Haunted Quantum Entanglement

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ABSTRACT

There are two steps in establishing a quantum entanglement. These two steps often are not considered as independent from one another. Step 1 involves the interaction through which the particles are to be entangled. Step 2 involves making the result of the interaction through which the development of the entanglement begins available to the environment. Step 1 can occur in isolation from the environment. Step 2 then occurs with making the result of the interaction available to the environment through no longer isolating the particles. The entanglement that begins to develop in step 1 can originate in a form where there is which-way information. With step 2, the entanglement is complete and which-way information is established (option 1). Instead of completing the entanglement with step 2, the developing entanglement can be eliminated with the result that which-way information is lost. The result is a distribution for each of the paired particles that exhibits interference (option 2). The elimination of the developing entanglement results in haunted quantum entanglement. Through the use of options 1 and 2, one need not associate measurements on each of two entangled particles after measurements on each of the particles in order to decipher information. Associating measurements can be done automatically as measurements are made through the ability to control whether a developing entanglement is allowed to be fully established or instead eliminated. Options 1 and 2 can be used in a communications device.

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Text

HAUNTED QUANTUM ENTANGLEMENT FROM A HISTORICAL VIEW

Mermin wrote papers in the American Journal of Physics (vol. 49, pp. 940-943, 1981) and Physics Today (April, 1985, pp. 38-47) on the argument of Einstein, Podolsky, and Rosen (vol. 47, pp. 777-780, 1935) and the work that the argument engendered. In these papers, he emphasized the need to associate measurements on each of two entangled particles *after* measurements on each of the entangled particles are made in order to decipher information.

Greenberger and YaSin's haunted measurement article in Foundations of Physics (Foundations of Physics, vol. 19, pp. 679-704, 1989) demonstrated that one could undo a which-way measurement. Greenberger and YaSin did this with a neutron traveling through an interferometer for which there was a movable mirror system along one arm (Figure 1). When the neutron struck the first mirror of the movable mirror system, there was a which-way measurement. When the neutron finished interacting with the movable mirror system, the neutron and mirror system were returned to their original states, i.e., the states they had before the neutron struck the first mirror of the movable mirror system. The neutron exhibited interference when it exited the interferometer. Greenberger and YaSin's result depended essentially on the isolation of the interactions of the neutron and movable mirror system from the environment.

Scully and his colleagues' article in Nature (Nature, vol. 351, pp. 111-116, 1991) on the quantum eraser showed that one could get interference in the forms of fringes and anti-fringes after having conducted a which-way measurement. In line with Mermin's articles, Scully's fringes and anti-fringes rely on associating measurements on each of two entangled particles after measurements on each of the entangled particles are made in order to decipher information.

Scully had an atom pass through a micromaser cavity system and emit a photon in one of the two cavities (Figure 2). Scully emphasized that the atom's emission of the photon did not affect the motion of the atom in any significant way. The atom passes through a double slit and begins its travel to a detection screen. Between the double slit and the detection screen, shutters open for each micromaser cavity and a photodetector is exposed between the two micromaser cavities. The photon may or may not be detected. One possibility regarding photon detection is associated with the fringe pattern of the atom at the detection screen, and the other possibility regarding photon detection is associated with the anti-fringe pattern of the atom at the detection screen. According to Scully, which-way information for the atom was firmly established with the atom's passage through the double slit. When the atom passes through the double slit, the emitted photon is in one or the other of the micromaser cavities. The entanglement of the atom and photon indicates through which slit the atom passed since there is a one to one correspondence between a micromaser cavity and slit. The sum of the fringe and anti-fringe patterns is an overall distribution pattern characteristic of which-way information that is established from the atom's passage through the double slit while the photon is in only one of the micromaser cavities.

Haunted Quantum Entanglement

The question arose whether one could adapt Greenberger and YaSin's haunted measurement which concerned a single particle to particles in the process of becoming entangled. One might then have a haunted quantum entanglement. Scully's method was altered in the following way (citations to author's work at end of paper). Instead of two shutters and a photodetector, just a single shutter was used between the micromaser cavities. If the shutter opens before the atom passes through the double slit screen, one loses which-way information for the photon (Figure 3). If the shutter remains closed until after the atom passes through the double slit screen, the atom exhibits a which-way distribution at the detection screen (no interference) in a series of runs of the setup in this mode (Figure 4). If the shutter opens before the atom reaches the double slit screen, the atom exhibits interference at the detection screen, the same form of distribution the atom would exhibit if there were no micromaser cavity system for the atom to pass through on its way to the double slit screen. (We are not dealing here with fringes and anti-fringes.)

