Maudlin's Challenge Refuted:
A Reply to Lewis

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ABSTRACT. Lewis has recently argued that Maudlin's contingent absorber experiment remains a significant problem for the Transactional Interpretation (TI). He argues that the only straightforward way to resolve the challenge is by describing the absorbers as offer waves, and asserts that this is a previously unnoticed aspect of the challenge for TI. This argument is refuted in two basic ways: (i) it is noted that the Maudlin experiment cannot be meaningfully recast with absorbers described by quantum states and (ii) the extant rebuttals to the Maudlin challenge in its original form are not in fact subject to the alleged flaws that Lewis ascribes to them. This paper further seeks to clarify the issues raised in Lewis' presentation concerning the distinction between quantum systems and macroscopic objects in TI. It is concluded that the Maudlin challenge poses no significant problem for the transactional interpretation.

1. Introduction and Background

In Lewis (2013), the author argues that the consistency of the Transactional Interpretation of quantum mechanics (TI) continues to face a significant threat from Maudlin's contingent absorber experiment (2002). While the author's interest in TI and related issues is very welcome, his discussion unfortunately contains quite a few errors and misconceptions. This paper will attempt to clarify some of these issues and to point out that the perception of a problem arises from apparent misunderstandings about TI, especially of its recent development in Kastner (2012a,b). In particular, the author's arguments do not take proper account of the current status of TI as an interpretation that has been fully extended into the relativistic domain, and which has clearly defined criteria for which systems can be considered offer waves and which cannot.

Maudlin developed his thought experiment as a specific challenge for John Cramer's original formulation of TI (Cramer 1986). Figure 1 illustrates the basic setup.

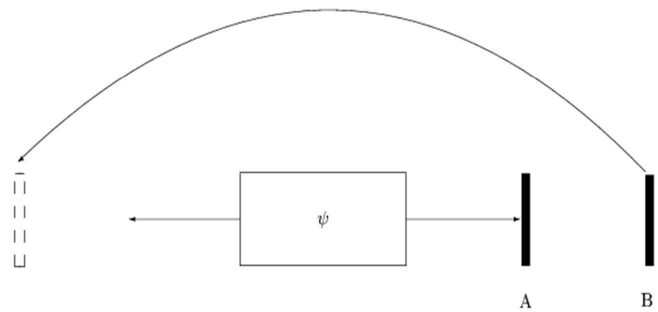

Figure 1: The Maudlin Experiment

As illustrated in Figure 1, a source emits massive (and therefore, Maudlin assumes, slow-moving) particles either to the left or right, in the state $|\Psi\rangle = \frac{1}{\sqrt{2}}\left[|R\rangle + |L\rangle\right]$, a superposition of 'rightward' and 'leftward' -propagating states. Offer wave components corresponding to right and left are emitted in both directions, but, in Maudlin's arrangement, only detector A can initially return a confirmation wave (since B is blocked by A). If the particle is not detected at A (meaning that the rightward transaction failed), a light signal is immediately sent to detector B, causing it to swing quickly around to intercept the particle on the left. B then is able to return a confirmation wave of amplitude $\frac{1}{\sqrt{2}}$. At this point, the particle is certain to be detected there, so Maudlin claims that the confirmation wave's amplitude of less than unity is evidence of inconsistency on the part of TI.

Maudlin's inconsistency claim has been rebutted by Kastner (2006, 2012b, Chapter 5) and Marchildon (2006) and Boisvert and Marchildon (2013). Lewis takes issue with these rebuttals, and argues that the only 'straightforward' way to resolve the challenge is to treat the absorbers as quantum systems. However, this approach fails to establish the author's claims; specific reasons will be discussed below. In addition, TI has been developed and elaborated by Kastner (2012a,b, 2014) into a fully relativistic interpretation with a possibilist ontology, the 'possibilist transactional interpretation' (PTI). This development makes much of Lewis's argumentation irrelevant. The irrelevant aspects depend on a misapplication of the transactional picture, in particular the assignment of offer waves (quantum states) to macroscopic objects that are not offer waves. In addition, the author characterizes the treatment of macroscopic objects in TI as 'murky,' while in fact this issue is disambiguated in Kastner (2012b, Chapters 6 and 7). In view of apparent ongoing confusion surrounding these issues, I will attempt to clarify that treatment of macroscopic objects here, with further details in Section 3.

