A HOMEMADE INTERFEROMETER

Many of the material conveniences we take for granted depend on the optical effect that imparts color to soap bubbles and blueness to the bluebird. An application of the effect is the interferometer, most elegant of yardsticks. The principle is explained in the following pages and a design appropriate for amateur construction is suggested

WHEN TWO BAYS OF LIGHT from a single source fall out of step (say after they have taken different paths and met at a common point), their waves reinforce or counteract each other, just as out-of-phase waves in water do. This effect accounts for the blueness of the bluebird, the fire of opals, the iridescence of butterfly wings and the shifting colors of soap bubbles. It also accounts indirectly for the accuracy of watches, the control of guided missiles, the quality of high-test gasoline and myriads of other achievements of technology which would not be possible without precise standards of measurement.

All measurements, in the final analysis, depend upon one standard—length. Nowadays the length of the meter is calibrated in terms of wavelengths of light. The most commonly accepted standard for determining the length of the meter is the wavelength of the red light emitted by glowing cadmium in the vapor state. By interferometer methods this wavelength has been measured to high precision and comes out to be 6,438.4696 \pm .0009 Angstrom units (an Angstrom unit is one 10-billionth of a meter). The meter is 1,553,164.60 \pm .22 times this wavelength.

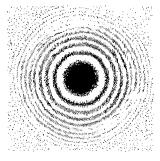
The interferometer, the most elegant of yardsticks, is a singularly finicky and frustrating gadget. A scientist once remarked: "Without a doubt the interferometer, particularly the

version of it developed by Michelson, is one of the most wonderful instruments known to science—when it is operated by A. A. Michelson!" In Michelson's hands the instrument certainly established an impressive row of scientific bench marks. It was he who measured the wavelength of the red cadmium line given above.

Making measurements with instruments capable of yielding precision of this order is not easy. One can fiddle with the controls of the interferometer for hours without seeing the fringes, or bands of interfering light, that serve as the graduations of length. No amateur would dream of making the instrument primarily for the purpose of using it regularly as a tool of measurement. But in constructing an interferometer and mastering the art of using it, one can learn a great deal about optics — as well as the technique of making accurate measurements, the art upon which all scientific advances are founded.

You can begin by repeating an experiment first performed by Isaac Newton, which demonstrates the basic principle. Simply press a spectacle lens against a glass plate and look directly into the light reflected by the combination from a wide source of light. If you use a magnifying glass, you will see several rainbow-colored rings, surrounding a tiny black spot about 1/64 of an inch in diameter at the point where the lens touches the plate, as illustrated in Figure 239.

The same effect can be observed with two sheets of ordinary window glass. An irregular pattern of interference fringes will



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Newton's Rings – seen by placing convex lens against plane glass. (Rings are greatly magnified in this illustration)

surround each point at which the surfaces of the glasses touch. The pattern will be more distinct if the light source has a single color, e.g., the yellow flame produced by holding a piece of soda glass (say a clear glass stirring rod) in a gas burner. If the glass sheets are squeezed even slightly during the experiment, the pattern of fringes will shift, indicating the minute change in distance between the inner faces of the sheets.

Thomas Young, an English physician, and his French colleague Augustin Fresnel demonstrated in the latter part of the 18th century why interference fringes appear. In so doing they established the wave nature of light. They explained that if two rays of light emitted from the same source encounter reflecting surfaces at different distances from the source, the two sets of waves will end up somewhat out of step, because one has traveled a greater distance than the other.

To the extent that the trough of one wave encroaches upon the crest of the other the waves interfere destructively, and the reflected light is dimmed. At various angles of view the apparent distance between the reflecting surfaces will be greater or less, and the intensity of the reflected light will appear proportionately brighter or dimmer, as the case may be. The total energy of the incident light remains unchanged by the interference. It is only the angles at which the energy is reflected that change. Hence the positions of the fringes with respect to the reflecting surfaces appear to shift when the observer moves his head.

Similarly, the apparent position of the fringes depends on the length of the waves. Long waves of red light may appear to annul one another completely in a certain zone, while the short waves of blue light may appear reinforced. In that case the zone will appear blue, although the light source may be emitting a mixture of both long and short waves. If the source is white light, a blend of many wavelengths, some of the colors are annulled and others are strengthened at a given angle of view, with the result that the fringes take on rainbow hues.

