A Fabry–Pérot Method for Testing the Speed of Light

Franc Rozman & UI

Abstract

The propagation speed of light is conventionally obtained from the relation between propagation speed, wavelength, and frequency. In most optical measurements, the propagation speed is introduced as an initial assumption, while wavelength and frequency are treated as equivalent descriptions of the same electromagnetic wave. Consequently, an independent experimental determination of the propagation speed is rarely performed.

This paper proposes an optical measurement method that determines the wavelength and frequency of incoming electromagnetic radiation independently. Two identical Fabry–Pérot interferometers are placed before and after a stationary diffraction grating. The first interferometer measures the wavelength of the incoming wave. The diffraction grating re-forms the electromagnetic wave while preserving its temporal frequency. Since the propagation speed of the re-formed wave in the laboratory medium is known, a second wavelength measurement provides an independent determination of the wave frequency. The propagation speed of the incoming light is then obtained by combining the independently measured wavelength and frequency.

The proposed method does not assume any particular experimental outcome. According to conventional electromagnetic theory, the measured propagation speed should be identical to the accepted speed of light in the laboratory medium. Any reproducible deviation would indicate that one or more assumptions concerning the optical transformation or propagation of electromagnetic waves require further investigation.

The principal contribution of this work is the presentation of a practical optical method that separates the experimental determination of wavelength and frequency, thereby providing a direct experimental test of the propagation speed of incoming electromagnetic radiation.

1. Introduction

The speed of light is one of the fundamental quantities in physics. In modern optics, the three parameters describing a monochromatic electromagnetic wave—its propagation speed, frequency, and wavelength—are related by

$$v = f\lambda.$$

For light propagating in a given medium, this relation connects the temporal and spatial properties of the wave. In vacuum, the propagation speed is taken to be the constant c, so that wavelength and frequency are generally regarded as two equivalent representations of the same physical phenomenon.

Most optical instruments determine wavelength rather than frequency directly. Diffraction gratings, prisms, and Fabry–Pérot interferometers all derive spectral information from the spatial properties of electromagnetic waves. Frequency is then obtained from the measured wavelength by assuming the known propagation speed of light in the corresponding medium. Consequently, wavelength and frequency are rarely determined independently, because the relation $v=f\lambda$ is introduced at the beginning of the measurement procedure.

The present work investigates whether these two quantities can instead be determined independently by combining two different optical principles. A Fabry–Pérot interferometer (FPI) is used to determine the spatial period (wavelength) of the incoming electromagnetic wave. The light is then transmitted through a stationary diffraction grating, which re-forms the propagating wave without changing its temporal frequency. Since the propagation speed of the re-formed wave in the laboratory medium is known, a second FPI measurement of its wavelength provides an independent determination of the wave frequency.

The incoming propagation speed can then be evaluated from two experimentally determined quantities: the wavelength measured before the diffraction grating and the frequency determined after the diffraction grating. The proposed method therefore separates the measurement of wavelength from the determination of frequency, allowing the propagation speed of the incoming light to be evaluated without introducing it as an initial assumption.

The method itself does not assume any particular experimental outcome. According to conventional electromagnetic theory, the calculated propagation speed of the incoming light should be equal to the accepted speed of light in the same medium. If the measured value differs, the result would indicate that one or more assumptions concerning the propagation or optical transformation of electromagnetic waves require further examination. In either case, the proposed method provides a direct experimental framework for independently comparing the spatial and temporal characteristics of electromagnetic radiation.

The purpose of this paper is therefore not to propose a new theory of light, but to present and analyse an optical measurement method capable of independently determining wavelength and frequency before combining them to evaluate the propagation speed of incoming electromagnetic radiation.

2. Measurement Principle

The proposed method is based on two independent optical measurements performed on the same incoming beam of light. The objective is to determine the wavelength and frequency independently, allowing the propagation speed of the incoming electromagnetic wave to be evaluated without assuming its value in advance.

