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On the role of the instrumental function of an entrance monochromator in the interferometric line profile analysis*

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Results of studies on the effect of the instrumental function of the entrance monochromator of a spectrometer with Fabry–Pérot interferometer on the parameters describing the Doppler and Lorentzian half-widths of the line are discussed.

1. Introduction

Measurements of profiles of collision broadened spectral lines in the region of very low pressures require the use of Fabry–Pérot interferometric methods. It is well known that at very low pressures the line shape can be approximated by the Voigt profile which is a convolution of the Lorentzian and Gaussian profiles corresponding to the collision and Doppler effects, respectively [1]. In order to determine the parameters describing the collision and Doppler broadening, firstly the instrumental component of the total line shape must be found. The role of the instrumental function of the Fabry–Pérot interferometer alone is quite well understood. In many cases this instrumental function can be sufficiently well approximated by means of an Airy profile, and its convolution with the Voigt profile can be then calculated using a method proposed by Ballik [2]. We should emphasize, however, that in all spectrometers with Fabry–Pérot interferometers it is necessary to use an entrance monochromator whose role is to make a choice of a particular spectral line under investigation.

The purpose of the present work is to provide results of our studies on the influence of the instrumental function of the entrance monochromator on the measured shape of the spectral line investigated by means of the Fabry–Pérot interferometer. While the influence of the instrumental function of the Fabry–Pérot etalon on the resultant line shape was the subject of many studies (cf. e.g. [2, 3]) the role of the instrumental function of the entrance monochromator has not been, as yet, sufficiently well clarified. In a recent work [4] on the selfbroadening of some neon spectral lines arising from the transitions between the levels belonging to confi-

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gurations $2p^5 3p$ and $2p^5 5s$ we have found that, for weak lines a least squares fit of the Voigt profile to the measured one can lead to erroneous results for the widths of the Gaussian and Lorentzian components of the total profile. This occurs for those weak lines in the vicinity of which there exist some strong lines. These strong neighbouring lines can have a noticeable effect on the profile of the line under investigation if the instrumental function of the entrance monochromator posesses sufficiently far wings. The existence of these far wings of the instrumental function of the entrance monochromator leads to the appearance of weak "quasi-satellite" lines in the Fabry–Pérot interferograms of the investigated line.

2. Instrumental "quasi-satellites"

In order to study the role of the entrance monochromator in the formation of the total shape of a spectral line we have performed very careful measurements of profiles of several neon lines arising from the $2p^5 3p$–$2p^5 5s$ transitions using a spectrometer with a Fabry–Pérot interferometer of the type described previously [5]. In this apparatus the DFS-8 grating spectrograph of 3 m focal length plays a role of an entrance monochromator. Our interferometric measurements of line profiles were carried out for the widths of slits of the grating spectrograph in the region from 0.1 to 0.4 mm. For such wide slits the instrumental function of the grating spectrograph is determined by the optical image of the entrance slit as well as by the diffraction of light in the spectrograph. However, the instrumental profile which includes all these effects cannot be expressed in terms of elementary functions (cf. e.g. [7]).

If the intensity of the line under investigation is equal to or greater than that of neighbouring lines then one can assume that the instrumental function is determined first of all by the optical image only. In this case the far wings of the instrumental function do not play any essential role. On the other hand, in cases when the neighbouring lines are much stronger than the line under investigation then the far wings of the instrumental function become very important and may even play a decisive role in the formation of the line profile. In particular, in some cases these far wings of the instrumental function of the entrance spectrograph can make impossible the measurements of profiles of very weak spectral lines.

The figure 1 shows an example of the images (full lines) of the "lasing" line $\lambda = 632.82$ nm of Ne I together with some neighbouring lines which can be obtained in the focus plane of the spectrograph for the width of the entrance slit equal to 0.15 mm. These images are presented in fig. 1 in the form of rectangular function, so that the role of wings of the instrumental function has been neglected. The broken lines in the fig. 1 indicate the