Similarly changes in the distance between the reflecting surfaces cause the fringes to shift, just as though the position of the eye had changed. That is why the fringes move when enough

pressure is applied to bend two sheets of glass not in perfect contact.

Another interesting simple experiment is to place an extremely flat piece of glass on another flat piece, separating the two at one edge with a narrow strip of paper, so that a thin wedge of air is formed between them. When the arrangement is viewed under yellow light, the interference fringes appear as straight bands of yellow, separated by dark bands, which cross the plates parallel to the edges in contact. The number of yellow fringes observed is equal to half the number of wavelengths by which the plates are separated at the base of the wedge.

When the paper strip is removed and the plates are brought together slowly at the base, the fringes drift down the wedge and disappear at the base, the remaining fringes growing proportionately wider. By selecting relatively large plates for the experiment, it is possible to produce a fringe movement of several inches for each change of one wavelength at the base. A version of the interferometer is based on this principle.

In short, any change which modifies the relative lengths of the paths taken by two interfering rays causes the position of the resulting fringes to shift. A change in the speed of either ray has the same effect, because the slowed ray will arrive at a distant point later than the faster one, just as if had followed a longer path. Any material medium will slow light to less than its speed in a perfect vacuum. Air at sea level cuts its speed by about 55 miles per second, short waves being slowed somewhat more than long ones.

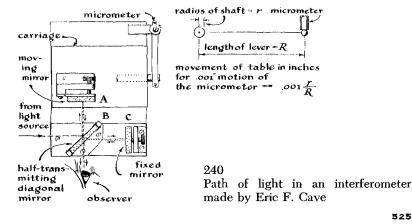
If two interfering rays are traveling in separate evacuated vessels and air is admitted into one of the vessels, the interference fringes will shift, as if that path had been lengthened. From the movement of the fringes it is possible to determine by simple arithmetic the amount by which the speed was reduced. The ratio of the velocity of light through a vacuum to its velocity through a transparent substance is called the refractive index of that substance. The interferometer is a convenient instrument for measuring the refractive indices of gases and of liquids.

Eric F. Cave, a physicist at the University of Missouri, has designed a simple interferometer which will demonstrate many of these interesting effects and enable even beginners in optics to measure the wavelength of light. With suitable modifications the instrument can be used for constructing primary standards of length, measuring indices of refraction and determining coefficients of expansion.

E. F. Cave describes the construction of the Cave interferometer

THE DESIGN PRESENTED HERE is intended to serve primarily as a guide. Most amateurs will be capable of designing their own instruments once the basic principles are understood. Optically the arrangement is similar to that devised by Michelson. A source of light, preferably of a single color, falls on a plate of glass which stands on edge and at an angle of 45 degrees with respect to the source. This plate serves as a beamsplitter.

Part of the light from the source passes through the plate. This portion proceeds to a fixed mirror a few inches away, where it is reflected back to the diagonal plate. The other part of the original light beam is reflected from the surface of the diagonal at a right angle with respect to the source. It travels to a mov-



able mirror, located the same distance from the diagonal plate as the fixed mirror, and it too is reflected back to the plate. Part of this ray passes through the plate to the eye. Here it is joined by part of the ray returned by the fixed mirror [see Fig. 240].

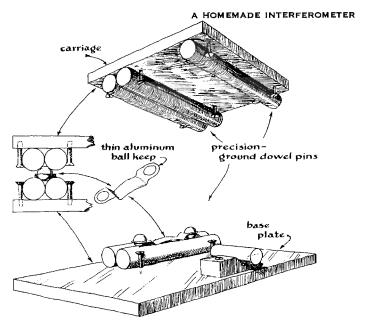
By adjusting the positions and angles of the two mirrors relative to the diagonal plate it is possible to create the illusion that the fixed mirror occupies the plane of the movable mirror. Similarly, by adjusting the angle of either mirror slightly, it is possible to create the optical effect of a thin wedge between the two mirrors. Interference fringes will then appear, as if the two reflecting surfaces were in physical contact at one point and spaced slightly apart at another. A change in the position of the movable mirror toward or away from the beam-splitter is observed as a greatly amplified movement of the fringes.

Beginners may expect to spend a lot of time in coaxing the instrument into adjustment. But careful construction will minimize the difficulty.

