The Role of Molecules in Low Temperature Plasmas for Lighting

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Presentation Outline

- Brief introduction to HID lamps
- Why molecules are needed
- Dynamics inside the plasma
- Molecular species in steady state
- Molecular species in transient phases
- Summary & Conclusions

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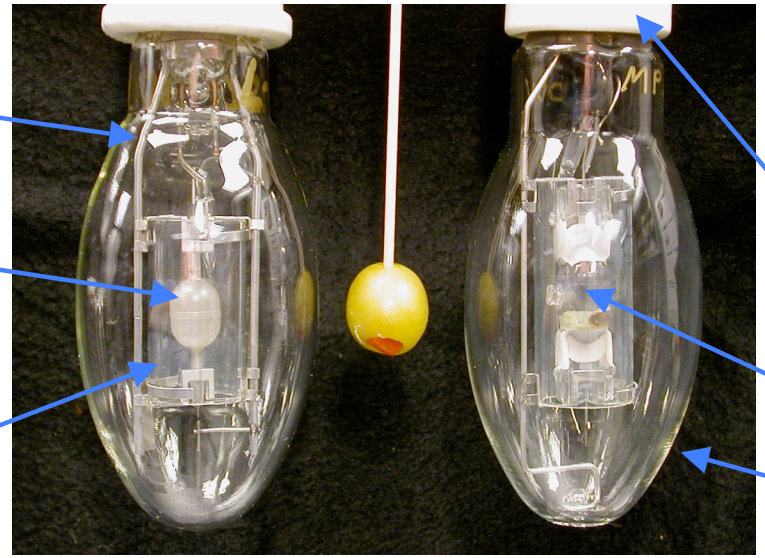
Introduction to High Intensity Discharge (HID) Lamps

- What is an HID lamp?
  - Sustained electrical discharge through a mixture of metal and metal salt vapors to produce visible light with good color properties.
- Some characteristics
  - Compact
  - Operates at elevated temperatures (>800C)
  - Refractory materials (Nb, Mo, W, vitreous silica, poly-crystalline alumina-PCA)
  - Sequestered in inert atmosphere
  - Negative V-I characteristic (arc lamps)



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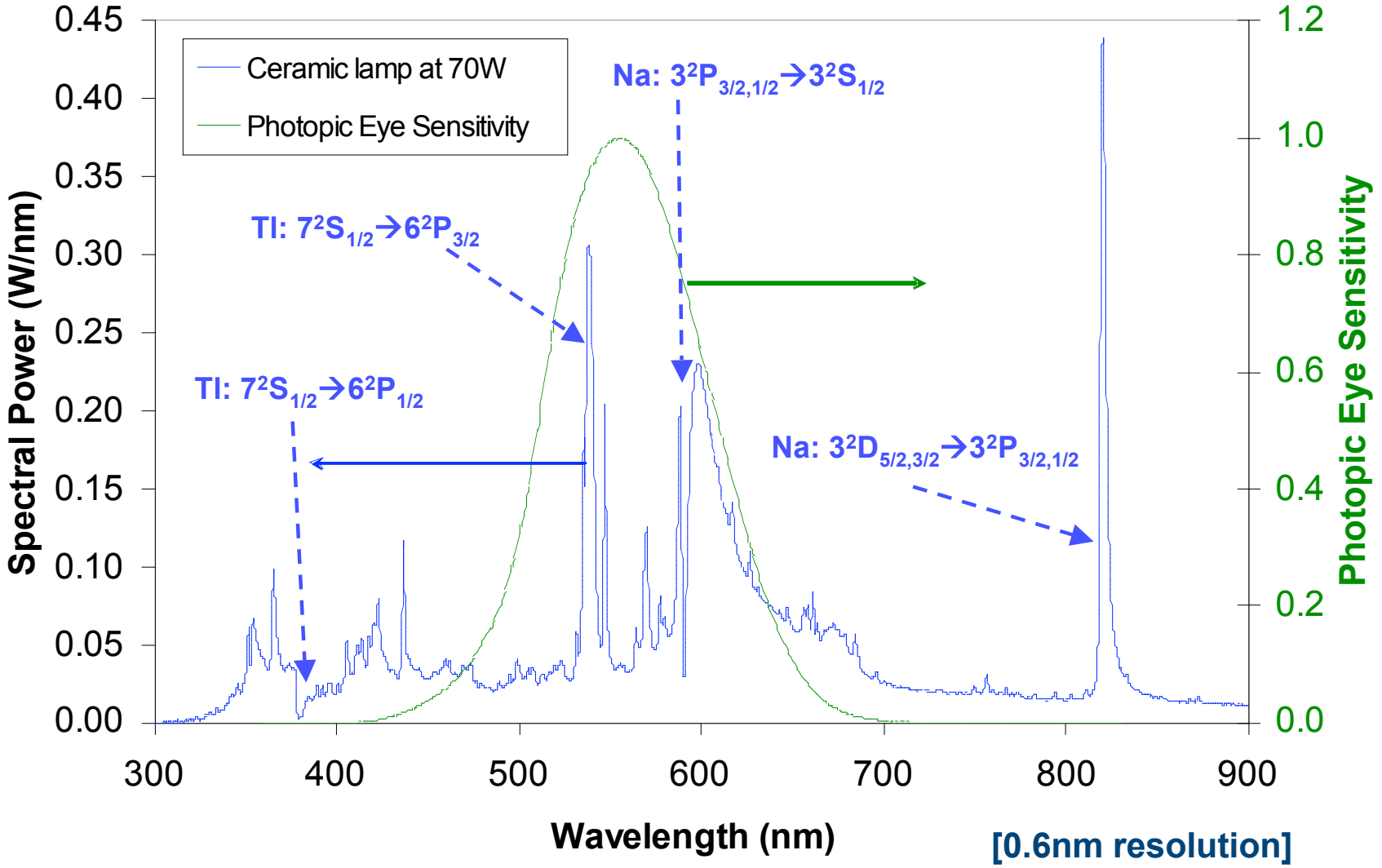
Introduction to High Intensity Discharge (HID) Lamps: Typical light output



[0.6nm resolution]