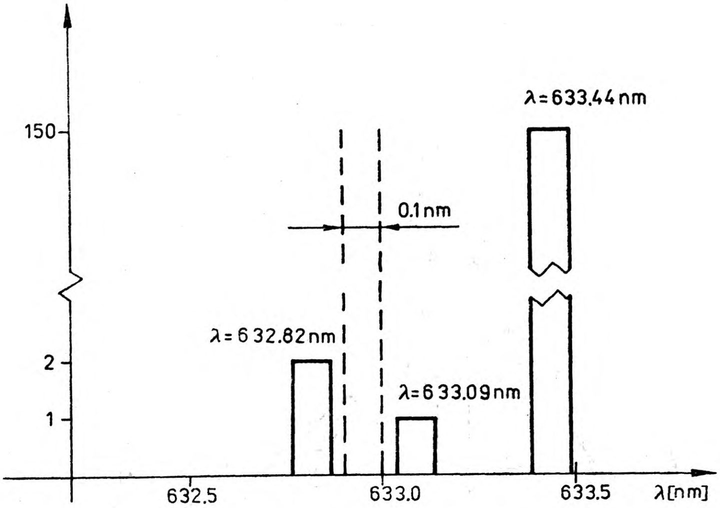

Fig. 1. The image of the 632.82 nm Ne I line and its neighbouring lines 633.09, 633.44 nm in the focus plane of the spectrograph. The broken line denotes the exit slit

spectral region chosen by means of an exit slit (0.15 mm) of the spectrograph.

In order to investigate the role of the instrumental function of the spectrograph we have performed measurements of the images of the neon line $\lambda = 632.82$ nm emitted from a helium-neon laser and the thallium line $\lambda = 535.05$ nm emitted from OSRAM Tl spectral lamp. Widths of these two lines differ very markedly from each other. The width of the Ne I line $\lambda = 632.82$ nm is much smaller and that of the Tl I line $\lambda = 535.05$ nm is much greater than the widths of other neon lines under investigation.

The figure 2 shows the results obtained for two different widths of the spectrograph slit. As can be seen from fig. 2 the wings of the spectrograph instrumental function are very long. At the distance of about 3 nm from the maximum of the line the value of the instrumental function decreases 10^4–10^5 times in comparison to the maximum and depends on the width of the slits. It is thus clear that weak spectral lines can be significantly perturbed by the strong neighbouring lines if they are situated very close to the weak lines. For instance, it is seen from fig. 2 that if the line under investigation has the intensity about 10^{-2} of the intensity of the neighbouring strong line and is located in the region less than 1.5 nm then the influence of the profile of the neighbouring line cannot be neglected.

Very significant effect of the profile of the strong neighbouring line on the profile of the line under investigation can be found if the difference of wavenumbers of these two lines is equal to $(k+1/2)\Delta\nu_i$, where k is the interference order and $\Delta\nu_i$ is the free spectral range of the Fabry–Pérot interferometer. In such a case in the vicinity of the minimum of the inter-

