Design of Experiment Course for Michelson Interferometer Measurement of He-Ne Laser Wavelength

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Abstract: This paper designs a course for the experiment of measuring He-Ne laser wavelength by Michelson interferometer in university physics experiments. It is mainly divided into two modules: course introduction and entry course. The entry course part is divided into experimental principles, experimental operation steps, and focus on science and technology. The front three parts give a detailed explanation of the experimental principles and experimental steps.

Keywords: Michelson Interferometer; Isotropic Interference; He-Ne Laser Wavelength

1. Course import

Why do insect wings have colored stripes under the sunlight? Soapy water is obviously transparent, why does it become colored when it is blown into bubbles? The reason for these phenomena is the thin-film interference phenomenon. The Michelson interferometer is based on the principle of equilateral interference in thin-film interference. The main content of this class is divided into the following four parts: experimental principle of Michelson interferometer, experimental steps and operations, experimental data processing and error analysis, and attention to cutting-edge technology.

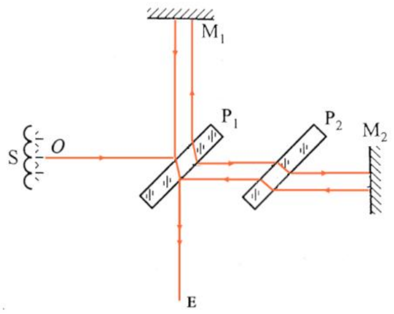
2. Entering the course

2.1 The experimental principle of the Michelson interferometer

2.1.1 Experimental instrument

The physical top view of the Michelson interferometer is simplified to a model diagram for easy understanding. It can be seen from the figure that M_1 and M_2 are two plane mirrors placed on two arms that are perpendicular to each other. M_2 is fixed, M_1 is controlled by a precision screw, which can move forward and backward along the arm axis, and its moving distance is read out by the turntable.

At the intersection of the two arm axes, there is a parallel flat glass plate P_1 at 45° to the two arm axes, and a semi-transmissive film is plated on the second plane of P_1, so as to divide the incident light into approximately equal amplitudes. Reflected light 1 and transmitted light 2, so the P_1 plate is also called a beam splitter. The light emitted from the extended light source S reaches the beam splitter P_1 and is divided into two parts. The reflected light 1 is reflected at P_1 and then moves towards M_1, and the transmitted light 2 passes through P_1 and then moves towards M_2. After the upward reflection, they return against their respective shooting directions, and finally reach E. [1] P_2 is also a parallel plane glass plate, called a compensation plate, which is placed in parallel with P_1, and has the same thickness and refractive index as P_1. The function of the compensation plate P_2 is to make the light beam 2 pass through the glass plate twice, so as to "compensate" beam 1 travels the extra optical path twice in the P_1 board, so that the interferometer can meet the requirements of equal optical path for light energy of different wavelengths at the same time. The two trains of light waves originate from the same point O on the light source, so they are coherent light, and the observer at E can see the interference pattern.



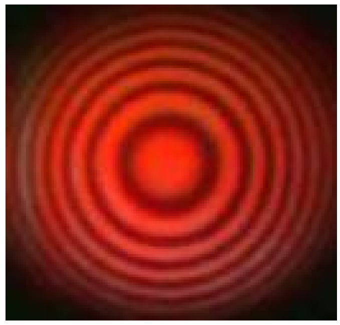


Figure 1: Experimental light path diagram Figure 2: Interference pattern

2.1.2 Calculation of optical path difference

Since the light returned from M_2 is reflected on the second surface of the beam splitter P_1, M_2 forms a virtual image M_2' parallel to M_1 near M_1, so the light from M_1 in the Michelson interferometer The reflections from M_1 and M_2 are equivalent to the reflections from M_1 and M_2'. When M_1 and M_2' are strictly parallel, the resulting interference is equivalent to the isometric interference produced by an air film of thickness h. As shown in the figure, the specific light emitted from the light source S is incident at the inclination angle i_1, i is the refraction angle, and the upper and lower reflected light rays converge through the action of the lens to form interference. The thickness of the film is h, the refractive index is n, and the refractive index above is n_1. How to calculate the optical path difference when the two reflected lights intersect at point P on the focal plane?

