ON THE SPECTRAL SHAPES OF NE II LINES RECORDED FROM THE CATHODE FALL REGION OF AN ABNORMAL GLOW DISCHARGE

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Schematic diagram of the central part of the Grimm glow discharge and the experimental setup
CS – cathode sheet, NG – negative glow region.

- Hollow anode \( l=30 \text{ mm}, 8 \text{ mm dia.} \)
- Longitudinal slot \((16 \text{ mm} \times 1.5 \text{ mm})\)
- Tungsten cathode \( l=18 \text{ mm}, 7.6 \text{ mm dia.} \)
- Gas flow 300 cm\(^3\)/min

- Ebert type spectrometer \( f=2 \text{ m} \)
- Reflection grating 651 g/mm blazed at 1050 nm
- Reciprocal dispersion 0.25 nm/mm
- CCD detector (1 \( \times \) 3648 pixels, 8 \( \mu \)m pixel width)

Gaussian instrumental profile; FWHM = 5.3 pm
### Spectral profiles of Ne II 371.30826 nm line
(Ne purity 99.999)

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Lower level configuration, term, J</th>
<th>Upper level configuration, term, J</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ne II 371.30826</td>
<td>$2s^22p^4(3P)3s^2P^\frac{3}{2}$</td>
<td>$2s^22p^4(3P)3p^2D^\circ^\frac{5}{2}$</td>
</tr>
<tr>
<td>Ne I 520.38962</td>
<td>$2s^22p^5(2P^\circ_{3/2})3p^2[3/2]_2$</td>
<td>$2s^22p^5(2P^\circ_{3/2})5d^2[5/2]^\circ_3$</td>
</tr>
</tbody>
</table>

### Figures

- **Side-on**
  - Graph showing intensity vs. wavelength shift for Ne II 371.30826 nm line.

- **End-on**
  - Graph showing intensity vs. wavelength shift for Ne II 371.30826 nm line.
Theoretical model

System of stationary kinetic equations, describing the cathode fall region of discharge:

\[
\begin{align*}
\vec{v} \cdot \frac{\partial f_i}{\partial \vec{r}} + \frac{e \vec{E}}{m} \cdot \frac{\partial f_i}{\partial \vec{v}} &= I_i(\vec{r},\vec{v}) \\
\vec{v} \cdot \frac{\partial f_0}{\partial \vec{r}} + \frac{e \vec{E}}{m} \cdot \frac{\partial f_0}{\partial \vec{v}} &= I_0(\vec{r},\vec{v}) \\
\frac{\partial}{\partial \vec{r}} \cdot \vec{E} &= \frac{e}{\varepsilon_0}(f_i - f_e) \\
\end{align*}
\]

\[
\sigma_{e,Ne^+}(|\vec{v}_e - \vec{v}_{Ne}|,b)|\vec{v}_e - \vec{v}_{Ne}| f_e(z,\vec{v}_e) f_0(z,\vec{v}_{Ne}) = \frac{n_{Ne^+}}{e} f_e(z) \sigma^{(eff)}_{e,Ne^+}
\]

\[
f_0(\vec{r},\vec{v}) = n_0 (m_0/2\pi k_B T_0)^{3/2} \exp(-m_0 v^2/2k_B T_0)
\]

Model equations also solved iteratively starting from the NG boundary

Formation of Ne II 371.30826 nm line profiles:

- central part: ionization (and excitation) of Ne atoms by electron impact;
- wings: mostly by excitation of (fast) Ne ions in collisions with matrix atoms.

Ne$^+$ + Ne $\rightarrow$ Momentum Transfer

Ne$^+$ + Ne $\rightarrow$ (fast) Ne + (slow) Ne$^+$

Ne$^+$ + Ne $\rightarrow$ (Ne$^+$)$^*$ + Ne
(a) Cross sections of the collision processes of electrons, incorporated in the model, for the neon discharge. 1: electron elastic collisions [24,25], 2: electron impact ionization of neon ground state atoms [24], 3: electron impact ionization of neon metastable atoms [26], 4: electron impact ionization of sputtered copper atoms [29], 5: total electron impact excitation of neon ground state atoms [25], 6: total electron impact excitation of neon metastable atoms [26,27], 7: electron impact excitation of neon ground state atoms to the metastable levels [28].

