The Phenomena

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1 Historical introduction

In retrospect, there was evidence for quantum theory all the way back in the time of Newton, when physicists started to understand that light displays both wave-like and particle-like features. But the story really gets started in the late 19th century with four puzzling phenomena.

1.1 Spectral lines

1.2 Blackbody radiation

1.3 Stability of the atom

1.4 Quantum two-valuedness

2 Two slit experiments

2.1 Single slit

2.2 Two slit

2.3 Two slit with monitoring

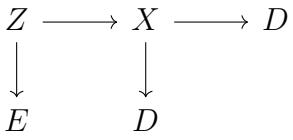
3 Stern-Gerlach

(Note: The experiments described in this section do *not* explicitly involve tensor products.)

In the following diagrams, the letters X and Z indicate Stern-Gerlach magnets oriented, respectively along the x and z axes. The arrows between nodes indicate the paths that the neutrons can follow. A path going to the right is "up" and a path going down is "down". The letter E indicates a eraser that wipes out neutrons. The letter D indicates a detector that counts the number of incoming neutrons. The letter R indicates a reflector that redirects that path of neutrons.

First experiment

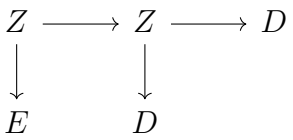
Two magnets, perpendicular orientation. i.e. send "up" from spin-z to a spin-x magnet



Phenomena: the detectors click individually (not at the same time), and in general there is a 50% chance of each detector clicking.

Second experiment

Two magnets, same orientation. i.e. send "up" from spin-z to a spin-z magnet



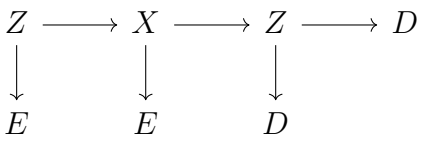
Phenomena: the top detector always clicks, and the bottom detector never clicks.

Third experiment

Two magnets, 45° orientation

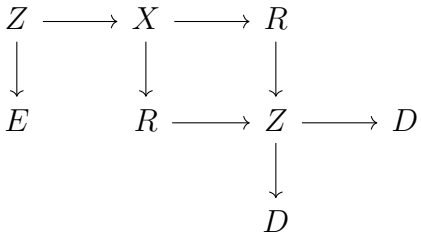
Fourth experiment

Three magnets: spin-z, spin-x, spin-z

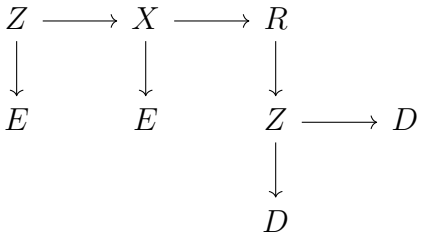


Phenomena: equal chance of detection for the top and bottom detectors.

Fifth experiment (recombination)



Phenomena: top detector always clicks, bottom detector never clicks.

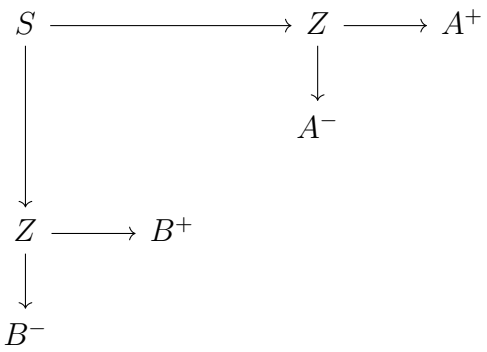


Phenomena: equal chance of detection, both detectors.

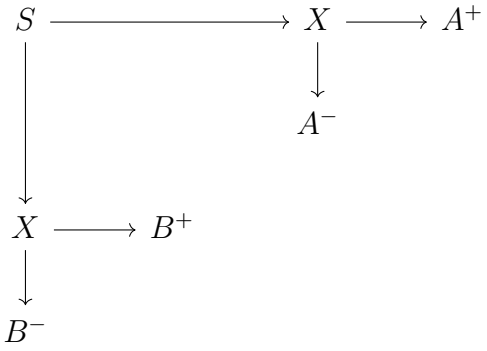
Things to add?

1. Changing path lengths
2. Polarization

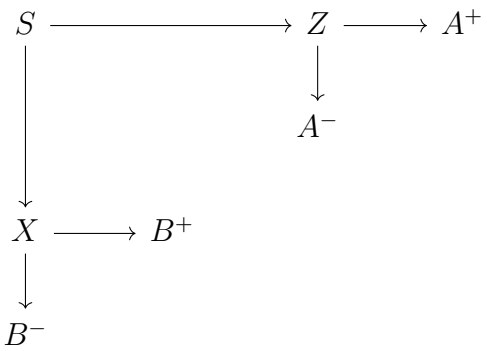
4 Nonlocality



Phenomenon: the detectors on the two sides are perfectly anti-correlated. A^+ clicks iff B^- clicks, and A^- clicks iff B^+ clicks.



Phenomenon: the detectors on the two sides are perfectly anti-correlated. A^+ clicks iff B^- clicks, and A^- clicks iff B^+ clicks.



Phenomenon: the detectors on the two sides are uncorrelated. For any pair, the probability of a joint detection is 0.25.

4.1 EPR argument

Reality criterion: If, without disturbing an electron, we can predict with certainty what it would do, then it has a feature (i.e. there is an **element of reality**) that determines that it would do that.

Concluson: The electron has a feature that determines whether it would go up or down for X, and it has a feature that determines whether it would go up or down for Z.