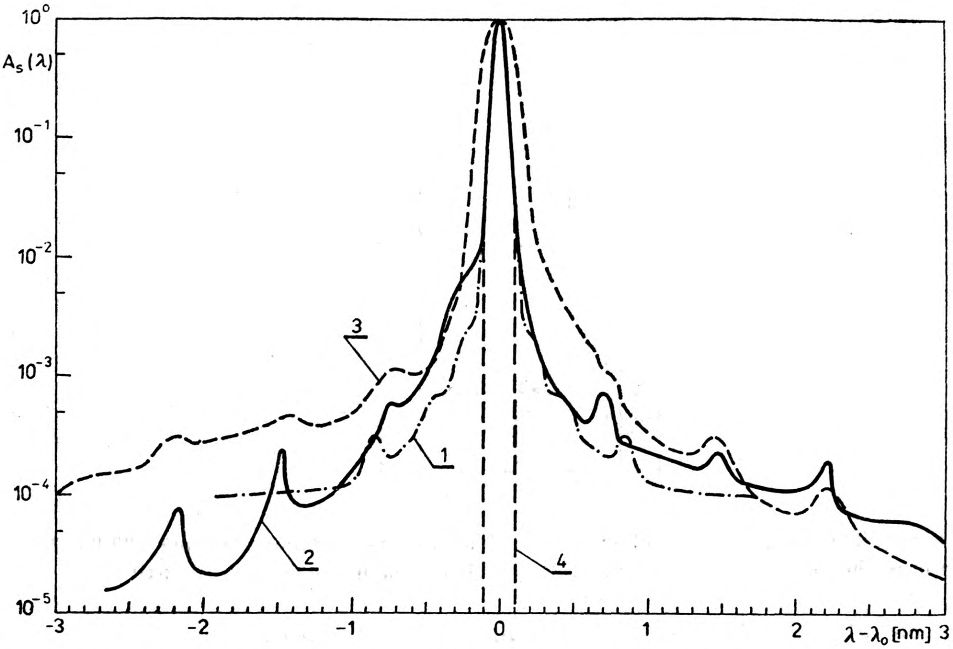

Fig. 2. The instrumental function $A_s(\lambda)$ of the spectrograph. Curve 1 — image of the 632.82 nm Ne I line for the width of slits equal to 0.15 mm. Curves 2 and 3 — images of the Tl I 535.1 nm line for the widths of slits amounting to 0.15 and 0.3 mm, respectively. Curve 4 — theoretical instrumental function determined from the geometric image for the slit width of 0.15 mm.

ferogram of the line under investigation a contour of the strong neighbouring line appears in the form of an additional intensity maxima which resemble a satellite band frequently observed for higher pressures of perturbing gases (cf. [8]). Such contours of strong neighbouring lines will be hereafter referred to as "quasi-satellites".

The figure 3 shows an interferogram of the NeI $\lambda = 621.39$ nm line (broken line) emitted from d.c. glow discharge in pure neon (discharge current 1.45 mA). In this case we note the appearance of a distinct quasi-satellite coming from the neighbouring neon line $\lambda = 621.73$ nm. In most cases, however, the effect of the profile of the neighbouring line on the weak line is not so clear as that in fig. 3. It should be emphasized that even in the case when distinct quasi-satellites does not appear, the profile of the weak line may be markedly perturbed by the strong neighbouring line. An example of such a case is shown in fig. 4, where the interferogram of the $\lambda = 632.82$ nm line of neon is presented. The appearance of such a quasi-satellite is the consequence of the real behaviour of the instrumental function of the entrance monochromator. In many cases this apparatus effect cannot be eliminated and therefore it is of interest to establish its influence on the line profile parameters such as the widths of the Lorentzian and Gaussian components determined from the interferometric analysis.

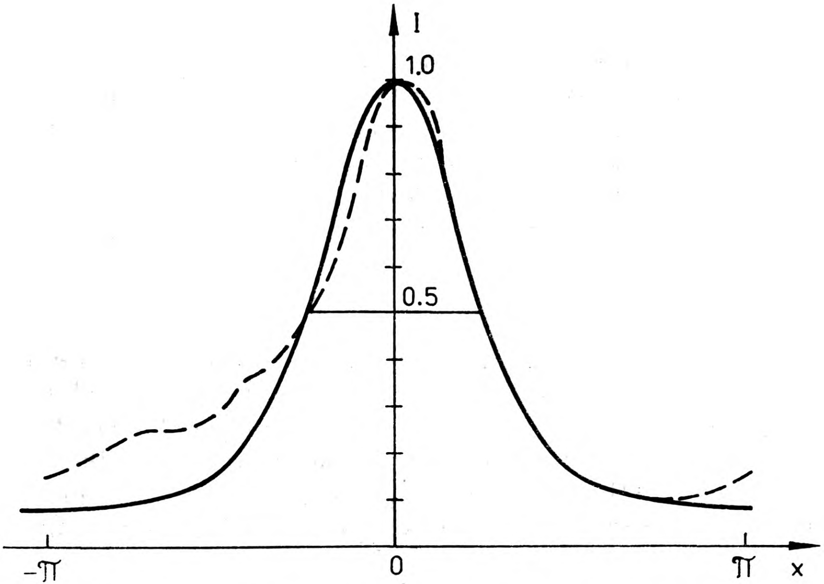

Fig. 3. The observed shape of the Ne I 621.39 nm line (broken line) and the Voigt profile (full line) fitted by using the method II for the neon pressure of 2793 Pa, the spacer of the Fabry–Pérot etalon equal to 1.513 cm, slit width of 0.15 mm, the discharge current of 1.45 mA

