Quantum Eraser (Item No.: P2220800)

Short description

Principle

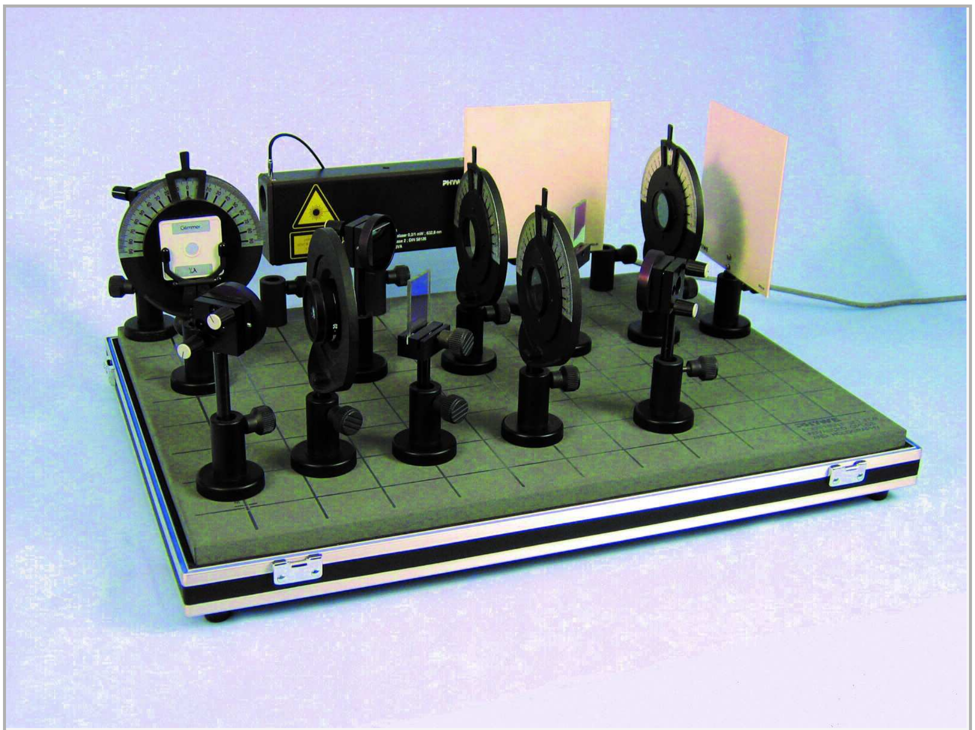

Fig. 1: Experimental setup

A Mach-Zehnder-interferometer is illuminated with an expanded laser beam. Circular interference fringes appear on the screens behind the interferometer. If polarisation filters with crossed polarisation planes are placed in the two interferometer paths the interference patterns will disappear. This experiment is perfectly explainable on the basis of traditional wave optics because light beams with different planes of polarisation do not interfere. A new interpretation can be added if quantum physics is applied: The polarisation filters impress an information (polarisation plane) on the photons. This information can be used to determine which of the two possible paths a photon has taken inside the interferometer. The path of the photons in the interferometer and the interference fringes of the photons are quantities which can not be observed simultaneously due to quantum mechanical reasons. Thus, if the path of a photon in the interferometer is defined the interference fringes disappear. Another polarisation filter mounted behind the interferometer acts as a “quantum eraser”. The polarisation plane of this filter is oriented at an angle of 45° with respect to both polarisation filters in the interferometer. All photons passing this filter have the same polarisation. These photons have lost the information concerning their path in the interferometer (the information has been erased). The interference pattern will reappear on the screen behind the quantum eraser.

Equipment

Fig. 1: Material required for experiment.

Position No.	Material	Order No.	Quantity
1	Optical base plate in covering case	08700-01	1
2	Laser, He-Ne, 0.2/1.0 mW, 230 V AC	08180-93	1
3	Surface mirror 30 x 30 mm	08711-01	4
4	Adjusting support 35 x 35 mm	08711-00	4
5	Beam splitter 1/1, non polarizing	08741-00	2
6	Holder for diaphragms and beam splitters	08719-00	2
7	Screen, white, 150x150 mm	09826-00	2
8	Lens, mounted, f +20 mm	08018-01	1
9	Lensholder for optical base plate	08723-00	1
10	Polarization specimen, mica	08664-00	1
11	Diaphragm holder for optical base plate	08724-00	1
12	Polarizing filter for optical base plate	08730-00	3
13	Magnetic foot for optical base plate	08710-00	13

Task

1. Set up the experiment and observe the interference pattern on the screen.
2. Change the polarization of the beams with the PF1 and PF2 polarizers and observe the influence on the interference pattern.
3. Use the third polarizer PF3 to cancel the polarization of the light in the two beams, and observe the reappearance of the interference pattern.

