Quantum eraser

Experiment Objectives

- Setup of a Mach-Zehnder interferometer
- Extension of the Mach-Zehnder interferometer to quantum eraser

Basic Information

A basic concept in quantum physics is the complementarity principle: every quantum physical object always has both wave and particle properties. But they can never be observed simultaneously, not even if the uncertainty principle is successfully bypassed. Besides location and stimulus, two other complementary variables are which-way information and interference. A quantum eraser can show this.

A possible assembly of a quantum eraser is based on the Mach-Zehnder inteferometer (cf. Experiment P5.3.5.1). This is illuminated with a light source such that only one single photon is ever in the interferometer. There is a detector at the interferometer's output, with space-resolved detection of the individual photons. Polarization filters are placed in the interferometer's two arms to detect which way the photon has gone. If the filters' directions of polarization match, then an interference pattern is observable – totaled from many individual photons. However with crossed polarization, the interference pattern disappears. If another polarization filter is integrated to an output of the Mach-Zehnder interferometer, at a 45° angle to each of the two other filters, then the interference pattern is observable again. However the interference pattern is still missing at the other output without an additional polarization filter.

The complementarity of which-way information and interference explains the test result. Individual photons' paths can be determined distinctly by the crossed polarization filter. Therefore no interference can then be observed. With another polarization filter behind one of the interferometer outputs, all photons then have the same direction of polarization again. The which-way information is "erased," making interference possible again.

The quantum eraser's setup for individual photons is very complex. The test is therefore conducted with a laser in the present experiment, as its capacity constantly causes many photons to be in the interferometer simultaneously. For this setup, the observed effects can also be explained in the framework of classic electrodynamics: only electromagnetic waves that have a common direction of polarization can interfere. If the directions of polarization are perpendicular to each other, then interference is impossible. If another polarization filter is added at 45° behind an interferometer output, then the filter only lets the portion of light parallel to the polarization filter through to each arm. These portions have the same polarization and can therefore also interfere again.

Apparatus

1 Laser optics base plate	473 40
1 He-Ne Laser, linearly polarised	471 830
1 Laser mount	473 411
9 Optics bases	473 421
2 Holders for beam divider	473 431
2 Beam dividers 50%	473 432
2 Planar mirror with fine adjustment	473 461
2 Spherical lenses f = 2.7 mm	473 471
3 Polarization filters for base plate for laser optics	473 49
2 Translucent screens	441 53
2 Saddle bases	300 11
1 Wooden ruler	311 03

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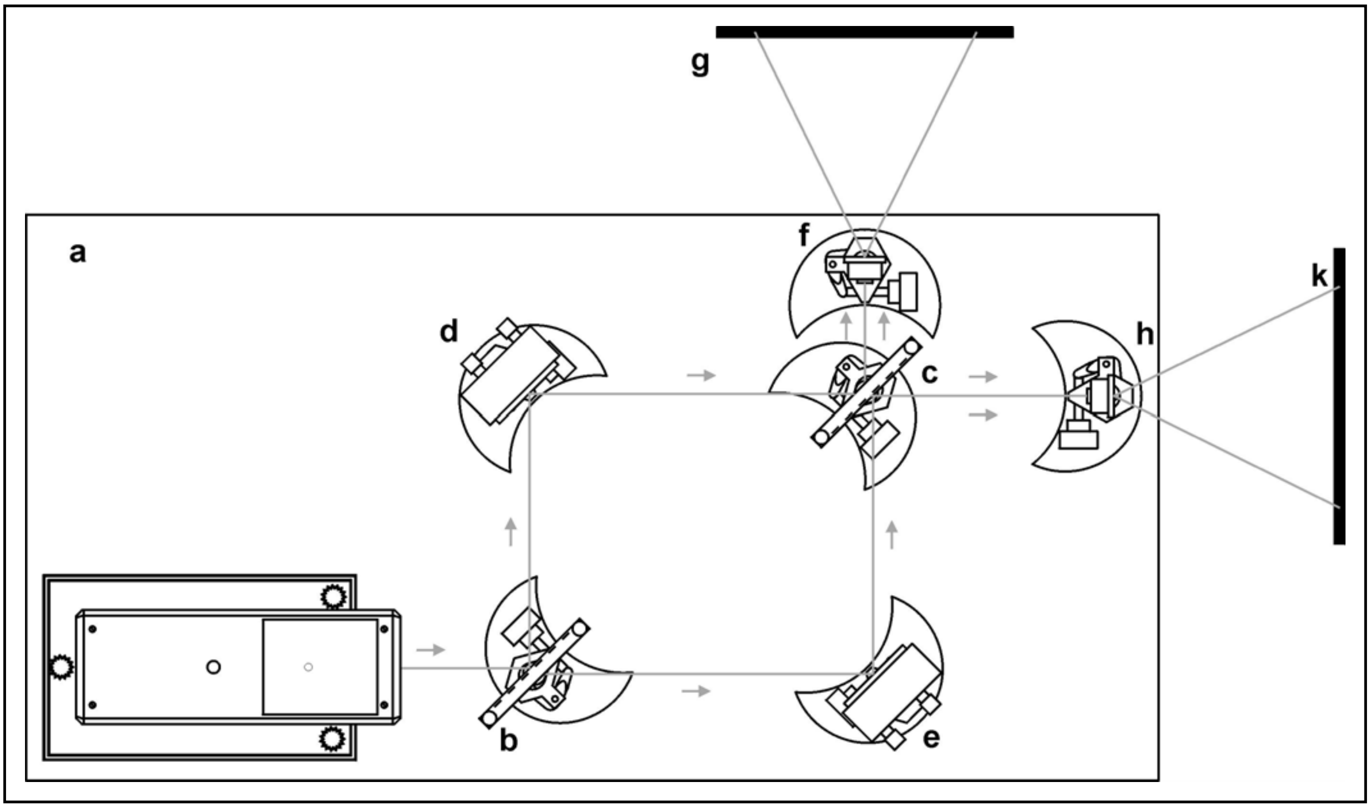