The base can be made of almost any metal, although amateurs without access to shop facilities are advised to procure a piece of cold-rolled steel cut to specified dimensions. The instrument can be made in any convenient size. The base of mine is nine inches wide and 14 inches long. You will also need two other plates of the same thickness and width but only about a quarter as long. They become the carriage for supporting the movable mirror and the table on which the diagonal plate and fixed mirror are mounted.

The carriage moves on ways consisting of dowel pins attached to its underside [see Fig. 241]. The ways are made of commercially ground drill rod, which can be procured in various sizes from hardware supply houses. Each way consists of a pair of rods, one set being attached to the carriage and the other to the base. The ways can be fastened in a variety of arrangements. I fitted them into a milled slot. Flat-headed machine screws will serve equally well as fastenings if you do not have a milling machine.

The bearing for the drive shaft can be a block cut with a V-shaped notch. If no shop facilities are available for machining

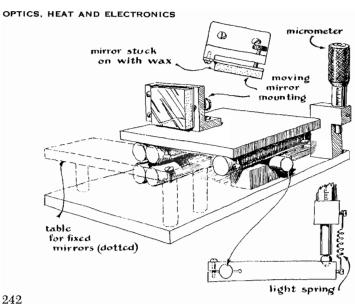


241 Details of the interferometer carriage assembly

it, you can drill four shallow holes in the base as retainers for four steel balls and simply let the shaft turn between the two sets. The height of the block or ball supports should be chosen so that the top of the carriage will parallel the top of the base when the machine is assembled. The ways move on two steel balls fitted with a ball-spacer made of thin aluminum as shown. In operation the carriage is driven back and forth by turning the drive shaft.

The shaft may be rotated either by a worm and wheel arrangement or by a "tangent screw." The latter consists of a screw pressing on a bearing in a lever arm, the other end of which is attached to the shaft [see Fig. 242]. A tangent screw permits only a small amount of continuous travel, but it is less expensive than a worm and wheel.

The lever arm should be rectangular in cross section. One end is drilled for the shaft, split as shown and fitted with a clamp-



Details of the interferometer base assembly showing micrometer-controlled carriage-translation lever

ing screw. The other end is drilled with a shallow hole for the steel ball bearing. The screw may be a machinist's micrometer mounted on a bracket as shown. The ball bearing is held in close contact with the micrometer by a spring. The length of the lever and the diameter of the drive shaft determine the amount by which the carriage will move when the micrometer is turned.

It should be possible to control the movement of the table smoothly through distances equal to at least one wavelength of the light under investigation. The wavelength of the yellow light emitted by glowing sodium is about one 50,000th of an inch. The tangent screw must therefore provide a geometrical reduction to distances of this order.

When the machinist's micrometer is turned one division, the screw moves the outer end of the lever arm a thousandth of an inch. By adjusting the effective length of the lever arm (the distance between the center of the ball bearing under the screw and the center of the shaft) with respect to the radius of the

shaft, the relative movement of the carriage can be reduced by any proportion desired. The reduction is equal to the radius of the shaft divided by the effective length of the lever arm. Thus a 10-inch arm coupled to a ¼-inch shaft yields a reduction of 80 to 1, and a turn of one micrometer division produces a carriage translation of .0000125 of an inch.

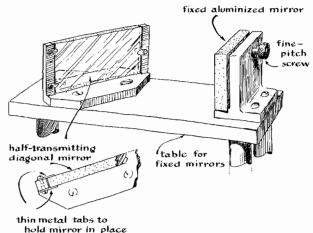
The quality of the optical parts will largely determine the experiments possible with the instrument and the extent to which it may be worth while later to add accessories and otherwise modify the design. Advanced telescope makers will doubtless prefer to grind and figure the three flats required. Those less skilled in figuring glass may order them from an optical supply house. All three elements should be flat to about a tenth of a wavelength or the resulting fringes will show serious distortion. Small squares can be cut from plate glass and tested for flatness by the method outlined in *Amateur Telescope Making* by Albert G. Ingalls.

If the instrument is to be used for testing lenses, mirrors, prisms and so on, the faces of the pieces of glass should be strictly parallel to one another. Both the fixed and the movable mirror should be silvered or aluminized on the front surface, and for best results the face of the diagonal plate also should be silvered slightly, so that it will reflect about as much light as it lets through.