Remark

This guideline for setting up the Experiment Quantum Eraser deals mostly with the alignment procedure and comprises some hints for the experiment. The theoretical background will only be touched at some points.

Set-up and alignment

Setup and alignment

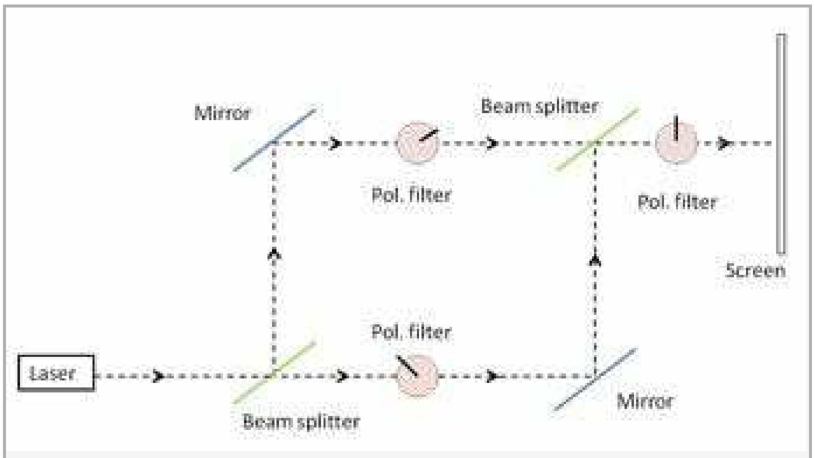

Fig. 2: Schematic diagram of the optical paths.

In this experiment a Mach-Zehnder Interferometer is used to split a light beam into two parts, send them along two different paths where they can be subjected to individual treatment and then to reunify the two beams again and observe interference effects (See Fig.2). Since the precise alignment of the Interferometer is crucial the individual steps will be described in the following and illustrated with photographs. In the final set-up shown in Fig. 3 the position of all the optical elements can been seen along with the names and abbreviations used for them in this set-up guide.

Fig. 3: Final setup

a) Fix the laser (HeNe 0,2/1mW) to the optical base plate so that the beam path height is about 12,5 cm above the plate (Fig. 4).

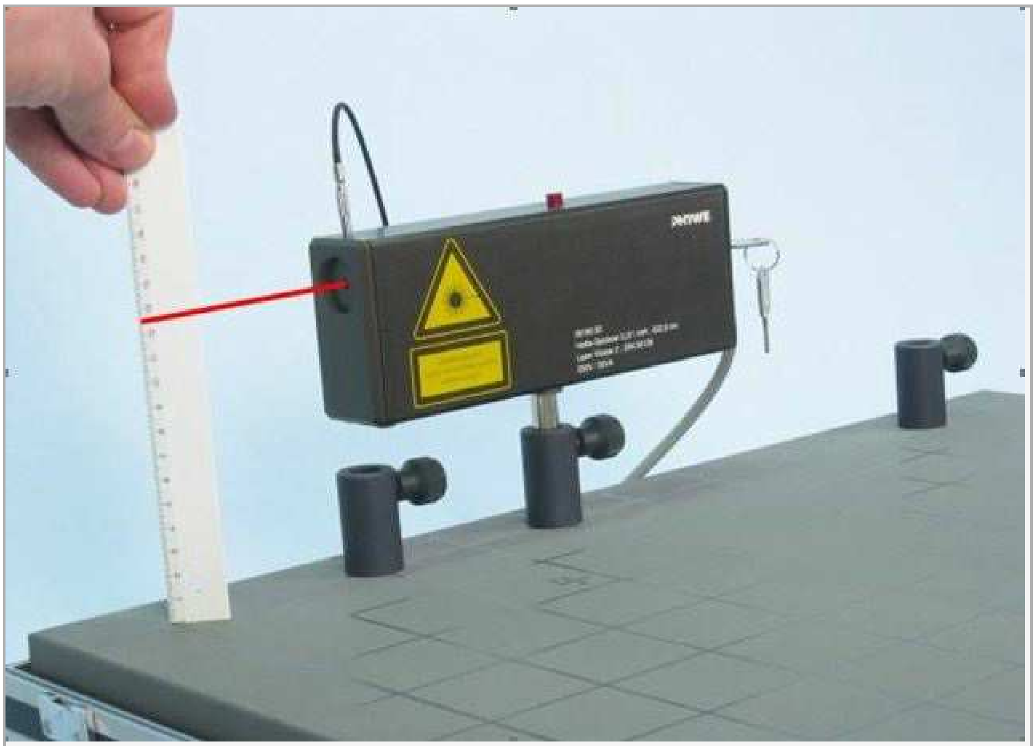

Fig. 4: Fixing the laser to the optical base plate.

b) Direct the beam with the mirror M1 to the right corner in the front of the plate. Adjust the mirror M1 so that the beam path height there is the same as at the exit point of the laser (Fig. 5).