The incoming beam is first analysed by a Fabry–Pérot interferometer (FPI-1), which determines the wavelength of the incident electromagnetic wave in the laboratory medium. This wavelength is denoted by

$$\lambda_1.$$

The same light is then transmitted through a stationary diffraction grating. The grating re-forms the propagating electromagnetic wave while preserving its temporal frequency. Since the propagation speed of the re-formed wave in the laboratory medium is known, its wavelength can be measured by a second Fabry–Pérot interferometer (FPI-2). The measured wavelength is denoted by

$$\lambda_2.$$

Because the propagation speed after the diffraction grating is known, the wave frequency is obtained from

$$f = \frac{v_{\text{lab}}}{\lambda_2},$$

where v_{lab} is the propagation speed of light in the laboratory medium.

The propagation speed of the incoming light is then determined by combining the independently measured wavelength λ1 with the independently determined frequency:

$$v_{\text{in}} = f\lambda_1.$$

Substituting the expression for the frequency gives

$$v_{\text{in}} = v_{\text{lab}}\frac{\lambda_1}{\lambda_2}.$$

This equation forms the basis of the proposed measurement method.

If the wavelength measured before and after the diffraction grating is identical,

$$\lambda_1 = \lambda_2,$$

the calculated propagation speed equals the accepted propagation speed in the laboratory medium,

$$v_{\text{in}} = v_{\text{lab}}.$$

Any measurable difference between the two wavelengths would result in a corresponding difference between the calculated incoming propagation speed and the propagation speed after the diffraction grating.

The remainder of this paper analyses the physical assumptions underlying this measurement principle and examines whether the proposed procedure provides an experimentally independent determination of the propagation speed of incoming electromagnetic radiation

3. Role of the Fabry–Pérot Interferometer

The proposed measurement method relies on two identical Fabry–Pérot interferometers. Their function is not to determine the frequency of the electromagnetic wave, but to measure its wavelength in the laboratory medium.

A Fabry–Pérot interferometer consists of two parallel partially reflecting mirrors separated by a precisely known distance. An electromagnetic wave entering the interferometer undergoes multiple reflections between the mirrors, producing a sequence of transmitted waves. Constructive interference identifies the geometrical condition in which an integer number of wavelengths fits within the optical path.

Consequently, the interferometer compares a precisely known mechanical distance with the spatial period of the electromagnetic wave. Interference serves only as an indicator that this geometrical condition has been satisfied.

After instrumental calibration, the measured wavelength is determined solely by the geometrical relation between the mirror separation and the number of wavelengths accommodated within the optical path. Instrumental parameters such as mirror reflectivity, transmission, phase shifts at the mirror coatings, and detector sensitivity affect the measurement accuracy but do not change the physical quantity being measured. These parameters are therefore treated as calibration constants rather than as part of the measurement principle.

In the proposed method, the first interferometer (FPI-1) measures the wavelength of the incoming electromagnetic wave before it reaches the diffraction grating,

$$\lambda_1.$$

The second interferometer (FPI-2) measures the wavelength of the re-formed wave after transmission through the diffraction grating,

$$\lambda_2.$$

Both interferometers operate in the same laboratory medium and are calibrated using identical procedures. Consequently, systematic effects associated with the optical medium, mirror coatings, and instrumental geometry are common to both measurements and largely cancel when the ratio of the two measured wavelengths is evaluated.

The Fabry–Pérot interferometers therefore provide two independent measurements of wavelength. They do not determine the wave frequency, nor do they require prior knowledge of the propagation speed of the incoming light. Frequency is obtained only after the second wavelength measurement, where the propagation speed of the re-formed wave is known from the properties of the stationary diffraction grating.

This separation of wavelength measurement from frequency determination constitutes the central feature of the proposed method.

Additional requirement for the Fabry–Pérot interferometer

To ensure an independent measurement of wavelength, the Fabry–Pérot interferometers must not include diffraction gratings, narrow slits, periodic masks, or any other optical elements that could act as secondary diffracting structures. The interferometers must measure the wavelength directly through multiple-beam interference alone, without any intermediate optical element capable of re-forming the electromagnetic wave.

4. Role of the Diffraction Grating

The diffraction grating performs a fundamentally different function from that of the Fabry–Pérot interferometer. Whereas the interferometer determines the wavelength of an electromagnetic wave, the diffraction grating serves as a passive optical element that re-directs and re-forms the propagating wave without introducing any intrinsic time dependence.

