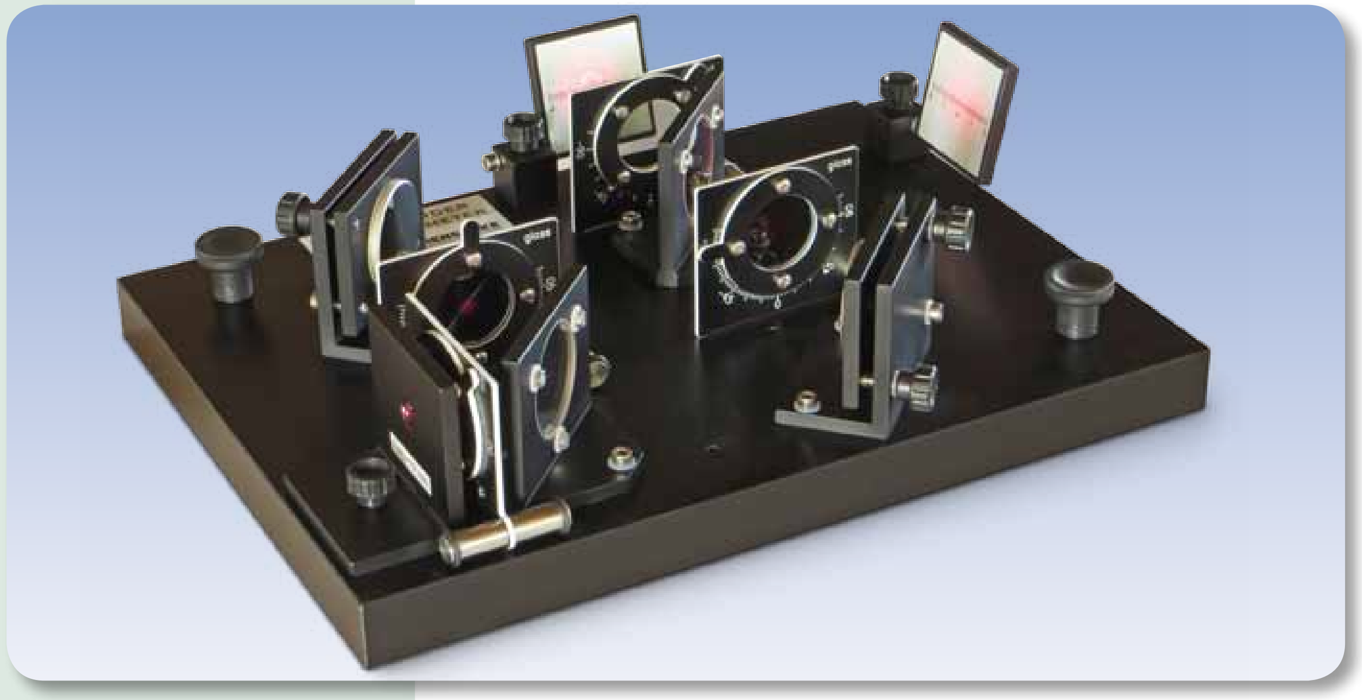
MACH-ZEHNDER INTERFEROMETER



EXPERIMENT PROCEDURE

- **Set up and calibrate a Mach-Zehnder interferometer**
- **Observe the interference pattern when the information is available, unavailable and "erased".**

OBJECTIVE

Demonstration of "quantum erasure" in an experiment by analogy.

SUMMARY

Light itself can be described in quantum mechanics by means of wave equations. From this it is possible to derive the spatial distribution of the probability density in the form of the square of the modulus of the wave function. Light is therefore suitable for experiments which demonstrate quantum mechanical phenomena by analogy. Such an analogy experiment demonstrates the so-called quantum eraser effect by setting up a Mach-Zehnder interferometer and observing interference between the split beams on a screen. If two perpendicular polarisers are placed in the paths of the split beams, the interference vanishes since, in quantum mechanical terms, it is possible to determine the path a photon has taken. If a third polarising filter set at an angle of 45° is placed directly in front of the screen, this quantum information is "erased" and the interference can be seen once again.

REQUIRED APPARATUS

Quantity	Description	Number
1	Mach-Zehnder Interferometer	1014617
1	He-Ne-Laser	1003165

BASIC PRINCIPLES

Light itself can be described in quantum mechanics by means of wave equations. From this it is possible to derive the spatial distribution of the probability density in the form of the square of the modulus of the wave function. The combination of two beams corresponds to superposition of two wave functions. The probability density then contains a mixed term which describes the interference pattern. Light is therefore suitable for experiments which demonstrate quantum mechanical phenomena by analogy.

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To demonstrate the so-called quantum eraser effect by means of an analogy experiment, a Mach-Zehnder interferometer is used. Coherent light is providing by letting light from a laser be diverged. With the help of beam splitter BS1, the light is divided into two split beams. Polariser P ensures that both split beams have the same light intensity (see Fig. 1). The two beams then follow different paths but are then brought back into superposition by a second beam splitter BS2.

