Modeling the Resupply, Diffusion and Evaporation of Cesium Based CPD Photocathodes

Zhigang Pan

P3 Photocathode Workshop 2012

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Advisor: Dr. Patrick G. O'Shea (UMD)

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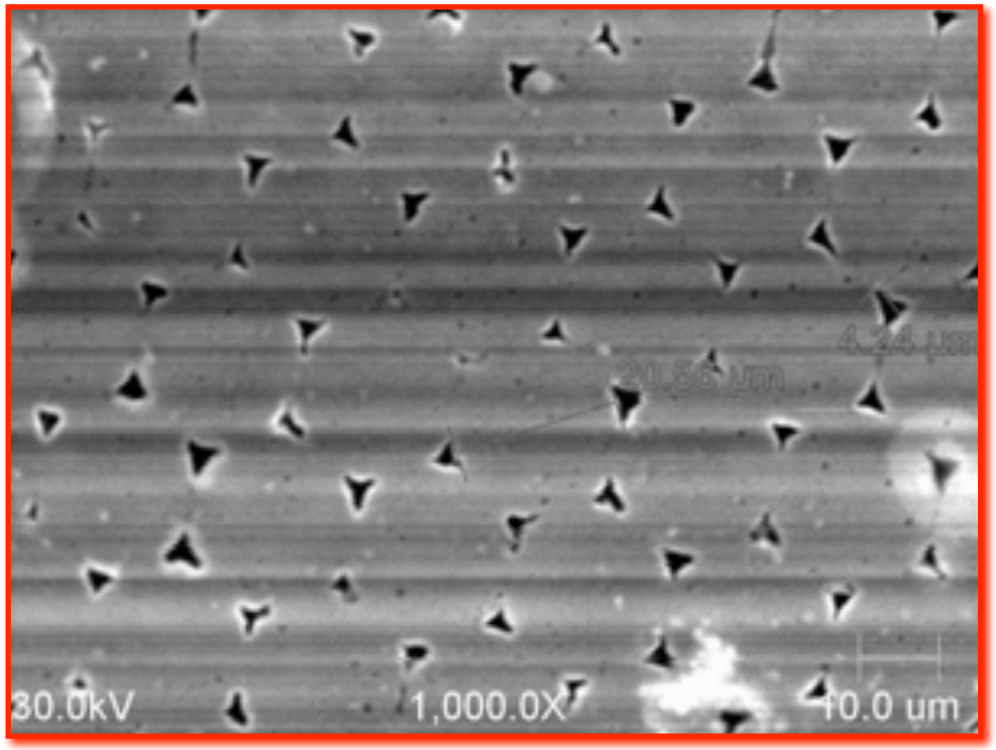
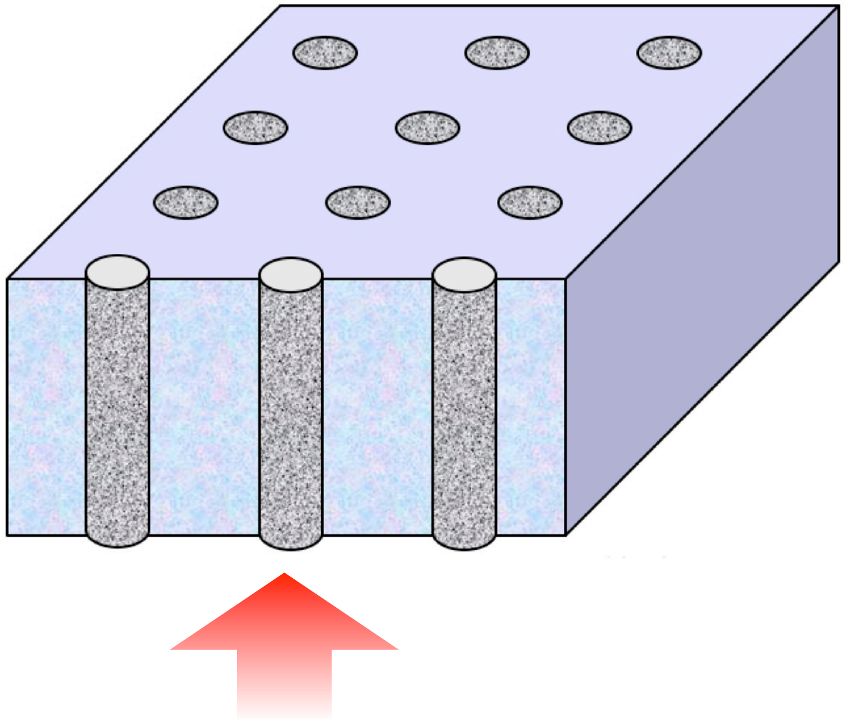
- Joint Technology Office, Office of Naval Research

Controlled Porosity Dispenser(CPD) Photocathodes

CPD prototype





Cs Cesium Reservoir

Controlled Porosity Dispenser(CPD) Photocathodes

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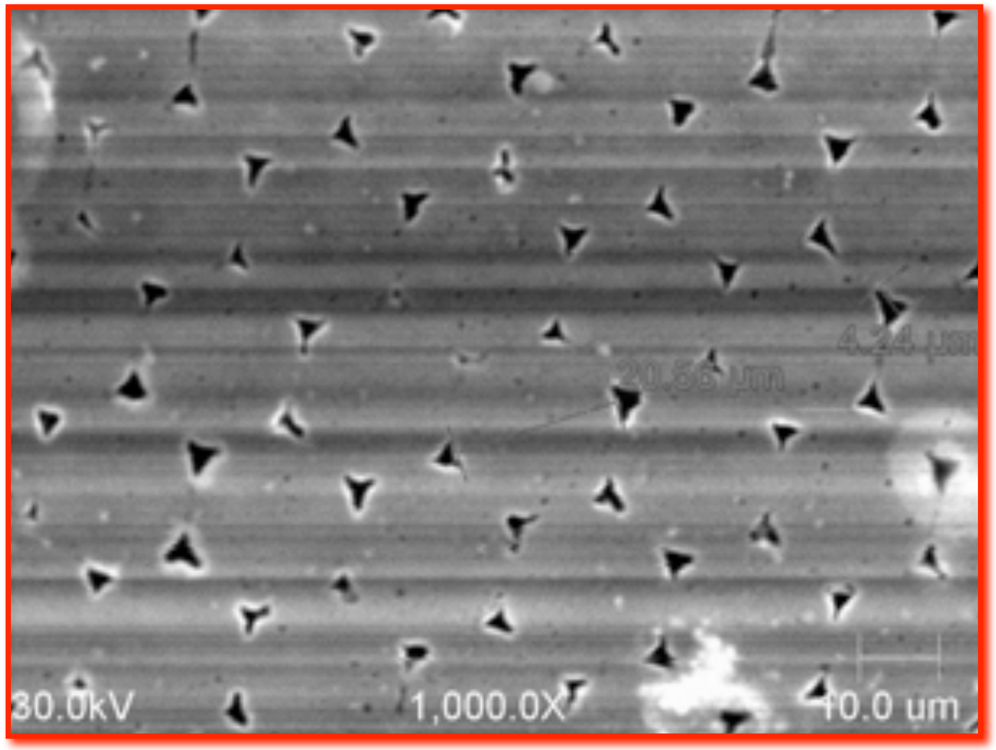
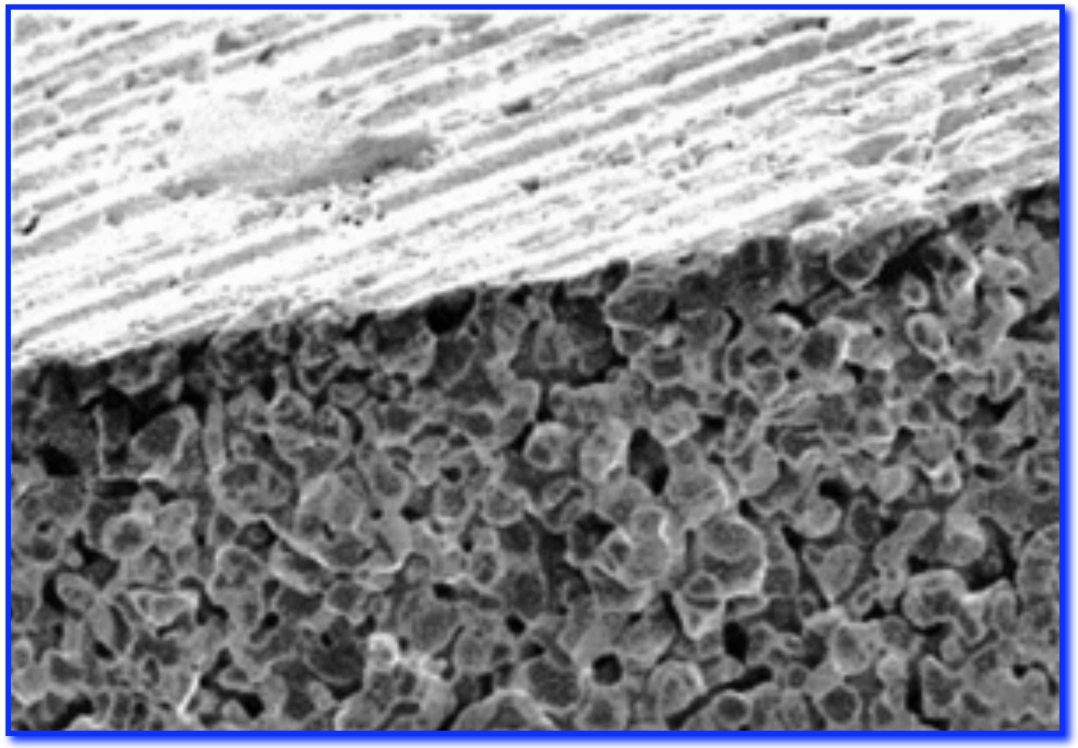
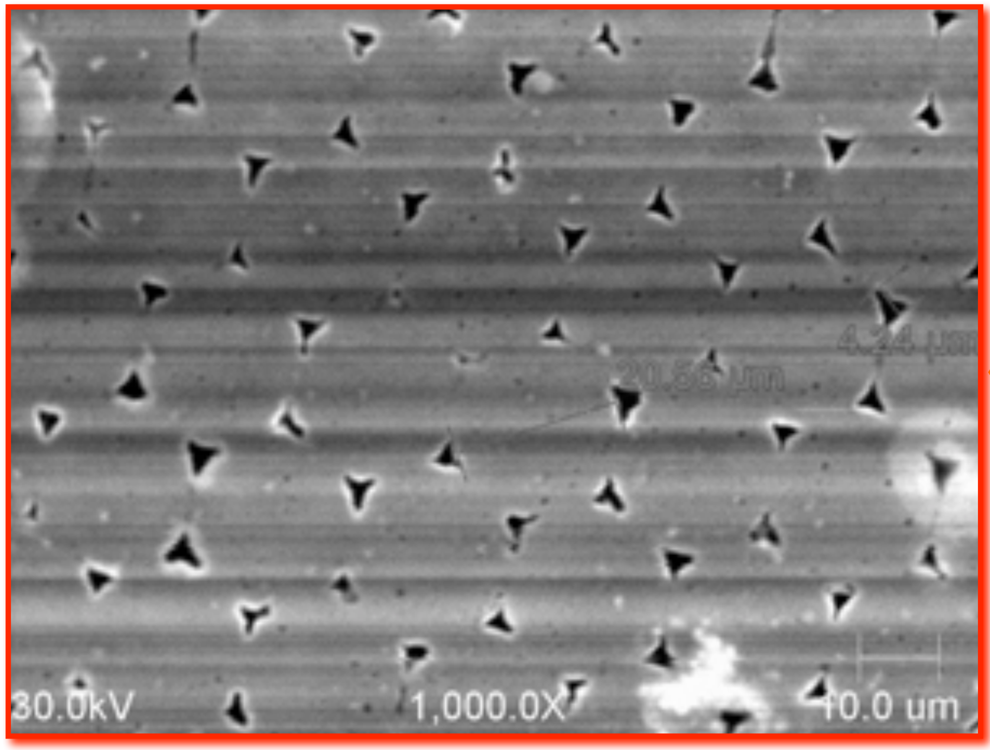