With the opening of the shutter in the manner noted, the developing entanglement is eliminated as well as the which-way information associated with it. This developing entanglement that is subsequently eliminated is a haunted quantum entanglement. Haunted quantum entanglement can be used to get around the need for associating measurements on each of two entangled particles *after* measurements on each of the entangled particles are made in order to decipher information. One controls whether a developing entanglement is allowed to be fully established or instead effectively eliminated through what happens with the single shutter between the micromaser cavities. After adapting Scully's experiment to show haunted quantum entanglement, an implementation using photons alone was developed (citations to author's work at end of paper).

STEPS IN ESTABLISHING A QUANTUM ENTANGLEMENT AND THEIR RELATIONSHIP TO HAUNTED QUANTUM ENTANGLEMENT

There are two steps in establishing a quantum entanglement. These two steps often are not considered as independent from one another. Step 1 involves the interaction through which the particles are to be entangled. Step 2 involves making the result of the interaction through which the development of the entanglement begins available to the environment. Step 1 can occur in isolation from the environment. Step 2 then occurs with making the result of the interaction available to the environment through no longer isolating the particles. The entanglement that begins to develop in step 1 can originate in a form where there is which-way information. With step 2, the entanglement is complete and which-way information is established (option 1). Instead of completing the entanglement with step 2, the developing entanglement can be eliminated with the result that which-way information is lost. The result is a distribution for each of the paired particles that exhibits interference (option 2). The elimination of the developing entanglement results in haunted quantum entanglement. Through the use of options 1 and 2, one need not associate measurements on each of two entangled particles *after* measurements on each of the particles in order to decipher information. Associating measurements can be done automatically as measurements are made through the ability to control whether a developing entanglement is allowed to be fully established or instead eliminated. A subsequent step is not needed. Options 1 and 2 can be used in a communications device (Figure 5).

An Example of How Haunted Quantum Entanglement Can Be Used in A Communications Device

For example, consider the alteration of Scully's experiment for the quantum eraser discussed above. Let the device that now allows for haunted quantum entanglement be run in sets of a predetermined number of runs of the device for each set (for example 100). In particular, it is known in advance how to divide up the data according to set from the stream of atoms impacting the detection screen as the impacts occur. For a set (of for example 100 runs), each run of the apparatus occurs with only one of the two options discussed above.

That is, for one specific set, each run could occur with the shutter opening before the atom reaches the double slit screen. The result is the development of a distribution of atoms that shows interference, the same form of distribution the atom would exhibit if there were no micromaser cavity system for the atom to pass through on its way to the double slit screen. (We are not dealing here with fringes and anti-fringes.)

For another specific set, each run could occur with the shutter remaining closed until after the atom passes through the double slit screen. For this set, the distribution of the atoms exhibits a which-way distribution at the detection screen (no interference) in this series of runs of the device.

As the sets occur, these distributions will develop as the data from the atom impacts are divided up according to set (where the number of runs in each set is predetermined). The associations between measurements are made clear automatically as the distributions develop as the data from the atom impacts are divided according to set. This procedure cannot be used in Scully's device because one does not know whether or not the photon will be detected by the photodetector ahead of time when the two shutters are opened. One has to go back after the data is collected and make individual associations between whether or not the photon was detected by the photodetector and the impact of the atom at the detection screen to develop fringe and anti-fringe distributions. This was also Mermin's point in his articles on EPR, namely that one has to go back after the data is collected and make individual associations in order to decipher information.

PREPRINTS AND PRESENTATIONS RELATED TO HAUNTED QUANTUM ENTANGLEMENT BY D. SNYDER

Note: In all of these preprints and presentations, the term “hidden” generally means “isolated.”