Illustration 1: Mach-Zehnder interferometer setup

Safety Instructions

The He-Ne laser complies with the provisions of Class 2 of EN 60825-1 "Laser equipment safety." Observing the corresponding notes in the operating manual makes the experimentation with the He-Ne laser safe.

- Do not look into the direct or reflected laser beam.
- Avoid crossing the glare threshold (i.e. no observer may get blinded).
- Limit the laser range with a cutoff at the required dimension, and avoid unnecessary reflections.

Mach-Zehnder Interferometer's Setup

Note: Optical components with damaged or dirty surfaces can cause disturbances in the interference pattern: handle planar mirrors, beam dividers and spherical lenses carefully, keep them dust-free and do not touch them with bare hands.

The Mach-Zehnder interferometer's arrangement on the laser optics base plate is represented in Illustration 1. The parts must be oriented with special care with regard to the beam's geometry. The assembly requires the following steps:

Laser optics base plate and laser:

- Inflate the air cushion.
- Install the laser optics base plate **(a)** with the air cushion level on the stable experiment table.
- Mount the laser on its mount and place it on the left side of the base plate.
- Attach the translucent screens **(g)** and **(k)** in a saddle base and install them according to Illustration 1, behind the laser optics base plate.
- Connect the laser and switch it on.
- Loosen the lock nuts of the laser mount's three set screws.
- Align the laser's height and inclination with the set screws so that the beam is perfectly horizontal about 75 mm above the base plate (thus enough of a clearance remains for readjustment); check the measurement with the wooden ruler.
- Tighten the lock nuts again.

Preliminary adjustment:

- Check if the beam dividers **(b)** and **(c)** reflect the laser light horizontally, by setting the beam dividers with optics foot at each end of the laser optics base plate in the beam's path and reflecting the light beam beside the laser's outlet.
- If necessary correct the inclination angle, and with it the beam's course, with the two screws on the shaft.
- Set the planar mirrors **(d)** and **(e)** with the upper set screws so that they reflect the laser light horizontally, by setting the planar mirrors with optics foot at each end of the laser optics base plate in the beam's path and reflecting the light beam beside the laser's outlet.

Beam dividers and planar mirrors:

Notes:

The adjustment is easier in a slightly dark room.

Besides the main beams, other so-called parasite beamlets, with lower intensity, appear from multiple reflections. These are later suppressed by the lens holder. The following information applies only to the main beams.

The reflected and transmitted beamlets should have similar intensity in each case. When using the variable beam divider (473 435), make sure that the laser beam reaches the beam divider near its center.