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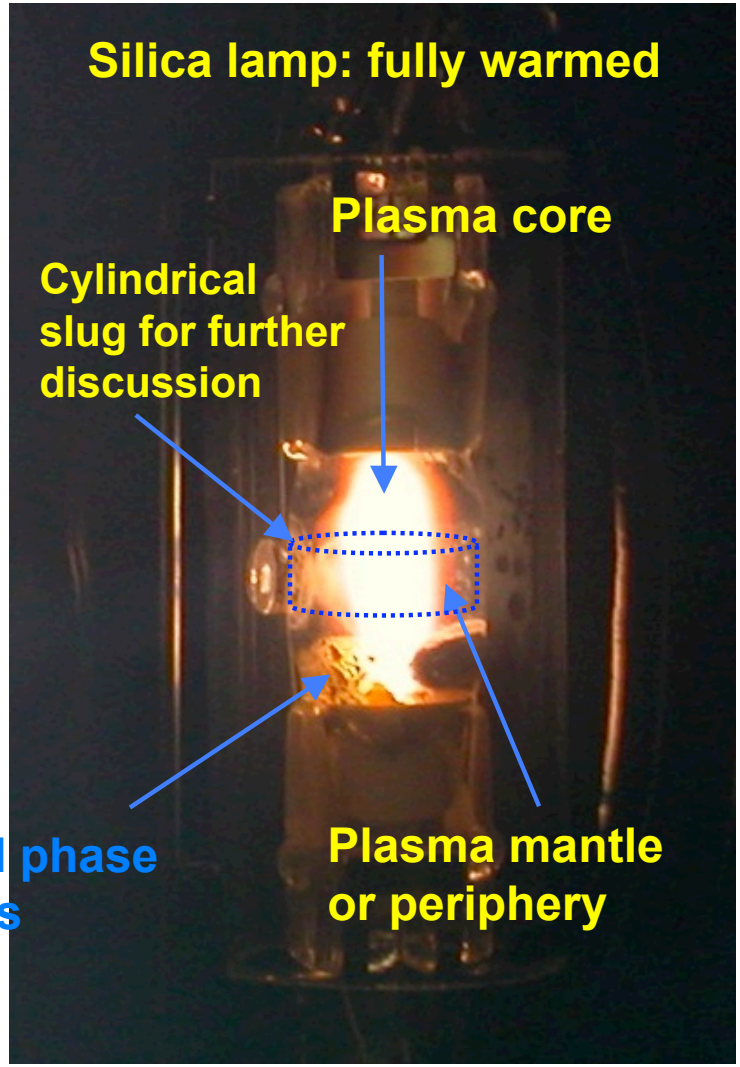
Introduction to High Intensity Discharge (HID) Lamps



Assumption of LTE:
(local thermodynamic equilibrium)