Sintered Tungsten



Scope of this Presentation

CPD Design and Optimization



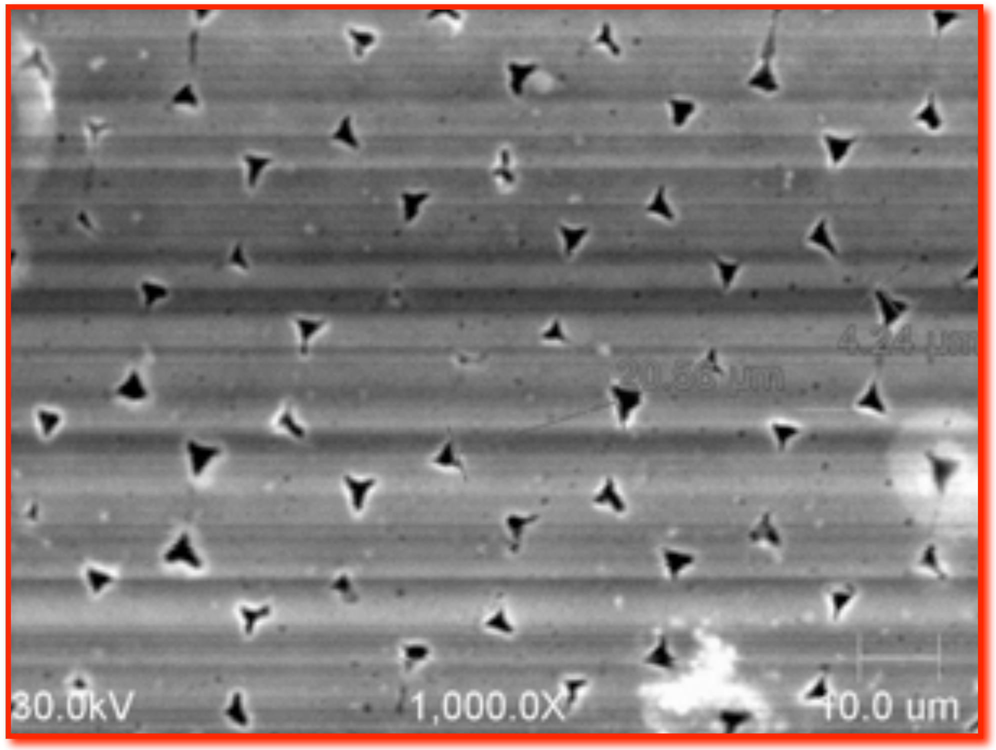
Cesium resupply

Cesium diffusion across surface

Cesium evaporation and loss

Roadmap to Modeling CPDs

CPD Design and Optimization



Equation to Model Cesium across the Surface:

$$\frac{\partial \Theta}{\partial t} = \boxed{D(T)\nabla^2\Theta} - \boxed{F_{evap}}$$

$$\Theta(\Omega) = \boxed{\Theta_{surf}}, \ \Omega \in \text{pore edges}$$

Modeling Θ_{surf}

$$\frac{\partial \Theta}{\partial t} = D(T)\nabla^2\Theta - F_{evap}$$

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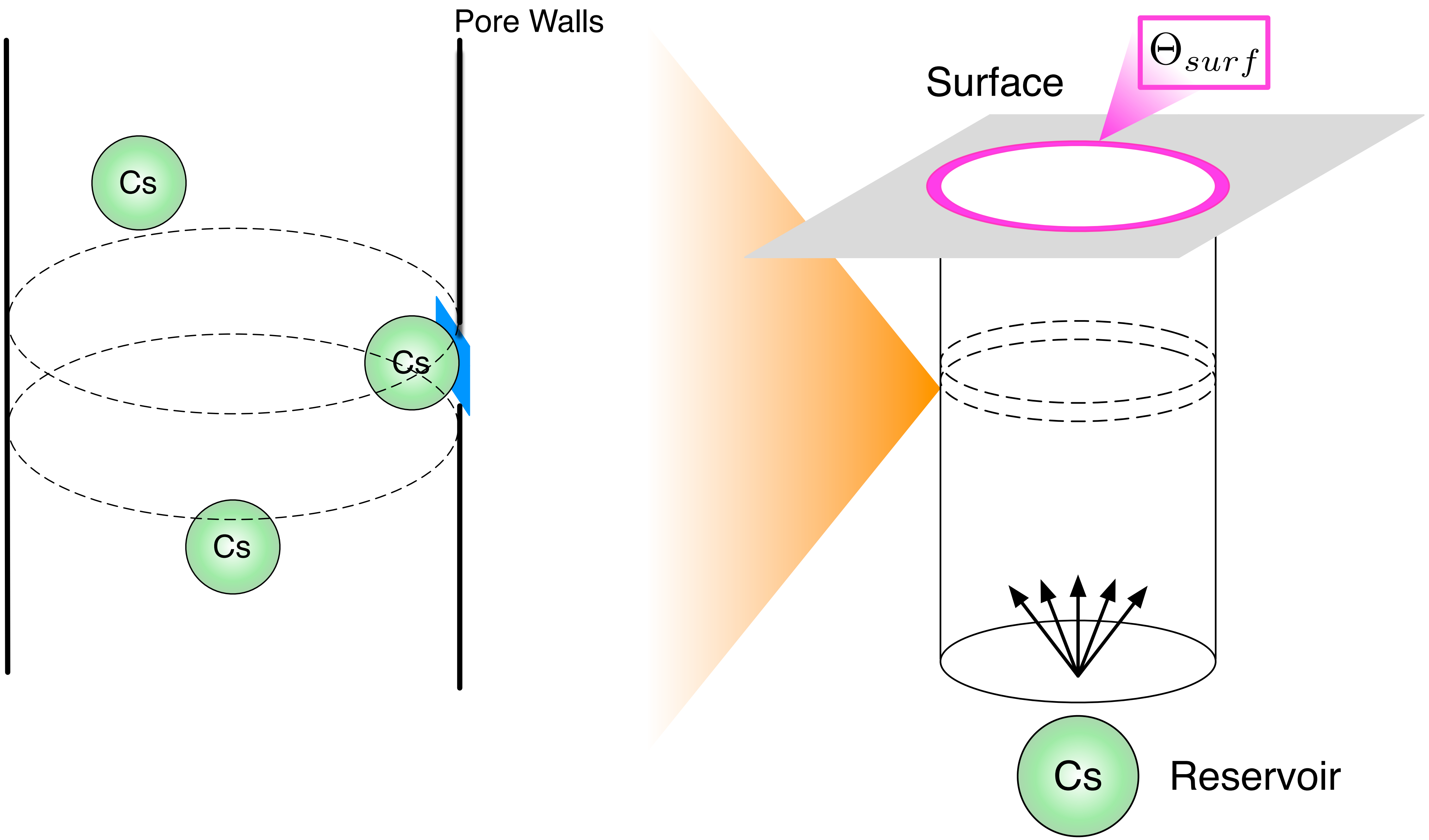

