

THE FABRY-PEROT INTERFEROMETER

MOTIVATION:

The Fabry-Perot interferometer is an extremely powerful and precise spectral analysis device; it is widely-used instrument in modern research for making fine spectral measurements. We wish to become familiar with a simple Fabry-Perot interferometer: how to align it, and what its characteristics and limits are.

REFERENCES:

Hecht & Zajac, pp. 301-311

Jenkins & White, pp. 270-283

THEORY:

The Fabry-Perot interferometer consists of two parallel, highly reflective surfaces. Light enters from one side and is multiply reflected between the surfaces, and these reflections interfere with themselves, producing the characteristic bullseye pattern. Read the attached pages for a full discussion and analysis of the Fabry-Perot; you will need to be familiar with the quantities discussed there to complete this lab.

It may seem that the Fabry-Perot interferometer is just a slightly different version of the Michelson, but the two are quite different in application. The Fabry-Perot fringes are very thin and sharp, unlike the Michelson fringes, and within a certain range of frequencies (the free spectral range) the fringe pattern reproduces exactly the spectral profile of the source. These sharp fringes allow a very precise wavelength measurement, but the small free spectral range means that only small portions of the spectrum can be conveniently scanned at a

time. (Generally, a filter or monochrometer is used to restrict the spectrum to values within the FSR, and frequently two or more Fabry-Perots are used together to extend the effective FSR.) The Michelson is also useful, but is generally used for Fourier transform spectrometry, in which the interferogram (from a scan over a large range of path differences) is interpreted as the Fourier transform of the spectrum of the source -- a very different approach.

During this lab you will observe an effect called self-reversal which merits some discussion. Recall that a spectral line from a sample of excited atoms is not truly monochromatic, but is "broadened" by Doppler or collisional processes, so that it has a lineshape that looks at least vaguely Gaussian (fig. 1). As the sample size is increased, it stands to reason that the line profile will increase in size but remain the same shape; however, as the sample becomes optically thick, each photon is emitted and reabsorbed several times before escaping the sample, and the sample begins to resemble a blackbody. The blackbody radiation curve for the sample's temperature effectively "clips" the line, and the result is a flat, thick line profile (fig. 2). This assumes a uniform temperature; now suppose there is a temperature gradient and the outside of the sample is cooler than the inside. On the outside the sample will actually tend to absorb the light (since there will be fewer excited atoms to emit photons and more atoms to absorb photons), and so a smaller absorption lineshape will be subtracted from the large, broad lineshape produced by the hot, thick center (fig. 3).