PREPRINTS FROM THE CERN PREPRINT SERVER

Is It Possible to Use a Quantum Eraser to Send Binary Data to a Remote Location? – 3, Mar 2007.
http://cdsweb.cern.ch/record/1019984?ln=en

Is It Possible to Use a Quantum Eraser to Send Binary Data to a Remote Location? – 2, Apr 2005.
http://cdsweb.cern.ch/record/835251?ln=en

Is It Possible to Use a Quantum Eraser to Send Binary Data to a Remote Location? – 1, 22 Aug 2004, report EXT-2004-101. http://cdsweb.cern.ch/record/789637?ln=en

Is It Possible to Find Complete Interference Once Whcich-Way Information is Obtainable?, 8 Jun 2004, report EXT-2004-096. http://cdsweb.cern.ch/record/787596?ln=en

The Demonstration of Particle and Wave Properties Witihin Co-Existing Complementary Structures in the Quantum Eraser Effect. 22 Sep 2003, report EXT-2003-058.
http://cdsweb.cern.ch/record/643594?ln=en

PRESENTATIONS

Haunted Quantum Entanglement, 2009 Joint Spring Meeting of the Ohio Sections of the APS and AAPT

An Optical Quantum Information Transfer Device, 2007 APS March Meeting.
http://meetings.aps.org/link/BAPS.2007.MAR.K1.160

A Variation of the Classic Double-Slit Experiment in Quantum Mechanics, 2206 APS March Meeting.
http://meetings.aps.org/link/BAPS.2006.MAR.Q1.195

The Conceptual Basis for the Possible Use of a Quantum Eraser to send Binary Data to a Remote Location, 2005 APS April Meeting.
http://meetings.aps.org/link/BAPS.2005.APR.S1.41