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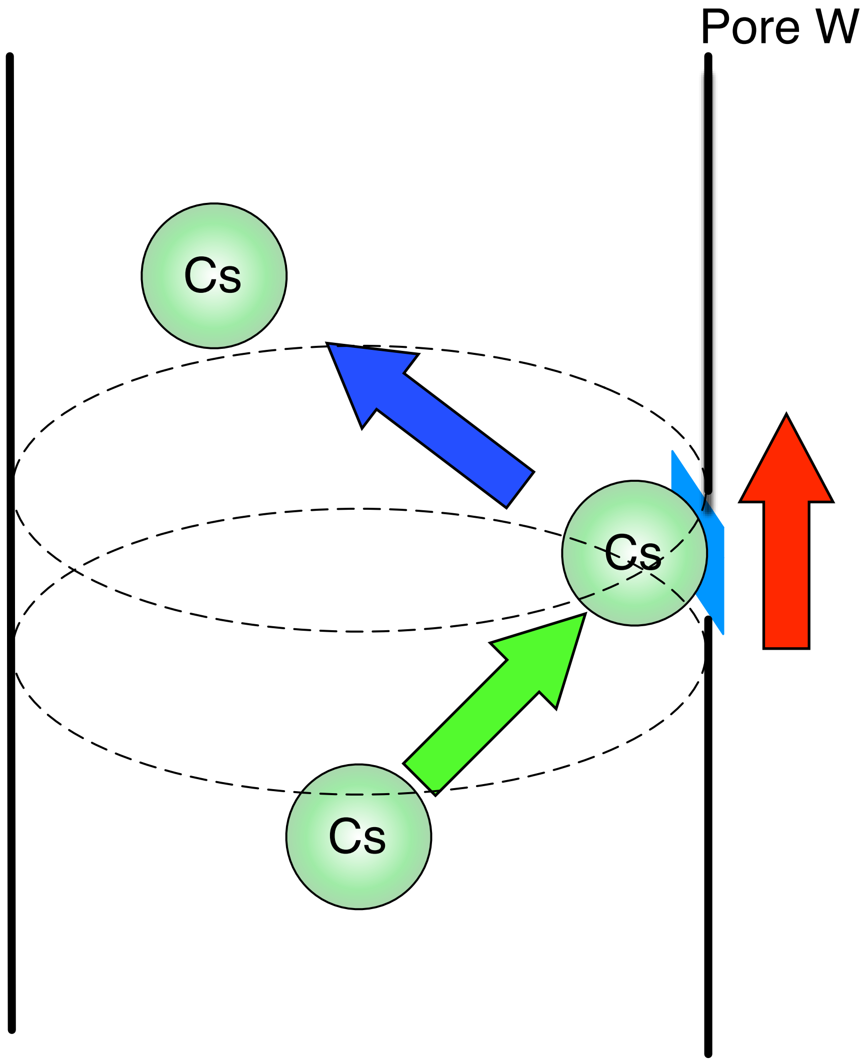

Flow of Cesium Through Pores :

$$\frac{\partial\Theta}{\partial t} = \overset{\text{Diffusion}}{\boxed{D\frac{\partial^2\Theta}{\partial z^2}}} + \overset{\text{Flux source}}{\boxed{J_z}} - \overset{\text{Evaporation}}{\boxed{F_{evap}}}$$

Boundary Conditions:

$$\Theta(0) = \Theta_0 \;,\;\; \Theta(L+\delta z) = \Theta_{surf}$$

Modeling Θ_{surf}

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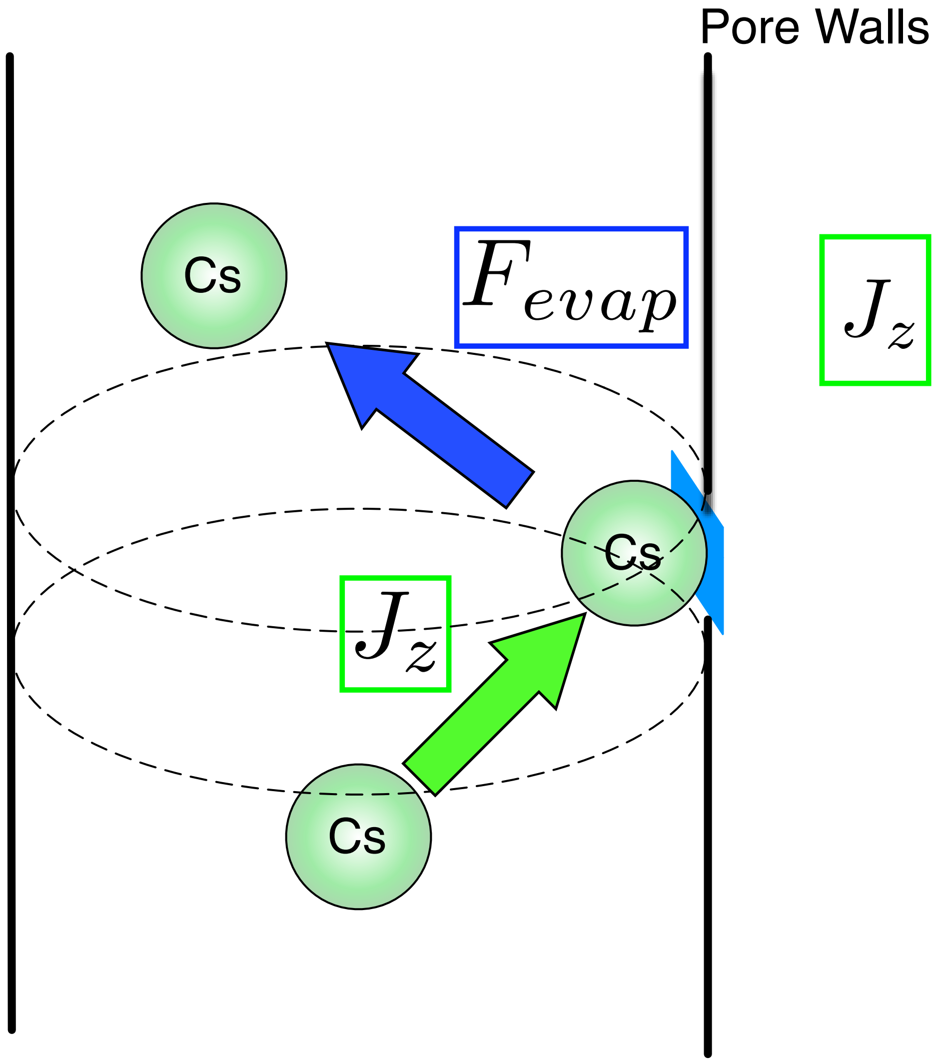

$$\boxed{J_z} = \int_{(z-L)/\sqrt{2}R}^{z/\sqrt{2}R} \boxed{\frac{\sqrt{2}\,F_{evap}}{2}} \left(1 - \frac{u(3+u^2)}{(2+u^2)^{3/2}}\right) \mathrm{d}u$$

$$\frac{\partial \Theta}{\partial t} = D\frac{\partial \Theta}{\partial z^2} + \boxed{J_z} - \boxed{F_{evap}}$$