$$T_e \cong T_i \cong T_g$$

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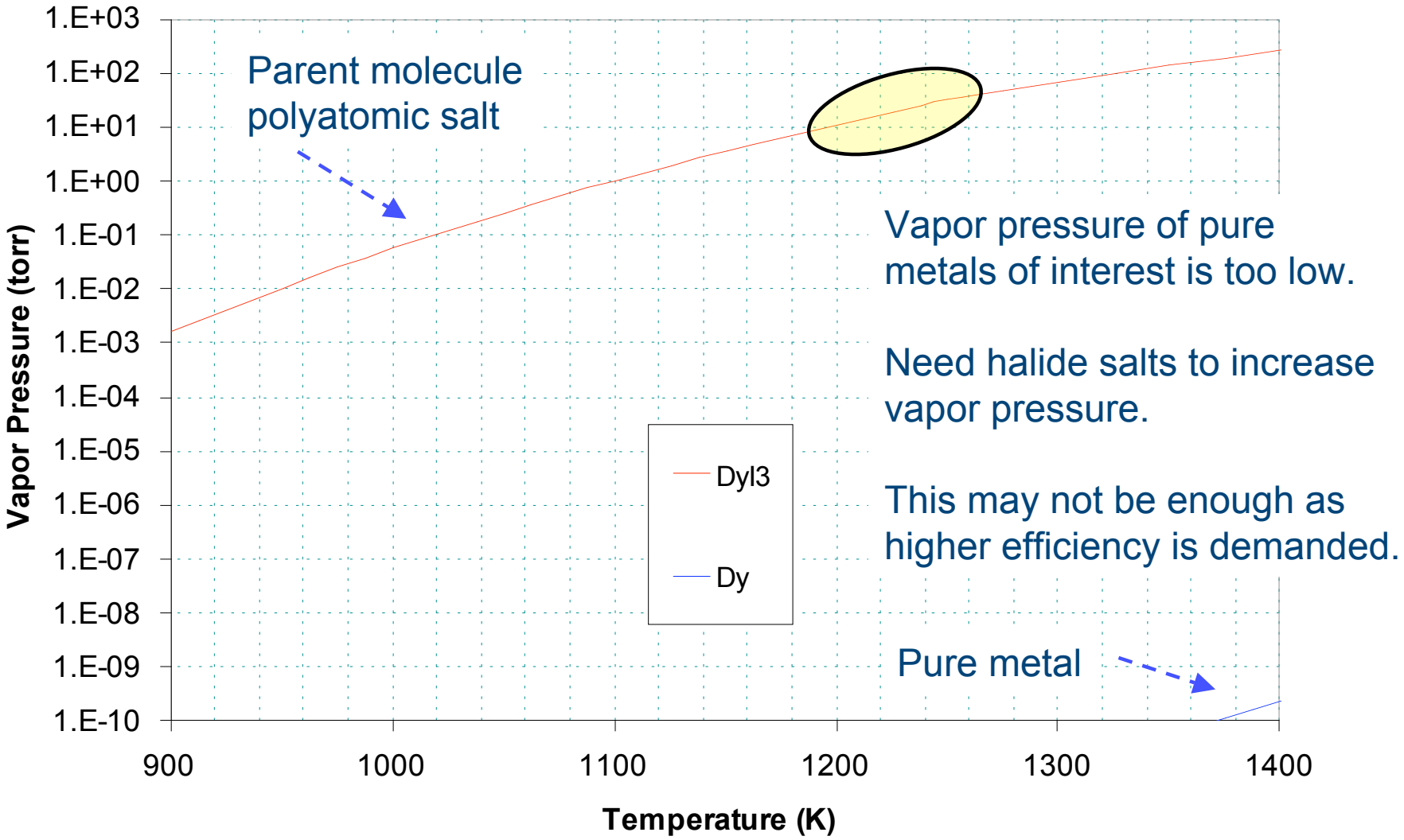
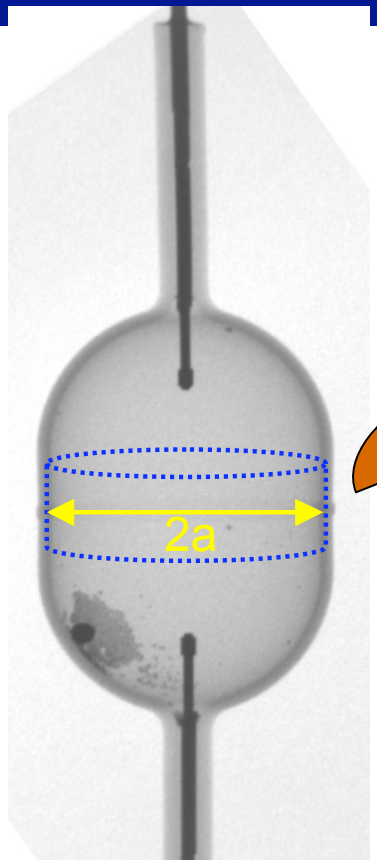
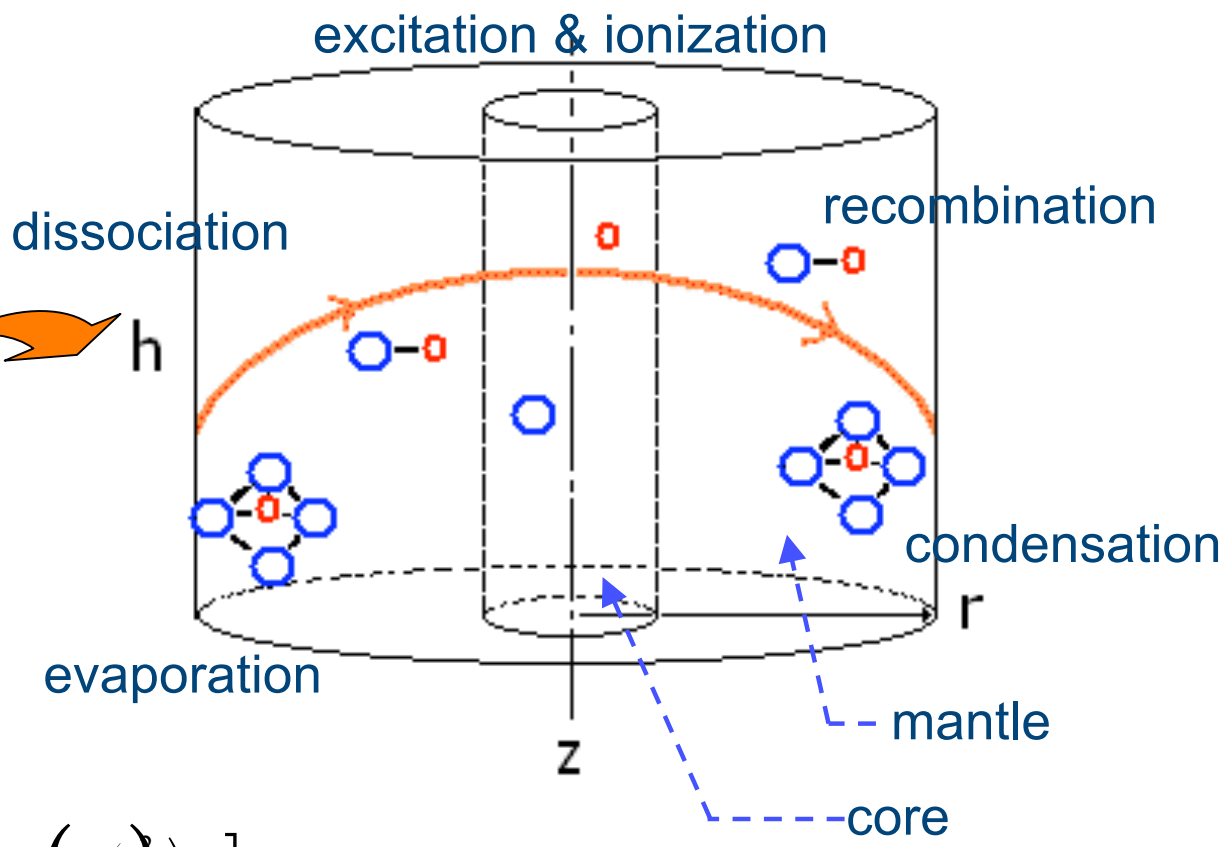
Why Molecules Are Needed