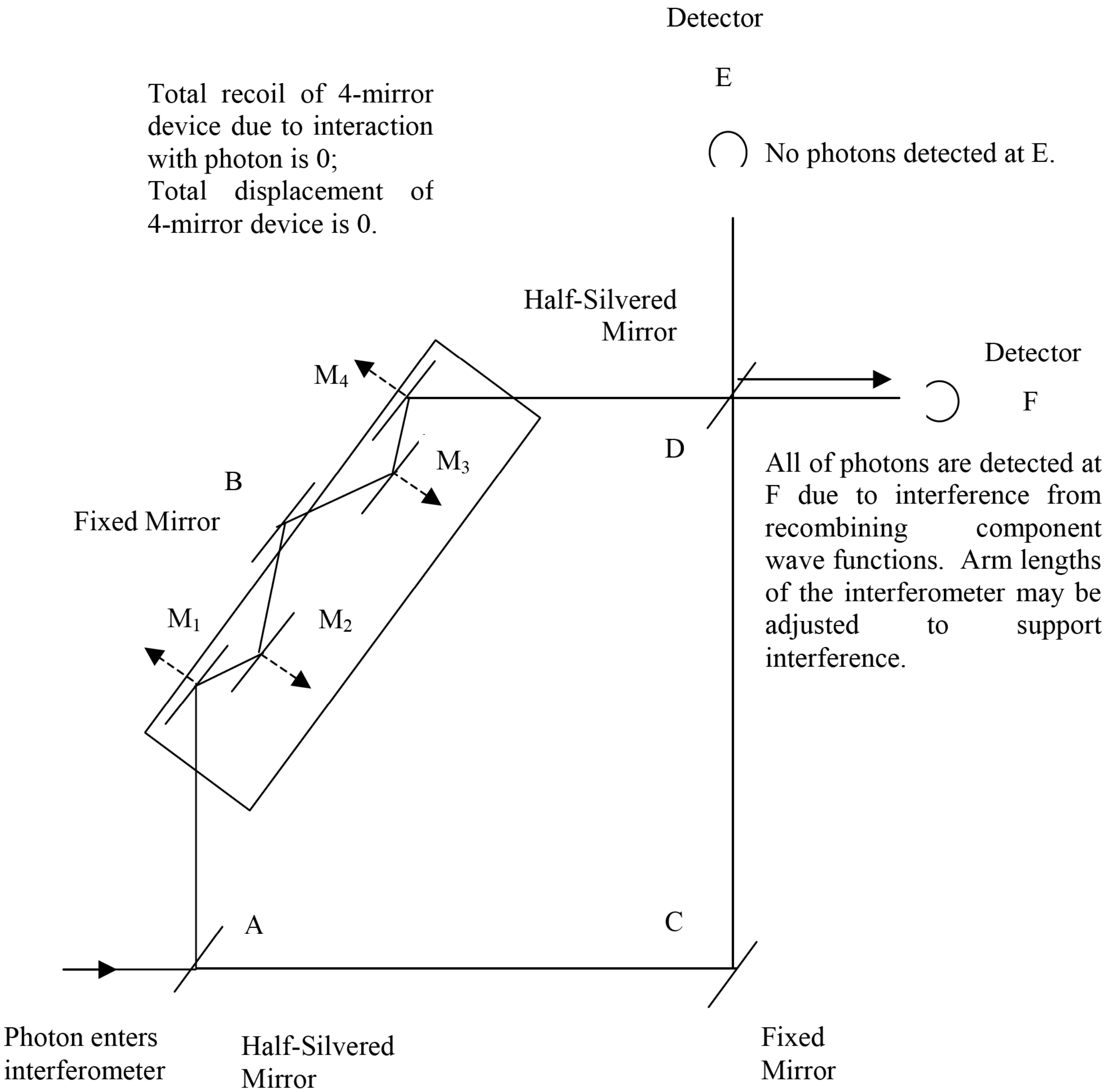
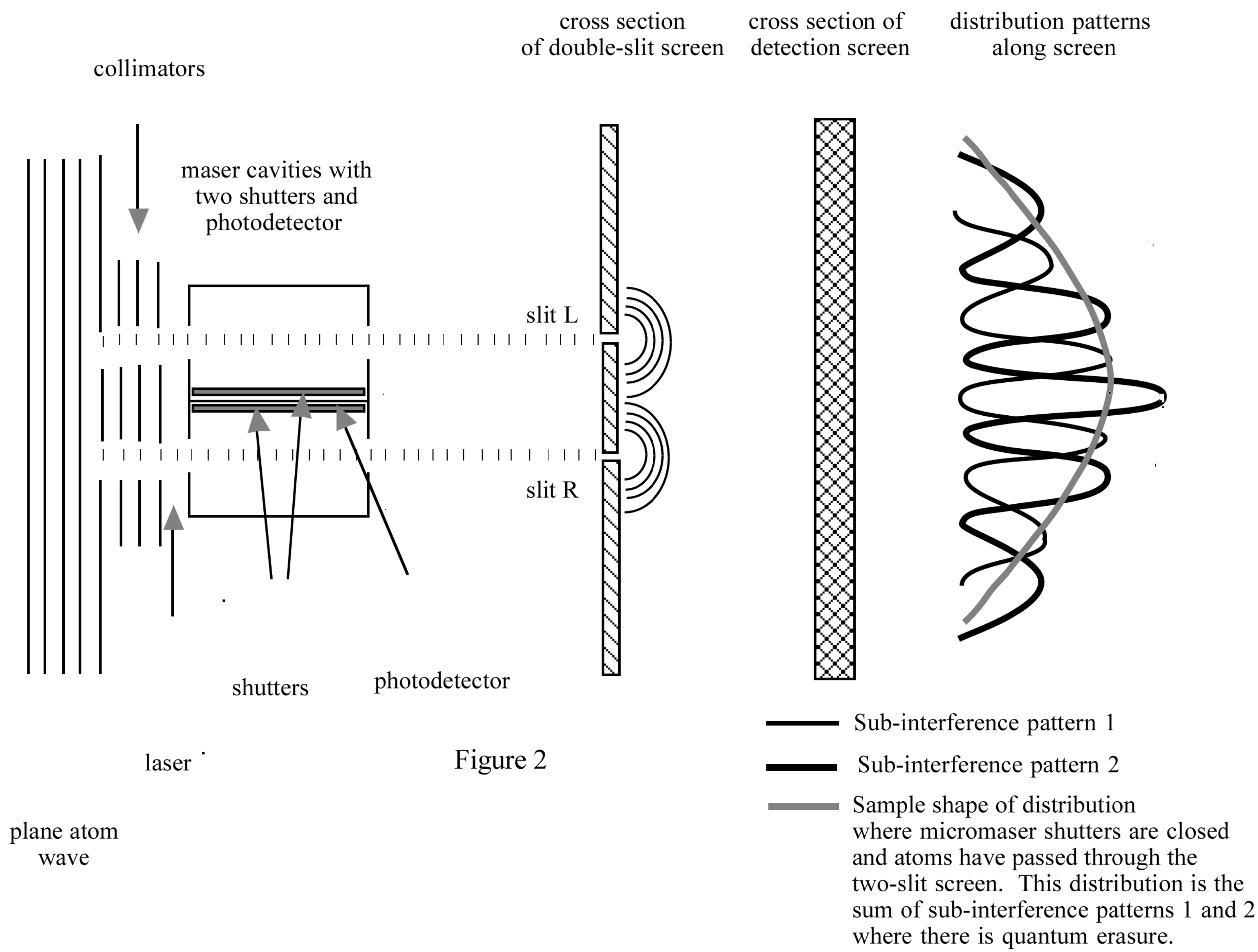