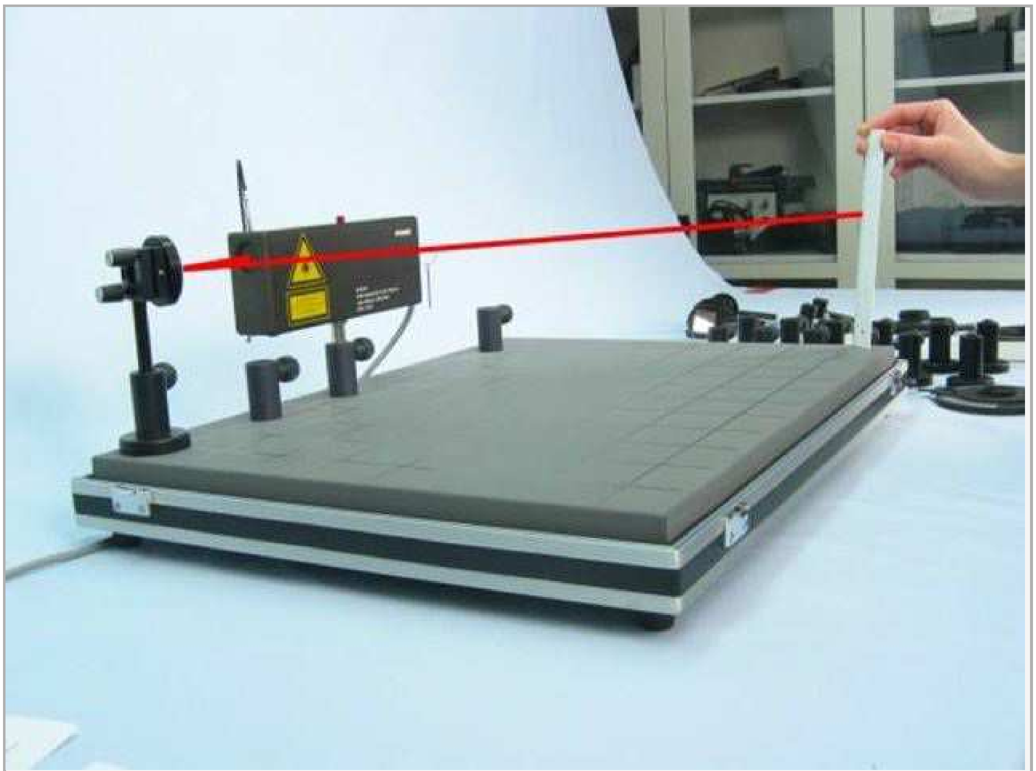

Fig. 5: Directing the beam with the mirror M1 to the right corner in the front of the plate.

c) In this step the mirrors M2, M3, M4 and the beam splitters BS1, BS2 will be preadjusted so that the beam height can be maintained. To achieve this, the respective elements are positioned in the right corner in the front of the plate. Their height is adjusted so that the beam coming from mirror M1 strikes them in the centre. The tilt should be adjusted so that the beam is reflected onto itself (Fig. 6).