Dynamics Inside the Plasma

Processes within the cylindrical slug during steady state





$$T_g(r) \cong T_a + (T_o - T_a) \cdot \left[\frac{\left(1 - \left(r/a\right)^2\right)}{\left(1 + b \cdot \left(r/a\right)^2\right)} \right]$$

Metal atom

Iodine atom

Molecular Species in Steady State

Equilibrium calculation of effect of complexing agents

Input Species (moles)

DyI3	1	DyI3	1
InI	1	**CaI2**	1
Xe	0.1	Xe	0.1

Output Species at 950C (1223K)

InI	**4.82E-01**	CaI2	7.68E-06
In2I2	2.35E-03	CaI	1.55E-10
DyI3	6.83E-02	DyI3	9.76E-04
Dy2I6	2.06E-02	Dy2I6	4.93E-05
InDyI4	**5.13E-01**	CaDyI5	2.33E-05
Total In	1.00E+00	Total Ca	3.10E-05
Total Dy	**6.22E-01**	Total Dy	**1.10E-03**
In/Dy	1.61E+00	Ca/Dy	2.82E-02

Complexing agent
= high vapor pressure material which draws lower vapor pressure material into the arc.

Objective is to increase the concentration of the rare-earth atoms in the discharge.

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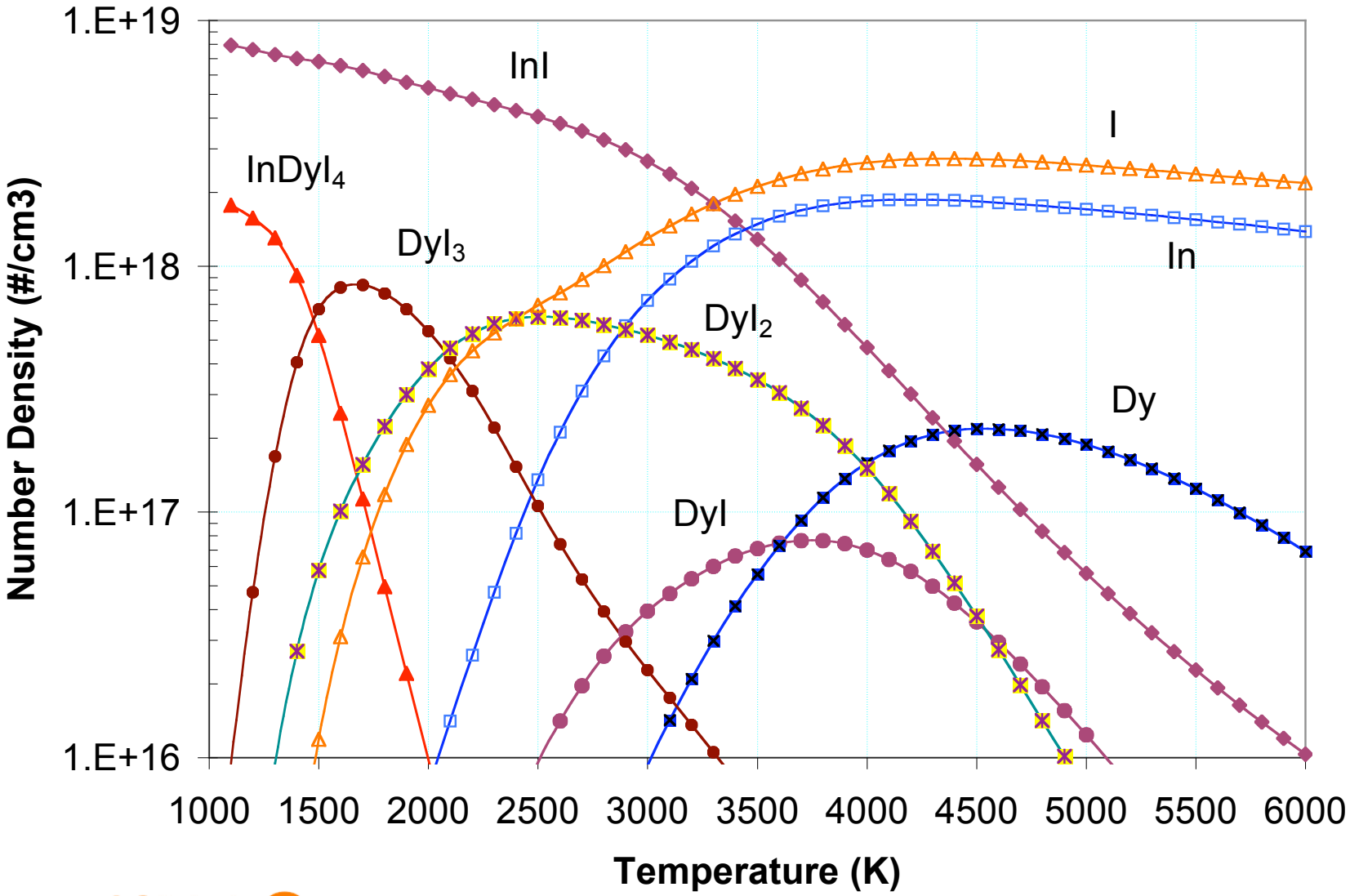
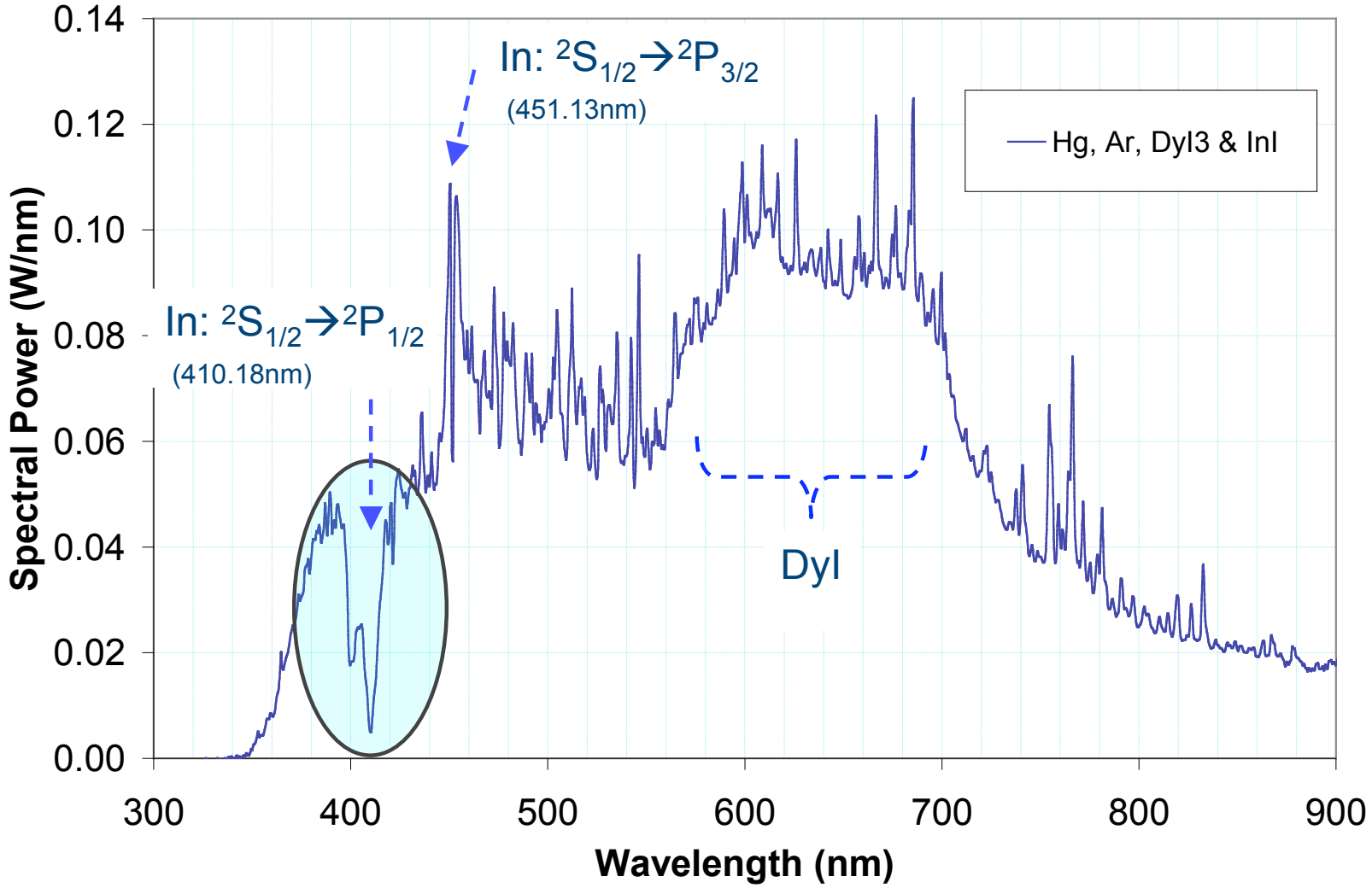
Molecular Species in Steady State

Equilibrium calculation of metal/salt concentrations [Factsage]



