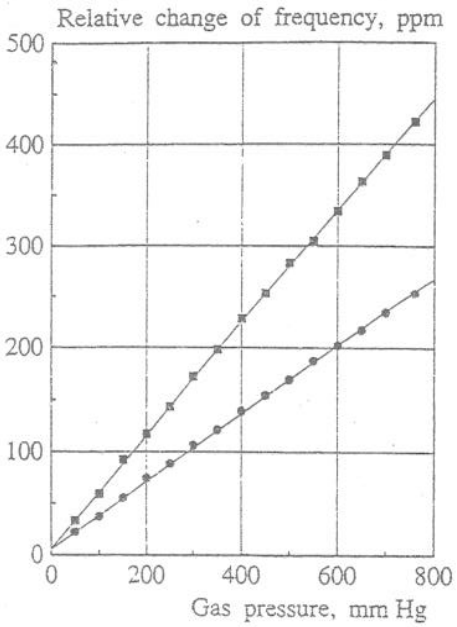

Fig. 2. Relative change of the resonance frequency versus gas pressure for carbon dioxide (■) and nitrogen (●).

However, it is necessary to take into account the fraction of the total capacitance that does not depend on the gas under study. This fraction is formed by the capacitance of the coil itself and of connecting cables, and by the input capacitance of the amplifier. The additional capacitance, C_0, is connected in parallel with the main capacitor, C. It is easy to see that the dielectric constant should be calculated from the relation

$$\epsilon - 1 = 2\Delta f(C + C_0)/fC.$$

There exist three ways to evaluate the correction factor $(C + C_0)/C$. First, the main capacitor, C, can be measured beforehand with a capacitance meter. The total capacitance, $C + C_0$, is then available from the resonance frequency and the value of L. Second, when a known capacitor is connected in parallel with the circuit, the resonance frequency decreases. The value of $C + C_0$ is available by comparing the two resonance frequencies. Lastly, the ratio of the resonance frequencies measured with and without the main capacitor shows the ratio $(C + C_0)/C_0$. All the methods give close results. The evacuation of the bell jar does not influence the results because it causes a relative change in the capacitance of less than 0.1%, while the correction factor is accurate to within about 1%. In our case, the correction factor equals 1.20.

The dielectric constant of air is close to that of nitrogen (1.000 536 and 1.000 548, respectively). However, when performing the measurements on air, one obtains results that are definitely higher than the true value. This is due to the humidity of air. The dielectric constant of saturated water vapor, i.e., at 100% humidity, is 1.000 22 at 20 °C (equilibrium vapor pressure is 17.5 mm Hg) and 1.000 37 at 30 °C (31.5 mm Hg). Hence, the sensitivity of the setup is sufficient to determine the humidity of air, unless it is very low. The dielectric constant of carbon dioxide is 1.000 922. The numerical data above are taken from a handbook.[1] In our measurements, the dielectric constants of nitrogen and carbon dioxide appeared to be 1.000 59 and 1.000 99, respectively, i.e., somewhat higher than the true values.

[1] *Handbook of Chemistry and Physics*, 75th ed., edited by D. R. Lide (CRC, Boca Raton, 1994), pp. 6–11, 6–204, 6–205.

Fabry–Perot interferometers for lecture demonstrations and laboratories

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(Received 5 October 1995; accepted 2 January 1996)

The centenary is drawing near of the first construction in 1897 of the multiple-beam interferometer by Charles Fabry and Alfred Perot. We outline here how to build fixed-spacing Fabry–Perot (F–P) interferometers (also called etalons) suitable for lecture and laboratory demonstrations.[1,2] Our general construction, shown in Fig. 1, is inexpensive compared with commercially available interferometers, easy to align and can generate large, bright ring patterns (over a meter in diameter, in one case).

An F–P interferometer consists of two highly reflecting plane surfaces that are kept parallel to each other at a gap distance "d" by appropriate "spacers" and an external housing. The greater the gap "d," the finer the interference effects that can be resolved but the more difficult the interferometer is to align and the greater the need for auxiliary optical devices in order to view the ring patterns.

