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# Precise measurements of the wavelength in KrCl laser spectral region (222 nm)

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**Abstract.** The technique for precise measurements of wavelengths in the range around 222 nm (45030 cm$^{-1}$) has been presented. The reciprocal linear dispersion of the spectrometer was 0.529 Å/mm. The measurements were made in the second spectral order for a grating with 2400 lines/mm. Identification of emission lines of hollow cathode lamp (Fe) was made in the spectral range 4428…4452 Å. The wavelengths were measured for 32 identified lines in the spectrum. The mean square error of measurements is ~0.0005 Å.

**Keywords:** gas laser, spectral line, hollow cathode lamp.

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## 1. Introduction

Precise measurement of wavelengths radiation in spectra allows to obtain information about radiating molecules (for example, calculations of vibrational constants, analysis of the potential curves for the upper and lower states of molecules, etc. [1, 2]). Despite the significant progress in laser development, and harmonic generation technique, KrCl laser remains one of the most powerful coherent sources in near vacuum UV spectral region (222 nm). Due to presence of a local minimum in potential curve of lower electron state, the laser spectrum may contain narrow lines under specific conditions. It can be interesting from both theoretical (calculation of vibrational and rotational constants of the molecule) and applications points of view, where spectral with of the source plays significant role. Thus, the precise knowledge of the line wavelength is important. The spectrum of iron radiation is widely used to identify the wavelengths in studied spectra from infrared to vacuum ultraviolet. However, the spectrum strongly depends on the type and parameters of the discharge. For precise measurements, it is preferred to use the spectrum of the radiation of iron lamp with a hollow cathode, since it gives narrower lines.

From the viewpoint of wavelength measurements, there are many different techniques that can be used. The most widely applied is that of diffraction grating based

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spectrometer with registration based on charge-coupled device (CCD) camera or CCD matrix. However, the sensitivity of such devices in the near vacuum UV region remains too low. To increase the sensitivity, one should increase the pixel size, which in turn decreases the resolution. For example, the pixel of CCD matrix from Hamamatsu that is sensitive to 222 nm is 14 µm. It corresponds to 72 pixels per 1 mm, and, for given reciprocal linear dispersion (0.529 Å/mm), the expected spectral resolution is equal to 0.0075 Å. At the same time, the photo-film sensitive to UV light (for example Fujifilm Neopan 400 Professional) can provide resolution more than 100 lines/mm, which corresponds to less than 0.0053 Å spectral resolution. Since the image of the spectra is obtained on photo-film, further conversion into digital format is easy procedure, which can be done by conventional high resolution scanner.

The present work describes a method of precise measurement of wavelengths in KrCl laser spectrum (222 nm).

## 2. Experimental technique

As a reference spectrum, we used the hollow cathode lamp (TSPC type, Fe) filled with low pressure Ne gas. The operation voltage was 190 V, and current – 29 mA. The lamp was located directly in front of the entrance slit of the spectrometer DFS-8. With the grating 2400 lines/mm and the slit width 16 µm, the resolution was 0,01 Å, and the inverse linear dispersion was 0.529 Å/mm in the second order of grating spectrum.

## 3. Method of measurements and experimental results

The TSPC lamp emission spectra and the spectra of KrCl laser were photographed on film through the Hartmann diaphragm. The KrCl laser spectrum was photographed through central aperture window, and through the next upper and lower windows the spectra of the lamp with a hollow cathode were photographed. Since KrCl laser emission spectra were recorded in the second order spectrum, and the intensity of iron lines near 222 nm range is low and not exhibited in the film, first order spectrum (444 nm) of hollow cathode lamp was used as a reference spectrum.

The spectra were recorded on photo-film Fujifilm Neopan 400 Professional, which is sensitive in the area of 222 nm. The film was further developed by using TETENAL Ultrafin Plus developer.

After developing and drying, the films with the spectra were scanned with high resolution (6400 dpi, Epson Perfection V750 PRO) and saved in digital

