative to a particular observable O:

O-equivalence class: $W' \in [W]_O$ if and only if $\forall W' \in [W]_O$: Prob $(W, O) =$ Prob (W', O), where Prob (W, O) stands for the probability distribution defined by W over all the eigenvalues of O.

Suppose that O is a discrete and not maximally degenerate observable of the system with spectral decomposition given by $\Sigma_n \lambda_n P_n$, where $P_n = \mathrm{P}_{[\phi n]} = |\phi_n\rangle \langle\phi_n|$. We can construct the *standard representative* $W(O)$ of the equivalence class $[W]_O$ as follows:

$$W(O) = \Sigma_n \mathrm{Tr}(\psi P_n) W_n, \qquad \text{where } W_n = P_n/\mathrm{Tr}(P_n).$$

It is now possible to make the following claim: for a given system in a state ψ, and a given observable O of this system, if ψ belongs to the equivalence class $[W]_O$, then $W(O)$ represents precisely the dispositional property O of the system.

A selection of observable O of a specific quantum system in state ψ is then a quantum mechanical interaction (of e.g. the pointer position observable of a measuring device) with the specific dispositional property of the system represented by $W(O)$; an interaction of some property of a macroscopic object with a dispositional property of a quantum object. Each dispositional property is *displayed* as a particular probability, or chance distribution, in each distinct test condition, or experimental arrangement.

Hence, these properties are *propensities* in the sense of Mellor (1974, pp. 70–82), who appropriately distinguished between chance distributions, or objective probabilities, and propensities. (No further commitment to any other aspects of Mellor's theory is hereby intended.) Both are theoretical entities, which go well beyond what can be observed – i.e. well beyond the observed frequencies. But while a chance distribution is a statistical expectation in a long term trial of some particular experimental set-up, a propensity is a property of a system, or systems, that gives rise to the chance distribution and thus might be said to explain it. In other words while the chance distribution might be inferred inductively from the observed relative frequencies, in the form of a particular probability distribution, the ascription of the propensity can only be inferred abductively from the chance distribution, or perhaps even only conjectured.

Now let us suppose that all quantum measurements are selections: in a measurement the pointer position property of the device interacts with only one property of the system, represented by $W_o(O)$. Fine (1987, 1992) employed this fact to solve the measurement problem: If the initial state that feeds into the Schrödinger equation could be construed as the appropriate mixture over the eigenstates of the object observable, the final state of the composite resulting from Schrödinger evolution would satisfy all the necessary conditions on a measurement having an outcome.

Consider the two-slit experiment again, where we typically describe the state of the particle as it passes the first screen by means of distinct eigenstates, ϕ_1 and ϕ_2, of a two-dimensional non-degenerate observable O, with distinct eigenvalues λ_1 and λ_2 respectively. ϕ_1 is the state of a particle that goes through the first slit, while ϕ_2 is the state of a particle that goes through the second. We are then asked to consider three O-distinguishable states, ϕ_1, ϕ_2 and ϕ_3, where ϕ_3 is the linear combination $\psi = 1/\surd 2\ \phi_1 + 1/\surd 2 \phi_2$. ψ represents the state of a particle in a superposition with respect to the slits in the first screen (or more properly, a complex state of the composite particle + first screen; see endnote 7 below). Given ϕ_3 and the spectral decomposition of $O = \lambda_1\ P_{[\phi 1]} + \lambda_2\ P_{[\phi 2]}$, we can construct the standard representative of ϕ_3's O-equivalence class, namely the mixed state: $W_o(O) = 1/2\ P_{[\phi 1]} + 1/2\ P_{[\phi 2]}$. According to the selections approach if we have set-up a measuring device to test for O (i.e. a detector on each slit in the first screen), then we must employ the mixed state representation to calculate the probabilities for the particle to land at the further screen. If, on the other hand, we set-up a measuring device to test for the position of the particles in the final screen then we must use the full state superposition, for only that state describes the interaction between the particle's propensities as it passes through the first screen.