In PTI, macroscopic emitters and absorbers are unambiguously defined in terms of their constituent microscopic field currents, which are capable of coupling to other fields. This coupling is characterized by an amplitude, the *coupling amplitude*, which is the amplitude for emission or absorption of another field, as in the emission of a photon by an electron. The value of the coupling amplitude for electrons and photons is the square root of the fine structure constant of quantum electrodynamics (the charge of the electron in natural units). A macroscopic emitter is a system composed of large enough numbers of microscopic emitting currents (e.g. excited electrons) such that the probability of emission of an offer by at least one of the microscopic currents constituting the object is virtually unity. The same definition holds for absorption: a macroscopic absorber, such as a detector in an experiment, is a system composed of large enough numbers of microscopic absorbing currents (e.g. ground state electrons) such that the probability of generation of a confirmation by at least one of the currents is virtually unity. This is discussed in detail in Kastner (2012a, §5), including a representative computation of the probability of generation of a confirmation by at least one of the constituent microscopic currents in a macroscopic sample.

The preceding sort of system is the only kind of absorber that instantiates the Maudlin contingent absorber experiment. An absorber cannot be represented by an offer wave undergoing unitary evolution, because the absorber constituting the Maudlin experiment always generates a confirmation and accompanying non-unitary collapse with a specific empirical measurement result. That is what makes it a contingent absorber experiment.

2. Lewis alternative experiments are not contingent absorber experiments

As noted above, much of the author's discussion concerns an alleged ambiguity of the applicability of the transactional picture to macroscopic objects. This issue he identifies as a second ‘unnoticed’ aspect of the Maudlin challenge (the first being the alleged inconsistency of the probability for detection at absorber B). However, PTI is unambiguous about what counts as a macroscopic object (and is decidedly not an offer wave) and what counts as a microscopic object (which could be described by an offer wave or at least as a bound state describable to a good approximation by a quantum state). Perhaps due to a misunderstanding of this work, the author presents two ‘alternative’ versions of the Maudlin experiment that misapply the transactional picture. In one of these, a quantum system, an antiparticle, is mis-identified as an absorber; while in the other, allegedly macroscopic absorbers are assumed to be describable as offer waves. Rather than elucidate an ‘overlooked’ aspect of the Maudlin challenge as the author claims, these scenarios unfortunately create confusion both about the Maudlin experiment and about TI.

Specifically, in eqs . (1) and (2) the author proposes an antiparticle offer wave as an absorber for a particle offer wave. (I assume that examples of the proposed particles would be an electron and a positron.) However, an antiparticle offer wave cannot be an absorber for a particle offer wave. An offer wave of a given field, such as the Fermi-Dirac field for fermions, does not couple to other offer waves of the same field, and therefore does not constitute an absorber for offer waves of the same field. Of course, a fermion offer wave may be *indirectly* detected by another fermion, for example in the case of a bound electron being excited by another approaching electron due to the transactional exchange of a photon. In that case, however, there is an actualized transaction and nonunitary collapse, and the evolution is not unitary as in the author’s alternative versions.

In addition, it is not the case that a confirmation wave is sent “from the point at which the particle and antiparticle annihilate” (Lewis 2013, discussion under eqn. (2)). Ordinary relativistic quantum theory treats the interaction between the particle and antiparticle offer waves as a scattering process, as does TI, especially in Kastner’s updated version (Kastner 2012b, §6.3). A process in which an incoming particle and antiparticle offer undergo scattering has a well-defined amplitude (less than unity) for annihilation, in which the outgoing states are two photons. Even if we ignore that and pretend (in a nonrelativistic approximation) that the amplitude for annihilation is unity, there is certainly no confirmation sent from that interaction stage. Those outgoing photons are just offer waves, so no confirmation is sent from the location of the interaction as claimed. Rather, the only information one could have concerning ‘which way’ the particle went is by way of photon confirmations sent from fixed, macroscopic photon detectors.

