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A Lego® Mach–Zehnder interferometer with an Arduino detector

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Abstract
In this paper, a Lego®-based interferometer, developed by a first-year bachelor physics student, is presented. The interferometer is home-built at low cost, using household items such as glass panes for beamsplitters and reflecting smartphone logos for mirrors. It is able to produce stable and visible fringes, of which shifting can be monitored. The presented methods allow students to build and conduct adequate optical experiments without the need for expensive optics lab materials, making them deployable in distance learning. Moreover this interferometer demonstrates the educational value of a free experimental assignment.

Keywords: Mach–Zehnder interferometer, lego, home experiment, first year bachelor, low cost, optics, Arduino

Supplementary material for this article is available online

1. Introduction

In the Covid-19 crisis, many undergraduate physics students have to conduct experiments at home [1], without (expensive) lab equipment.

Designing and conducting such an experiment requires creativity and comprehension of lab components, with students having to devise household alternatives. We will demonstrate that these (open) at-home experiments can still teach students various research skills.

For low-cost educational setups, Lego® can provide stable (optical) setups [2], and Arduino micro-controllers can function as sensory multi-tools [3].

In this paper, a Mach–Zehnder interferometer (henceforth 'MZI') is presented. A first-year BSc student, the first author, developed it in an open at-home optics experiment, using Lego®, detectors coupled to an Arduino and household materials.

This interferometer offers the possibility of conducting decent optics experiments in situations where students have no expensive optics lab materials at their disposal, such as the current

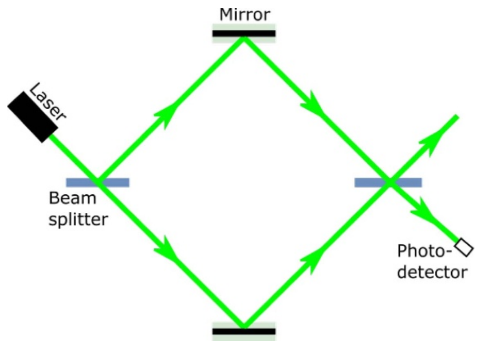

Figure 1. Schematic representation of an MZI.

at-home education. It can be used for qualitative and quantitative (demonstrational) experiments on the wave-like nature of light.

2. Theory

In an MZI (figure 1) the two light paths reaching the light detector are reflected and transmitted once by beamsplitters before reaching a light detector. Consequently both beams are of equal intensity, even without a 50/50 beamsplitter. This is a great advantage for the presented low-resource experiment.

The output beams of a well-aligned interferometer show fringes (figure 3). These fringes shift when the relative optical path length of the two paths is changed.

We manipulated this path length by applying a local temperature change ΔT between $280\ \text{K} < T < 340\ \text{K}$ to one arm of the MZI. For these temperatures, the refractive index changes by $\frac{dn}{dT} \approx -10^{-6}\,\text{K}^{-1}$ [4].

3. Setup

The setup is demonstrated in a video (link provided in [5]) and a schematic overview is provided in figure 2, where the used red laser light is indicated in green. It is highly convenient for coarse alignment to place the mirrors and beamsplitters parallel to one another in a rectangular shape. This shape is achieved by placing the mirrors and beamsplitters parallel to the knobs of a (double sized Lego®) base plate.

The light source is a 650 ± 20 nm (red) laser pointer, directed diagonally over the knobs. The laser was fixed in a Lego® mount, with its on-button permanently being pressed (figure 2(b)). One of the batteries' poles was disconnected from the laser and two wires were attached to the battery and the laser respectively. Connecting the wires through a screw terminal turns the laser on remotely without affecting alignment.

The beamsplitters consist of glass panes from picture frames, clamped between two parallel Lego® Duplo frames. The light strikes the beamsplitters at 45%. Small spacings in the Lego® block connections allow small movements for alignment. Glass reflects little (≈4%) of the incident light, which, however suboptimal, is sufficient for an MZI. The considerable pane thickness caused front- and back-face reflections, resulting in visually separated partial output beams.

To prevent more cases of multiple reflections in the setup, reflecting logos on the back of smartphones were used as mirrors. These logos consist of a metal surface which reflects the beam directly, whereas a common household mirror reflects the beam twice; both at the front and the back surface of the glass pane.