The quantum propensities that selections interact with are also very similar to Healey's *dispositional probabilities* (Healey 1989).[3] But there are also some important differences. Like Healey the selections approach takes it that the manifestation of a quantum disposition is essentially probabilistic, because the application of Born's rule does not typically yield precise values, but precise *probabilities* for values. But selections go further than Healey since they ascribe a dispositional property ("momentum", "position", "spin", etc.) over and above the probability distribution in question, a dispositional property that can be ascribed to the system even if the system has no actual value.

An electron, for instance, possesses a momentum-propensity – let us call it "momentum" – which is displayed only in the appropriate selection; but the electron typically lacks a specific value of momentum (its wavefunction will rarely be sufficiently peaked in momentum space). The possession of "momentum" by the electron is "unconditional", in the terminology of Martin (1994) and Mumford (1998, p. 21): the electron possesses it in the actual world, just like any ordinary object possesses any of its categorical properties. This is perfectly consistent with the electron never in its lifetime acquiring a specific value of momentum; for in the absence of the appropriate selection a propensity may never display itself, or become manifest – just as a fragile glass may never break. Hence we are adopting a sufficiently robust sense of propensities, that takes them to be possessed by systems even when the test conditions required for their manifestation fail to obtain.[4]

A slightly more careful formulation would demand the ascription of two distinct properties: "spin", which would obtain when and only when a value of spin obtains, and – let us call it – "spinable", which would be the dispositional property that obtains regardless. "Spinable" would then be analogous to the dispositional "fragility", and "spin" to the categorical "breaks". The possession of "spinable" would explain the occurrence of "spin", but the dispositional property would not be reducible to the categorical. However, we may want to keep our ontology as simple and as close to practice as possible. Physicists certainly do not ascribe two distinct properties; it is simpler to assume just one dispositional property which obtains always regardless of whether it is manifested.

5. AVOIDING MILNE'S ARGUMENT AND GROSSMAN'S CRITIQUE

5.1. *The Propensities of Selections*

I now want to argue that the propensity interpretation of selections is able to avoid both Milne's and Grossman's arguments against Popper's interpretation. The propensity interpretation of selections shares with Popper's interpretation an emphasis on the quantum probability distribution as the basis for the ascription of dispositions. To the extent that propensities can be defined as probabilistically quantified dispositional ascriptions, the selections account is also a propensity-based one. However, the similarities end there. The selections account either denies or is non-committal about Popper's thesis 1–5. Instead, on the selections approach,

1. Propensities may well be real properties instantiated in nature, but they may also be analysed as true law like conditional statements, whose antecedents stipulate test-conditions sufficient for the manifestation of the propensity (i.e., experimental set-ups that give rise to the observed probability distributions).
2. Propensities are inherently relational only in the sense that they require a measurement set-up in order to *manifest* themselves in the form of probability distributions; the *ascription* of the propensity that yields and explains such manifestations is not necessarily relational though. A one-electron system may possess such propensities, even if the universe contained only this electron, and there were no possible way for the electron to manifest its propensities.
3. Quantum theory is not an essentially probabilistic theory, in the sense that it is not a theory only of the probabilities that certain outcomes obtain in certain experimental set-ups, but also of the dispositional properties that underlie and explain these probabilities.
4. The quantum wavefunction, or state, is a very economical way to represent all the possible manifestations of underlying quantum propensities, but it does not itself represent any real property.
5. Simply providing an objective interpretation of the probabilities as propensities can not be enough to solve the philosophical puzzles concerning quantum mechanics. In order to do this, a new theory of quantum measurement interactions in terms of selections must be provided.

5.2. *Response to Milne's Argument*

Milne's argument essentially depends on the relational character of Popperian propensities, as properties of experimental set-ups. However, on the selections approach propensities are not relational properties of experimental set-ups, and might well be monadic properties of individual isolated systems.[5] What will at any rate be relational is the manifestations of quantum propensities, which will be displayed in the form of probability distributions over measurement outcomes of particular measuring devices in experimental set-ups.