Mounting brackets should support the optical elements perpendicular to the plane of the base after assembly. They should provide for finely controlled angular adjustment of the mirrors around the horizontal and the vertical axes. In the illustration shown in Figure 243 the movable mirror is mounted with wax, but for anything more than an initial demonstration this is not good practice, especially if the supporting member is subject to flexure. The diagonal plate and fixed mirror are mounted on a rectangular table fixed to the base, and are located so that the center of the beam of light from the source strikes the center of the diagonal plate and is reflected at right angles to the center of the movable mirror.

Two important conditions must be fulfilled if the instrument is to function properly. The light must originate from an ex-

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Details of the interferometer beam-splitter and fixed-mirror assembly

tended source several feet away, and it must be monochromatic. The yellow flame obtained with soda glass is not strictly monochromatic, because most of the light comes from the brilliant spectral doublet of sodium, but it is adequate for demonstrating the instrument.

When in operation the instrument should rest on a solid, vibrationless support. The movable mirror is placed as precisely as possible at the same distance from the beam-splitter as the fixed mirror. Preliminary adjustments are then made with the aid of a point source of light -e.g., the highlight reflected from a small polished steel ball 1/16 of an inch in diameter, placed about 10 feet away. The ball should be lighted with a concentrated beam such as that provided by a 300-watt slide projector.

The ball is located to the left of the observer when he faces the movable mirror and in line with the center of the beamsplitter and fixed mirror. When you look at the movable mirror through the beam-splitter, you will see two images of the source. You change the angles of both mirrors by means of the adjusting screws until the images of the source coincide.

Now you substitute the sodium source of light for the ball.

If the distances of the mirrors from the beam-splitter are essentially equal, you should see a number of concentric circles in orange and black like those of a rifle target. The orange color is characteristic of the sodium doublet, while the black circles mark zones of destructive interference between beams reflected by the two mirrors. Remember that you are making exquisite adjustments requiring patience.

To measure the wavelength of sodium light, first note the precise position of the micrometer and then turn it slowly while counting the number of times the bull's-eye of the target changes from orange to black and back to orange again. From orange to orange or black to black is a half wavelength. Count, say, 100 of these color changes. The carriage has then moved 100 times the half wavelength of sodium light. Read the micrometer setting and subtract it from the first reading. This difference, when divided by the geometrical reduction provided by the tangent serew, is equal to 50 wavelengths of the light.

In reality we are working with the sodium doublet, of course. The wavelength of one of the sodium lines is .000023188 of an inch and the other is .000023216 of an inch. If your experiment comes out correctly, therefore, your instrument will show the average of the two, or .000023202 of an inch. The fact that you are dealing with light of two close wavelengths may cause poor contrast between the orange and dark fringes at certain positions of the carriage. A slight displacement of the carriage from this position will produce maximum contrast.

This design is intended merely to whet an appetite for interferometry. The instrument and theory discussed here are mere introductions to the subject. Before the instrument can yield results comparable with those achieved by Michelson, it must be provided with a monochromatic source, such as the light emitted by the red line of cadmium. Advanced instruments are provided with a small telescope for viewing the fringes. In addition, Michelson inserted a second diagonal plate in the path between the beam-splitter and the movable mirror. It is unsilvered but otherwise identical with the beam-splitter. This plate equalizes the thickness of glass traversed by the two beams and prevents

the short waves in one beam from being retarded more than those in the other.

Interferometers can be equipped with accessories for measuring the physical constants of solids, liquids and gases. Glass containers provided with optically flat windows can be introduced into the beams. When the air in one is slowly displaced with a gas, the fringes will drift across the field just as if the carriage were being moved. A count can easily be reduced to the index of refraction of the gas. The coefficient of expansion of a solid with respect to changes in temperature can be determined by clamping the specimen, fitted with a thermometer, between the carriage and base. A count of the fringes is then converted into the dimensional change of the specimen. This information, together with the temperature difference, enables an experimenter to compute the desired coefficient.

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A PIEZOELECTRIC CLOCK

When connected in an appropriate electronic circuit, a wafer cut from crystalline quartz will vibrate with extreme constancy because of the piezoelectric effect. Moreover, it will control the frequency of the current. When powered by such current an electric clock keeps remarkably good time. W. W. Withrow, a radio ham of Teague, Texas, explains how to build and operate the apparatus

LIKE MOST AMATEURS who make a hobby of science, particularly of those branches which have to do with physics, I have long wanted a good clock. Ordinary electric clocks do for most purposes and nearly everyone takes it for granted that they keep good time. But do they? The accuracy of electric clocks