An F–P interferometer with a gap of less than a tenth of a millimeter is more than adequate for a group showing of fine-structure effects (on the order of angstroms) stemming from electron spin; for example, the six angstrom wavelength difference of the sodium doublet.

An F–P interferometer with a gap of 3 to 4 mm can reveal hyperfine-structure effects on the order of hundredths of an angstrom, for example the 0.02 Å splitting of the green line of mercury for even and odd isotopes or Zeeman splittings for a field intensity of 7000 to 8000 Gauss. Here, the viewing requires augmenting the ring pattern by auxiliary equipment—a telescope for individual viewing or a video camera and display for group viewing.

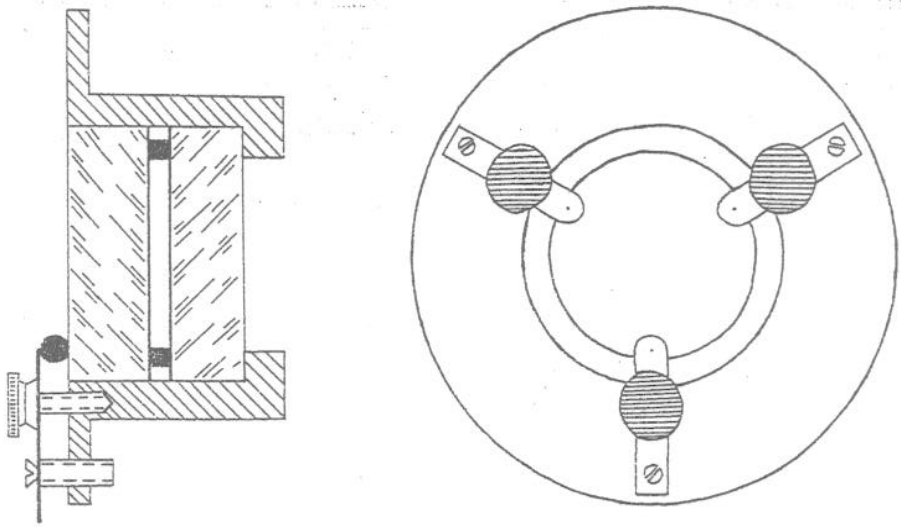

Fig. 1. General structure of a simple F–P interferometer. Two glass flats each coated with a highly reflecting plane surface are separated by "spacers" in a cylindrical steel housing. The pressure exerted on a spacer by a ballbearing soldered to a thin metal strip is adjusted by two screws.

An F–P interferometer with a gap of 200 to 300 mm can resolve effects a thousandths of an order of an angstrom, such as Doppler shift of spectra when light is reflected off a surface moving at 200 m/s. But, for such a large gap, aligning the device for a uniform gap over its entire cross-section is laborious and, again, viewing the ring patterns is done through a telescope.

Now, we describe how to construct the interferometers. We begin with the common components: two "identical" glass flats whose diameter is 50 to 60 mm, whose thickness is 10 to 20 mm and whose flatness variation is $\lambda/5$ or better. Such flats can be ordered off-the-shelf through optical supply catalogues. In commercial F–P interferometers the plates are *very* smooth—say $\lambda/50$ or $\lambda/100$—and hence expensive. For our purposes, $\lambda/5$ is adequate.

One face of each of the flats must now be coated for maximum reflection. A silver coating tends to deteriorate over time because of reaction with the air. A 500 Å layer of aluminum works reasonably well. A better long-term option is a multiple layer of quarter wavelength dielectric films, even though producing the stack may require a commercial coating service. A seven layer, quarter-wave stack yielding a reflection coefficient of 92% for a wavelength of 5461 Å can be composed as follows: LHLHLHL, where L is a low refractive index material such as cryolite (Na_3AlF_6) or magnesium fluoride (MgF_2) and H is a high refractive index material such as zinc sulfide (ZnS) or titanium dioxide (TiO_2). This same dielectric stack works well over the range 5000 to 6000 Å.

The two coated glass plates, separated by appropriate "spacers" (to be specified) at the plate's circumference, are set into a cylindrical steel housing with an external mechanism to alter slightly the pressure on each spacer–thereby finely adjusting the gap "d" in the region of the spacer. In the simple mechanism shown in Fig. 1 screws regulate the pressure exerted by a ballbearing soldered to a metal strip. Clearly the size of the interferometer housing depends on the choice of spacers.