$$\Theta(0) = \Theta_0\ ,\ \Theta(L+\delta z) = \Theta_{surf}$$

Modeling Evaporation

$$\frac{\partial\Theta}{\partial t} = D(T)\nabla^2\Theta - \boxed{F_{evap}}$$

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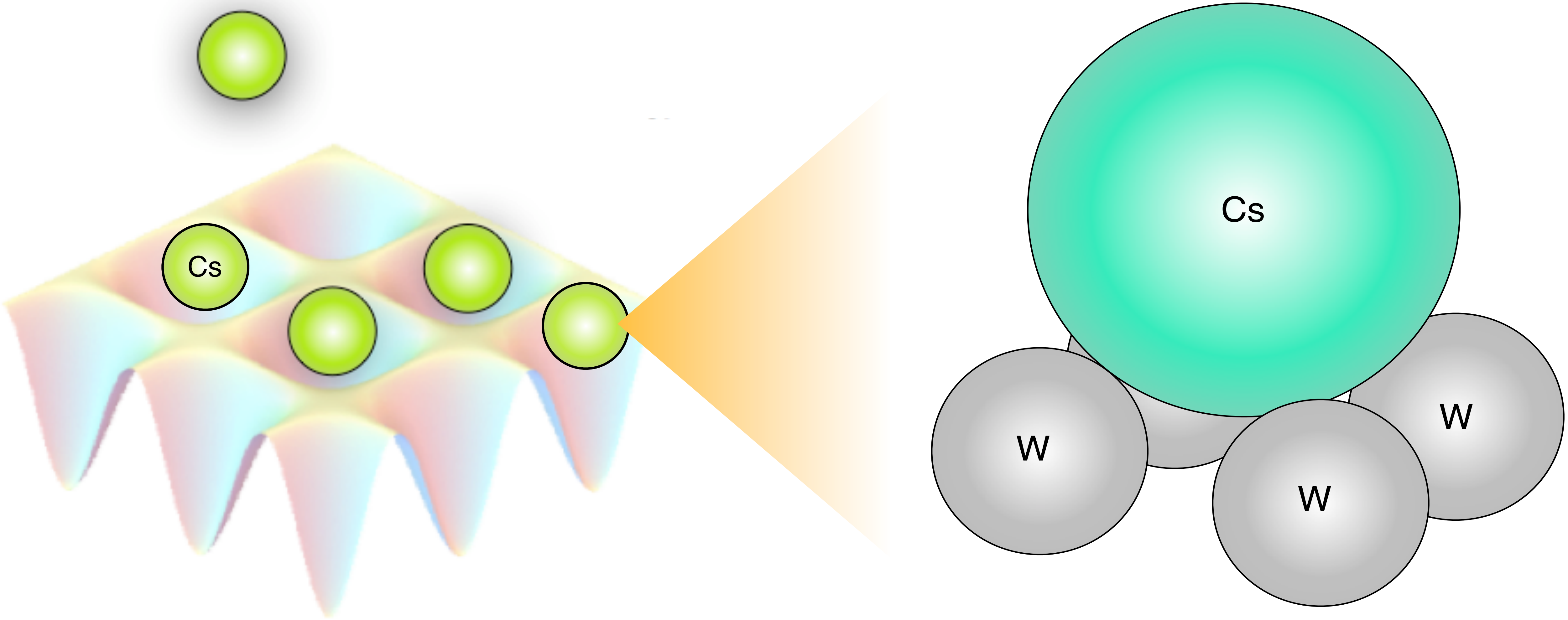

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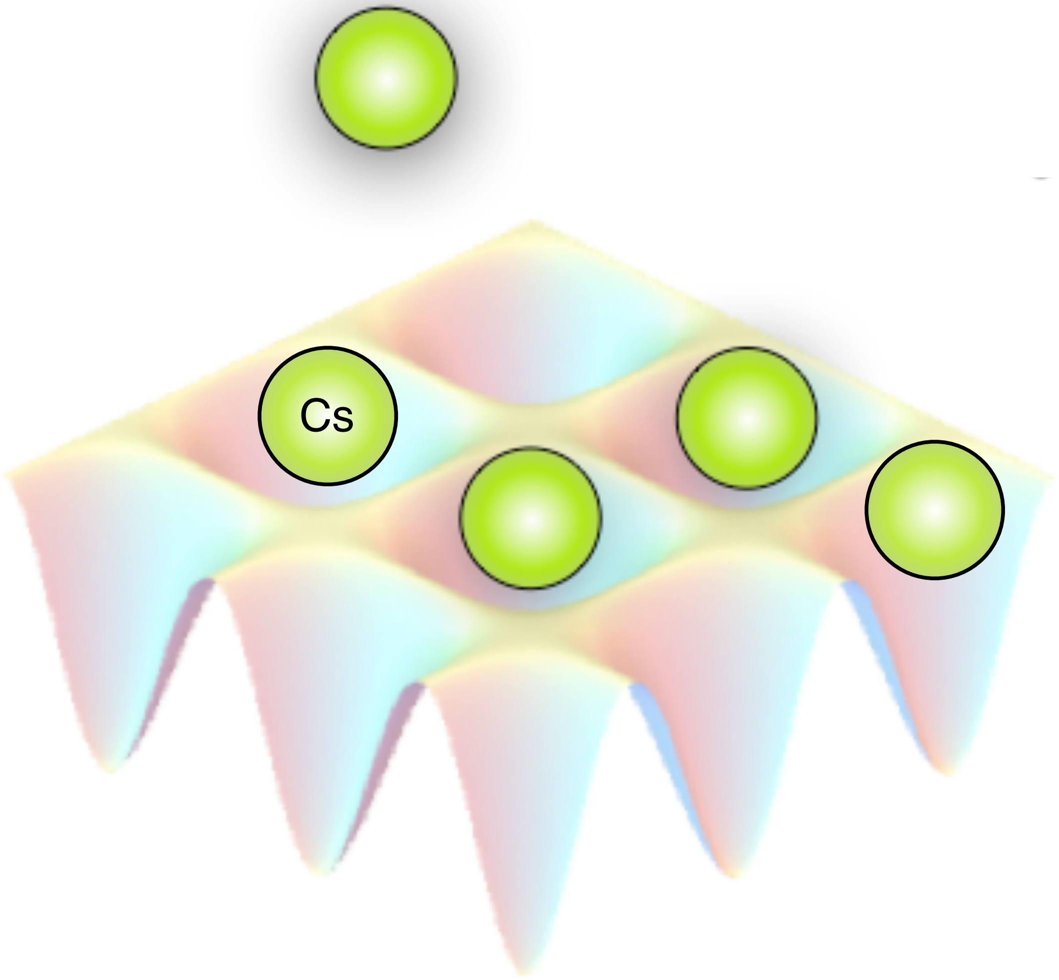
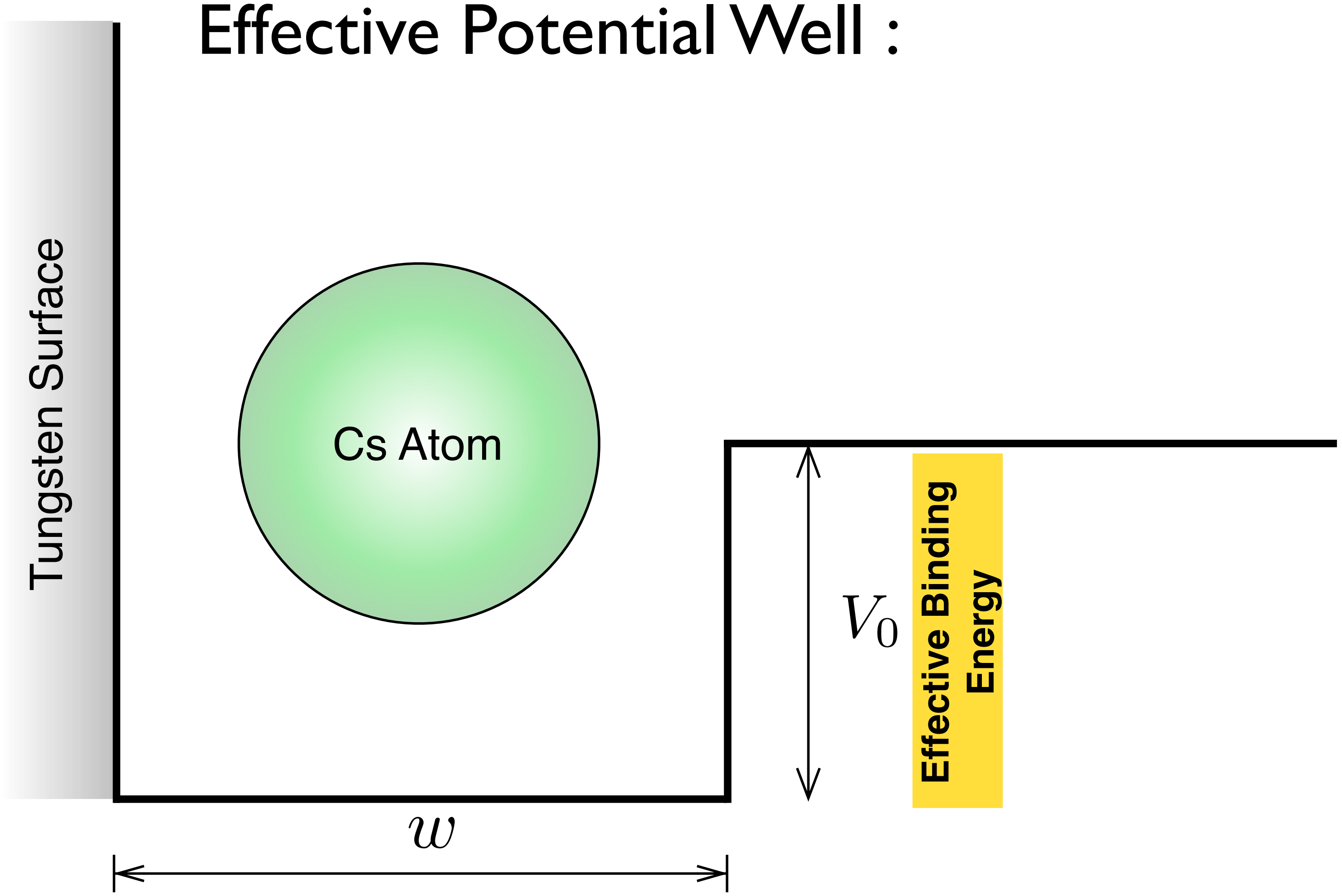