(b) Cross sections of the collision processes of neon ions and fast atoms, incorporated in the model, for the neon discharge. Solid lines: neon ion collisions. 1: ion symmetric charge transfer [30], 2: ion elastic collisions [30], 3: ion impact ionization [31], 4: ion impact excitation to the metastable levels [32]. Dashed lines: neon fast atom collisions, 5: atom elastic collisions [33,34], 6: atom impact ionization [35], 7: atom impact excitation to the metastable levels [36].
Backscattering of Ne atoms from tungsten cathode

Ne atoms originate from incident Ne ions that are neutralized and subsequently backscattered from the tungsten cathode.

\[ dP(\theta) = \sin(\theta)\, d\theta \]

SRIM-2008, Ziegler J F, Ziegler M D and Biersack J P (www.SRIM.org)
Sputtering

Average sputtering yield $\approx 0.6$ for 500 eV Ne ions

SRIM-2008, Ziegler J F, Ziegler M D and Biersack J P (www.SRIM.org)
Experimental determination of the electric field distribution
(from shifts due to quadratic Stark effect of Ne I 520.39 nm line)

\[ I_{\text{Ne}}(\Delta \lambda; H, c, b) = A \Im(\Delta \lambda) + \Im \ast G(\Delta \lambda; H_{\text{Ne}}, c_{\text{Ne}}, w_{\text{Ne}}) + b_{\text{Ne}} \]

\[ G(\Delta \lambda; H_{\text{Ne}}, c_{\text{Ne}}, w_{\text{Ne}}) = H_{\text{Ne}} \exp \left[ -\left( \frac{2\sqrt{2} \ln 2}{w_{\text{Ne}}} \frac{\Delta \lambda - c_{\text{Ne}}}{w_{\text{Ne}}} \right)^2 \right] \]

\[ \Im = \frac{2}{w_{\text{inst}}} \sqrt{\frac{2}{\pi}} \exp \left[ -\left( \frac{2\sqrt{2} \ln 2}{w_{\text{inst}}} \frac{\Delta \lambda}{w_{\text{inst}}} \right)^2 \right] \]

\[ \Delta \lambda \approx -\lambda_0^2 CE^2 \]

\[ \lambda_0 = 520.389 \text{ nm}, \ C = -0.0238 \text{ cm/kV}^2 \]

Results:

Electric field strength, $E$, vs distance from cathode, $d$, determined with the aid of Ne I 520.38962 nm line. Discharge conditions: pressure $p = 6$ mbar, discharge voltage $V = 900$ V, discharge current $I = 10$ mA.
Results (1):

Intensity vs wavelength shift for the spectral profile of the Ne II 371.30826 nm line recorded side-on at the 0.125mm distance from the cathode. Discharge conditions: pressure $p = 6$mbar, discharge voltage $V = 900$V, discharge current $I = 10$mA.
Results (2):

Same as in previous graph, but for distances:
0.250mm, 0.375mm, 0.500mm, 0.625mm, 0.750mm, 0.850mm.
Best fit values of model parameters:

<table>
<thead>
<tr>
<th>Model parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode sheath thickness</td>
<td>$(1.2 \pm 0.1)$ mm</td>
</tr>
<tr>
<td>Temperature</td>
<td>$(570 \pm 50)$ K</td>
</tr>
<tr>
<td>Electron – Ne ionization cross-section</td>
<td>$(1.6 \pm 0.3) \times 10^{-20}$ m²</td>
</tr>
<tr>
<td>Ne⁺ number density at NG boundary</td>
<td>$(1.1 \pm 0.2) \times 10^{17}$ m⁻³</td>
</tr>
</tbody>
</table>

Predicted voltage = $(930 \pm 40)$ V vs experimental 900 V
Ion current at cathode = $(3.2 \pm 0.4)$ mA out of 10 mA

What next?

- Variation of discharge conditions
- Different cathode material
- Prediction of end-on profile
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Thank you for your attention