For our first F–P interferometer (shown furthest to the right in Fig. 2) each spacer is chosen to be a pair of metal snips each of thickness 0.035 mm. Three sets of spacers, set equidistantly at the circumference of the glass flats, yield a gap of 0.07 mm. The interferometer is illuminated by a diffuse mercury or sodium lamp of at least 45 W—a 500 W lamp is needed in large lecture halls—through a 50 mm focal-length convergent lens that focuses the lamp image into the gap between the glass flats.

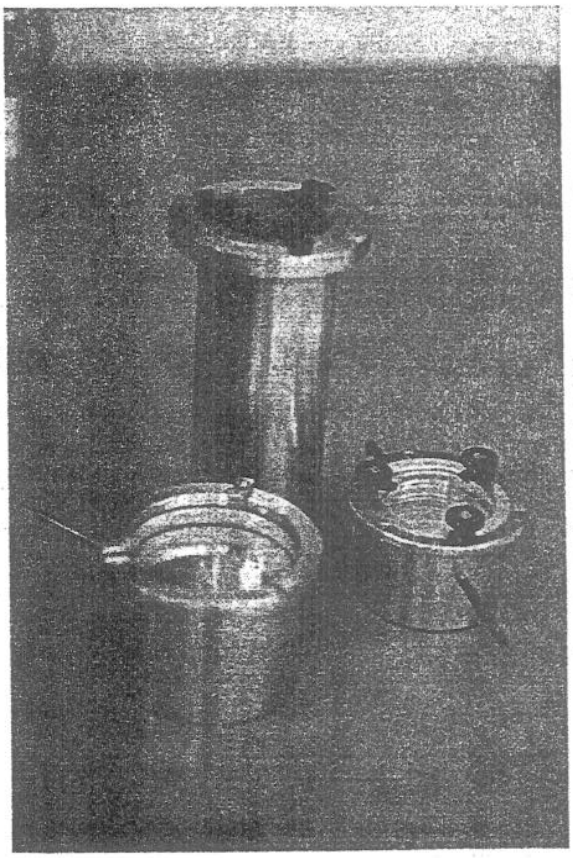

Fig. 2. Three F–P interferometers with gaps of various sizes: on the right, 0.07 mm; on the left, 4 mm; at the rear, 200 mm.

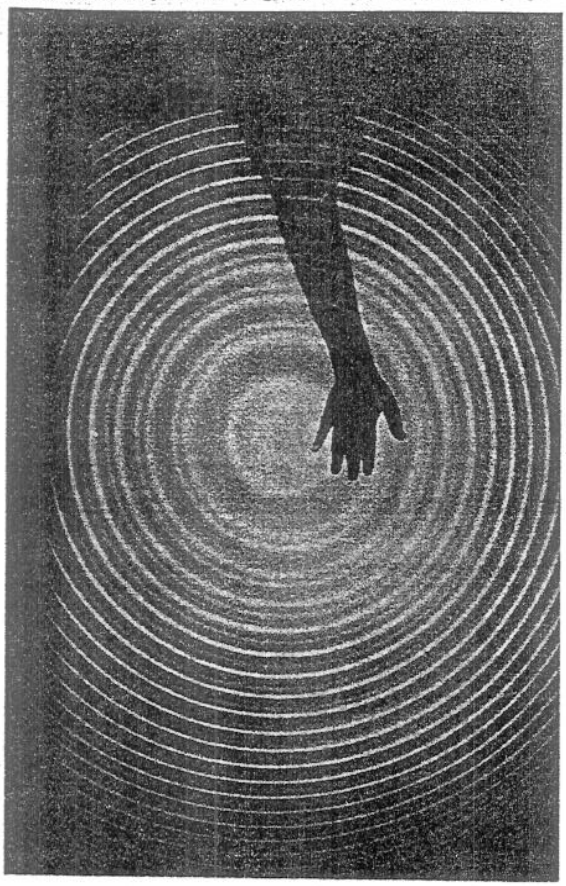

Fig. 3. Ring pattern for a mercury source using the small-gap interferometer.