In other words, a particle in a two-slit experiment possesses exactly the same propensities regardless of whether one slit only is open, or both are open, or both closed; it is the probability distributions over position measurements of the particle at the further screen that *are* dependent upon the experimental arrangement. Hence we may suppose a particle to have two distinct propensities to land at any point of the screen having gone through slit A, or slit B; let us refer to them as propensity A_p, and propensity B_p. The measuring device is then the second screen, against which position is measured.

In experimental arrangement "A" (see Figure 1), the measuring device interacts only with the propensity of the particle to land in a particular region of the screen, having gone through the upper slit (propensity A_p). Thus P_a does not represents this propensity, but rather the probability distribution that *in this particular arrangement* displays this propensity. Similarly P_b represents the probability distribution that in arrangement "B" (Figure 2) displays the propensity of the particle to land in any point on the screen, having gone through the lower slit (propensity B_p). In arrangement "A", B_p is displayed by a zero probability distribution everywhere, as is A_p in arrangement "B"; since by definition the measuring device in arrangement "A" does not interact with, and cannot measure, B_p; while in arrangement "B", the measuring device does not interact with, and cannot measure A_p.

In arrangement "C" by contrast the measuring device interacts with both A_p and B_p and gives rise to a different display, P_c. There is nothing however in this picture that suggests that P_c ought to be the sum of P_a and P_b. The interaction of the measuring device in "C" is not with A_p and B_p separately but jointly, and therefore tests not only A_p or B_p, but also their mutual interaction.[6] Since there has been no separate test for A_p and B_p, according to the selections approach, the full superposed state must be used to calculate the resulting state of the particle in hitting the latter screen. This yields the interference pattern probability distribution, P_c.

The important point throughout is that the possession of the different propensities A_p and B_p by the particle is unconditional, i.e. independent of whether the arrangement is "A", "B" or "C", or indeed on whether there is any experimental arrangement at all. [7] We may then suppose that P_a, P_b and P_c are all displays of the same set of propensities in three completely different and independent test-conditions or experimental set-ups. There is absolutely no need to suppose that arrangements "A" and "B" must be *co-present* in arrangement "C"; nor is there reason to expect this; and it was precisely this supposition that gave rise to Milne's contradiction.

The propensity interpretation of selections is thus able to show in what way Popper's statement to have resolved the two-slit paradox by means of propensities is correct. Popper was in a sense right to claim that the propensity interpretation could resolve the paradox; he was wrong, however, as Milne precisely pointed out, to think that relational propensity ascriptions to whole experimental set-ups would do the job.

5.3. *Response to Grossman's Critique*

Grossman's example is a quantum particle in an infinite one-dimensional potential well with a state given by the wavefunction: $\psi=(1/\sqrt{2})\ U_1 + (1/\sqrt{2})\ U_2$; with $U_n=\sqrt{(2/L)}\ \sin\ (n\pi x)/L$, where L is the width of the potential well. What is then the probability of finding, on a measurement of position, the particle in the first quarter of the well? Let us employ the selections formalism in order to answer that.

The localisation measurement may be modelled as a selection of the property of the particle that is responsible for its being localised in the first quarter of the potential well. We first need to write down the spectral decomposition of the operator we are interested in, namely $L_{1/4}=\Sigma_n\ \lambda_n\ P_n$, where $P_n=P_{[\phi n]}=|\phi_n\rangle\ \langle\phi_n|$. We are then able to construct the *standard representative* $W(L_{1/4})$ of the equivalence class $[W]_{1/4}$ as

$$W(L_{1/4}) = \Sigma_n \mathrm{Tr}(\psi P_n) W_n, \qquad \text{where } W_n = P_n/\mathrm{T}r(P_n).$$