In terms of conventional wave optics, the electrical fields of the two split beams E_1 and E_2 are then added together:

(1) $$E = E_1 + E_2$$

In quantum mechanical terms, their wave functions Ψ_1 and Ψ_2 can also be summed as follows:

(2) $$\Psi = \Psi_1 + \Psi_2$$

Therefore

(3) $$|E|^2 = |E_1|^2 + |E_2|^2 + 2 \cdot E_1 \cdot E_2$$

and

(4) $$|\Psi|^2 = |\Psi_1|^2 + |\Psi_2|^2 + 2 \cdot \langle \Psi_1 | \Psi_2 \rangle \ ,$$

The mixed terms in equations (3) and (4) both describe the interference pattern which can be observed on a screen. Equation 4 describes the behaviour of an individual photon. Such a photon interferes with 'itself' as long as it is observed by any process of measurement or if it is not possible to observe the actual path it has travelled. It is said with regard to this that "in the absence of information regarding its path, a photon behaves as a wave and exhibits interference". If information regarding the path taken is available, however, the photon "behaves" like a classical particle and it is not possible for interference to occur.

Two additional polarisers P1 and P2 placed in the paths of the split beams 1 and 2 cause the interference pattern to be affected. If the polarisers are aligned at right angles to one another, the scalar product $E_1 \cdot E_2$ vanishes in the classical description of equation (3), as does the interference term $\langle \Psi_1 | \Psi_2 \rangle$ in the quantum mechanical representation of Equation (4). This results in the disappearance of the interference pattern. In the quantum mechanical case, this is because the polarisation means that it is possible to specifically determine which path, path 1 or path 2, has been taken by each photon.

However, if a third polariser A, aligned at 45° to the others, is placed behind the second beam splitter, the interference pattern reappears. In quantum mechanical terms, this is so because polariser A "erases" the path information, i.e. beyond polariser A it is no longer possible to determine which path has been taken by any individual photon. In the classical representation, the third polariser would be expected to dim the polarised split beams but they would be expected to retain their polarisation.

EVALUATION

In the absence of both polarisers, P1 and P2, there will be no information available regarding the path taken by the light and interference therefore occurs. Once the two polarisers are employed, it is possible to distinguish paths and interference does not occur.

The third polariser, A, "erases" the path information and interference occurs once more.

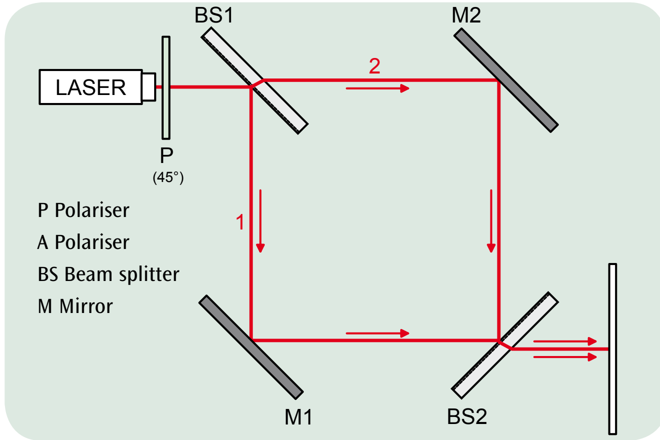

Fig. 1: Paths through the Mach-Zehnder interferometer (no path information)

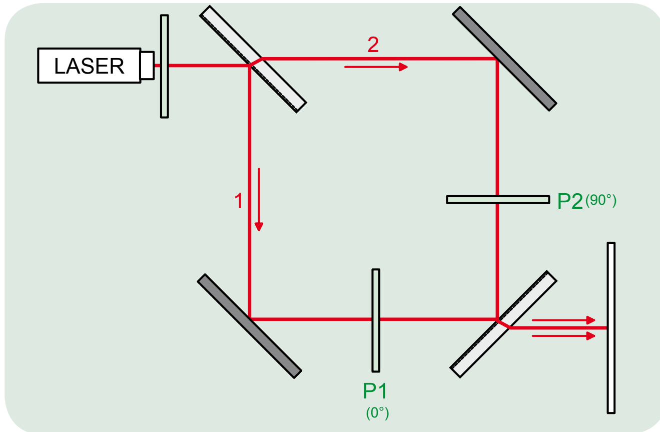

Fig. 2: Paths through the Mach-Zehnder interferometer (polarisers P1 and P2 placed in the two split beams means path information can be obtained)

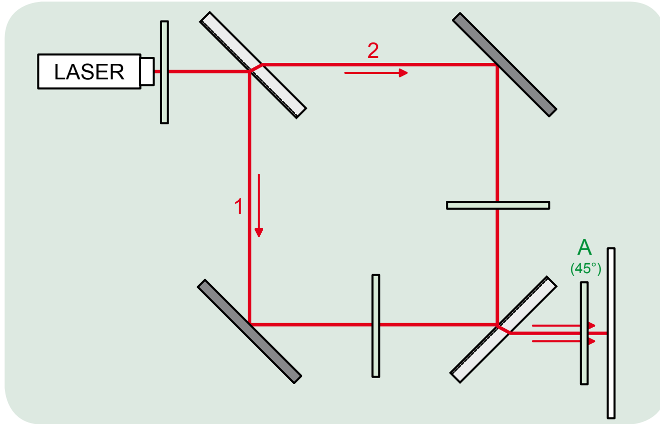

Fig. 3: Paths through the Mach-Zehnder interferometer (polariser A "erases" the path information)