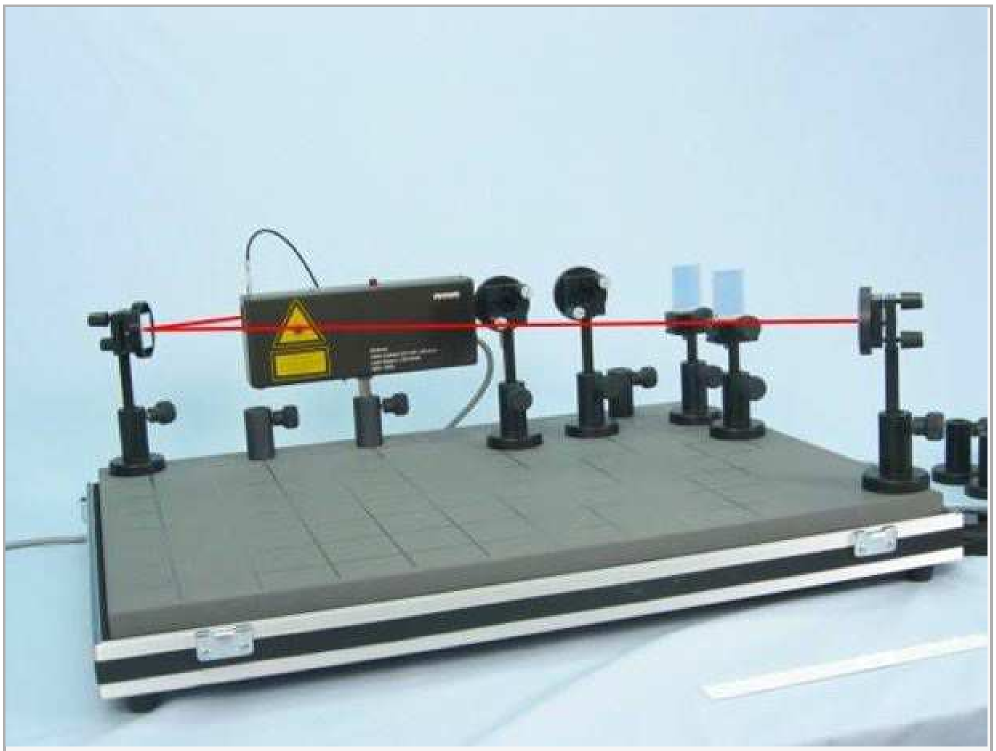

Fig. 6: Adjusting the mirrors M2, M3, M4 and the beam splitters BS1, BS2.

d) The mirrors M1, M2, M3, M4, the beam splitters BS1, BS2 and the screens are positioned as shown in Fig. 7 so that the indicated light-path forms. One should make sure that the coated side of the beam splitter BS1 is located on the side pointing towards mirror M2 and the coated side of beam splitter BS2 points toward mirror M4.
The beams should preferably travel parallel to the lines on the base plate and strike the optical elements in the centre.

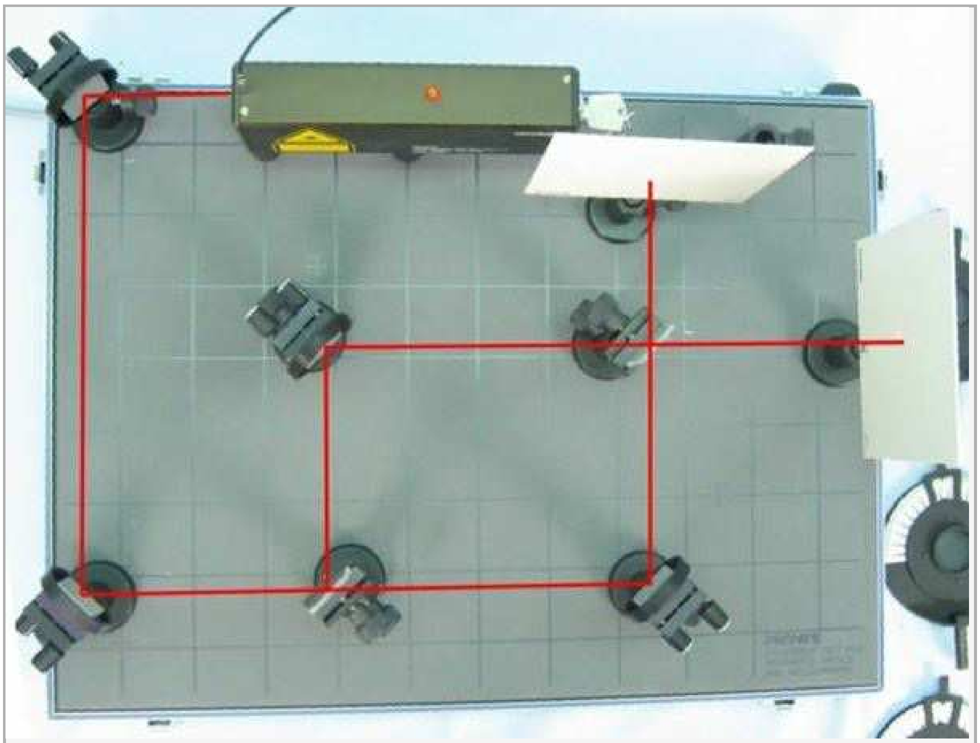

Fig. 7: Correct set-up of the mirrors and the beam splitters.

e) The goal of this step is to achieve a perfect coincidence of the pairs of beams going from the beam splitter BS2 to the screens. For adjustment one uses the mirror M4 and the beam splitter BS2.
One of the two screens should be quite close to the beam splitter BS2 the other one far away (Fig. 8).