Molecular Species in Steady State

Effect of complexing agents on spectral output



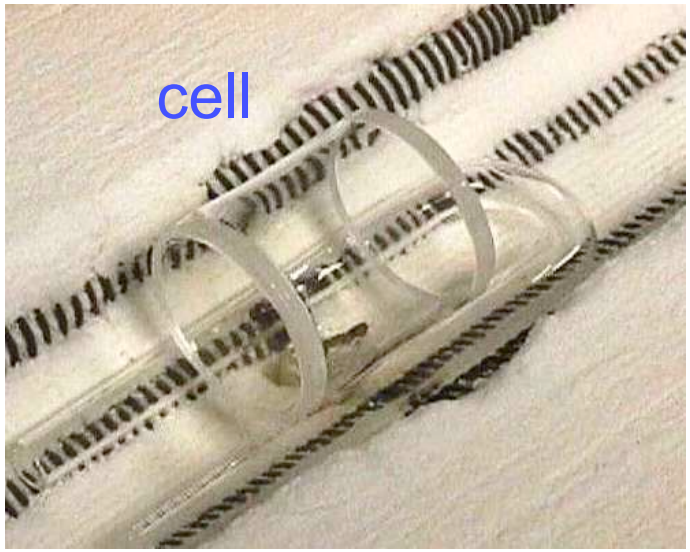
Molecular Species in Steady State

Absorption of Indium Monoiodide: Cell verification

oven

Light source

detector



Identify absorption features in the lamp without broadening of the lines.

Suprasil cells: InI, 5 torr Ar

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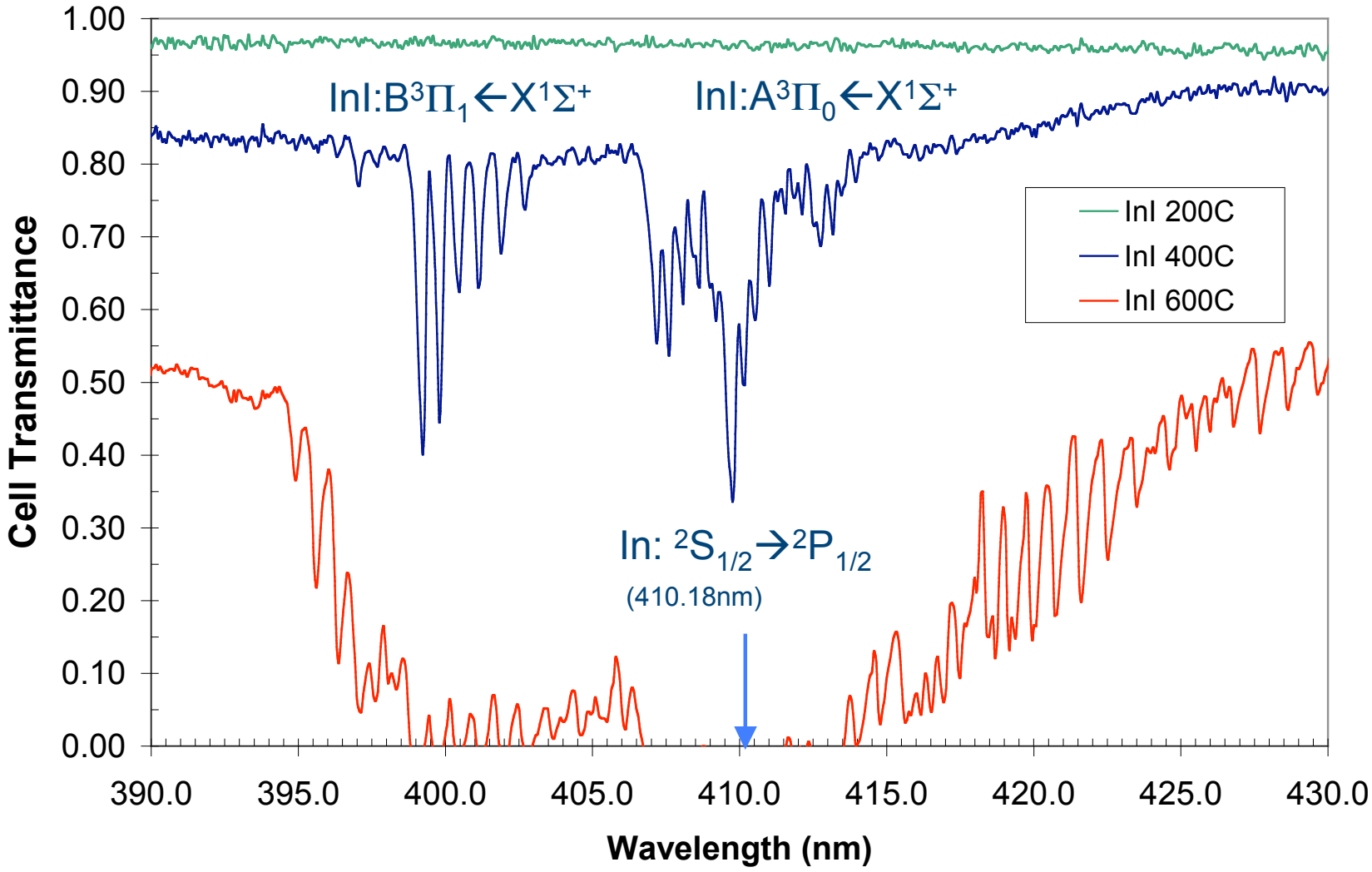
Molecular Species in Steady State