According to the selections approach $W(L_{1/4})$ represents the propensity of the particle to be found, on a measurement of the particle's position, in the first quarter of the potential well. The selections approach then recommends using this state to model the localisation process. Whatever form the $\{W_n\}$ take, and whatever the interaction Hamiltonian set-up between this particle and an appropriate measuring device one thing is certain: by construction $W(L_{1/4})$ is statistically indistinguishable from ψ with respect to the observable $L_{1/4}$. Hence the probability of finding the particle in the first quarter of the potential well must necessarily be given by Grossman's *direct route* expression (route b):

$$P(L_{1/4}) = \int_0^{L/4} W(L_{1/4})^* W(L_{1/4}) dx = \int_0^{1/4} \Psi^*\Psi dx$$

This is indeed the correct quantum mechanical expression. Grossman shows however that commitment to the reality of the probability function as a propensity wave leads to a different calculation, via a different route (a). What might motivate, on the selections approach, using this alternative route, via the conditional probabilities, which Grossman rightly rejects? That route involves a prior measurement on the system in order to find out whether the state of the system is really U_1 or U_2; and then finding out, by conditional probabilities, what the overall probability is of subsequently finding the particle in the first quarter of the potential well.

According to the selections approach, however, the prior measurement counts as a distinct selection of its own, and modelling it appropriately would require using its own distinct standard representative, which will necessarily diverge from $W(L_{1/4})$. It is not surprising then that the results in both cases diverge: they *must* diverge, or there would be something seriously wrong with selections! For in one case (route b) we are selectively interacting with a particular propensity $W(L_{1/4})$ directly, in order to test that dispositional property and no other; while in the other case (route a) prior to testing that propensity we have first interacted with the system in order to test an altogether different propensity – which has changed the whole set of properties of the system. (In just the way in which it is customary to say that a chemical interaction of a particular kind with a glass may well result in the glass losing its fragility).

6. CONCLUSIONS

To sum up, the propensity interpretation of selections very naturally avoids both Milne's and Grossman's arguments. This shows how markedly different the propensity interpretation of selections is from Popper's own propensity interpretation of quantum mechanics. But it also serves to vindicate one of Popper's basic intuitions, albeit in a rather distinct and weaker form, that the use of propensities can help to solve the paradoxes of quantum mechanics.

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NOTES

[1] See e.g. Cartwright (1974).

[2] *Selections* are an extension of the *selective interactions* first introduced by Arthur Fine (1987). I define selections, and show how to employ them in order to solve the measurement problem in Suárez (2004).

[3] In fact, the selections approach is perhaps best understood on a version of a modal interpretation with a propensity state added onto the value and dynamical states (see Suárez 2004 section 7.3).

[4] In agreement with the theories of Martin (1994), Mellor (1974, 2000) and Mumford (1998). One difference with Mumford's theory, however, is that the selections interpretation does not need to go as far as to rule out empiricist conditional analyses of propensities, as long as those analyses are sophisticated enough to allow for the ascription of propensities to systems that have never and will never be tested for their manifestations. It seems to me that any conditional analysis that is worthy must allow this, and Mellor (2000) provides an useful attempt in that direction.

[5] This is not intended to rule out holistic relational propensities, i.e. dispositional properties of arrays of systems that cannot be reduced to the properties (dispositional or otherwise) of their constituent systems. It is only intended to deny that propensities can only be ascribed to whole experimental set-ups that test them.

[6] The discussion in terms of A_p and B_p simplifies what would otherwise be a more complicated treatment in terms of position and momentum propensities of the particle as it goes through the first screen.

[7] This point requires a careful formulation. The usual treatment of the two-slit experiment takes it that the state of the particle itself depends on the state of the two-slit screen; a particle can be in one of the two eigenstates of the observable "having gone through slit A and not through B", or in a superposition of both. Hence, according to this usual treatment, the measuring device measures not the state of the particle at the source, but the state of the composite system (particle + two-slit screen) at the time the particle reaches the two-slit screen. Milne's argument ignores this nuance, and assumes instead that the measuring device simply interacts with the particle. I have followed Milne's assumption for the sake of consistency and simplicity, since it makes no difference either to Milne's objection against Popper, or to my argument in favour of the selections approach. Nothing would change substantially if the term "particle" was replaced with "particle and first screen" throughout the main text.

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