While these corrections perhaps do not nullify the intent of the author's alternative experiment, which is to describe the moveable absorber (B) by an offer wave, his proposed experiment fails to capture the contingent absorber features of the Maudlin challenge. The antiparticle is not really an absorber, and the absorbers actually generating the confirmations are fixed. Thus the translation of the Maudlin challenge into a 'quantum mechanical' form makes it vacuous, rather than offering a 'straightforward solution' to the problem as the author contends. Of course, there is no challenge, and the situation is perfectly describable in TI, but this is not a contingent absorber experiment. Nor does this argument demonstrate that nullifying the experiment is the only way to resolve the puzzle presented by the experiment in its non-nullified, original form. The same basic point applies to the second alternative version in which quantum states representing offer waves are erroneously assigned to macroscopic absorbers. This second version will be discussed further below.

3. Macroscopic objects well-defined in PTI

It has been objected in the past that a 'macroscopic object' is an allegedly ill-defined or problematic concept in TI: this may once have been the case, but it is long past the time that this criticism was a fair one. The concept of an absorber as a macroscopic object is discussed in detail in Kastner (2012a, section 5). As noted above, absorbers are defined in terms of coupling amplitudes, which are naturally interpreted in a direct-action theory (such as the Wheeler-Feynman (1945, 1949) and Davies (1971, 1972) theories upon which TI is based) as the amplitudes for both the emission of offer waves and the generation of confirmations.[1] A macroscopic absorber, such as Maudlin's detectors A and B, is a system in which the amplitude for the generation of a confirmation by at least any one of its constituent coupling microscopic currents approaches unity. A macroscopic absorber is virtually guaranteed to generate a confirmation due to its composition by large numbers of microscopic currents capable of

[1] Feynman himself noted that the coupling amplitude for QED is the amplitude for a real photon to be emitted or absorbed (Feynman 1985). In a direct-action picture such as that of Wheeler-Feynman (1945, 1949) or Davies (1971, 1972), upon which TI is based, this is the amplitude for emission of an offer wave *or* for generation of a confirmation wave.

coupling to a given offer wave. Similarly, a macroscopic emitter (such as a laser) is virtually guaranteed to generate offer waves.

Upon the actualization of a transaction, both the emitter and the absorber are localized and are therefore macroscopic, spacetime events. Therefore, such an object is never accurately described by a quantum state (offer wave), since it is continually being localized due to ongoing emission or absorption, and collapse. In contrast, offer waves are nonlocal objects, since they are field excitations.[2] This is how PTI naturally demonstrates the emergence of a classical, macroscopic realm from a domain of quantum possibilities. Since it is the macroscopic, collapsing kind of absorber that creates the Maudlin challenge in the first place, the situation discussed in equations (4) and (5) in which macroscopic absorbers are erroneously described by offer waves, fails both as a version of Maudlin's challenge and as an application of TI.

The author unfortunately creates further confusion about TI's treatment of macroscopic objects in the following statement: "The worry about incorporating macroscopic objects into a TI-style analysis is that it opens the door for macroscopic objects to have indeterminate trajectories." This is certainly not the case, and alleging such a 'worry' again ignores the recent literature on TI. In fact, it is never appropriate to describe macroscopic systems – by which we mean systems composed of enough microscopic currents to generate either offers or confirmations with certainty -- by quantum states. This is because quantum states only apply to systems that are either excited states of fields (offer waves) or quantum bound states with very small amplitudes (i.e. of the order of the fine structure constant) of emitting offers or generating confirmations. In contrast, as noted above, macroscopic objects are always localized by ongoing actualized transactions. That is how the existence of macroscopic objects is explained in PTI – they are continually undergoing collapse that localizes them in spacetime, so they can't have indeterminate spacetime trajectories.[3]

