Interference Filters

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1 Introduction and Theory

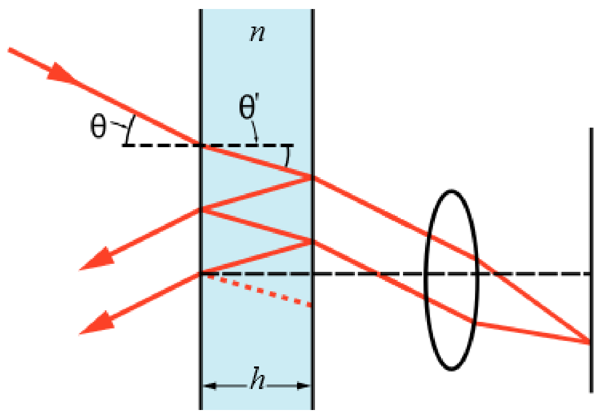

Figure 1: The Fabry Perot interference filter.

A filter is a device through which light passes that selectively transmits certain wavelengths of light while reflecting or absorbing others. The two main types of filters are absorptive filters and interference filters. Absorptive filters are relatively straightforward in that the compound that the filter is made up of simply absorbs certain wavelengths of light while transmitting others. Interference filters are somewhat more complex. An interference filter consists of one or many reflecting cavities. These cavities generally have a dielectric surrounded by a reflective surface at either end.

The most basic of these filters is known as the Fabry Perot interference filter. This consists of two mirrors surrounding a dielectric material of refractive index n. As can be seen in the figure, light is incident on the filter at an angle θ and is refracted to an angle θ'. At each point of incidence with a reflecting surface, some of the light is reflected and some of the light is transmitted depending on the angle of incidence as well as the composition of the reflecting surfaces. The light rays transmitted will emerge parallel and will have to be focused by a suitable lens. For constructive interference to occur, the path length difference between adjacent rays must be an integer number of wavelengths. The path difference between two adjacent rays is $\Delta = 2hn\cos(\theta') = 2h\sqrt{n^2 - \sin^2(\theta)}$. This means that the expression must correspond to a whole number of wavelengths in order for constructive interference to occur:

$$m\lambda = 2hn\cos(\theta')\,. \tag{1}$$

In the case of an interference filter with no absorption, the transmission factor is given by

$$T = \frac{1}{1 + F\sin\left(\frac{\delta}{2}\right)}, \tag{2}$$

where the finesse coefficient is

$$F = \frac{4R}{(1 - R^2)}. \tag{3}$$

If the wavelength λ_0 produces a solution to the above equality, so to will wavelengths of the form $\frac{\lambda_0}{m}$ where m is an integer. So in order to produce an extremely selective filter, an absorptive filter must be added to remove these lower wavelengths.

Important characteristics that define filters include the value of maximum transmission T_{max}. This is the proportion of light that is let through at the peak transmission wavelength relative to the unfiltered spectrum. The bandwidth is effectively the full width at half maximum height of the intensity versus wavelength graph. In other words, it is the range of wavelengths that allow more than half of the maximum transmission T_{max} to pass through. The contrast factor is the ratio of the maximum transmission of the spectrum to the minimum transmission value.

2 Experimental Method

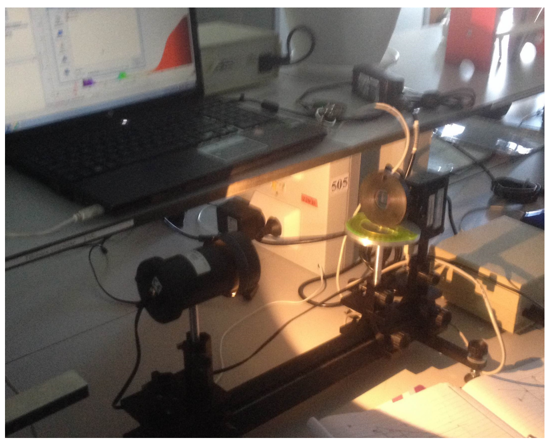

Figure 2: The experimental setup for determining the velocity of light.

