Wheeler's Delayed Choice Interference Experiment (Realised)

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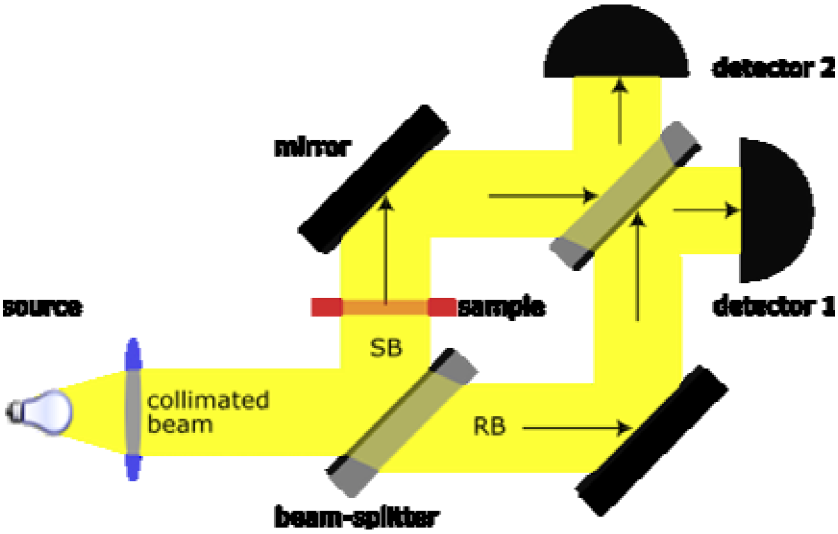
Consider a Mach-Zehnder interferometer (see Figure 1). The manifestation of interference in this device is that all output photons appear in detector 1, and none in detector 2 (see http://rickbradford.co.uk/QM13Counterfactuals.pdf). We know that if we measure which path the photon takes then interference is destroyed, and photons will be found by both detectors.

In the case of a double slit experiment, the same destruction of the interference fringes occurs if a measurement is made to determine the path of the photon between the slits and the screen. Wheeler posed the following gedanken experiment. Suppose that at a time after the photon has passed through the slits we choose randomly whether to leave the screen or to snatch it away revealing a telescope which will observe whether the photon originated from the left or the right slit. Considering only those cases when the screen is left in place, the interference pattern will (one presumes) be found. But the remaining cases (when the screen is whipped away) have no interference pattern, just two peaks seen by the telescope. But the photon is already committed when the decision to leave or remove the screen is taken, in the sense that it has already passed beyond the slits.

The same quantum weirdness can be displayed by a Mach-Zehnder interferometer. Consider the final beam splitter (top right in Figure 1).

Figure 1 The Mach-Zehnder Interferometer

RB = Reference Beam; SB = Sample Beam



If the final beam splitter were omitted, detector 1 would measure only photons taking the path SB, and detector 2 would measure only photons taking path RB. Both would occur with equal frequency (assuming the first beam splitter is 50/50). There is no interference (rather trivially in this case since, in the absence of the final beam splitter, the two paths are never brought together in order to interfere).

But we can now consider leaving or removing the final beam splitter randomly, and at a time after the photon has passed through the first beam splitter. To be more precise, we can ensure that the event defined by the photon passing through the slits cannot be causally influenced by the decision to retain or remove the final beam splitter. If quantum mechanics is correct, if we confine attention to those randomly selected cases when the final beam splitter is retained, we shall find all the photons enter detector 1 and none into detector 2 (which is the manifestation of interference).

This version of Wheeler's experiment, employing a Mach-Zehnder interferometer has actually been performed (see Ref.[1]). The retention or removal of the final beam splitter is achieved electronically and the decision is made by a random number generator. Interference occurs unambiguously when the final beam splitter is activated, thus confirming the quantum mechanical expectation.

What does this result imply? The interpretation would seem to be that…

(i) For randomly selected cases, causally unconnected with the photon prior to passing through the slits, the photon must be regarded as "going both ways at once" in order to generate the observed interference pattern.

(ii) But the photon must therefore also "go both ways at once" for the remaining cases, when the final beam splitter is removed, since there is no causal link between this decision and the photons prior to the slits.

(iii) This suggests that the "collapse of the wavepacket", which leads to detection in one or other of the two detectors, does not occur until the photon encounters the detectors. Hence, when the final beam splitter is absent, detection of a photon in detector 1 does not quite mean that the photon took path SB. Prior to detection, either of detectors 1 or 2 might register the photon since the photon would have been in a superposition of both states. The counterfactual, that it might have taken path RB, only became a counterfactual after the detectors had detected a photon. Before that, both options were open. The outcome of the detection is truly indeterminate – there are no hidden variables.

References

[1] V.Jacques, E.Wu, F.Grosshans, F.Treussart, P.Grangier, A.Aspect, and J.-F.Roch, "Experimental Realization of Wheeler's Delayed Choice Gedanken Experiment", arXiv: quant/ph-0610241.