A stationary diffraction grating possesses a fixed spatial structure but no characteristic temporal frequency. Consequently, it cannot generate or modify the temporal oscillation frequency of the incident electromagnetic field. The oscillation frequency of the transmitted wave therefore remains identical to that of the incoming wave.

Accordingly,

$$f_{\text{out}} = f_{\text{in}}.$$

This conservation of frequency is the only property of the diffraction grating required by the proposed measurement method.

After passing through the diffraction grating, the electromagnetic wave propagates in the laboratory medium. Its propagation speed is therefore the accepted propagation speed of light in that medium,

$$v_{\text{out}} = v_{\text{lab}}.$$

The wavelength of the transmitted wave can then be measured by the second Fabry–Pérot interferometer (FPI-2). Since both the propagation speed and the wavelength are known, the wave frequency is obtained directly from

$$f = \frac{v_{\text{lab}}}{\lambda_2}.$$

Because the diffraction grating preserves the temporal frequency,

$$f_{\text{in}} = f_{\text{out}} = f,$$

this frequency is also the frequency of the incoming electromagnetic wave before it reached the grating.

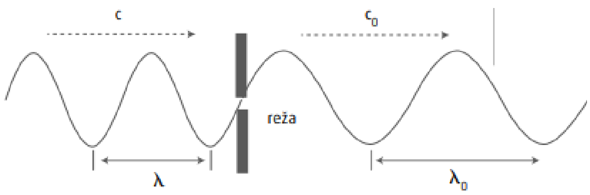

Figure 1. *Principle of the proposed measurement method. The first Fabry–Pérot interferometer measures the wavelength of the incoming wave (λ1\lambda_1λ1). A stationary diffraction grating re-forms the electromagnetic wave while preserving its temporal frequency. The second Fabry–Pérot interferometer measures the wavelength of the outgoing wave (λ2\lambda_2λ2), from which the frequency and subsequently the incoming propagation speed are determined.*

Within the proposed method, the diffraction grating therefore does not act as a wavelength-measuring device. Its role is to provide an outgoing electromagnetic wave of known propagation speed while preserving the temporal frequency of the incoming radiation. This enables the frequency to be determined independently of the wavelength measured by the first Fabry–Pérot interferometer.

The following section examines the physical origin of the outgoing wave and explains why its propagation speed is determined by the optical properties of the laboratory medium rather than by the propagation history of the incoming radiation.

5. Formation of the Electromagnetic Wave Behind the Diffraction Grating

The proposed measurement method requires one additional physical assumption concerning the electromagnetic wave emerging from the diffraction grating. This assumption is stated explicitly because it forms the basis for determining the wave frequency.

When an electromagnetic wave reaches a stationary diffraction grating, the incident field interacts with a large number of identical grating elements. Each element is excited by the oscillating electric field of the incoming wave and becomes a secondary source of electromagnetic radiation. The outgoing wave is formed by the coherent superposition of the radiation emitted by all grating elements.

Since the diffraction grating is stationary, every grating element oscillates with the same temporal frequency as the incident electromagnetic field. Consequently, the secondary waves generated by the grating possess the same temporal frequency as the incoming wave. Their coherent superposition therefore produces an outgoing electromagnetic wave of identical frequency,

$$f_{\text{out}} = f_{\text{in}}.$$

The propagation of the outgoing wave is determined by the electromagnetic properties of the surrounding laboratory medium. Once the wave has been re-formed by the coherent superposition of the secondary sources, it propagates in the same manner as any other electromagnetic wave generated within that medium. Its propagation speed is therefore

$$v_{\text{out}} = v_{\text{lab}}.$$

The wavelength of the outgoing wave is consequently

$$\lambda_2 = \frac{v_{\text{lab}}}{f_{\text{in}}}.$$

This wavelength is measured by the second Fabry–Pérot interferometer. Since the propagation speed in the laboratory medium is known, the frequency of the incoming wave is obtained directly from

$$f_{\text{in}} = \frac{v_{\text{lab}}}{\lambda_2}.$$

The proposed method does not require any assumptions concerning the propagation speed of the incoming light before it reaches the diffraction grating. Only the propagation of the re-formed wave in the laboratory medium is required to determine the frequency.

Combining this independently determined frequency with the wavelength measured before the diffraction grating yields the propagation speed of the incoming electromagnetic wave.