The aims of the experiment were to investigate the properties of Fabry Perot interference filters, to determine the transmission spectra of three interference filters at normal incidence and to record values of the characteristic quantities: T_{max}, λ_{max}, the bandwidth $\delta\lambda$, the contrast factor $\frac{T_{max}}{T_{min}}$ and the reflectance R, and to investigate the relationship between both the bandwidth and $lambda_{max}$ with the incidence angle θ.

The apparatus was set up as shown in the above picture. The spectral program was opened in the laptop and the spectrometer was switched on. The light source was switched on and the signal acquisition time was adjusted so that the spectrometer was no longer saturated and that the signal produced no more than 3500 counts. First the spectrometer was covered with a hand and the background "dark spectrum" was measured and calibrated to remove. Then the reference spectrum of the unfiltered light source was measured and recorded. The program was then switched into registration mode. This mode showed the percentage intensity of light versus wavelength relative to the reference spectrum. The interface was adjusted to only show wavelengths in the region of $450 - 900$nm.

For the first part, the first filter C_1 was placed on the optical rail so that the filter was perpendicular to the light source and the spectrometer. The spectrum of the filter was then displayed on the screen.

The maximum transmission value, the wavelength of maximum transmission and the bandwidth were all recorded. This procedure was repeated for two filters C_2 and C_3.

For the second part, the first filter C_1 was replaced onto the optical rail perpendicular to the source and the spectrometer. The filter was rotated by $10°$ and the spectrum was observed. Again, the maximum transmission value, the wavelength of maximum transmission and the bandwidth were recorded. This procedure was repeated, each time rotating the filter by an additional $10°$, and a table of values was recorded.

3 Results and Analysis

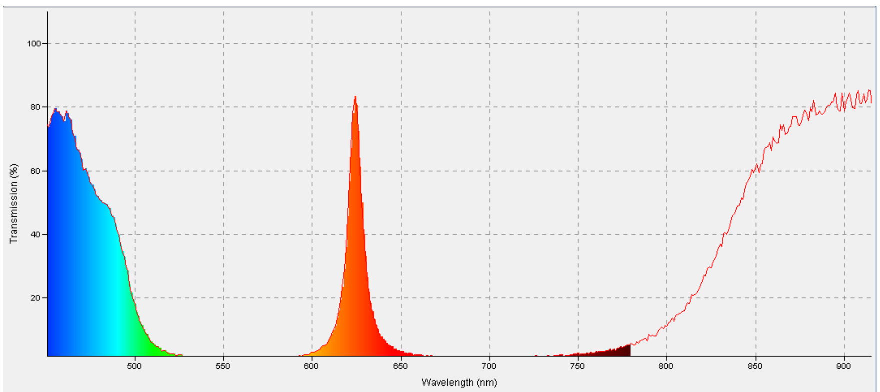

Figure 3: The C_1 filter.

Shown are the spectra for the different filters. The various quantities were recorded for the different filters and are recorded in the table below.

	$T_{max}(\%) \pm 1\%$	$\lambda_{max}(\text{nm}) \pm 1\text{nm}$	$\delta\lambda(\text{nm}) \pm 1\text{nm}$	$\frac{T_{max}}{T_{min}} \pm 2$	R
C_1	84	624	9	168	0.857 ± 0.003
C_2	75	529	6	750	0.9295 ± 0.002
C_3	74	509	7	$\frac{74}{0}$	1.000

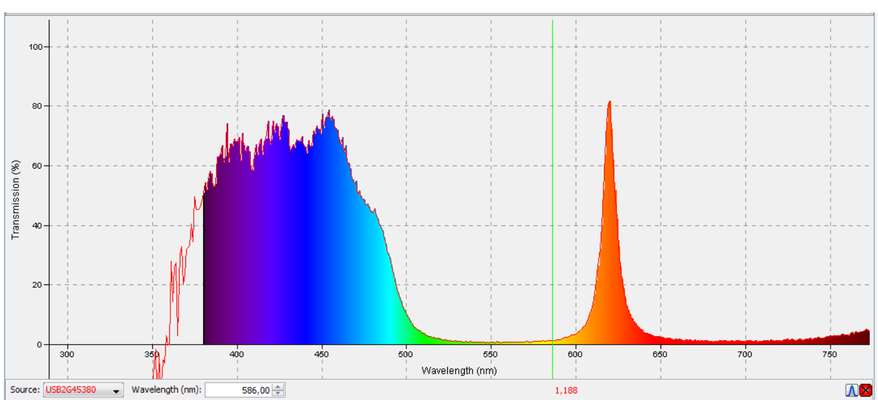

Figure 4: $\theta = 10°$.