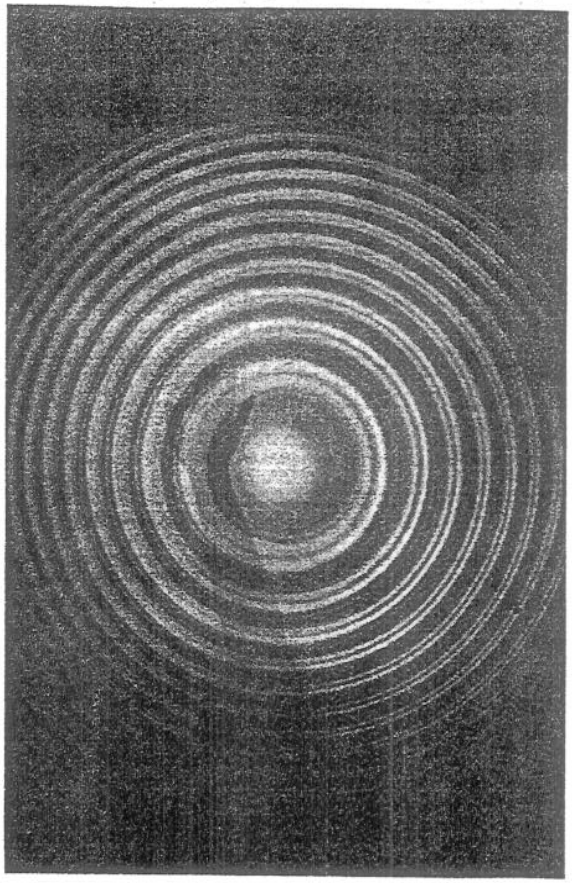

Fig. 4. Fine structure ring pattern generated by a sodium source for the small-gap interferometer.

To achieve a uniform gap, first look directly into the illuminated interferometer. A ring pattern is visible. Keep the direction of viewing vertical to the flats and move your head so an eye traces along a diameter starting at one of the spacers. If a new ring pops out of the center or if a ring is swallowed up or if the ring pattern changes in radius, then the gap has varied along that diameter and has affected the interference pattern. Adjust the pressure screws so that no rings appear or disappear when checking along the particular diameter. Repeat this process along the diameters at the other two spacers. Now the gap is uniform.

The output of the illuminated interferometer can be directed onto a screen or white wall a meter or two away. A large ring pattern is obtained. Figure 3 shows the ring pattern for a mercury source.

Figure 4 shows the ring pattern for the sodium doublet where the splitting is 6 Å. This splitting, $\Delta\lambda$, between the 5896 Å line and the 5890 line can be determined from

$$\Delta\lambda=(R_2^2-R_1^2)\langle\lambda\rangle/(2L^2), \tag{1}$$

where R_1, R_2 are the radii of a doublet, L is the distance between the interferometer and the screen, and $\langle\lambda\rangle$ is the average wavelength.

Our second interferometer, shown furthest to the left in Fig. 2, uses as spacers three ball bearings each of the same diameter, 3 to 4 mm. To prevent them from rolling about, it helps to encompass each ballbearing in a tiny metal ring. The alignment for a uniform gap is done by the naked eye in the same way as previously specified.

To see hyperfine structure, use a mercury source with a green filter. Details of the ring pattern for the 5461 Å line are clearly seen through a simple telescope. Just inside the strong green lines (from even-isotope sources) there are two weaker satellite rings (from odd-isotope sources). The wavelength differences are of the size of a fiftieth of an angstrom. Quantitative measurements can be performed by using an ocular micrometer.

The third interferometer, shown in the upper part of Fig. 2, uses as a spacer a 200 mm cylinder from which three rows of three slices have been cut out; this is in order to allow some "give" when the pressure screws are applied.

ACKNOWLEDGMENT

We thank Victor Neeman for assistance with the photographs.

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[1]S. Tolansky, *High Resolution Spectroscopy* (Methuen & Co., London, 1947).

[2]B. Sh. Perkalskis, *Application of Modern Scientific Instruments for Physical Demonstrations* (Nauka Fizmatgiz, Moscow, 1971), in Russian.