The smartphones' angular shape simplified the construction of a stable mount. Each phone was placed on a smaller Lego® base plate, clamped in between Lego® pillars (red and yellow in figure 2(d)). By mounting this plate on a horizontal wheel, with its axle pointing upward, the plate could be rotated to achieve high precision alignment.

After the second beamsplitter beams from both arms join. With correct alignment, the beams coincide (i.e. overlapping at both the beamsplitter and the detector) and interfere to form fringes. This joint output beam is enlarged by lenses (magnifying glasses) (see central schematic in figure 2). The enlarged fringes (figure 3) are twice the size of the light detectors, making them detectable as well as clearly visible.

The local temperature change was achieved by an ice block or a (closed) container of hot water in an EPS ('Styrofoam') box (length $L = 18.4 \pm 0.1$ cm) in one arm of the MZI. The light traveled through the box and the air inside while it was heated/cooled.

The fringe intensity was measured using four light detectors (used type: HW5P-1 photodiodes,

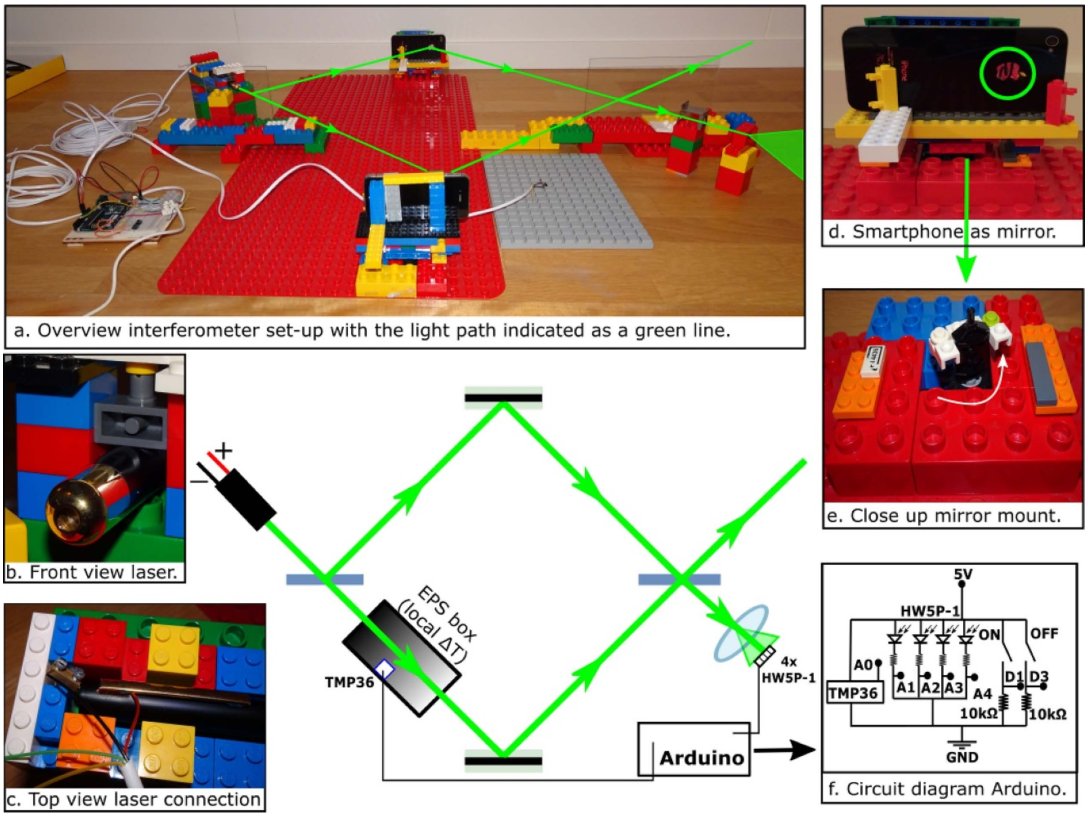

Figure 2. An overview of the setup in different subfigures.