Shown are the spectra for the different angles of incidence. The quantities were also recorded for different incident angles for the C_1 filter.

$\theta° \pm 1°$	$T_{max}(\%) \pm 1\%$	$\lambda_{max}(\text{nm}) \pm 1\text{nm}$	$\delta\lambda(\text{nm}) \pm 1\text{nm}$	$\frac{T_{max}}{T_{min}} \pm 2$	R
10	80	620	9	160	0.85347 ± 0.003
20	76	613	9	152	0.8499 ± 0.004
30	74	598	9	148	0.8490 ± 0.004
40	68	582	10	136	0.842 ± 0.005

The equation for the path difference leads to the following expression for λ_0:

$$\lambda_0{}^2 = 4h^2n^2 - 4h^2\sin^2(\theta)\,, \tag{4}$$

which can be used to obtain values for h and n. The above equation was plotted and the slopes and intercepts were used to obtain the values ($m = -4h^2$, $c = 4h^2n^2$).

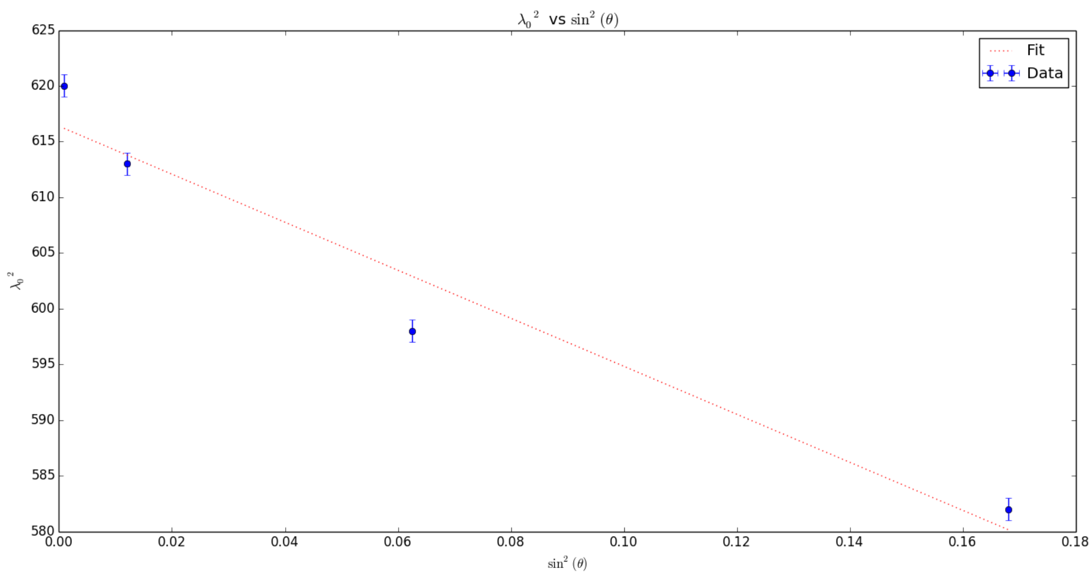

Figure 5: The graph of $\lambda_0{}^2$ vs $\sin^2(\theta)$

The values obtained for the slope and intercept from the graph were $m = -215 \pm 3$ and $c = 616 \pm 3$, respectively, giving values of $n = 1.69 \pm 0.05$ and $h = 7.33 \pm 0.05$nm.

4 Discussion and Conclusions

One notable result was that the C_3 filter gave a value for $\frac{T_{max}}{T_{min}}$ of the form $\frac{1}{0}$. But since the reflection coefficient R is given by

$$\frac{T_{max}}{T_{min}} = \frac{(1+R)^2}{(1-R)^2}, \tag{5}$$

then we must have $R = 1$ since it also gives an answer of the form $\frac{1}{0}$. Physically this corresponds to all the light being reflected, which makes sense since $T_{min} = 0$ means that no light is transmitted. The bandwidth seems to increase slightly with the angle of incidence, although there is a lot of room for improvement in the accuracy of these measurements.