Absorption of Indium Monoiodide: Bound-bound absorption



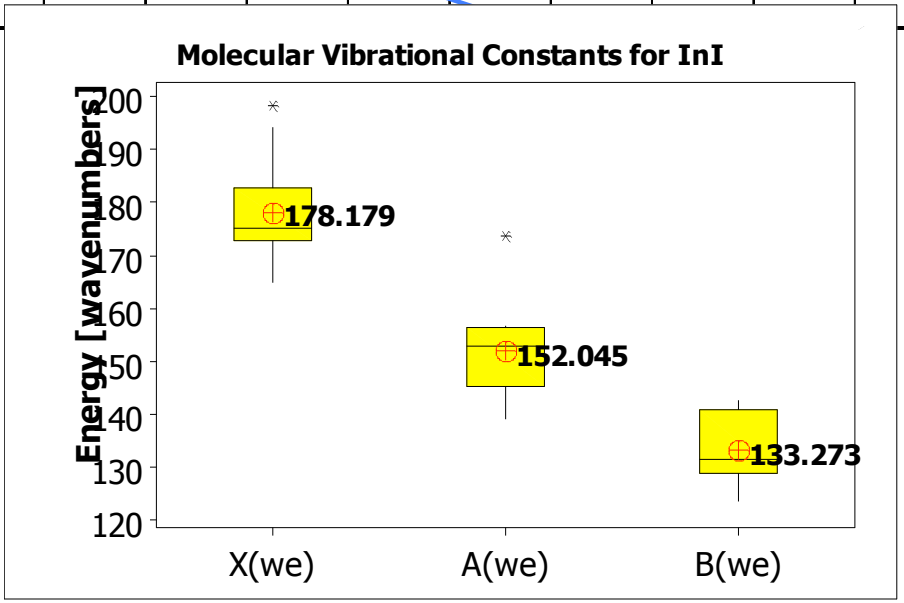
Molecular Species in Steady State

Absorption of Indium Monoiodide: Deslandres analysis

	A<-X																
v"	0		1		2		3		4		5		6		7		8
v'																	
0	24404.41	177.26	24227.15			171.48	23884.19										
	154.63		152.39				150.97										
1	24559.04	179.50	24379.54	177.01	24202.53			179.01	23844.50								
			154.26		156.29				156.50								
2			24533.80	174.98	24358.82	172.68	24186.14			186.66	23812.81						
					145.64		143.76				150.46						
3					24504.46	174.56	24329.89	172.39	24157.51			194.05	23769.40				
							141.16		139.11				156.70				
4							24471.06	174.45	24296.61					192.78	23718.26		
									153.26								
5									24449.88	185.69	24264.19					198.93	23667.41
											173.50						
6											24437.69	198.20	24239.49				
7																	

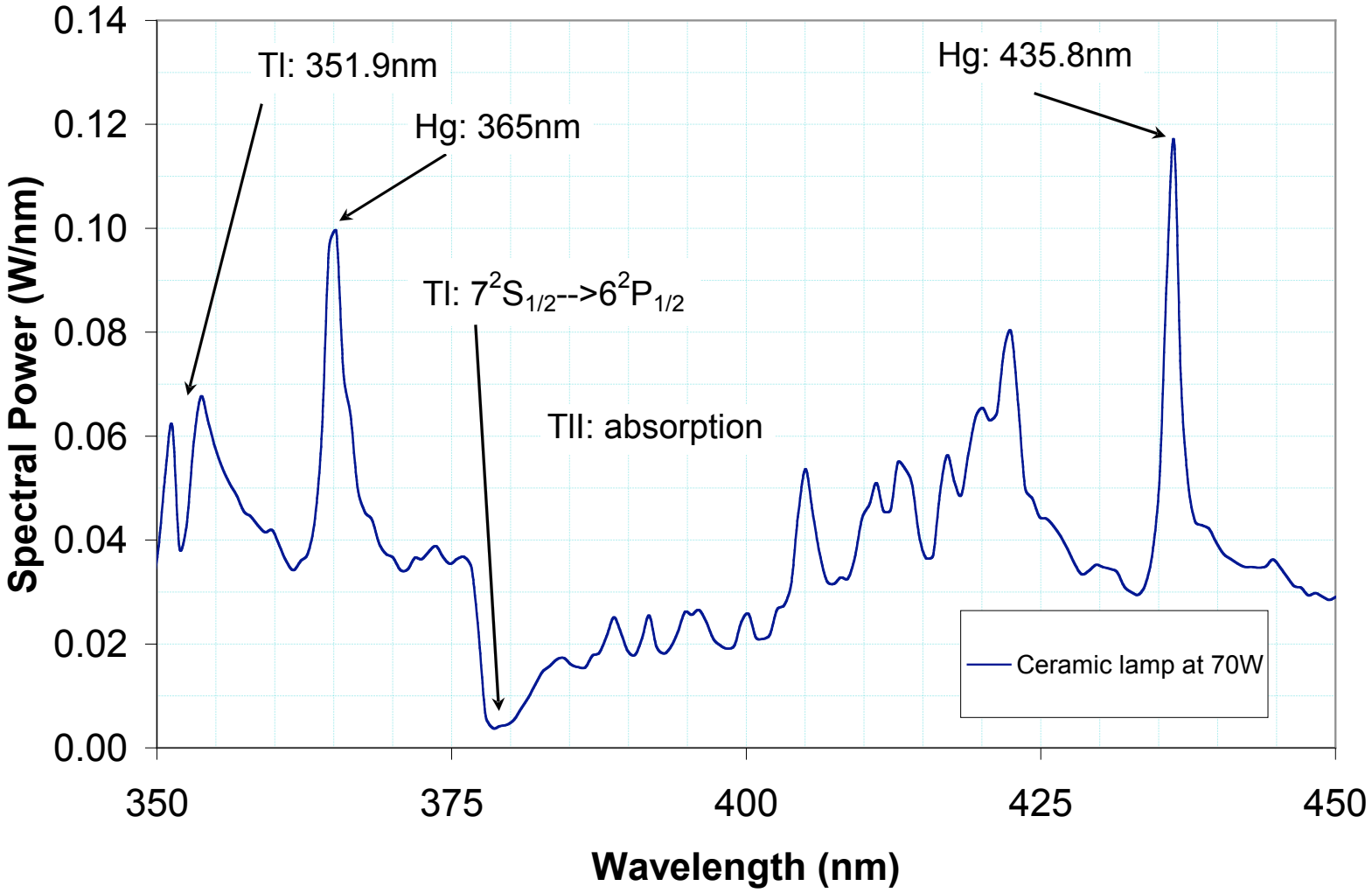
$$E(v,J) \cong T + G(v) + B(J)$$

$$\Delta E \cong \left(T^{A} - T^{X}\right) + \omega_e^{A}\left(v' + \tfrac{1}{2}\right) - \omega_e^{X}\left(v'' + \tfrac{1}{2}\right) + \square$$