- Bring the beam divider **(b)** with optics foot to a 45° angle to the beam's path, as in Illustration 1, by correctly turning the beam divider's semitransparent film toward the laser.
- Set the planar mirror **(d)** in the beamlet reflected by the beam divider **(b)** so that the laser beam reaches its center.
- Align the planar mirror by turning the optics foot on the interferometer base plate so that the beam is deflected by 90° and runs parallel to the transmitted beamlet.
- Add the planar mirror **(e)** to the assembly in the transmitted beamlet according to Illustration 1, opposite the planar mirror **(d)**, so that the laser beam reaches its center. There should be at least a 10 cm clearance between the planar mirror **(e)** and the end of the laser optics base plate.
- Align the planar mirror likewise by turning the optics foot on the interferometer base plate so that the beam is deflected by 90°.
- Arrange the translucent screens **(g)** and **(k)** so that their centers are hit.
- Arrange the beam divider **(c)** antiparallel to the beam divider **(b)** so that both beamlets meet it at a 45° angle, at which the semitransparent film of the screen **(g)** is averted.
- Move the planar mirror **(e)** parallel to the laser optics base plate's length and arrange it so that the beamlet it reflects and the beamlet reflected from the planar mirror **(d)** cover each other both on the beam divider **(c)** and on the translucent screen **(g)**.
- Change the distance between the screens **(g)** and **(k)** and the second beam divider **(c)** and check if the sheens of the respective beamlets stay nearly one on top of the other, and so run sufficiently parallel to each other.

Readjustment:

a) Readjustment of the vertical beam:

In case the beamlets diverge on the vertical plane:

- Measure the beamlets' exact height above the laser optics base plate behind each optical component with the wooden ruler and if necessary readjust the planar mirrors' and the beamlets' inclinations.
- Align the most intense beam of the two sheen groups appearing on each translucent screen by readjusting the assembly parts.
- Change the distance between the screen **(g)** and the second beam divider **(c)** once more, to check the two beamlets' parallelism.
- Repeat the readjustment if necessary.

b) Readjustment of the horizontal beam:

The beamlets should leave the beam divider **(c)** at nearly the same spot and should meet each other on the translucent screen. In case the beamlets diverge on the horizontal plane:

- Check the beamlets' course from the beam divider **(b)** to the beam divider **(c)** and correct the appropriate parts' alignment in case the beam does not create approximately a right angle.
- Move the planar mirror **(e)** parallel to the laser optics base plate's length and arrange it so that the beamlet it reflects and the beamlet reflected from the planar mirror **(d)** cover each other both on the beam divider **(c)** and on the translucent screen.

Spherical lens:

- Position the spherical lens **(f)** (with the small inlet toward the beam divider) on the laser optics base plate between the beam divider **(c)** and the translucent screen **(g)**.
- Position the spherical lens **(h)** (with the small inlet toward the beam divider) on the laser optics base plate between the beam divider **(c)** and the translucent screen **(k)**. Enough room should remain between the beam divider **(c)** and the spherical lens **(h)** for a polarization filter.
- Arrange the spherical lenses laterally and vertically so that the two beamlets pass through them.
- The beam's path may need to be corrected by readjusting the planar mirrors.

Fine tuning:

In case still no striped pattern can be recognized on the translucent screens:

- Change the beam's path by slightly adjusting the beam divider or the mirror, and if necessary readjust the spherical lens.

The better the two beamlets' parallelism between the beam divider **(c)** and the screen **(g)**, the bigger the interference fringe's width and distance:

- Set the interference pattern to a conveniently observable format with small modifications to the beamlets' and mirrors' alignments.

In case the fine tuning misses the mark:

- Adjust the interferometer's arrangement once again from the beginning.

The interference pattern is considerably brighter and therefore easier to observe if the laser is switched to an output of 1 mW. Since the beam's path can thus be slightly changed, the beam's course or the spherical lens's position must be readjusted if necessary.