Effective Potential Well :



Modeling Evaporation

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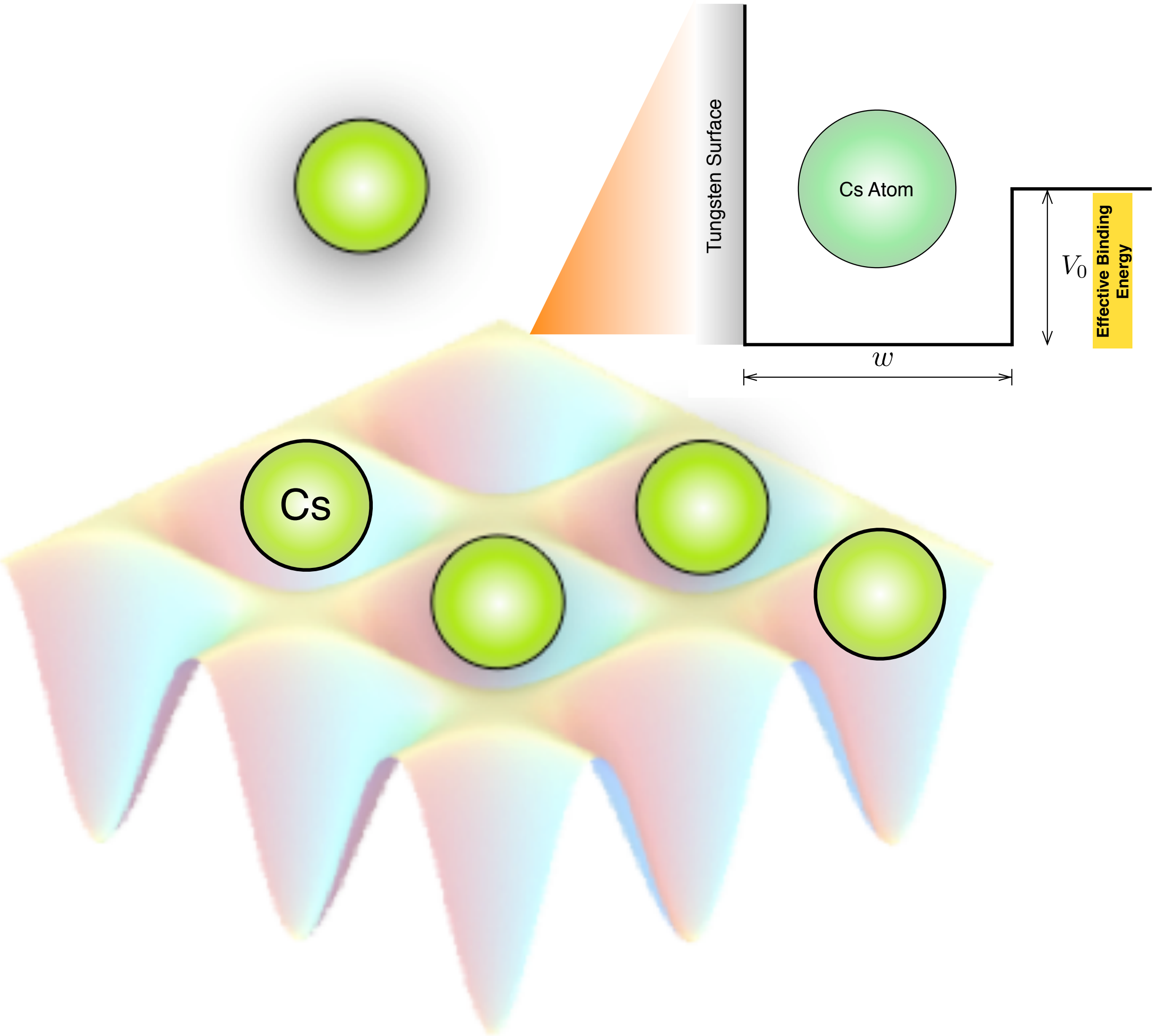

Evaporation Rate :

$$\boxed{F_{evap}} = \frac{1}{\tau}\,\boxed{P}\;\sigma\;\theta$$

Probability of $E > V_0$:

$$\boxed{P} = \frac{\sum_{free} e^{-E/kT}}{\sum_{i=0}^{n} e^{-E_i/kT} + \sum_{free} e^{-E/kT}}$$

Modeling Evaporation

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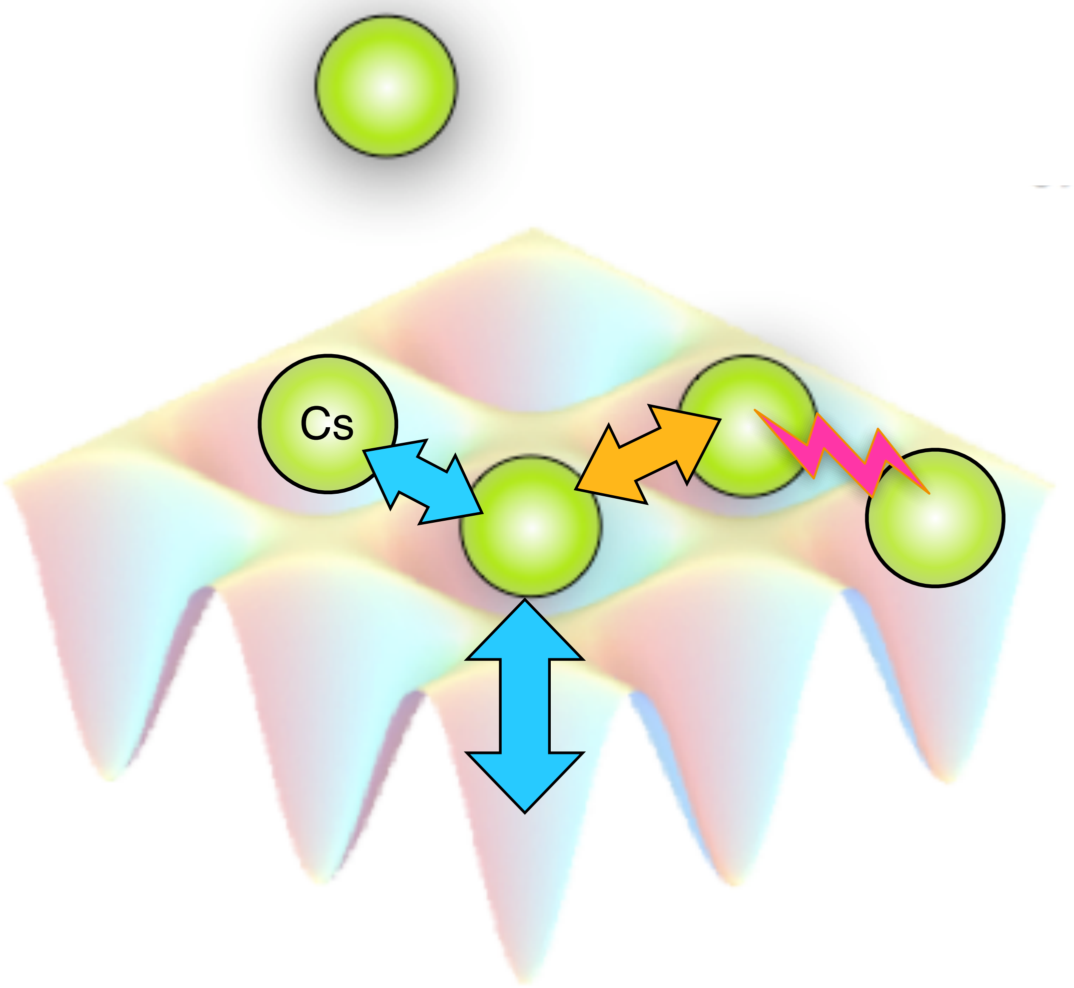

Contributions to V_0:

- ⟷ Coulomb Forces
- ⟷ Lenard Jones Interactions
- ⚡ Thermodynamics

Modeling Evaporation

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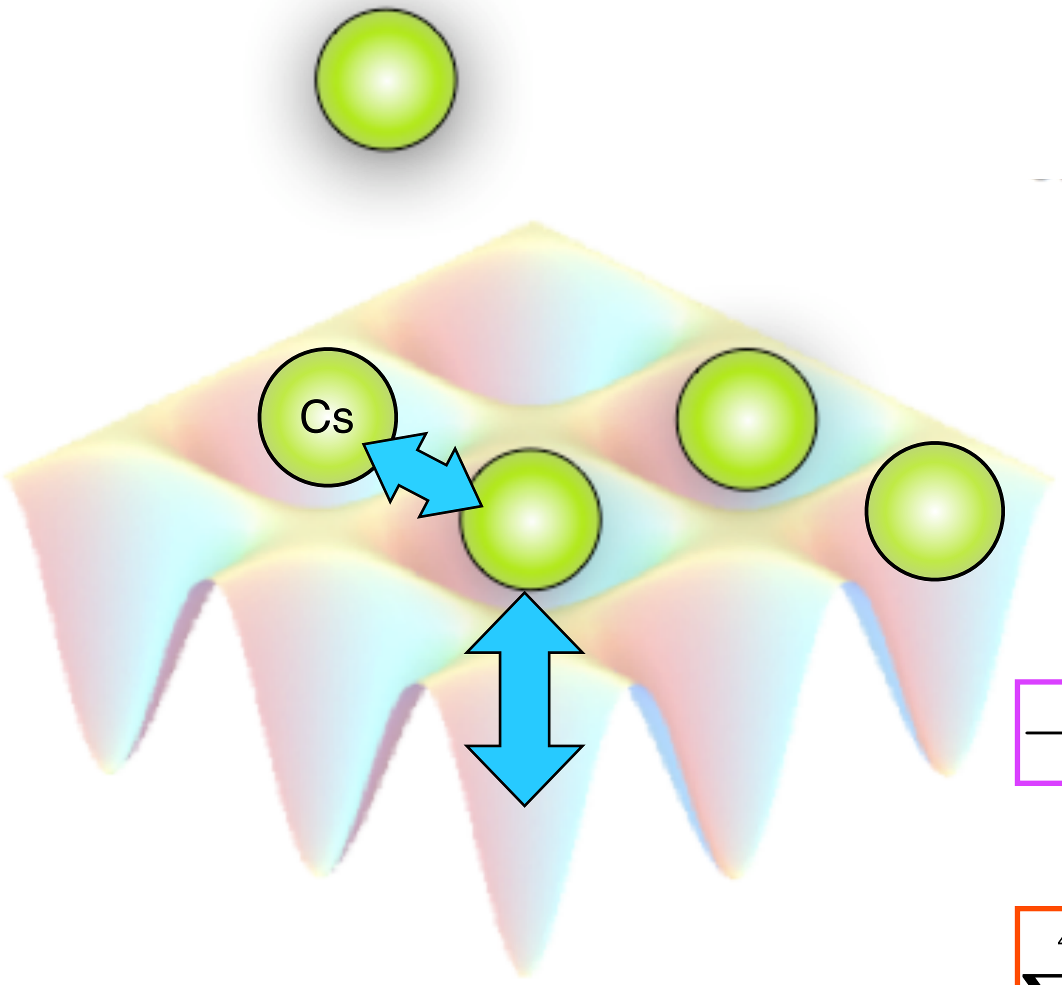

↔ Coulomb Contribution to V_0 :

$$V_C = \boxed{\delta} - \boxed{F\psi_e + F^2V_f} + \boxed{\sum_{i=0}^{4} N(i,\theta)V_{nn}^{i}}$$

$\boxed{\delta}$ = Global long range electrostatic cesium cesium interactions

$\boxed{-F\psi_e + F^2V_f}$ = Correction for charge neutrality after evaporation

$\boxed{\sum_{i=0}^{4} N(i,\theta)V_{nn}^{i}}$ = Nearest neighbor electrostatic cesium-cesium interactions

Modeling Evaporation

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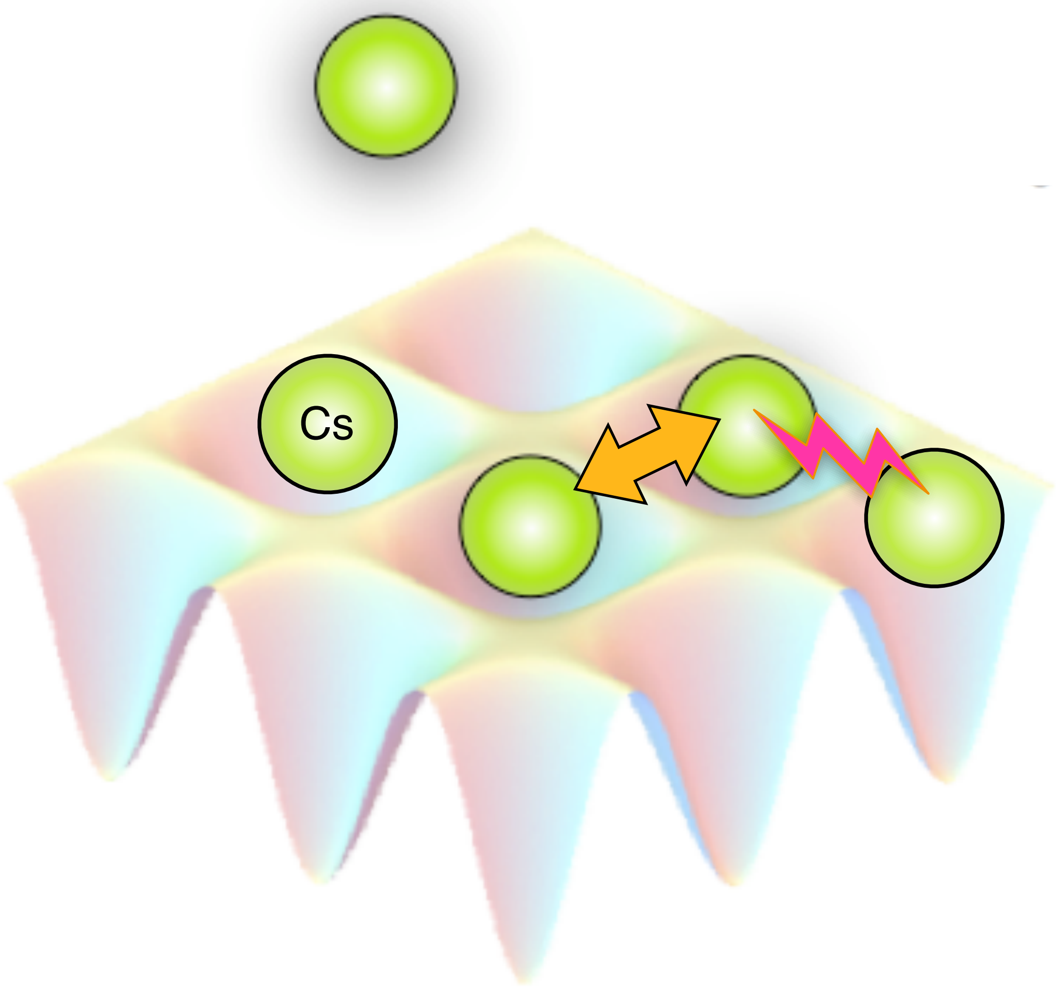

⇔ Lennard Jones Contribution to V_0 :

$$V_{LJ} = \sum_{i=0}^{4} N(i,\theta) L_i$$

$$L_i = i4\varepsilon\left[\left(\frac{r_m}{a}\right)^{12} - \left(\frac{r_m}{a}\right)^{6}\right]$$

⚡ Thermodynamic Contribution to V_0 :

$$V_\mu = kT\theta\left(\frac{\partial(\mu/kT)}{\partial \log\theta}\right)_{T,A}$$