Figure 1

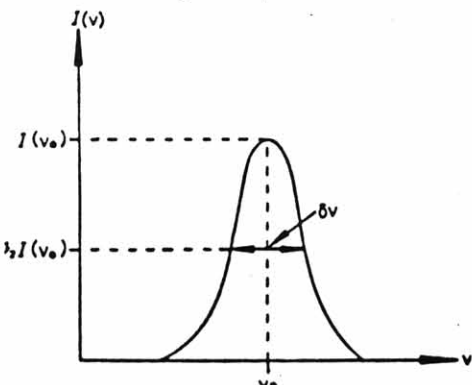


Figure 2

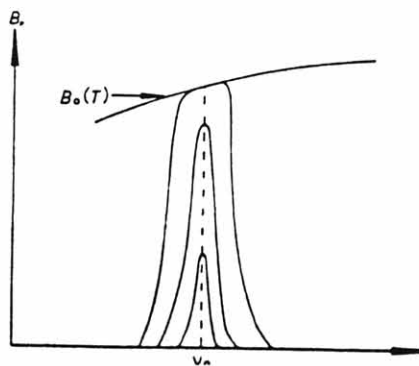
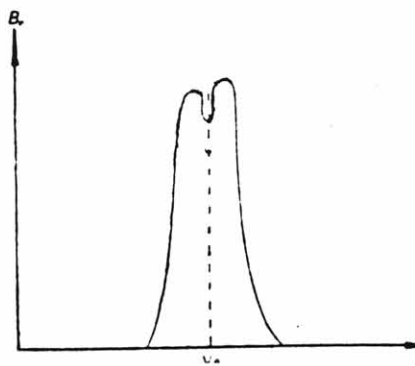
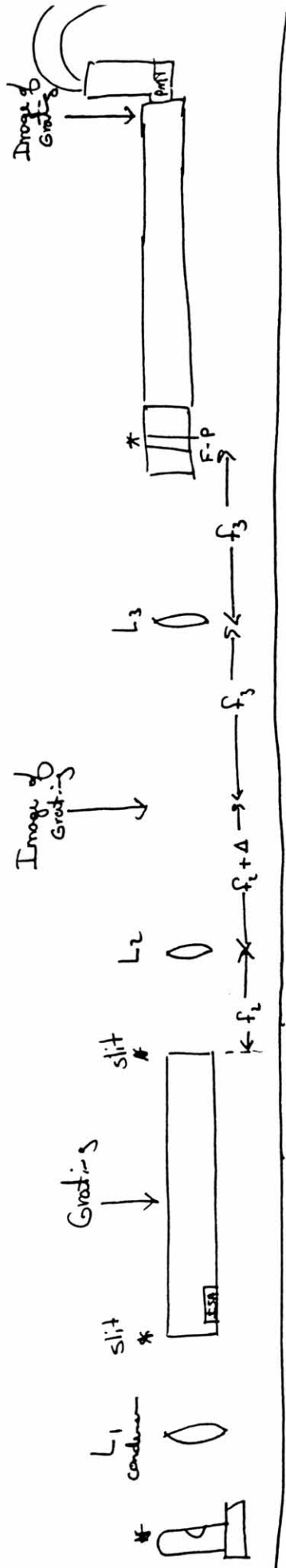


Figure 3



New Fabry-Perot Experiment Coupling Scheme



* \Rightarrow slits or images of slits

\downarrow \Rightarrow position of grating or images of grating

Pressure Scanned Fabry Perot

The pressure scanned Fabry Perot is set up for photoelectric detection. It is a research quality instrument. This Fabry Perot has an optically contacted fused silica spacer of 3.0 mm. You will not need to align these Fabry Perot plates.

B1) Align the detection system. The adjustable iris in front of the photomultiplier should be one focal length ($f=51.9$ cm) from the lens. Open the iris near the lens. Illuminate the Fabry Perot with the Na lamp. Observe the bullseye pattern from the Na lamp on a piece of white paper. The paper should be placed over the iris in front of the photomultiplier. The center of the bullseye pattern must coincide with the center of the iris in front of the photomultiplier. The bullseye pattern can be moved by tipping the Fabry Perot in its pressure chamber. The Fabry Perot is tuned by varying the N_2 gas pressure between the plates to vary the index of refraction n .

B2) Remove the paper, turn on the voltage to the photomultiplier, and record a spectrum of the Na lamp. Notice the self reversal in recorded spectrum. Determine the index of refraction of N_2 at 589 nm from your data. A scan from atmospheric pressure to +1000 Torr will cover several free spectral ranges.

B3) Record a spectrum of the 546 nm line from the low pressure Hg lamp. Compare your spectrum to the spectrum on page 7-122 of the AIP handbook. If you do not resolve 7 of the 8 lines, then you should check that the bullseye pattern is centered on the photomultiplier iris and check that the photomultiplier iris is closed as far as possible. You may also need to partially close the iris near the lens.

FINAL QUESTION:

Why is the spectral resolution of the pressure scanned Fabry Perot improved by partially closing the iris near the lens?

Mercury I. This spectrum is very useful because of the ease with which it can be obtained. Any low-pressure mercury tube gives sharp lines; for example, a commercial so-called bactericidal lamp is suitable. High-pressure lamps give broader lines and very-high-pressure lamps (commercial type H6) a continuous spectrum. The mercury spectrum is useful as a general reference spectrum. Under high dispersion most lines show elaborate isotopic and hyperfine structure because there are six isotopes with considerable abundance: 196 (0.15 per cent), 198 (10.12 per cent), 199 (16.84 per cent), 200 (23.13 per cent), 201 (13.2 per cent), 202 (29.80 per cent), and 204 (6.85 per cent). The two odd ones have lines with hyperfine structure. The structure of the lines is sometimes useful for obtaining the resolving power of spectrographs (for details of structure, see Schüller and Burns and Adams¹). An example is shown in Fig. 7g-6.

