MODELING OF THE NET EMISSON COEFFICIENT IN HIGH INTENSITY DISCHARGE (HID) LAMPS

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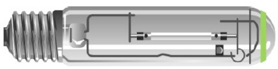
Net Emission Coefficients in HID Lamps



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Introduction

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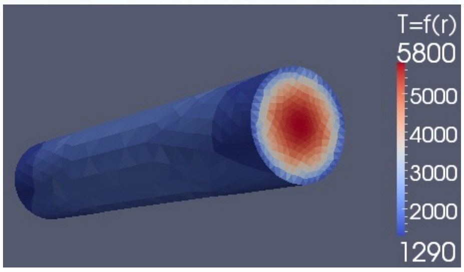

Problem Positioning

- **HID Lamps**
- **Cylindrical Symmetry**
- **Resolution Of Radiative Transfer Equation**
- **Assume LTE**
- **Atomic constants calculated by BORN**
- **Atomic constants calculated by Stromberg**

Objectives:

Evaluation:
- ➢Spectral Intensity
- ➢Spectral Flux
- ➢Photometric characteristics
- ➢Photometric curves.
- ➢Comparison BORN & Stromberg

Radiations of plasma discharge lamps come from different mechanisms that take place inside the lamp. The knowledge of atomic data responsible for these radiations is essential to describe the radiations that take place inside them. A ray tracing method based on the resolution of radiative transfer equation is adopted. The discharge is divided into small cells responsible for launching rays in all directions. The calculations consider that the discharge has a cylindrical symmetry and assume the plasma is at local thermodynamic equilibrium (LTE). Hence, the only knowledge of temperature profile and pressure is sufficient to calculate the plasma composition and to account the mechanisms of broadening of spectral lines in the treatment of radiative transfer. In this work, the atomic data is the only resource to calculate both coefficients. We will show the results for a pure mercury HID lamp. For each spectral line, the local absorption and emission coefficients are strongly dependent on the broadening constants. Calculations reported in the literature use different values for these constants, leading to marked differences in output of the models

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Importance of atomic constants

Atomic constants calculated by BORN

line (nm)	E_b (eV)	E_h (eV)	G_b	G_h	A_{ki} (10^8 s^{-1})	C_3 (10^{-15} m^3 s^{-1})	C_4 (10^{-22} m^4 s^{-1})	C_6 (10^{-42} m^6 s^{-1})
404.7	4.66	7.73	1	3	0.20	2.97	3	2.5
435.8	4.88	7.73	3	3	0.55	3.86	3	2.5
546.1	5.46	7.73	5	3	0.48	0	6	2
577.0	6.7	8.85	3	5	0.23	6.24	0.046	2.76

Atomic constants calculated by STROMBERG

line (nm)	E_b (eV)	E_h (eV)	g_b	g_h	A_{ki} (10^8 s^{-1})	C_n (10^{-36} m4)	C_S (10^{-33} m4)	C_{QS} (10^{-62} m7)
404.7	4.66	7.73	1	3	0.17	1	0	1
435.8	4.88	7.73	3	3	0.37	1.3	0	1.3
546.1	5.46	7.73	5	3	0.52	0.6	0	0.3
577.0	6.7	8.85	3	5	0.58	19	17	4

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Plasma at local thermodynamic equilibrium L.T.E

- **Temperature profile**

$$T(r) = T_c - (T_c - T_p)\left(\frac{r}{R}\right)^{\beta}$$

Number of atoms at « j » level by unit volume (Boltmann law)

$$n_j = g_j \frac{N_T}{U(T)} \exp\left(-\frac{E_j}{kT}\right)$$

Number of electrons , n_e, or ions, n_i ($n_e = n_i$) by unit volume (Saha's law)

$$n_e^2 = 2N_T \frac{U_{ion}(T)}{U_{atome}(T)} \frac{(2\pi m_e kT)^{3/2}}{h^3} \exp\left(-\frac{E_i}{kT}\right)$$

- **Pressure P**

Total number of atoms by unit volume

$$N_T = \frac{P}{kT}$$

Partition function

$$U(T) = \sum_j g_j \exp\left(-\frac{E_j}{kT}\right)$$

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Doppler & Stark Broadening

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- Doppler broadening (negligible)
- Pressure broadening
  - ✓ **Neutral broadening**

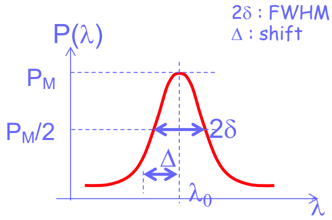
$$\Delta_n = 0.36\delta_n \qquad \delta_n = C_n N_T$$

$$C_n = \frac{\lambda_0^2}{4\pi c} 8.08 C_6^{2/5} v_n^{3/5} \qquad v_n = 4\sqrt{\frac{k_b T}{\pi M}}$$