$$V_\mu = kT\left(\frac{\theta}{1-\theta}\right)$$

Modeling Evaporation

$$\frac{\partial\Theta}{\partial t} = D(T)\nabla^2\Theta - \boxed{F_{evap}}$$

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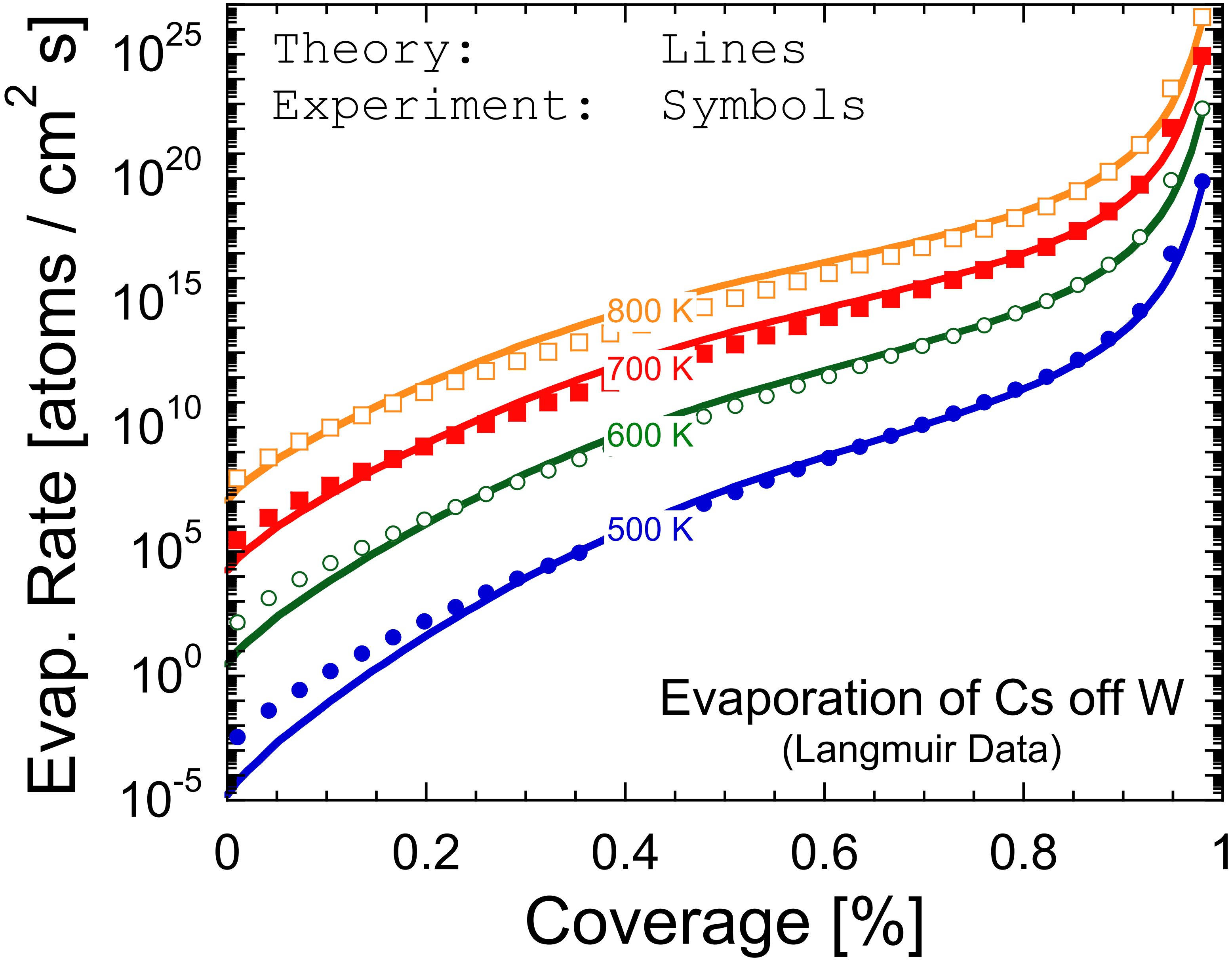
Theory vs Experiment for F_{evap}



Modeling Diffusion on the Surface

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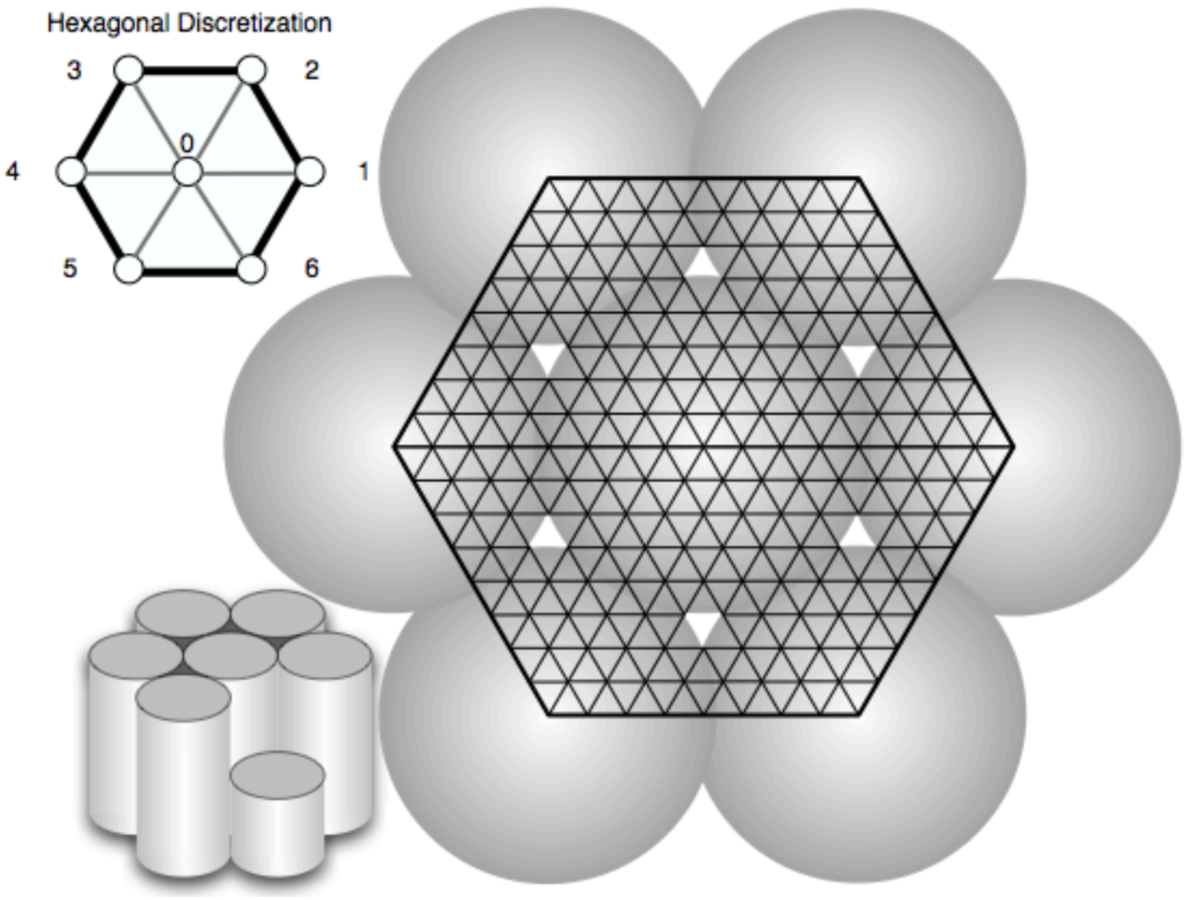