Fig. 8: Adjusting the beams.

Initially on both screens two bright points will be visible. With the adjustment screws at mirror M4 these points can be brought to coincide on one of the two screens. But the adjustment is only done when the points coincide on both screens (the close one and the far one) simultaneously. A twinkling of these points then already indicates interference effects.
Typically the simultaneous coincidence of both pairs of points can not be realized with the adjustment screws on mirror M4 alone. Additionally the mirror M4 has to be moved to the left or to the right to achieve this. If the two dots appear in different heights on one of the screens while they coincide on the other one, this can be corrected by tilting the beam splitter BS2.

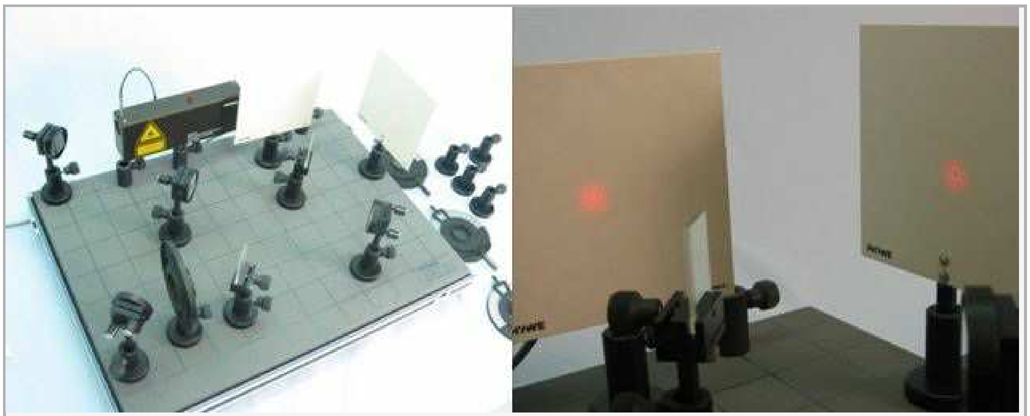

Fig. 9: Centering the interference pattern.

f) The expansion lens (f = 20 mm) is brought into position. The interference pattern visible on both screens should be centred with the aid of the adjustment screws of the mirror M4 (Fig.9).

Fig. 10: Set-up of the λ / 4 plate.

g) Now the λ/4 plate is brought into position. The role of this plate is to transform the linear polarized laser light into circular polarized light. This has the advantage that the orientation of the polarizers relative to the beam coming from the laser is of no importance. The λ/4 plate should be oriented so that the writing on it is in an upright position (Fig. 10).

h) Finally the three polarizing filters PF1, PF2, PF3 can be placed. The photographs below show the complete setup.

Fig. 11: Complete experiment setup, side view.

Fig. 12: Complete experiment setup, top view.

Experiment

Qualitative investigation of interference

With the Mach-Zehnder setup the essential effects of interference can be demonstrated impressively and easily: If one blocks one of the two paths in the interferometer, on the screens a relatively homogeneous spot is visible. If one opens now the blocked path, the spot does not become brighter everywhere, but there are regions (rings) where the brightness drops. This means, adding light to more light can result in darkness. If one blocks only half of one path, direct comparison is possible as shown in the photographs.

Analogy experiments to a quantum eraser

First the polarizing filter PF3 is shifted out of beam path. The polarizing filters PF1 and PF2 are oriented so that light passing them has the same polarization. Under these circumstances interference rings are visible on both screens.
If one rotates PF1 so that light passing it is polarized perpendicular to light passing PF2 the interference effect on both screens vanishes. The quantum mechanical reason for this is, that now one could in principle determine which path in the interferometer a photon took by analysing its polarisation after it left the interferometer. The quantum information about the path of a photon, imposed upon it by the polarisors, destroys its ability to interfere.
The next step is to introduce the polarizing filter PF3 and use it to erase the quantum information of the photons that pass it. For this task PF3 has to be oriented at an angle of 45 degrees with respect to PF1 and PF2. On the screen SC2 behind PF3 the interference pattern will be visible again since it is not possible any more by analysing the photons arriving there, to determine which path they took in the interferometer.
Amore detailed discussion and interpretation of the results (classical and quantum physics interpretation) is beyond the scope of this set-up guide and will be published later.