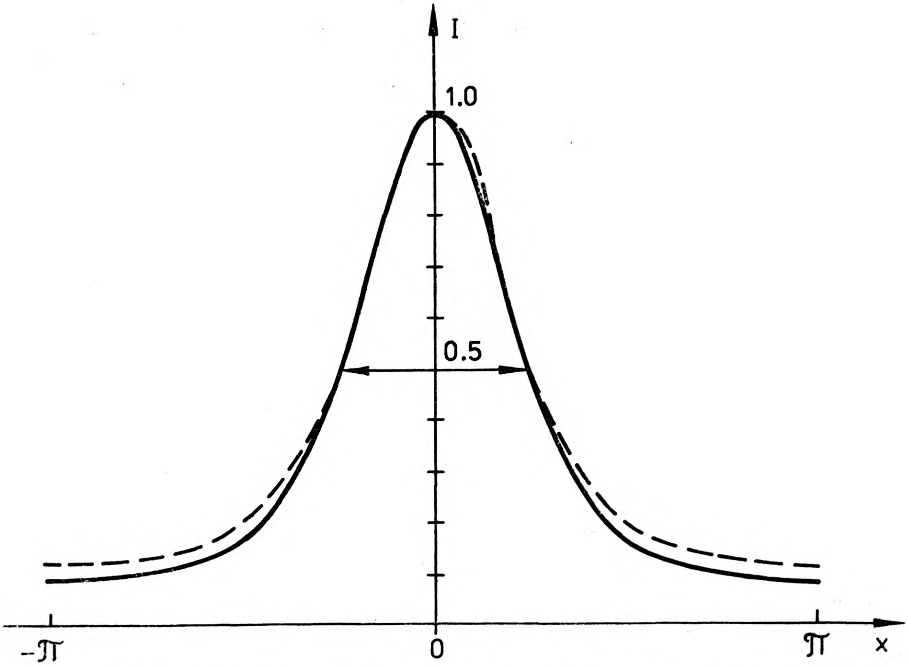

Fig. 4. The observed shape (broken line) of the Ne I 632.82 nm line and Voigt profile (full line), fitted by the method II. Further explanation see fig. 3

3. Line profile analysis

In order to study the influence of instrumental quasi-satellite on the Lorentzian and Gaussian half-widths of the line we have performed measurements of profiles of three selfbroadened spectral lines of neon: 632.82, 621.39 and 632.3 nm emitted from low pressure glow discharge in pure neon. Experimental detailes were identical to those described in our previous works [4, 6]. The measured Fabry–Pérot interferograms of these lines were analyzed by two numerical methods.

Method I

For very low pressures the line shape is described by the Voigt profile. The first method used by us consists in the assumption that the convolution of the Voigt profile and the instrumental profile of the Fabry–Pérot interferogram are given by an analytical formula derived by Ballik [2]. Using a least squares method the values γ_L and γ_D of the width of the Lorentzian (γ_L) and Gaussian (γ_D) components of Voigt profile have been determined.

Method II

In this method the observed profile is fitted to the Voigt profile in such a way that the half-width of the observed profile and that of the fitted one are equal. Such a fit is made under additional assumption that the half-width of the Gaussian width is known.

The plots of the Lorentzian and Gaussian half-widths of the 632.82 nm Ne I line vs. the neon pressure are shown in fig. 5. In this figure curves 1

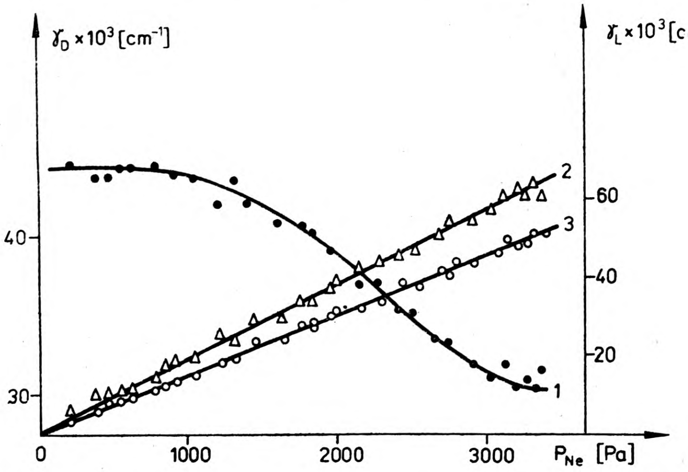

Fig. 5. Plot of the Gaussian and Lorentzian half-widths of the Ne I 632.82 nm line vs. the neon pressure (the slits width 0.15 mm). Curve 1 — Gaussian half-widths determined by the method I, curves 2 and 3 — Lorentzian half-widths determined by the method I and II, respectively