As shown in Figure 3, the vertical line CB, which is the reflection line on both sides, according to the equal optical path between the object images, the optical path (BP)=(CP), so ΔL=(ARC)-(AB). As CD is perpendicular to the refraction line AR, because $\overline{AB} = \overline{AC}\sin i_1$, $\overline{AD} = \overline{AC}\sin i$, so $\overline{AB}/\overline{AD} = \sin i_1/\sin i = n/n_1$.

And because (AD)=(AB), therefore $\Delta L = \left(DRC\right) = n\left(\overline{DR} + \overline{RC}\right)$, the vertical line KR of the upper and lower surfaces of the film, and K are the vertical lines KM and KN of AR and RC respectively, it is not difficult to see that $\overline{MD} = \overline{AM} = \overline{NC}$. Thus $\Delta L = \left(\overline{MR} + \overline{RN}\right)$, and because $\overline{MR} = \overline{RN} = \overline{KR}\cos i = h\cos i$, ΔL=2nhcosi is finally obtained.

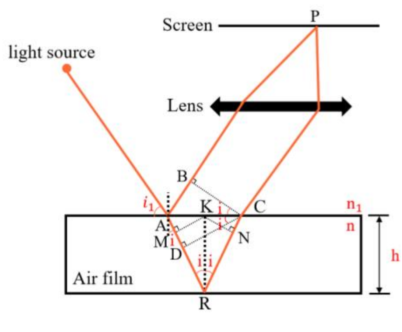


Figure 3: Isotonic interference model diagram

2.1.3 Analysis of interference fringes variation

By observing the plane diagram of the equilateral fringe experimental device, it can be seen that the distance from the P point to the curtain center O only depends on the inclination angle. It can be seen from the perspective that the reflection rays with the same inclination are arranged on a conical surface and the trajectory of their intersection on the screen will be an O-centered circle. Because the optical path difference between the coherent rays intersecting at each point on the circle is equal, that is, the interference fringes seen on the screen are concentric circles with O as the center.

At the same time, it can be seen from the coordinate diagram that when the optical path difference is equal to the integer times of the wavelength, it presents bright stripes, and when the optical path difference is equal to odd times of half wavelength, dark stripes appear, that is, a group of bright and dark concentric circles can be observed on the focal plane of the convergent lens placed at E. The characteristics of these stripes are as follows: (1) The smaller the inclination i corresponding to the O stripes, the greater the optical path difference, and the higher the order of the stripes. (2) The distribution of interference fringes is denser far away from the center.

At the center of the interference pattern, because the vertical incidence i = 0 , the refractive index of the air is n = 1, and the equal inclination interference formula is $\Delta L = 2nhcosi$, The condition for the bright spot in the center of the circle is $\Delta L = 2h = k\lambda$, The order of the interference fringes at the center of the circle is $k = 2h/\lambda$, When the distance h between M_1 and M_2' increases gradually, for any first order interference fringes, such as the k order, the $2hcosi_k = k\lambda$ must be satisfied by reducing the value of its $cosi_k$, so the interference fringes change to the direction that $\cos i_k$ becomes smaller (that is, i_k becomes larger), that is, it expands outward. At this point, the observer will see that the stripes seem to "gush out" from the center, and a stripe gushes out every time the spacing h increases by λ / 2. on the contrary, when the spacing gradually decreases from large to small, the stripes closest to the center will "fall" into the center one by one. and each time it is caught in a stripe, the change of spacing d is also λ / 2. [2]Therefore, if there are N fringes gushing out or trapped from the center, it indicates that M_1 moves farther or closer to $\Delta h = N\lambda/2$ relative to M_2'. Therefore, if the distance of M_1 movement and the number of interference fringes are known, the wavelength of light wave can be calculated.

2.2 Experimental steps and operations

2.2.1 Adjustment of Michelson Interferometer

When we turn on the laser power, we should follow the principle of whole and then local, rough adjustment and fine adjustment in physics experiment. So let's first take a look at the instrument as a whole, such as whether the light source is stable, whether the instrument is damaged, whether the various components of the instrument are complete, and whether there are any seriously improper parts, first roughly adjust it.