Figure 1: Interferometer with 4-Mirror Device Separated from the Environment and Additional Half-Silvered Mirror: Component Wave Functions Are Recombined to Demonstrate Interference



cross section
of double-slit screen
cross section of
detection screen
distribution patterns
along screen
collimators
maser cavities with
two shutters and
photodetector
slit L
slit R
shutters
photodetector
laser
plane atom
wave
Sub-interference pattern 1
Sub-interference pattern 2
Sample shape of distribution
where micromaser shutters are closed
and atoms have passed through the
two-slit screen. This distribution is the
sum of sub-interference patterns 1 and 2
where there is quantum erasure.

Figure 2

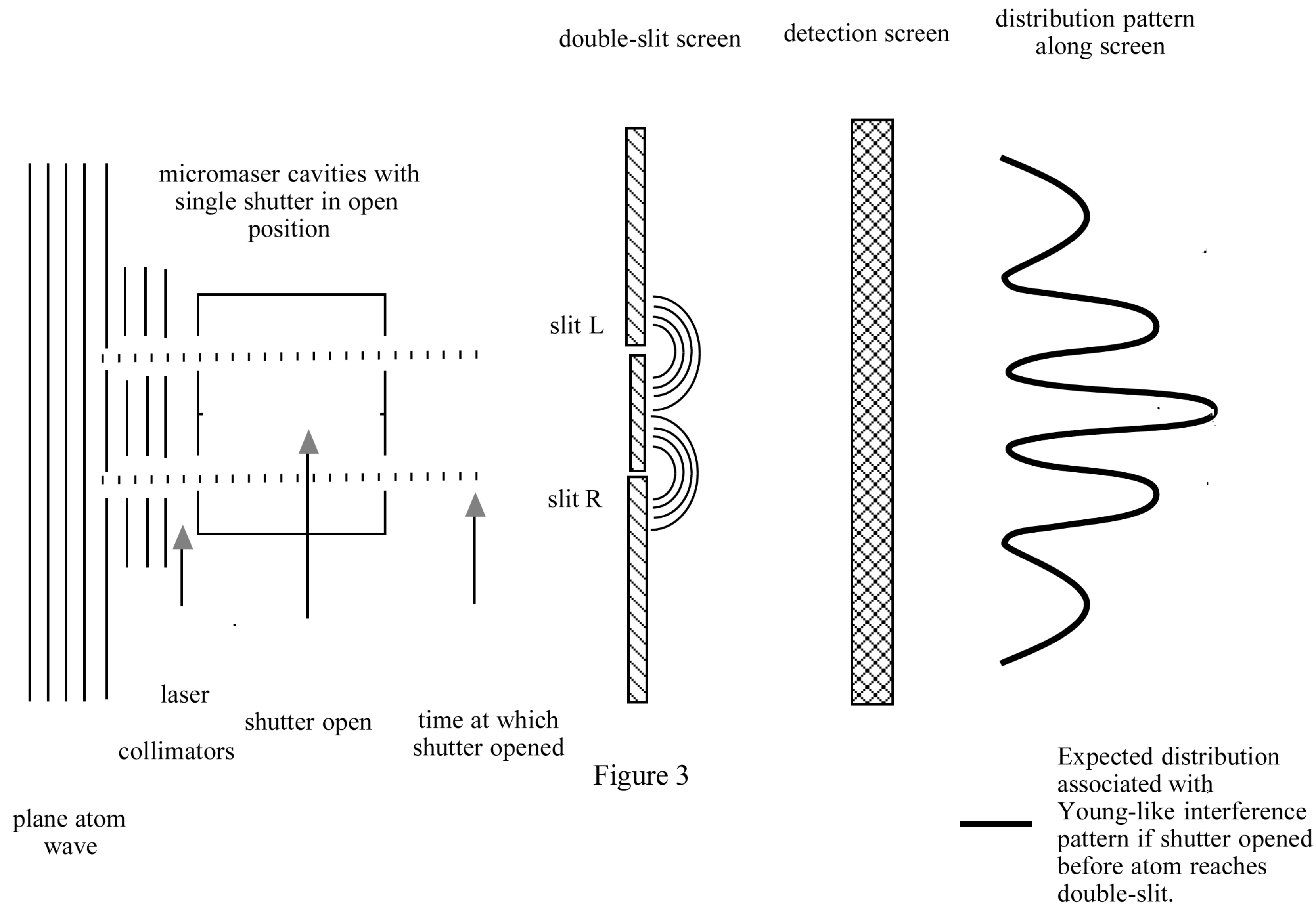

double-slit screen
detection screen
distribution pattern along screen
micromaser cavities with single shutter in open position
slit L
slit R
laser
shutter open
time at which shutter opened
collimators
plane atom wave
Expected distribution associated with Young-like interference pattern if shutter opened before atom reaches double-slit.