and 2 represent the Gaussian γ_D and Lorentzian γ_L half-widths determined by the method I, while the curve 3 represents the Lorentzian half-width determined by the method II. The value of the Doppler temperature (330 K) used in the method II was obtained from the measurements of selfbroadening of spectral lines belonging to transitions between levels of configurations $2p^5 3p$–$2p^5 4d$ and carried out in identical conditions [4]. As can be seen from fig. 5 the two methods applied here yield linear dependence of the Lorentzian width on the pressure, but for different values of the pressure broadening coefficient $\beta = \Delta\gamma_L/\Delta p$. We have obtained $\beta = 1.86 \times 10^{-5}$ cm^{-1}/Pa from the method I and $\beta = 1.5^{-5} \times 10^{-1}$ cm/Pa from the method II.

It is seen in fig. 5 that the Gaussian half-width of the 632.82 nm Ne I line determined from the method I decreases with the increase of pressure. The Gaussian width remains constant only at very low pressure (below 1.33 kPa). It is interesting to note that the Doppler temperature (295 K) determined from this pressure region is less than the value 330 K determined by measurements of selfbroadening of the $2p^5 3p$–$2p^5 4d$ lines. All results shown in fig. 5 were obtained from the measurements performed with the widths of slits equal to 0.15 mm. Similar results obtained for the lines 621.39 and 631.3 nm of neon are shown in figs. 6 and 7.

We have found that the effect of the decrease of the Gaussian half-width with the increasing pressure can be eliminated if the measurements are carried out at very narrow slits. Figure 8 shows the plots of the Gaussian and Lorentzian half-widths of the 623.82 nm Ne I line vs. the neon pressure for the width of slits equal to 0.075 mm. As can be seen from fig. 8 in this case both methods yield for the Lorentzian component the same value

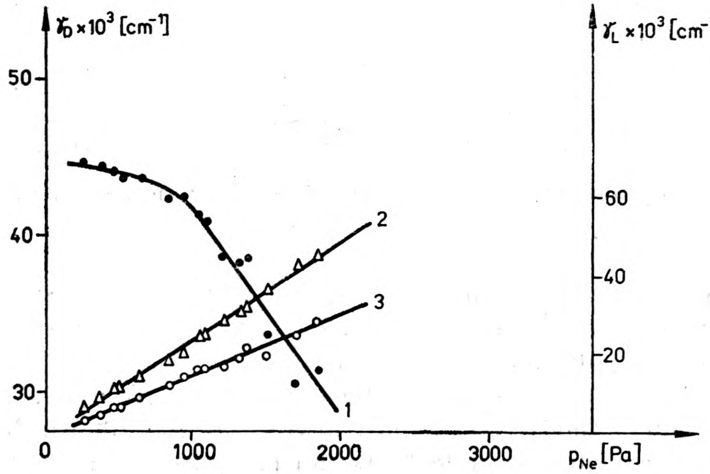

Fig. 6. Plot of the Gaussian and Lorentzian half-widths of the Ne I 621.39 nm line vs. neon pressure. Further explanation see fig. 5

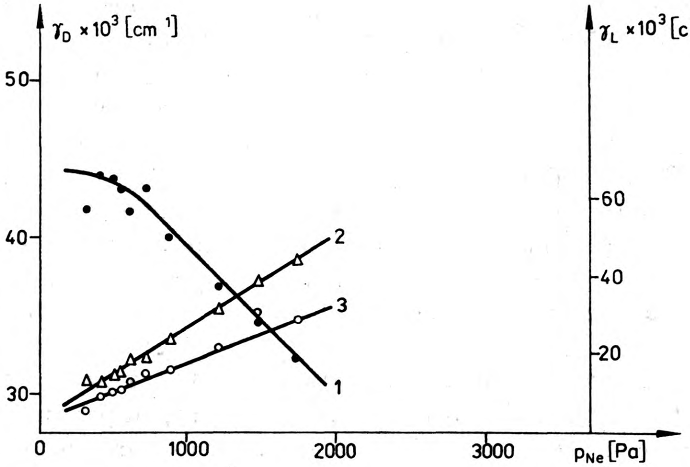

Fig. 7. Plot of the Gaussian and Lorentzian half-widths of the Ne I 631.37 nm line vs. the neon pressure. Further explanation see fig. 5