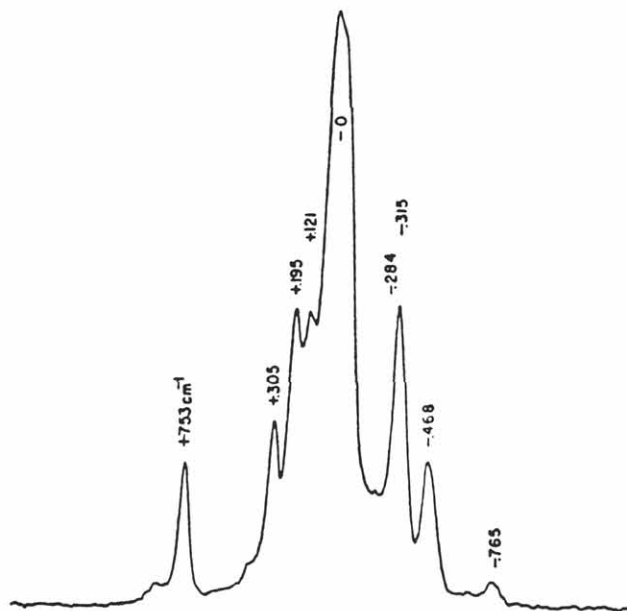


FIG. 7g-6. High-dispersion photoelectric trace of the 5,461-Å line of ordinary mercury showing isotopic and hyperfine structure. Resolving power was 400,000.

Pure Hg^{198} can be obtained by irradiation of gold with neutrons. Lamps with this isotope are now commercially available and the spectrum shows very sharp single lines. Meggers has proposed to adopt the wavelength of the green line (5,461) of Hg^{198} as a primary standard of length. International adoption of this proposal, however, awaits investigation of the variability of the wavelength with discharge conditions. In the meantime most of the strong lines of Hg^{198} , particularly those marked *S* in Table 7g-7, may be used as standards for interferometric wavelength measurements.

Hg^{202} is the most abundant isotope in natural mercury. Tubes with nearly pure Hg^{202} are also available and their wavelengths may also be used as standards.

Table 7g-7 gives the wavelengths of natural mercury, Hg^{198} and Hg^{202} . All values listed between 2,300 and 6,900 Å are recent interferometric wavelengths; those outside this interval are known with much less accuracy.

¹ Schüller and Keyston, *Z. Physik* **72**, 423 (1931); Schüller and Jones, *Z. Physik* **79**, 631 (1932); Burns and Adams, *J. Opt. Soc. Am.* **42**, 716 (1952).

Optional:

An ambitious procedure: Determine the exact order in which the F-P is working and hence measure the spacer to ~ 1 part per million! The idea is to start with a rough estimate of the order number $k = 2\mu\ell\sigma\cos\theta$ and refine it step by step using

known wavenumbers of various spectral lines. You will need to make careful comparisons of the pressures at which various peaks (5461, 5770, 5791) appear on the scans. This can be done (i) using a good pressure gauge or (ii) by measuring 2 or more lines simultaneously, as in (B) above. By putting the grating in zero order, all lines can be let through and dye filters used to select those of interest. For work of this precision, don't forget to take into account the refractive index of N_2 , $\mu = 1.000279$ at 20°C and 760 torr for 5461. The relevant vacuum wavenumbers are

$\lambda 5461$	$\sigma_1 = 18307.479 \text{ cm}^{-1}$
5770	$\sigma_2 = 17327.439$
5791	$\sigma_3 = 17264.401$

A procedure might go like this:

- 1) As in (B) above, accurately measure the order separation of σ_2 and σ_3 and hence estimate the spacer:

$$\begin{aligned}k_2 &= 2\mu_2\ell\sigma_2 \\k_3 &= 2\mu_3\ell\sigma_3 \\2\ell^* &= \frac{(k_2 - k_3)}{\mu_2\sigma_2 - \mu_3\sigma_3}\end{aligned}$$

- 2) The actual spacer can only be one of the values, $\lambda/2$ apart, which satisfy

$$2\ell\mu_2\sigma_2 = k_2 = \text{integer.}$$

So now you have a list of a few possible ℓ 's near the estimate ℓ^* . The length of the list depends on the uncertainty in your estimate ℓ^* .

- 3) The spacer must also satisfy (for the green line)

$$2\ell\mu_1\sigma_1 = k_1 = \text{integer}$$

This yields another short list of possibilities, only one of which should agree with the list in (2).

This procedure is known as the exact fractions technique. For multilayer coatings, the phase shift on reflection can be a nonlinear function of wavenumber, thus complicating this simple picture for widely separated lines.