Molecular Species in Steady State

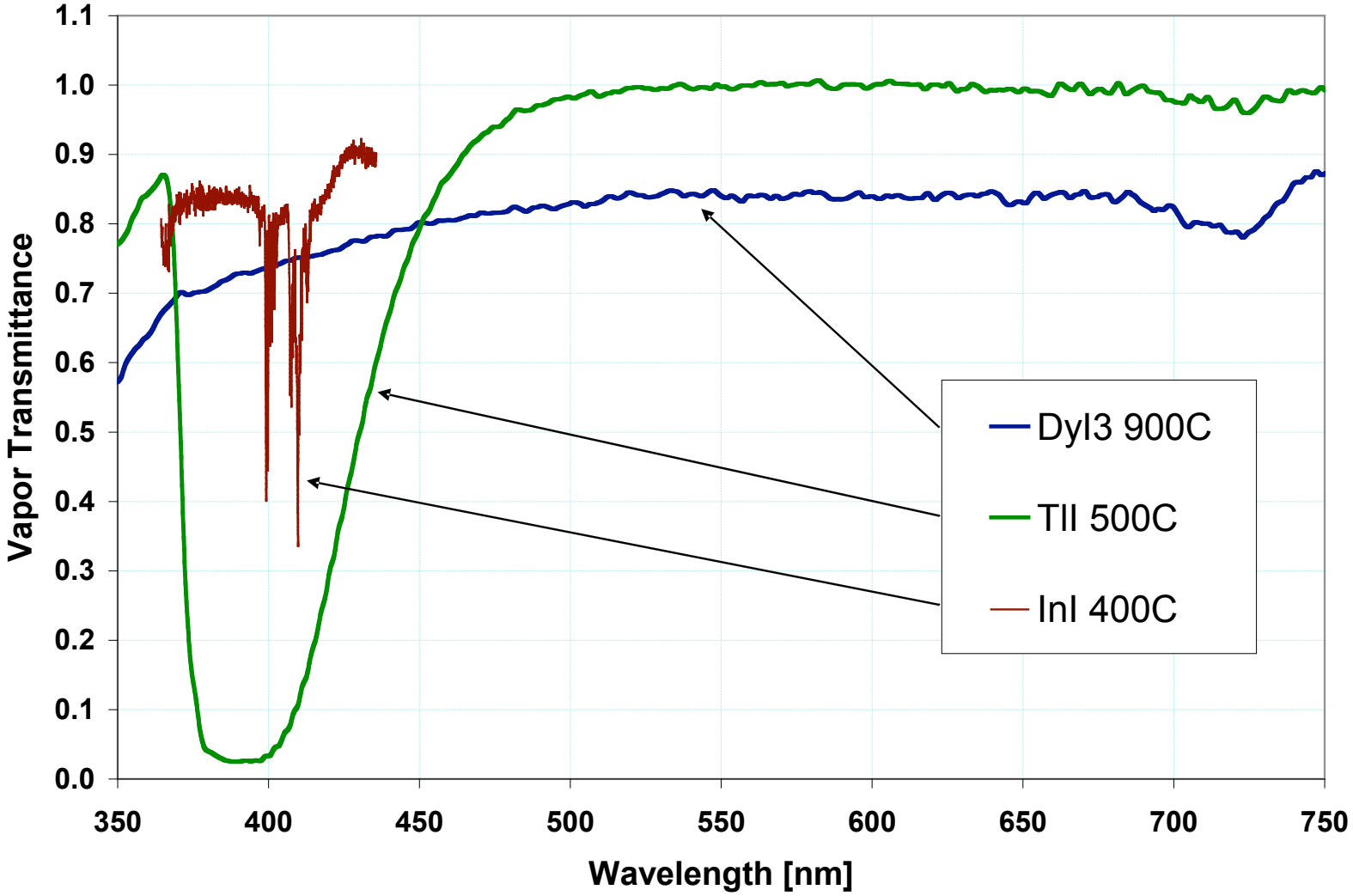
Absorption of Thallium Monoiodide: Bound-free absorption



$$TlI : X^1\Sigma^+(v'') + h\nu \rightarrow Tl + I^* + KE$$

Molecular Species in Steady State

Absorption of polyatomic species in the mantle



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Molecular Species in Transient Phases

Plasma composition changes over time

- Loss of complexing agents over time
  - Reactions with contaminants

$$2MI_3(g) + 3H_2O(g) \rightarrow M_2O_3(g) \downarrow + 6HI(g)$$

  - Reaction with liberated iodine
    - Mercury containing discharge

$$Hg(g) + 2I(g) \rightarrow HgI_2(g)$$

    - Mercury-free discharge

$$InI(g) + 2I(g) \rightarrow InI_3(g)$$

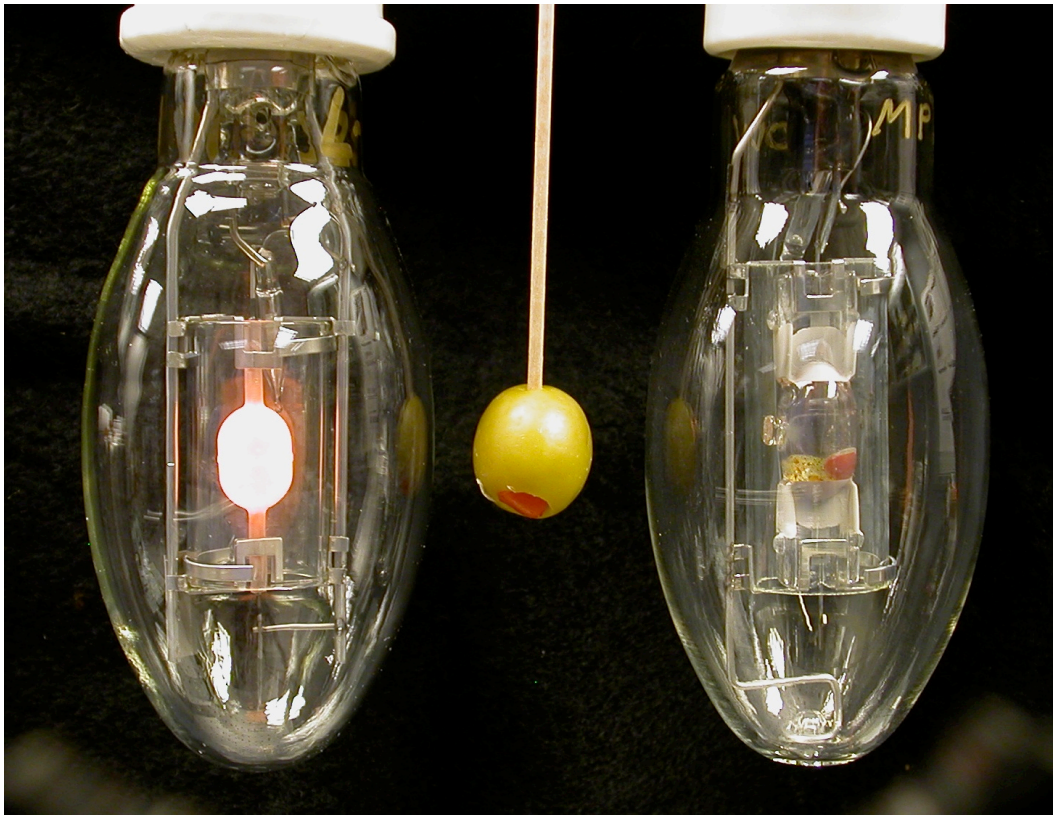
  - High volatility species affect ignition

Molecular Species in Transient Phase

Effect on Lamp Re-ignition

Voltage needed to re-ignite the lamp is higher (>15kV).

Must break down 6-8bar of gas with electron attaching additives versus 150mbar Ar when cold (<4kV).