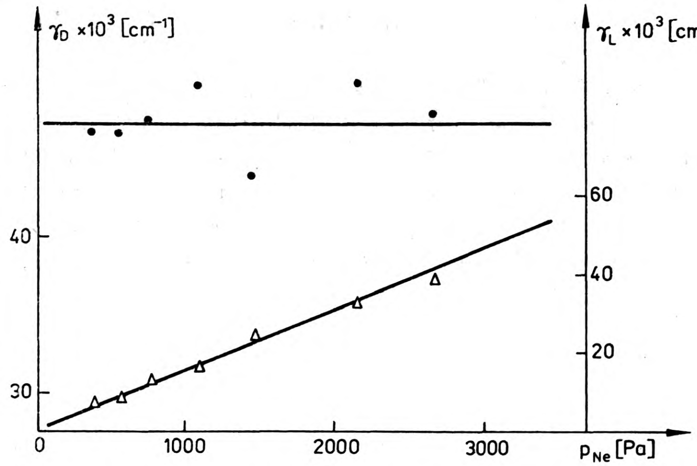

Fig. 8. The Lorentzian and Gaussian half-widths of the Ne I 632.82 nm line for the slits widths 0.075 nm

of the pressure broadening coefficient $\beta = 1.5 \times 10^{-5}$ cm^{-1}/Pa. The Gaussian width determined by the method I is then independent of the pressure and corresponds to the Doppler temperature of 327 K.

The values of the pressure broadening coefficient β for the Ne I 632.82 nm line determined from methods I and II for two values of the slits width and various pressures are listed in table 1. As can be seen from table 1 the method II yields the same results regardless of the slits widths and pressure used in measurements. We have performed many tests which

Table 1. Values of the pressure broadening coefficient β (in units of 10^{-5} cm^{-1}/Pa) for the 632.89 nm neon line (for explanation see text)

Slits width [mm]	Pressure region [Pa]	β	
		Method I	Method II
0.15	100–3,300	1.86	1.50
0.15	100–1,300	1.68	1.51
0.075	100–2,700	1.39	1.51

have shown that the effect of the decrease of the Gaussian width with the increase of pressure occurs for those spectral lines only in the neighbourhood of which some strong lines are located. It seems thus reasonable to assume that this effect is caused by the appearance of the instrumental quasi-satellite. To justify this assumption we have determined the shape of the quasi-satellite by subtracting the observed profile from the profile found on the basis of method II. Such a profile of the quasi-satellite at the 621.39 nm Ne I line is shown in fig. 9, where it is compared with the profile of the strong neighbouring Ne I line 621.73 nm. Let us observe that the latter is strongly distorted by the reabsorption. We have estimated the "theoretical" intensities of quasi-satellite for three spectral lines of neon using the instrumental function of the entrance monochromator shown in fig. 2. The values of the "theoretical" intensities of quasi-satellites and those measured directly from interferograms are listed in table 2.

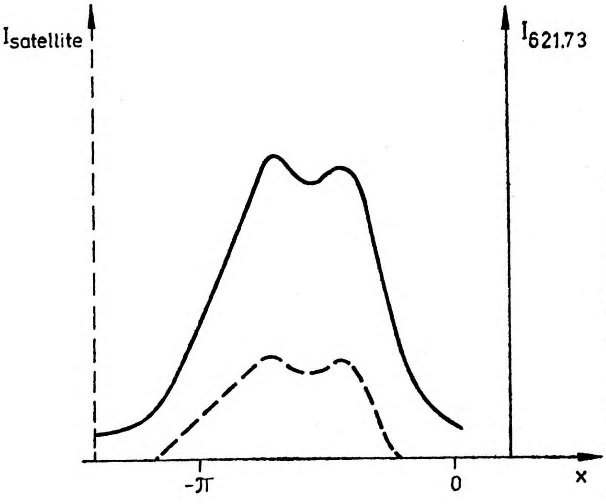

Fig. 9. The shape of the "quasi-satellite" (broken line) from the interferogram shown in fig. 3 for the Ne I 621.39 nm line. The full line is the interferogram of the neighbouring strong neon line 621.73 nm. Zero corresponds to the position of the maximum of the 621.39 nm line. The Ne I 621.73 line is strongly affected by reabsorption