Figure 3

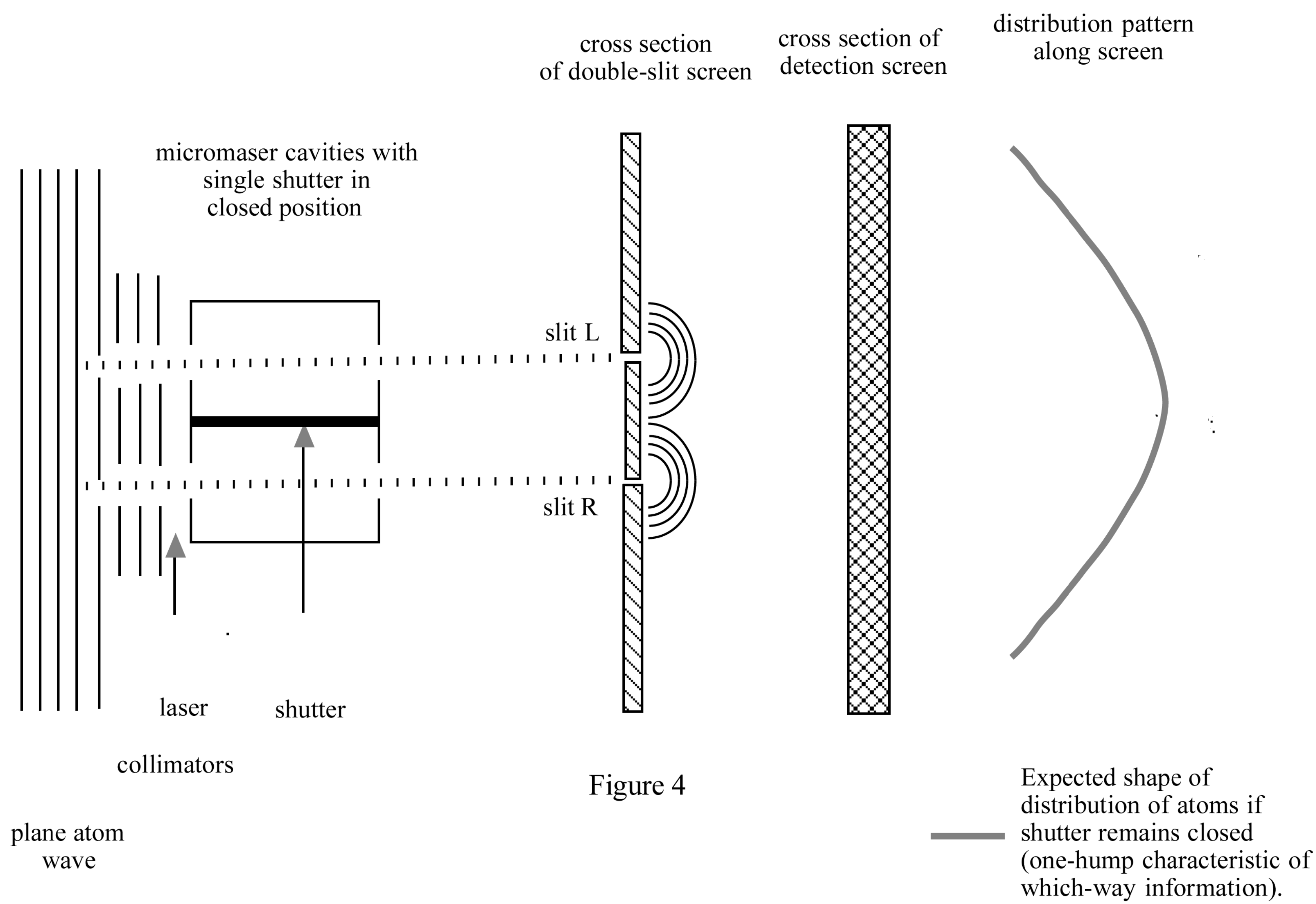

cross section
of double-slit screen
cross section of
detection screen
distribution pattern
along screen
micromaser cavities with
single shutter in
closed position
slit L
slit R
laser
shutter
collimators
plane atom
wave
Expected shape of
distribution of atoms if
shutter remains closed
(one-hump characteristic of
which-way information).