  - ✓ **Stark broadening by electron and ions,**

$$\Delta_S = 0.86\delta_S \qquad \delta_S = C_S n_e$$

$$C_S = \frac{\lambda_0^2}{4\pi c} 11.37 C_4^{2/3} v_e^{1/3} \qquad v_e = \sqrt{\frac{8k_b T}{\pi m_e}}$$



$$\int P(\lambda)d\lambda = 1$$

$P(\lambda)$: normalized line profile

- Spectral line profile = convolution of different profiles

$$\delta = \delta_n + \delta_S \qquad \Delta = \delta_S + \delta_n$$

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Local Emission and Mesh

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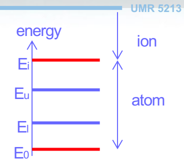
Local emission and absorption coefficients:

For a spectral line :Upper level E_u → Lower level E_l $\quad \frac{hc}{\lambda_0} = E_u - E_l$

$$\varepsilon_\lambda(\lambda) = \frac{hc}{4\pi\lambda_o} n_u A_{ul} P(\lambda)$$

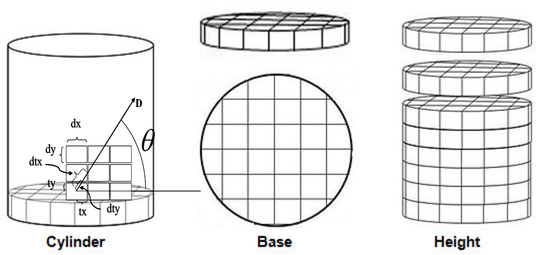


Schematic atomic structure

Source Function : $S_\lambda(\lambda) = \varepsilon_\lambda(\lambda)/k(\lambda)$

At E.T.L: $S = \frac{2hc^2}{\lambda_o^5}\exp(-\frac{hc}{\lambda_o KT})$

Mesh



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Radiation Transfer Equation

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Integral Form of radiation transport equation

$$I_\lambda(x) = I_\lambda(x_0)\exp\left(-\int_{x_0}^{x}\kappa(\lambda,x')dx'\right) + \int_{x_0}^{x}\varepsilon_\lambda(\lambda,x')\exp\left(-\int_{x'}^{x}\kappa(\lambda,x'')dx''\right)dx'$$

Discretized form:

$$I_\lambda(x_{i+1}) = I_\lambda(x_i)\exp\left(-\kappa(\lambda,i)\Delta x_i\right) + \frac{\varepsilon_\lambda(\lambda,i)}{\kappa(\lambda,i)}\left(1-\exp\left(-\kappa(\lambda,i)\Delta x_i\right)\right)$$

Homogeneous Medium :

$$I_\lambda(x) = I_\lambda(x_0)\exp\left(-\kappa(\lambda)(x-x_0)\right) + \frac{\varepsilon_\lambda(\lambda)}{\kappa(\lambda)}\left(1-\exp\left(-\kappa(\lambda)(x-x_0)\right)\right)$$

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Influence of atomic constants on output flux

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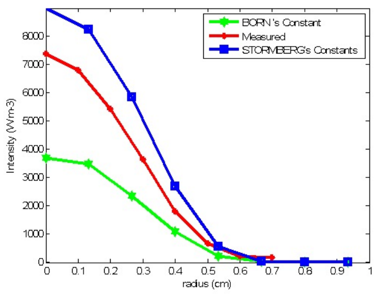
Model output:

line (nm)	404.7	435.8	546.1	577.0
Flux (W) calculated by Born's Constants	45.5	70.37	59.6	31
Flux (W) calculated by Stromberg's Constants	27.49	49.3	41.6	70.8



Influence of atomic constants on total intensity for the line 577 nm

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More Results

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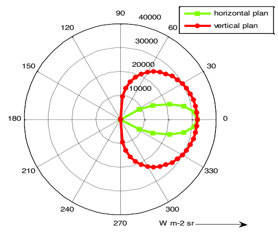
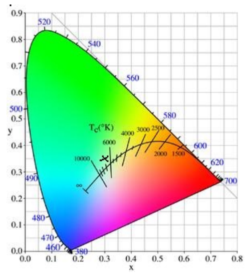
Photometric curves

Color temperature





The photometric curves are calculated from the side-on Intensity for different directions in the horizental and vertical plan.

For this discharge, we find 86 lm/W as luminous efficacy. In addition, the proximal color temperature is about 6630K

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Thank you

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