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[2] This may seem to indicate a 'preferred observable' in that conserved quantities such as energy and momentum are actualized and transferred in transactions. This is a natural reflection of the fact that position is not an observable in relativistic quantum theory, which is the more accurate theory. Nonrelativistic quantum theory, which treats position as an observable, is only an approximation, and should never be viewed as a free-standing theory. It is through actualized transactions that objects become localized – spacetime is just the arena of actualized transactions, and spacetime events are actualized emission and absorption events. We never really 'observe' position. We simply participate in transactions that transfer conserved physical quantities between our sense organs and other objects.

[3] One can assign an 'effective quantum state' to a macroscopic object, but only as a kind of correspondence principle, e.g., by ascribing to it a center-of-mass position state with so little uncertainty that it can be regarded as having a determinate position. However, in general, macroscopic objects are conglomerates of actualized transactions, and therefore are not quantum objects. In any case, such a system is certainly not an offer wave.

Thus, neither the antiparticle nor the putative 'quantum absorbers' function as real absorbers in the author's proposed alternative version of the Maudlin experiment. By definition, an 'absorber' in TI is a macroscopic object that generates confirmations with certainty, and that always results in collapse, a nonunitary process. However, the author's reworking of the experiment with quantum states for the detectors A and B describes the entire process as unitary; thus the 'absorbers' are not really absorbers. The whole point of the Maudlin challenge is as a contingent absorber experiment. But in the author's versions, the generation of a confirmation wave is not contingent on anything, since all the relevant detectors are fixed. These are the photon detectors overlooked in the author's first version, and unspecified other fixed detectors bringing about the 'destruction' of the particles putatively comprising the detectors A and B in his second version. So the author fails to construct a 'quantum' version of the Maudlin experiment, and his arguments based on that premise fail as well.

4. Criticism of Marchildon rebuttal fails

The author claims that the only 'straightforward' solution to the Maudlin experiment is by essentially treating all the objects as offer waves – which means, in view of our arguments above, to nullify the Maudlin experiment by changing it into something else entirely. Does this mean that the rebuttals of Kastner and Marchildon fail to resolve the challenge? No, because those rebuttals have apparently been misunderstood.

Let us begin with the author's criticism of Marchildon's solution (2006) , which is elaborated in Boisvert and Marchildon (2013). Marchildon notes that in the original conception of the Wheeler-Feynman direct-action theory, there is always absorption somewhere for any emitted offer wave; the universe is a 'light-tight box'.[4] Thus Marchildon includes a remote, background absorber C, which always returns confirmations from the left side. (The left side is where the closer, moveable absorber B moves if the right-hand detector A does not fire.) This means that there are always confirmations from both the left and the right, and there are always two incipient transactions with probabilistic weights of ½, correctly reflecting the observed frequencies of detection on the right and the left. When detector A does not fire, it means that the

[4] Recall that the Wheeler-Feynman (1945, 1949) and Davies (1971, 1972) theories of the direct-action picture, upon which TI is based, are empirically equivalent to standard theories of fields if the universe is a 'light-tight box' or if other equivalent boundary conditions obtain -- an alternative BC is explored in Cramer (1983).

particle is emitted to the left and is intercepted by B. The author presents Marchildon's solution and comments:

"Marchildon's account retains the inconsistency …. regarding absorber B; absorber B definitely receives the particle if it has a probability of 1/2 of doing so. Furthermore, his account adds a new inconsistency regarding absorber C; absorber C definitely does not receive the particle when it has a probability of 1/2 of doing so. The contradiction at the heart of Maudlin's challenge remains." (Lewis 2013)

No, the alleged contradiction does not remain. The mistake in the above argument is in ascribing the probabilities to detectors. The probabilities apply to the realization of the properties of the quantum being transferred, not to a particular detector. This is so because *it is the confirmed field itself*, not emitters or absorbers, which instantiates the physical probabilities. So for example, the photon offer wave component that reaches C is characterized by a particular energy and momentum. It does not matter whether that actualized photon is ultimately absorbed by the movable detector B or at C; it is the energy and momentum of the photon that is actualized, not 'detection at B' or 'detection at C.' Regardless of which detector ends up receiving the energy, *the same photon, with the same energy and momentum, is detected*. And it is detected (actualized) on the left with a probability of ½, meaning that half the time a photon with leftward momentum is actualized and half the time a photon with rightward momentum is actualized. Thus, there is no inconsistency.