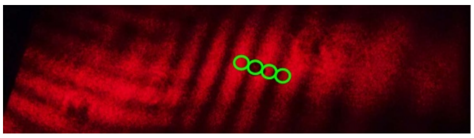

Figure 3. The fringes in the enlarged beam. The four circles represent the four light sensors.

any photodiode suffices). The local temperature change ΔT was recorded using semi-conductor temperature detectors (type: TMP36). All detectors were connected to the Arduino's analogue read pins A0–A4, (see figure 2(f)). The light detectors were connected via resistors, of 1.0 MΩ, yielding a signal well within the Arduino's 0–5 V measuring range. The ON/OFF buttons shown on the right in the diagram were used to start and stop the measurements.

The temperature-induced refractive index change causes a fringe shift. This shift is measured as rising and falling intensity by the light detectors and visually counted. These fringes shift predominantly stable, sometimes interrupted by periods of instability caused by e.g. a passing car outside.

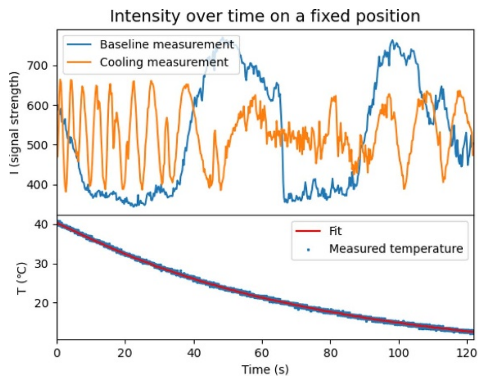

Figure 4. Experimental results for two measurements. During cooing the fringes are unstable between $t = 50$ s and $t = 80$ s.

4. Results

We analysed the shifts in periods of fringe stability of 16 measurements (4 baseline, 6 heating and 6 cooling) (available online at stacks.iop.org/PED/56/023004/mmedia). Figure 4 shows temperature change increases the fringe shift.

The fringes are clearly visible, showing strong destructive interference with a high to low intensity ratio as low as ≈0.25.

On average baseline measurements show a net fringe shift of 1.2 ± 0.9 fringes per minute, likely caused by setup relaxation. Changing temperature increases this to 7 ± 6 fringes per minute. The calculated fringe shift over temperature [4] is ≈3 K per fringe [4]. We measured 3 ± 2 K per fringe, which is in accordance. The large measurement error is inherent to a home-built Lego® interferometer.

5. Conclusion

The presented low-cost home-built Lego® MZI generates stable, visible fringes, sensitive to slight refractive index changes and external disturbances (e.g. passing cars). The setup may become even more accessible, when replacing the smartphones by common household mirrors and the Arduino detectors by a regular thermometer and visually counting the fringe shift.

The presented methods allow students to build and conduct adequate optical experiments in times of distance education. Through such experiments, students acquire the research skills that are essential in undergraduate physics education. Especially instructive of at-home experiments, is that thorough comprehension of their components is needed to find household alternatives.

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References

[1] Pols F and Levert T 2020 Nederlands Tijdschrift voor Natuurkunde August 2020 28–31
[2] Koch G 2014 *LEGO® Optics: Projects in Optical and Laser Science with LEGO®* (CreateSpace Independent Publishing Platform)
[3] Lee W S 2020 *Phys. Educ.* **55** 023002
[4] Edlén B 1966 *Metrologia* **2** 71–80
[5] Feenstra L and Wayenburg B 2020 (available at: www.youtube.com/watch?v=kSzgz0CJ80o)

Louw Feenstra started his double bachelor physics and astronomy at Leiden University in 2019. His interests are experimental research and physics education. He plans to do a master in (experimental) physics after finishing his bachelors.

Julia Cramer recently started the research group 'Quantum and Society' at the faculty of science at Leiden University to explore the boundary between quantum technology and science communication. She has a background in experimental quantum physics and science communication research and is active in practical outreach in various forms.

Paul Logman is responsible for the Bachelor labs at the Leiden Institute of Physics at Leiden University which recently have been renewed to contain more open assignments for the students. He has a background in physics didactics and his interests lie in (open) Bachelor experiments, didactics for the concept of energy, and teacher training.