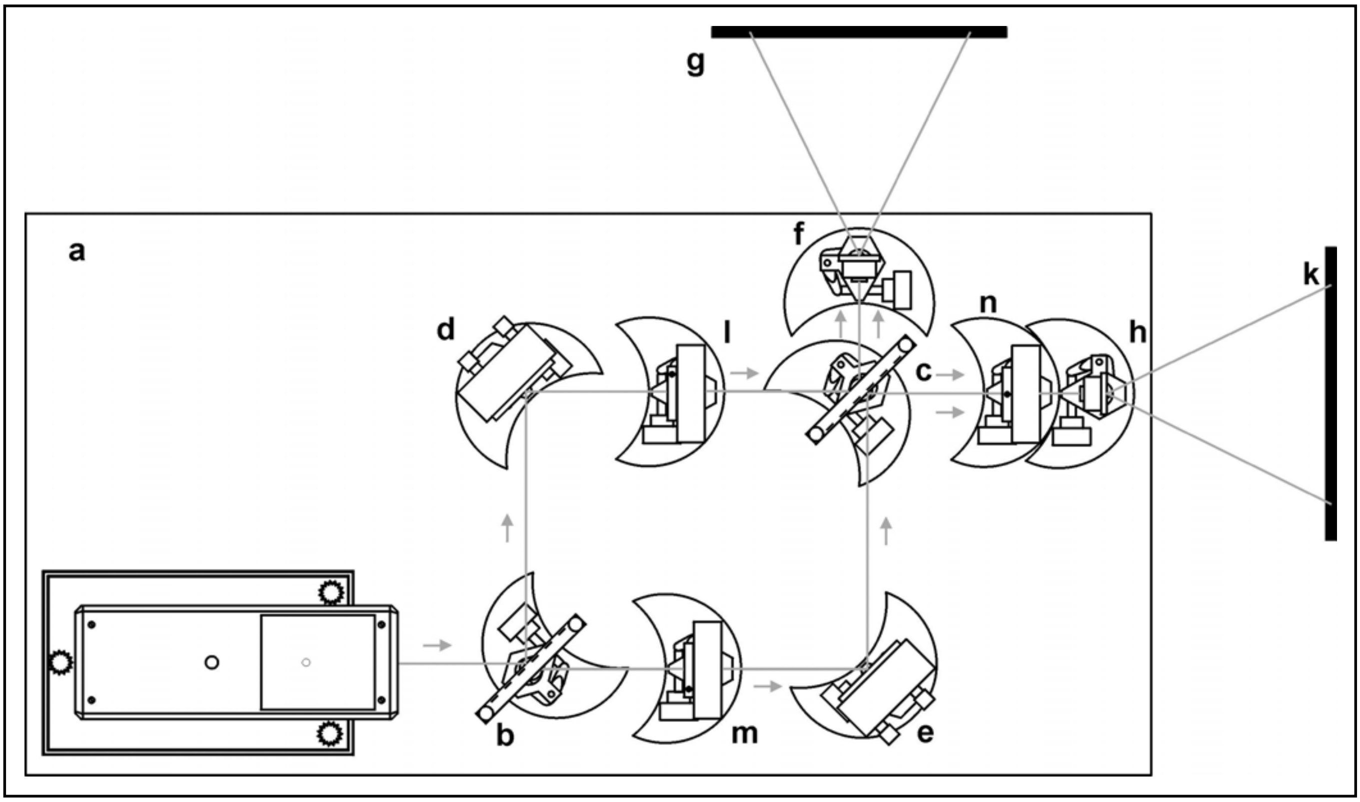

Illustration 2: Quantum eraser setup

Extension to Quantum Eraser

- Set a polarization filter **(l)** in the beamlet reflected by the planar mirror **(d)** so that the laser beam reaches its center.
- Set the direction of polarization for the polarization filter **(l)** to +45°.
- Set the second polarization filter **(m)** in the beamlet transmitted by the beam divider **(b)** so that the laser beam reaches its center.
- Likewise set the direction of polarization for the polarization filter **(m)** initially to +45°.

Inserting the polarization filters darkens the interference patterns on the screens **(g)** and **(k)**, since the polarization filter's transmission does not amount to 100%; there is no other change.

Procedure and Analysis

- Slowly set the direction of polarization of the polarization filter **(m)** to -45°.

Observation and explanation:

The interference's fringe contrasts less and less; the interference pattern has completely disappeared at -45°. The photons' path in the interferometer can be precisely determined with crossed polarizers, therefore no interference is possible.

- Set the polarization direction for the third polarization filter **(n)** to 0°.
- Set the polarization filter **(n)** between the beam divider **(c)** and the spherical lens **(h)** so that the laser beam reaches its center.
- Slowly vary the direction of polarization of the polarization filter **(n)**.

Observation and explanation:

If the polarization filter **(n)** is on 0°, then the interference fringe on the screen **(k)** is observable again, while still no interference is observable on the screen **(g)**. The polarization filter **(n)** deletes the path information, therefore interference is possible again.

If the direction of polarization is modified for the polarization filter **(n)**, then the interference's contrast slowly diminishes. The interference disappears at ±45°. Modifying the polarization filter's direction means the path information is no longer completely deleted. Only part of the light can still interfere.