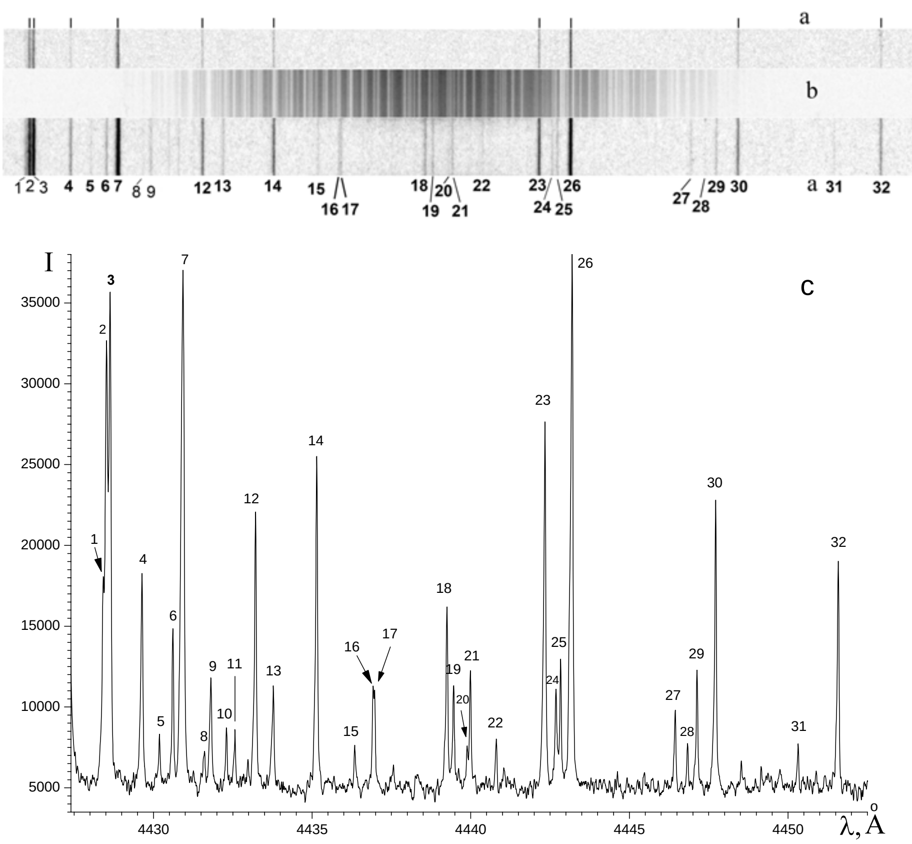


**Fig. 1.** (a) – spectrum of the hollow cathode lamp radiation, obtained in the first diffraction order, (b) – emission spectrum of KrCl laser obtained in the second diffraction order, (c) – densitograms of the hollow cathode lamp spectrum.

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format, which enabled us further digital image processing with conventional computer programs. At first, we provided linking the KrCl laser spectrum wavelength axes to the known wavelength of hollow cathode lamp spectrum [4], and later we plotted the dependence of the laser lines intensity on wavelength (or wavenumber). Finally, we measured the wavelength of the laser spectral lines.

Fig. 1a demonstrates the scanned image of KrCl laser spectrum (222 nm) obtained in the second order of grating spectrum, and the radiation spectrum of the lamp with a hollow cathode in the region of 444 nm obtained in the first order of grating spectrum. The upper and lower spectra of the lamp were obtained at different exposure times. The densitograms of the hollow cathode lamp spectrum is shown in Fig. 1b. Numbers below every line in Fig. 1a shows a correspondence of those lines to the lines in Fig. 1b.

The measured wavelengths of spectral lines of the lamp with hollow cathode are shown in Table. The numbers in this table correspond to the numbers in Figs. 1a and 1c.

During the measurements of iron spectral lines wavelength, the best precision was reached when the dispersion curve was approximated by quadratic polynomial. In this case, usually from 3 to 5 lines were used as reference points.

Fig. 2 shows the standard deviation of the measured lines from the reference values in the range of 444 nm. The vertical dashed lines show the interpolation region. The root mean square deviations of the measured lines from the reference values are 0.00046 Å.

The spectral lines in Fig. 1b were used as the references ones for the measurement of wavelengths in the spectra of the KrCl laser radiation.