Figure 4

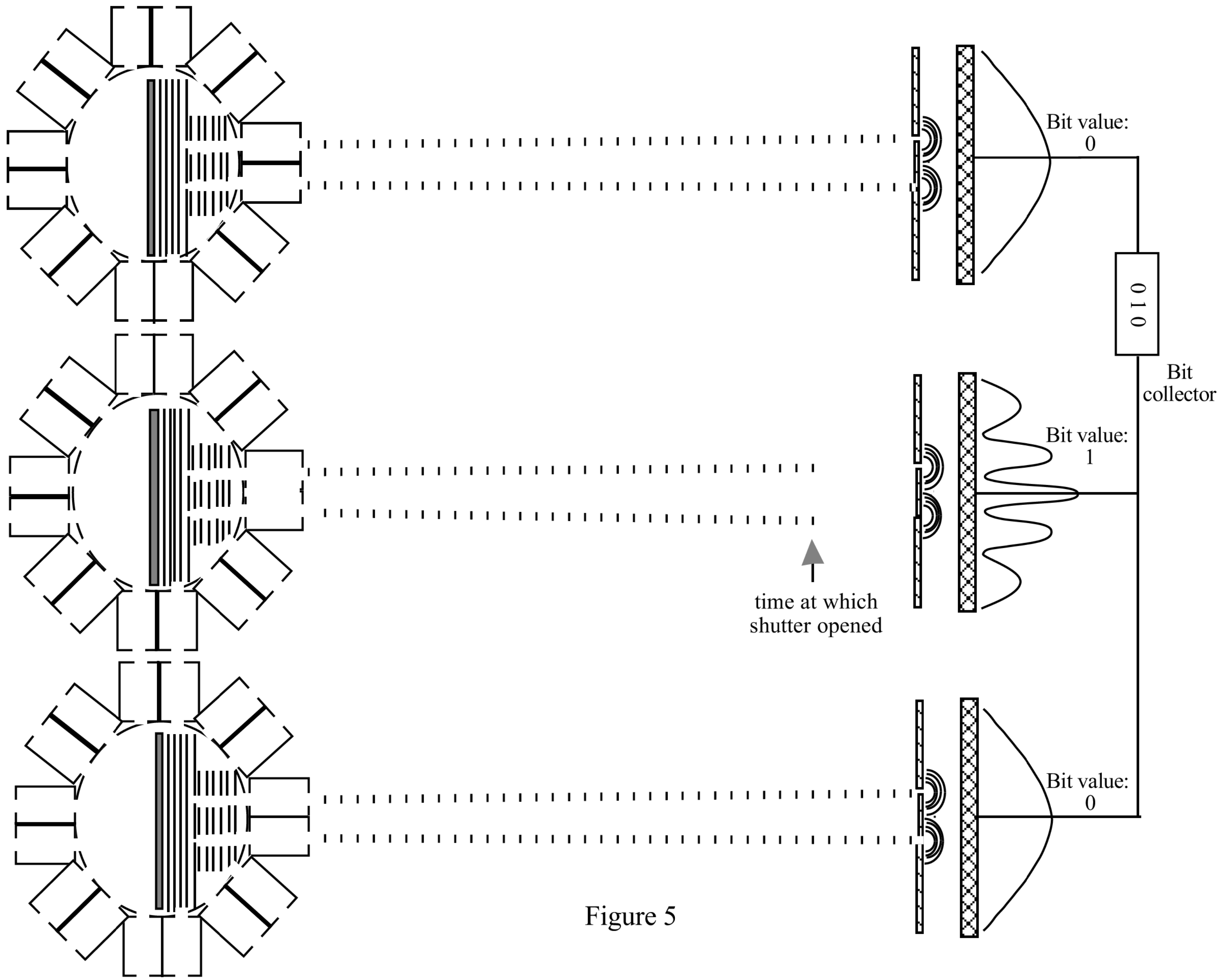

Bit value:
0
0 1 0
Bit
collector
Bit value:
1
time at which
shutter opened
Bit value:
0

Figure 5