The mistake in the author's argument is in attributing probabilities to specific detectors, rather than to the entities actually described by the probabilities – the quanta being emitted and absorbed. This misconception is understandable, since standard applications of quantum theory routinely attribute the probabilities to detection sites for pragmatic purposes. But the probabilities themselves actually apply to *the transfer of the physically conserved quantities described by the quantum states* (energy, momentum, angular momentum, etc.) So clearly, including a distant absorber resolves any apparent inconsistency concerning the physical meaning of the weights of the incipient transactions, which function as probabilities of actualization of those transactions. Whenever the rightward transaction is not actualized, the leftward one is, and they both have a probability of ½, and those are expressed in the observed frequencies of the respective outcomes. Claiming that there is any inconsistency here is either overstating the situation, or insisting on applying the probabilities to the wrong entities and processes.

5. Criticism of Kastner rebuttal fails

It is clear from the above that Marchildon's solution is a very straightforward one. However, it does depend explicitly on the 'light tight box' condition. Meanwhile, Kastner (2012b, Chapter 5), in considering the possibility of no distant absorber on the left side,[5] has pointed out that even in this case, Maudlin's experiment presents no more inconsistency problem for TI than Wheeler's 'delayed choice experiment' does for standard quantum theory (Wheeler, 1978). In a nutshell, that rebuttal points out that the delayed choice experiment presents a kind of causal loop that poses, for ordinary quantum theory, an apparent probability inconsistency of precisely the same kind as the Maudlin experiment. The causal loop consists in the fact that, according to Wheeler's own interpretational approach, the choice of an experimenter, at a time t_2, whether to do a 'which way' or 'both ways' measurement exerts some causal influence on the past of a photon at a time $t_1 < t_2$; that is, it affects whether the photon *previously* 'went through both slits' or 'went through only one slit'. In the usual block world formulation, the future choice at t_2 must therefore *already be determined* according to what the photon does at the slits at t_1. This gives rise to an apparent causal loop of the same kind as the Maudlin challenge: given whatever the photon does at t_1, the experimenter *must* choose the corresponding measurement at t_2. If one replaces the experimenter's choice by a quantum coin flip with probabilities of ½ for each option, then the probabilities applying to the quantum coin flip are inconsistent.

To see this, suppose 'heads' instructs us to 'measure which slit' and 'tails' instructs us to 'measure both slits and get interference.' Each time the coin flips (according to the block world picture), its outcome *must already be decided* by whatever the photon did before the coin flip. If the photon went through both slits, then it is certain that the coin will come up 'tails,' yet the quantum probability for that outcome is only ½. This is exactly the same alleged inconsistency that the Maudlin experiment presents, but clearly it has not been considered a fatal, or even

[5] Since direct-action theories require full absorption, or an equivalent boundary condition (such as a perfectly reflecting t=0 condition) for empirical equivalence with standard theories of radiation, any scenario lacking full absorption is speculative, and responses to the Maudlin challenge on those terms necessarily inherit that speculative quality.

significant, problem for standard quantum theory. At most, it is an interesting puzzle, to the extent that it has even been noticed at all.