Adjust the vertical horizontal adjustment screws behind M_1 and M_2 visually to make them perpendicular to each other. Since the backplane behind the two lenses is strictly perpendicular to each other, it is only necessary to make the two lenses parallel to the backplane. First, adjust the position of the moving mirror by rough adjusting the handwheel, so that the optical path of the two interference optical paths is roughly the same, and then remove the ground glass screen.

When you look directly at the splitter, you can see two rows of bright spots, each of which has the brightest spot, which is the image point of the laser source reflected by the planar mirror. We need to overlap the two brightest spot adjustments by rotating the two knobs behind the fixed plane mirror. What we see here are two rows of bright spots, not two bright spots, because in the Michelson interferometer, the two surfaces of the splitter and compensation plate can also reflect light, and the other bright spots are the image points of the light source formed by these surfaces.

After adjusting and coincident the two brightest spots, we reset the ground glass bottle. Generally speaking, the interference fringes of light and dark can be seen on the ground glass screen at this time. If not, it means that the two bright spots in the previous step do not completely coincide and need to continue the adjustment in the previous step. If you find that the center of the interference ring is not in the center of the field of view at this time, you need to adjust the knob behind the fixed plane mirror to adjust the center of the interference ring to the middle of the field of view. If the interference fringes are found to be too dense, it is necessary to rotate the coarse adjustment handwheel and change the position of the moving mirror, so as to further reduce the optical path difference between the two interference optical paths. If the center of the ring is found to deviate from the center of the field of view, we still need to adjust the knob behind the fixed plane mirror, which must be very soft and slow. By rotating the fine-tuning handwheel, you can see that the center stripes pop up or fall into it. However, in the process of measurement, we can only rotate the fine-tuning handwheel in one direction to prevent the return error. If there is a reverse rotation of the first wheel or leakage in the experiment, we should re-experiment to ensure the rigor of the experiment and the scientific results.

2.2.2 Reading and measurement

Before starting counting, the minimum grid value of the rough handwheel in front of the instrument is 10^{-2}mm， The minimum partition value of the right micro-wheel is 10^{-4}mm, which can be estimated to 10^{-5}mm, and the final reading is equal to the main ruler reading plus rough wheel reading plus micro-wheel reading. note that the final reading should be accurate to one place after the minimum reading of the micro-wheel.

We first record the position of the moving mirror M_1, turn the micro-hand wheel, record the number of stripes gushing out (or trapped), stop turning when it reaches k=50, record the position of the moving mirror M_1 again, measure many times, record at least five sets of data, and fill in the form. Using the formula, we can calculate the wavelength of He-Ne laser, take the average value of five groups of data and record the uncertainty, compare it with the standard value and analyze the error source.

2.2.3 Matters needing attention

In the experiment, we should pay attention to:

(1) keep the instrument, pay attention to dustproof, moistureproof, shockproof; do not touch the optical surface of the element.

(2) all adjusting screws should be relaxed before and after the experiment.

(3) when adjusting, it should be in the middle state first, leaving room for adjustment, and the adjustment action should be uniform and slow.

(4) when rotating the micro-hand wheel for measurement, it is especially necessary to prevent the return error.

2.3 Paying attention to cutting-edge science and technology

Not only can the Michelson interferometer be used to measure the optical path difference more accurately in the experiment, but it has also been promoted in the frontier field of measuring gravitational waves. The European "Virgo" gravitational wave detector itself is a huge Michelson interferometer with an arm length of 3 kilometers. The detector is sensitive to small changes in distance, which is a function of the amplitude of gravitational waves in a particular frequency range. This makes the direct detection of gravitational waves is no longer out of reach, which greatly promotes the progress and development of science. Contemporary young people should also cherish innovative enthusiasm, constantly explore, and contribute to the cause of science.

References

[1] Xiao WB, He XD, Zhu QH, Wang Q & Chen XG. (2010). Error analysis of measuring laser wavelength by Michelson interferometer. Laboratory Science (05), 86-87.

[2] Han TK & Qi LM. (2021). The application of successive difference method and Origin software in the experimental data processing of Michelson interferometer for measuring laser wavelength. College Physics experiment (05), 116-118.