Table 2. "Theoretical" and experimental intensities (in relative units) of the quasi-satellite for Ne I at the neon pressure of 3192 Pa

Slits width [mm]	Wavelength of		Intensity at the maximum of		Calculated limits of quasi-satelite intensity		Measured intensity of quasi-satellite
	line under investigation [nm]	neighbouring line [nm]	line under investigation	neighbouring line	min	max	
0.15	621.39	621.73	150	18 000	12	72	20
0.175	632.82	633.44	200	15 000	3	12	8
0.30	631.37	630.48	200	30 000	3	20	20

Let us note a very good agreement between "theoretical" and measured values of intensities of quasi-satellites. The decrease of Gaussian half-width of weak Ne I spectral lines with the increase of neon pressure (figs. 5–7) can be explained by the fact that the quenching of the levels belonging to the $2p^5 5s$ configuration is stronger than that of levels belonging to the $2p^5 3p$ configuration, which are the initial states of spectral lines for which the quasi-satellites appear. Figure 10 shows the plot of intensities of the 632.82 nm and 540.0 nm lines arising from the $2p^5 3s$–$2p^5 3p$ transition. The behaviour shown in fig. 10 corroborates the assumption that the far wings of the instrumental function of the entrance monochromator are responsible for the occurrence of the quasi-satellites.

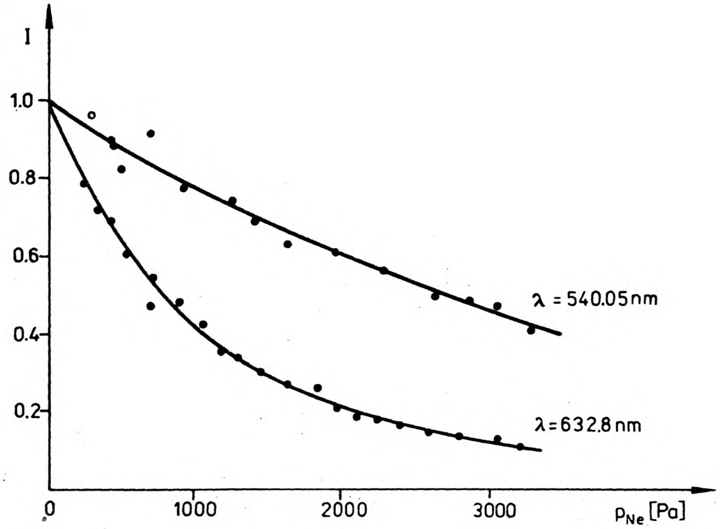

Fig. 10. The intensities of the 632.82 nm ($3s_2$–$2p_4$) and 540.06 nm ($1s_4$–$2p_1$) Ne I lines vs. the neon pressure

4. Concluding remarks

In the conclusion we should emphasize that in some cases erronuous results of the pressure broadening coefficients may be obtained even in the case when the Gaussian half-width of the line remains constant with pressure. This is of particular importance if the measurements are carried out for small pressure regions. Significant effect of the instrumental function of the entrance monochromator on the profile of a weak line is observed if the strong line is located in the close vicinity of the weak line under investigation. In such a case the Gaussian half-width of the weak line decreases with the increase of pressure if the quenching of the distorting neighbouring line is small, on the other hand, if the quenching of this line is great the Gaussian half-width γ_D tends to increase to its real value. Results obtained in the present work indicate that the instrumental function of the entrance monochromator should be taken into account in low pressure measurements of profile of weak spectral lines carried out by means of the Fabry–Pérot interferometers.

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О роли инструментальной функкйии предварительного монохроматора в интерферометрическом анализе профилей линии

Представлены результаты исследования влияния инструментальной функции предварительного монохроматора в спектрометрах с эталоном Фабры–Перо параметры, описывающие допплеровскую и лоренцовскую полуширину линии.