Lewis acknowledges this crucial argument, but fails to rebut it. Instead, he comments that standard quantum theory has unresolved conceptual problems, such as the measurement problem[6], and argues that it should not be considered reassuring to be told that TI is no more threatened by the Maudlin challenge than standard quantum theory is by the delayed choice experiment. But, as noted above, standard quantum theory is not at all threatened by the delayed choice experiment: nobody has suggested that 'quantum theory collapses' because of this interesting puzzle about the probabilities in the delayed choice experiment. Nevertheless, in an attempt to support the notion that the delayed choice experiment presents a significant problem for standard quantum theory, the author claims that this was a motivation for John Cramer in developing TI, and invokes Cramer's discussion (1986, p. 671) of that experiment. But this is misleading. In the cited section, Cramer was discussing how TI can provide an observer-free account of measurement, and pointing out that including the response of absorbers resolves the alleged *involvement of a conscious observer* in determining whether a photon retroactively went through one or both slits in the delayed choice experiment. Thus, clearly Cramer's intent was to eliminate the conscious observer and to solve the measurement problem in physical terms, not to claim that the delayed choice experiment specifically posed a consistency problem for quantum theory .

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[6] Of course, TI solves the measurement problem, so that isn't a problem for quantum theory in TI. The author cites other interpretations that supposedly solve the measurement problem yet are not subject to Maudlin's challenge: the Bohmian theory, Everettian (MWI) approaches, and the GRW theory. However, all these interpretations suffer from serious deficiencies not faced by TI, such as difficulty explaining the Born Rule, or what causes the frankly *ad hoc* 'collapses' of the GRW approach. (Also, the status of GRW approaches as comprehensive interpretations capable of dealing with both nonrelativistic and relativistic realms is far from clear, and their alleged 'resolution' of the measurement problem is bought at the high price of changing quantum theory.) It is not even clear that the Bohmian theory does solve the measurement problem (see, e.g., Brown and Wallace 2005), so the author cannot take this for granted. In addition there is great difficulty in extending the Bohmian theory to the relativistic domain, while TI applies seamlessly to both the nonrelativistic and relativistic domains as shown in Kastner (2012a,b, 2014). Regarding MWI, Kent (1990) argues that "no plausible set of axioms exists for an MWI that describes known physics." He extends his critique in a more recent publication (2010), concluding that "...no known version of the theory (unadorned by extra ad hoc postulates) can account for the appearance of probabilities and explain why the theory it was meant to replace, Copenhagen quantum theory, appears to be confirmed, or more generally why our evolutionary history appears to be Born-rule typical" (Kent 2010) So it is far from established that the alternative interpretations cited by the author succeed in resolving the measurement problem or other challenges in understanding quantum theory.

In view of the author's invocation of Cramer in this context, it is especially surprising that in the same paper the author alleges that TI can be viewed as similar to the Copenhagen Interpretation (CI). These two interpretations – TI and CI -- could scarcely be more different. Indeed, Cramer (1986) takes great pains to *contrast* TI with CI, and presents TI as a better approach which clearly defines the measurement process rather than taking macroscopic objects as primitive and relying on the intentions and behaviors of conscious observers to define measurement, as in CI. It is thus quite inaccurate to suggest that TI has anything in common with CI.

6. Conclusion: Maudlin challenge has been decisively refuted

While the author's interest in TI is certainly welcome, it has been shown that his arguments fail to establish an ongoing significant problem for TI due to the Maudlin experiment. In several instances the author's arguments mischaracterize and/or misapply the transactional picture, and his alternative version of the Maudlin experiment are not in fact contingent absorber experiments. An attempt has been made herein to clarify issues that have been subject to apparent confusion, especially the treatment of macroscopic objects in the latest incarnation of the transactional picture, PTI. Macroscopic emitters and absorbers are unambiguously defined in PTI, and cannot usefully be described by quantum states, since they are continually undergoing collapse and attendant spacetime localization. Thus such objects cannot have indeterminate trajectories as suggested by the author, nor can they be treated as offer waves. In addition, rebuttals of the Maudlin challenge by Marchildon and Kastner have been shown to be perfectly effective when correctly understood. Thus Maudlin's challenge has been effectively disarmed, and no longer presents a significant problem for the transactional interpretation.

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