Approximately 5 seconds after turn-off
Salts are still molten (not fully condensed)
Pressure inside burner is 6-8 atmospheres (mostly Hg)

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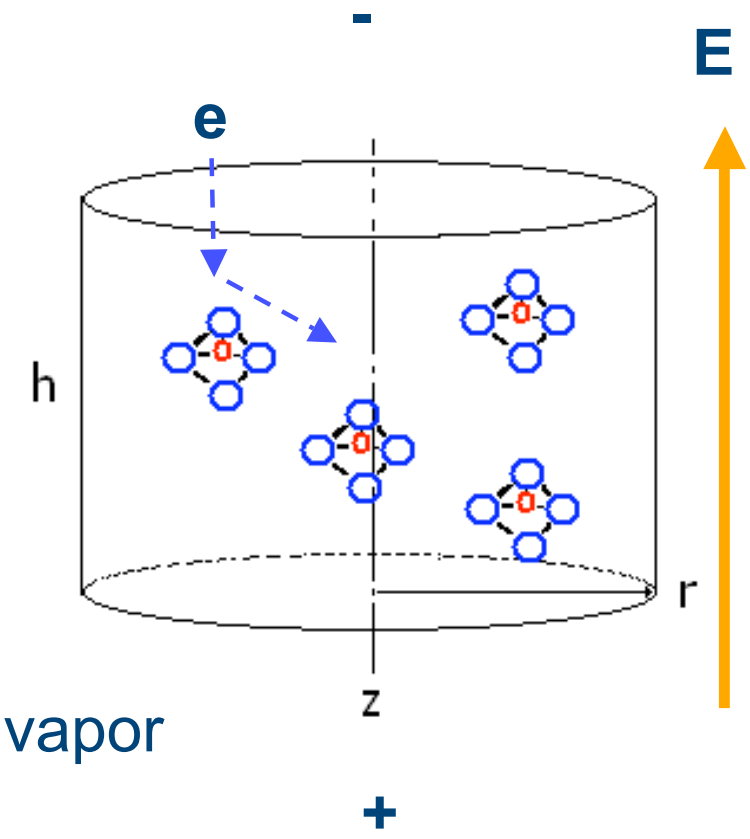
Molecular Species in Transient Phases

Effect on Lamp Ignition & Re-ignition

Electrons are driven through and scatter from a high density gas filled with large molecular species.

Unknowns:

- molecular structures
- excitation/ionization cross sections
- electron attachment
- heavy ion mobility in dense Hg vapor



Motivation: lower re-ignition voltage

Molecular Species in Steady State
Summary & Conclusions

- Role of molecules includes
  - Transport of parent species
  - Enhancement of concentrations
  - Absorption of light from the discharge core
  - Significant contributors to radiative output
  - Potential for raising ignition voltage during hot re-light
- More data are needed to fully understand these effects on lighting related plasmas.
  - Improved potential energy surfaces
  - Electron impact data – scattering cross sections
  - Ionization potentials
  - Electron attachment data
  - Mobility of large ions in mercury / rare gases

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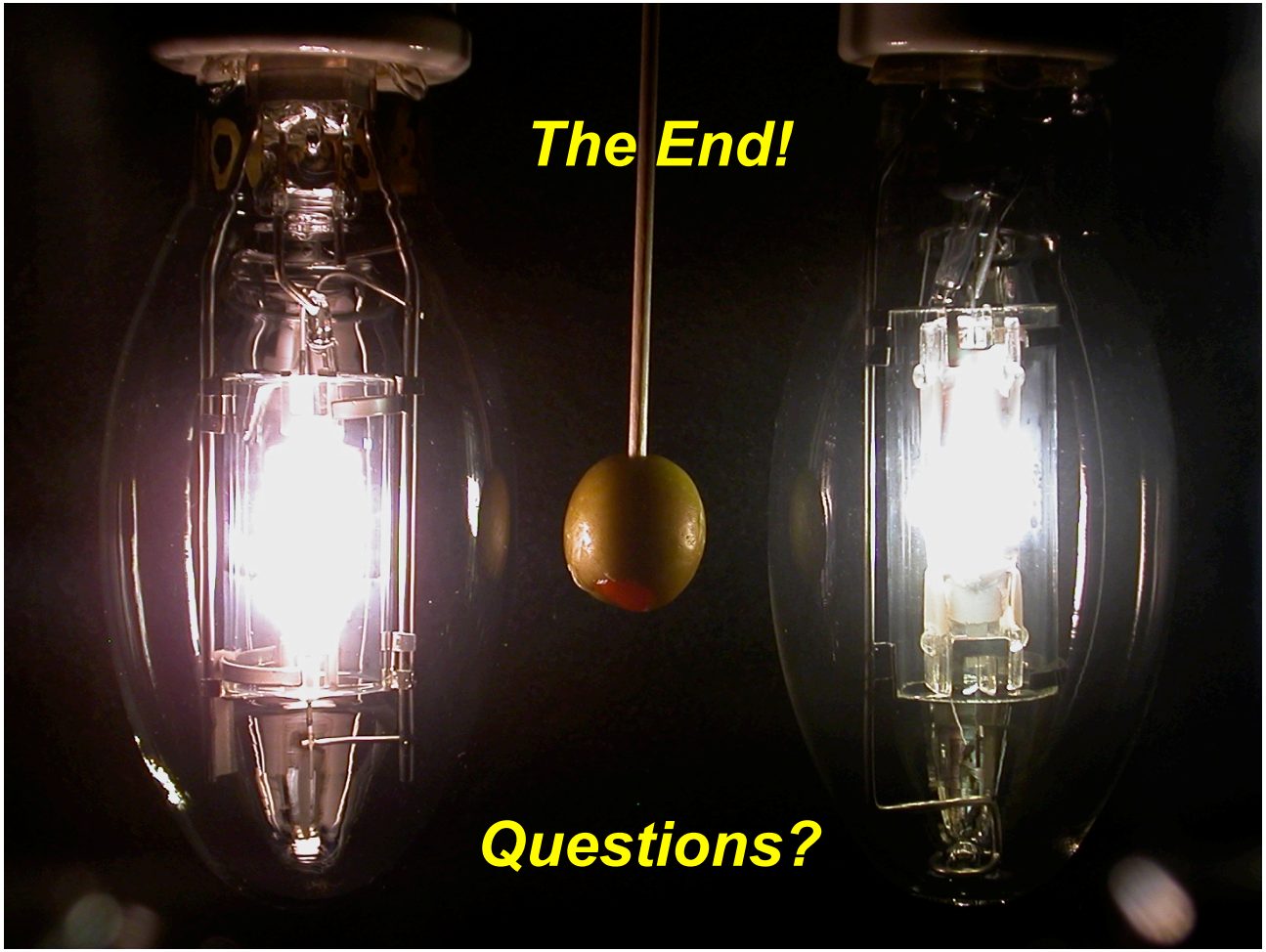

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