**Table. The wavelengths of the emission spectrum of the lamp with hollow cathode in 444 nm region (Fig. 1).**

| N | Ours λ Å | Ref. λ Å | Element | Ref. | Δλ Å |
|---|---|---|---|---|---|
| 1. | 4428.41957 | 4428.409 | Ne II | 3 | 0.0106 |
| 2. | 4428.52221 | 4428.516 | Ne II | 3 | 0.0062 |
| 3. | 4428.63417 | 4428.634 | Ne II | 3 | 0.0002 |
| 4. | 4429.63711 | 4429.6441 | Ne II | 3 | –0.007 |
| 5. | 4430.1875 | 4430.1896 | Fe I | 4 | –0.0021 |
| 6. | 4430.61193 | 4430.6142 | Fe I | 4 | –0.0023 |
| 7. | 4430.93373 | 4430.942 | Ne II | 5 | –0.0083 |
| 8. | 4431.60993 | 4431.61 | Co I | 5 | –0.0001 |
| 9. | 4431.81045 | 4431.810 | Ne II | 3 | 0.0005 |
| 10. | 4432.30006 | 4432.303 | Ne II | 3 | –0.0029 |
| 11. | 4432.56584 | 4432.5659 | Fe I | 4 | –0.0001 |
| 12. | 4433.21858 | 4433.216 | Fe I | 4 | 0.0026 |
| 13. | 4433.77803 | 4433.7813 | Fe I | 4 | –0.0033 |
| 14. | 4435.1485 | 4435.1485 | Fe I | 4 | 0.0 |
| 15. | 4436.34163 | 4436.35 | Mn I | 5 | –0.0084 |
| 16. | 4436.92414 | 4436.9208 | Fe I | 4 | 0.0033 |
| 17. | 4436.97074 | 4436.979 | Ne II | 3 | –0.0083 |
| 18. | 4439.24907 | 4439.2530 | Ne II | 3 | –0.0039 |
| 19. | 4439.46335 | 4439.4600 | Ne II | 3 | 0.0034 |
| 20. | 4439.88725 | 4439.8809 | Fe I | 4 | 0.0064 |
| 21. | 4439.98972 | 4439.9924 | Ne II | 3 | –0.0027 |
| 22. | 4440.80482 | 4440.804 | Ne II | 3 | 0.0008 |
| 23. | 4442.33697 | 4442.3379 | Fe I | 4 | –0.0009 |
| 24. | 4442.68619 | 4442.6857 | Ne II | 3 | 0.0005 |
| 25. | 4442.83519 | 4442.8308 | Fe I | 4 | 0.0044 |
| 26. | 4443.19371 | 4443.1930 | Fe I | 4 | 0.0007 |
| 27. | 4446.4475 | 4446.4421 | Ne II | 3 | 0.0054 |
| 28. | 4446.83376 | 4446.8330 | Fe I | 4 | 0.0008 |
| 29. | 4447.13159 | 4447.1294 | Fe I | 4 | 0.0022 |
| 30. | 4447.7179 | 4447.7179 | Fe I | 4 | 0.0 |
| 31. | 4450.31852 | 4450.3174 | Fe I | 4 | 0.0011 |
| 32. | 4451.5836 | 4451.59 | Mn I | 5 | –0.0064 |

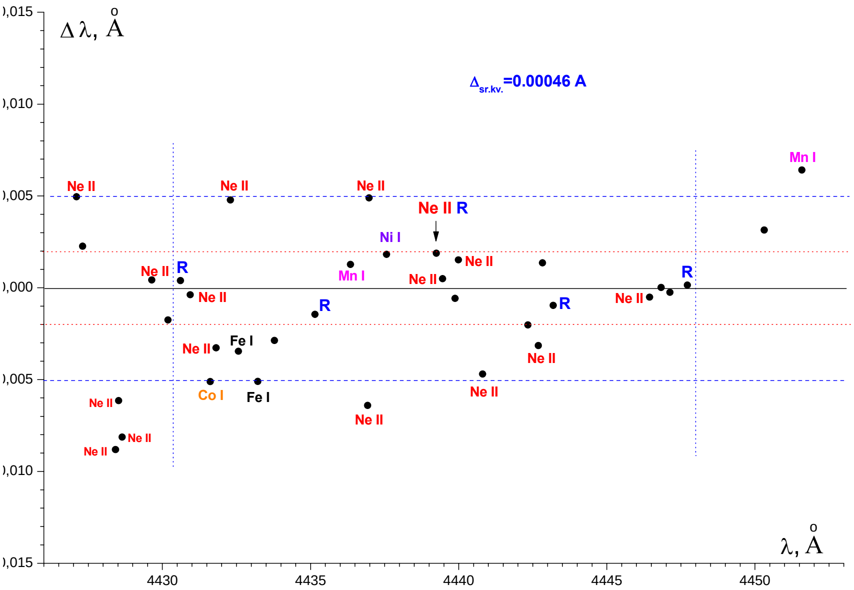


**Fig. 2.** The root mean square deviations of the measured lines from the reference values in the range of 444 nm.

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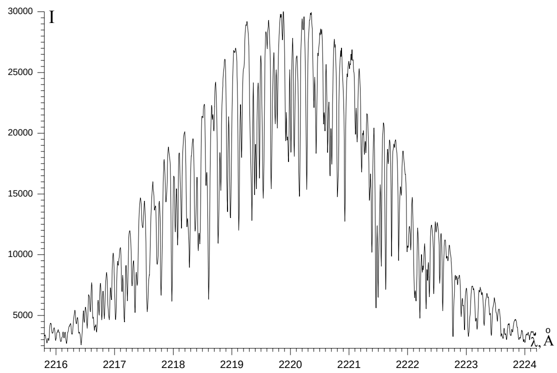


**Fig. 3.** The spectrum of KrCl laser radiation at 0.3 atm presure inside of the cavity.

Fig. 3 shows the spectrum of KrCl laser obtained in the second order of grating spectrum. Dips in the spectrum are the absorption lines, due to the presence of HCl molecules in active medium [5].

Analysis of the fine structure in the spectrum of KrCl laser will be presented in our next publication.

## 4. Conclusions

The method described above allows with a great accuracy (not worse than 0.005 Å) to measure the wavelengths in the range of 222 nm. We identified and measured 32 lines in the spectrum of Fe lamp with a hollow cathode near the region of 444 nm. Many of the lines in the spectral region belong to other elements (Ne, Ni, Al, Co), and can be used as the reference lines for the given spectral region. Fig. 3 can be used as a spectral map for the region 4426…4452 Å.

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