The principal objective of the proposed method is not to replace existing descriptions of light propagation but to provide an independent experimental procedure by which the underlying assumptions can be tested directly.

6. Determination of the Incoming Propagation Speed

The preceding sections established two independent experimental quantities.

The first Fabry–Pérot interferometer (FPI-1) determines the wavelength of the incoming electromagnetic wave,

$$\lambda_1.$$

The stationary diffraction grating preserves the temporal frequency of the wave while re-forming an electromagnetic wave that propagates in the laboratory medium. The second Fabry–Pérot interferometer (FPI-2) measures the wavelength of this outgoing wave,

$$\lambda_2.$$

Since the propagation speed of the outgoing wave in the laboratory medium is known, its frequency is determined from

$$f = \frac{v_{\text{lab}}}{\lambda_2}.$$

Because the diffraction grating preserves the temporal frequency,

$$f_{\text{in}} = f.$$

The propagation speed of the incoming electromagnetic wave is then obtained from the independently measured wavelength and frequency,

$$v_{\text{in}} = f\lambda_1.$$

Substituting the experimentally determined frequency yields

$$v_{\text{in}} = v_{\text{lab}}\frac{\lambda_1}{\lambda_2}.$$

This equation is the principal result of the proposed measurement method.

If the two measured wavelengths are identical,

$$\lambda_1 = \lambda_2,$$

the calculated propagation speed of the incoming wave is

$$v_{\text{in}} = v_{\text{lab}},$$

which is the prediction of conventional electromagnetic theory.

If, however, the two measured wavelengths differ, the calculated propagation speed differs proportionally,

$$\frac{v_{\mathrm{in}}}{v_{\mathrm{lab}}} = \frac{\lambda_1}{\lambda_2}.$$

The proposed method therefore determines the incoming propagation speed directly from two independent wavelength measurements without requiring the propagation speed of the incoming light to be assumed in advance.

Unlike conventional spectroscopic methods, the incoming wavelength and the wave frequency are obtained in separate experimental steps. The propagation speed is calculated only after both quantities have been independently determined. This separation of wavelength and frequency measurements is the defining characteristic of the proposed method.

7. Predictions

The proposed measurement method provides a direct comparison between the wavelength of the incoming electromagnetic wave and the wavelength of the wave re-formed by the stationary diffraction grating. The experimentally determined propagation speed is given by

$$v_{\mathrm{in}} = v_{\mathrm{lab}} \frac{\lambda_1}{\lambda_2}.$$

The experimental outcome therefore depends entirely on the measured ratio of the two wavelengths.

According to conventional electromagnetic theory, the propagation speed of light is completely determined by the optical properties of the propagation medium. Consequently, the incoming wave and the wave emerging from the diffraction grating are expected to exhibit identical wavelengths when measured in the same laboratory medium,

$$\lambda_1 = \lambda_2.$$

The proposed method therefore predicts

$$v_{\mathrm{in}} = v_{\mathrm{lab}}.$$

This result represents the expected outcome if the incoming electromagnetic wave and the re-formed wave propagate identically in the laboratory medium.

The proposed experimental method, however, does not require this equality to be assumed in advance. It independently measures both wavelengths and determines the incoming propagation speed directly from their ratio.

If the measured wavelengths differ,

$$\lambda_1 \neq \lambda_2,$$

the calculated propagation speed becomes

$$v_{\mathrm{in}} = v_{\mathrm{lab}} \frac{\lambda_1}{\lambda_2},$$

indicating that the propagation characteristics of the incoming wave differ from those of the wave re-formed by the diffraction grating.

The experiment therefore distinguishes between two possible outcomes:

Prediction A (conventional expectation):

$$\lambda_1 = \lambda_2, \qquad v_{\mathrm{in}} = v_{\mathrm{lab}}.$$

Prediction B (alternative possibility):

$$\lambda_1 \neq \lambda_2, \qquad v_{\mathrm{in}} \neq v_{\mathrm{lab}}.$$

The proposed method does not favour either outcome. Its purpose is to determine experimentally which prediction is supported by observation.

A positive result, corresponding to Prediction A, would provide an independent experimental confirmation that the incoming electromagnetic wave and the re-formed wave possess identical propagation speeds in the laboratory medium.

A measurable deviation from Prediction A would not, by itself, identify the physical origin of the discrepancy. Instead, it would demonstrate that at least one of the assumptions underlying the propagation or optical transformation of the electromagnetic wave requires further investigation. Determining the physical explanation would then become the subject of subsequent experimental and theoretical studies.

8. Discussion

The proposed method differs from conventional spectroscopic techniques by separating the determination of wavelength from the determination of frequency. Instead of assuming the propagation speed of the incoming electromagnetic wave, it combines two independent optical measurements to evaluate this quantity experimentally.

The method is based on three principal assumptions.

The first assumption is that a stationary diffraction grating does not alter the temporal frequency of the incident electromagnetic wave. This follows from the fact that the grating is a passive optical element possessing a fixed spatial structure but no intrinsic temporal frequency. The outgoing wave is formed by the coherent superposition of radiation emitted by the grating elements, each oscillating at the frequency of the incident field.

The second assumption is that the electromagnetic wave emerging from the diffraction grating propagates according to the optical properties of the surrounding laboratory medium. Once the outgoing wave has been formed, its propagation speed is therefore taken to be the accepted speed of light in that medium.

The third assumption is that the Fabry–Pérot interferometer determines the spatial period of the electromagnetic wave by comparing its wavelength with a precisely known mechanical distance. Instrumental effects such as mirror reflectivity, transmission, coating phase shifts, detector response, and geometrical tolerances are treated as calibration parameters common to both interferometers.

An important characteristic of the proposed method is that both Fabry–Pérot interferometers operate under identical laboratory conditions. They use the same propagation medium, identical optical principles, and equivalent calibration procedures. Consequently, systematic effects common to both instruments largely cancel when the ratio of the two measured wavelengths is evaluated.

Unlike many indirect determinations of light propagation speed, the proposed experiment does not rely on astronomical timing measurements or long-distance time-of-flight observations. All quantities are determined within a single laboratory instrument using the same incoming beam of light. This substantially reduces the number of independent experimental parameters that must be controlled.

The outcome of the experiment is therefore determined primarily by the measured ratio of the wavelengths before and after the diffraction grating. If the two wavelengths are equal within the experimental uncertainty, the result is consistent with the conventional description of electromagnetic wave propagation. If a reproducible difference is observed, the experiment would indicate that at least one of the assumptions concerning the optical transformation or propagation of the electromagnetic wave requires further investigation.

Regardless of the experimental outcome, the proposed method offers a direct and internally consistent procedure for independently determining wavelength and frequency before combining them to evaluate the propagation speed of incoming electromagnetic radiation.

9. Conclusions

This paper has presented an optical method for experimentally determining the propagation speed of incoming electromagnetic radiation without introducing that speed as an initial assumption. The method is based on two independent wavelength measurements performed by identical Fabry–Pérot interferometers placed before and after a stationary diffraction grating.

The first interferometer measures the wavelength of the incoming electromagnetic wave. The stationary diffraction grating preserves the temporal frequency while re-forming an outgoing wave whose propagation speed is determined by the laboratory medium. A second wavelength measurement therefore provides an independent determination of the wave frequency. Combining the independently measured wavelength and frequency yields the propagation speed of the incoming electromagnetic wave.

The proposed method differs from conventional spectroscopic approaches by separating the experimental determination of wavelength from that of frequency. As a result, the propagation speed is obtained only after both quantities have been independently measured.

According to conventional electromagnetic theory, the measured wavelengths before and after the diffraction grating are expected to be identical, leading to the accepted propagation speed in the laboratory medium. The proposed experiment provides a direct test of this prediction without embedding it as an initial assumption in the measurement procedure.

Regardless of the experimental outcome, the method offers a clear experimental framework for analysing the relationship between wavelength, frequency, and propagation speed. Agreement with the conventional prediction would provide an independent confirmation of the established description of electromagnetic wave propagation. Any reproducible deviation would indicate that the physical assumptions governing the optical transformation or propagation of electromagnetic waves deserve further experimental and theoretical investigation.

The principal contribution of this work is therefore methodological. It proposes a practical optical procedure by which the propagation speed of incoming electromagnetic radiation can be determined from independently measured wavelength and frequency, providing a direct experimental test of one of the fundamental relationships used throughout wave optics.