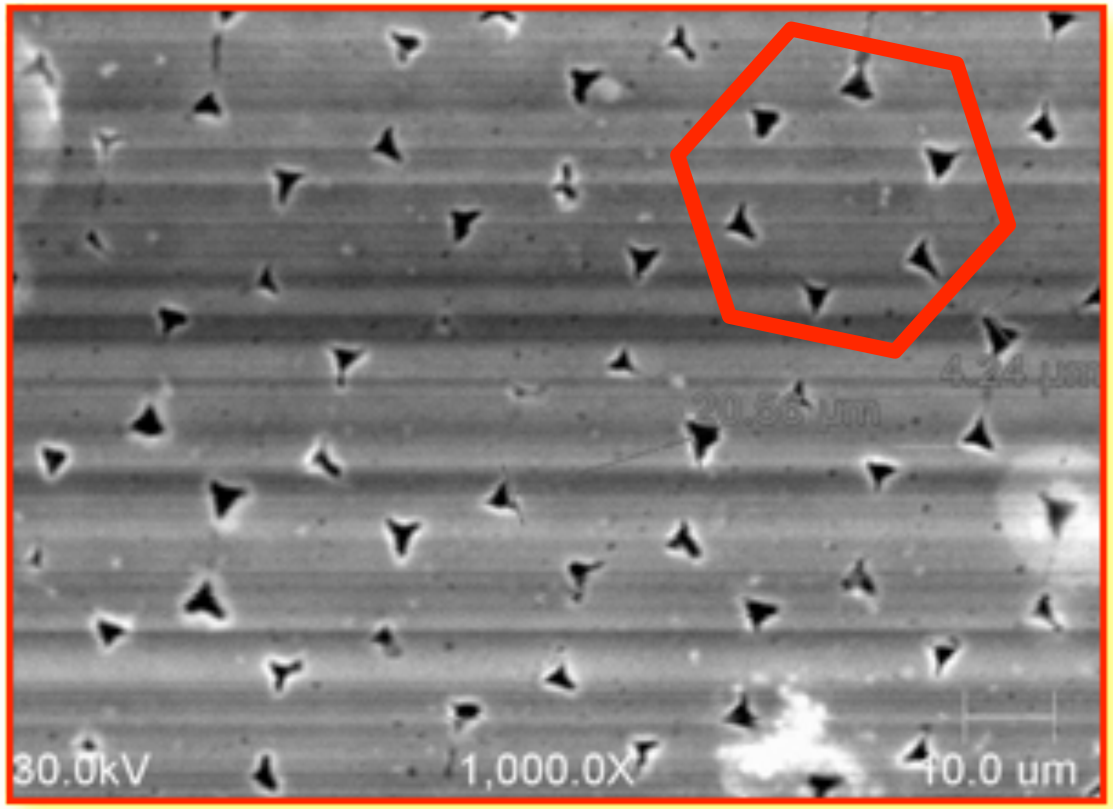

Laplacian Operator on a Hex stencil

$$\frac{\partial\Theta}{\partial t} = \boxed{D(T)\nabla^2\Theta} - F_{evap}$$

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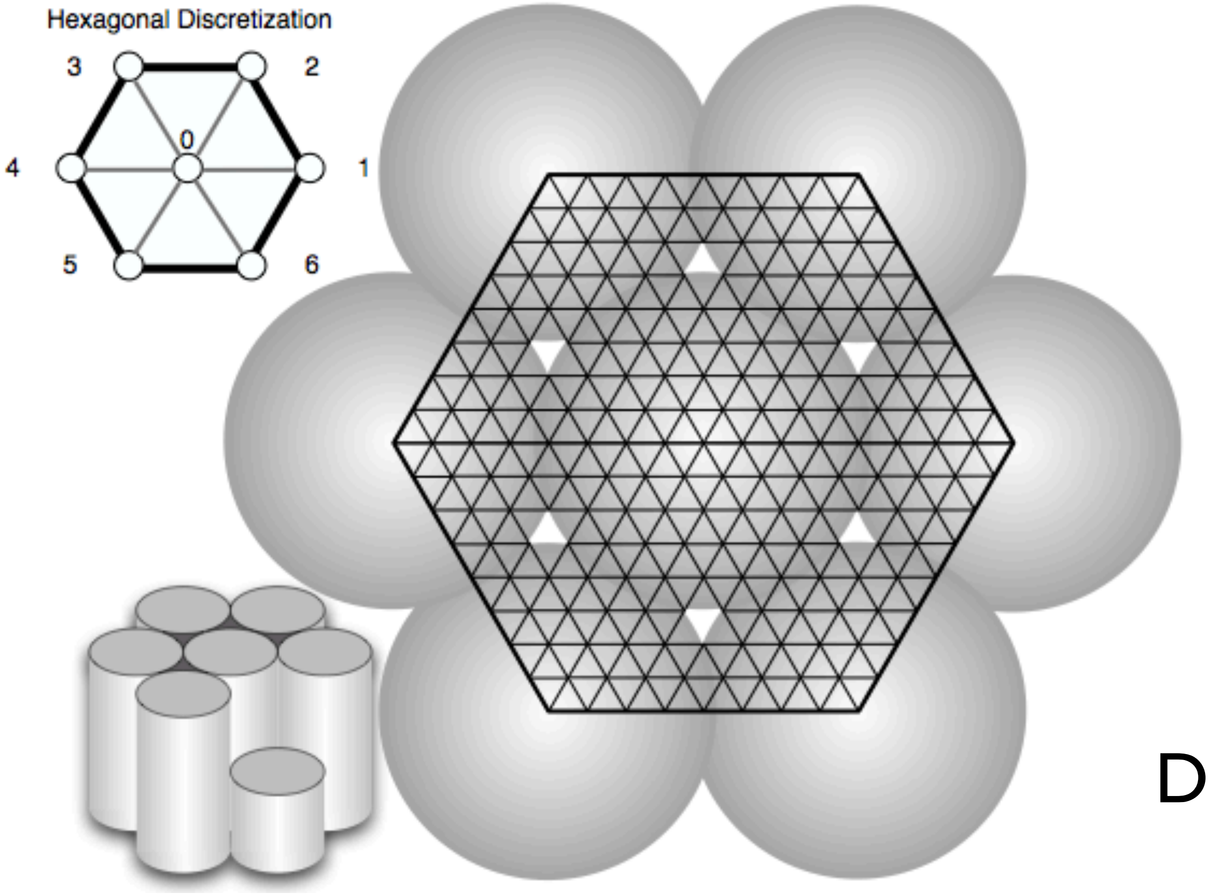
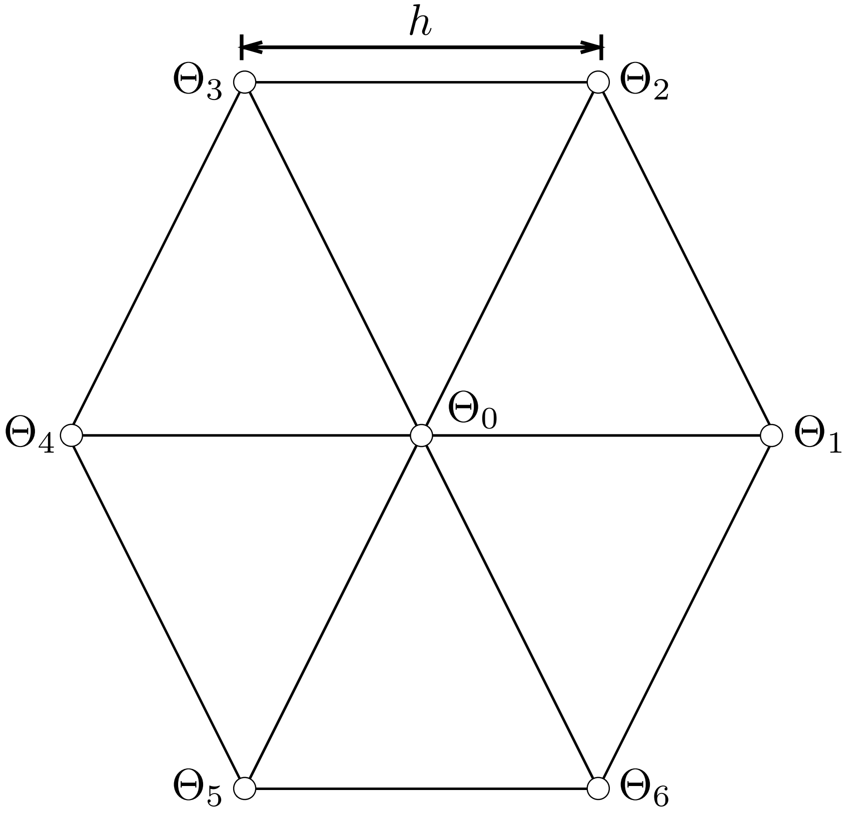


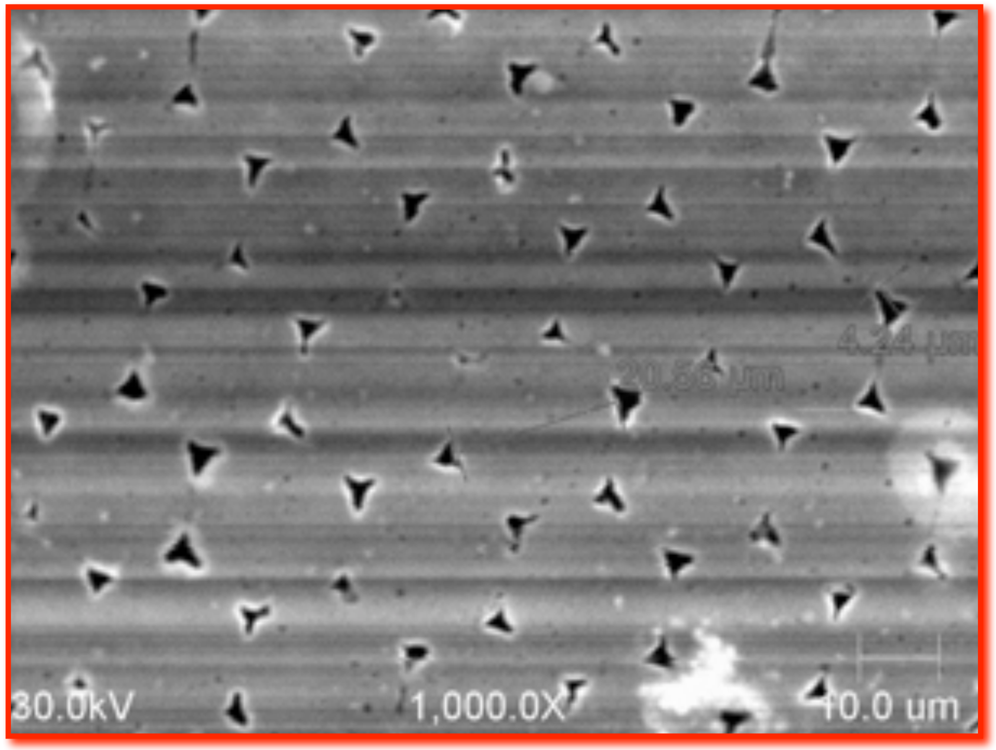


Diffusion Operator for Hex Lattice:

$$\nabla^2\Theta = \frac{2}{3h^2}\left(-6\Theta_0 + \sum_{i}^{6}\Theta_i\right) + O(h^3)$$

Questions the Model Aims to Answer

CPD Design and Optimization



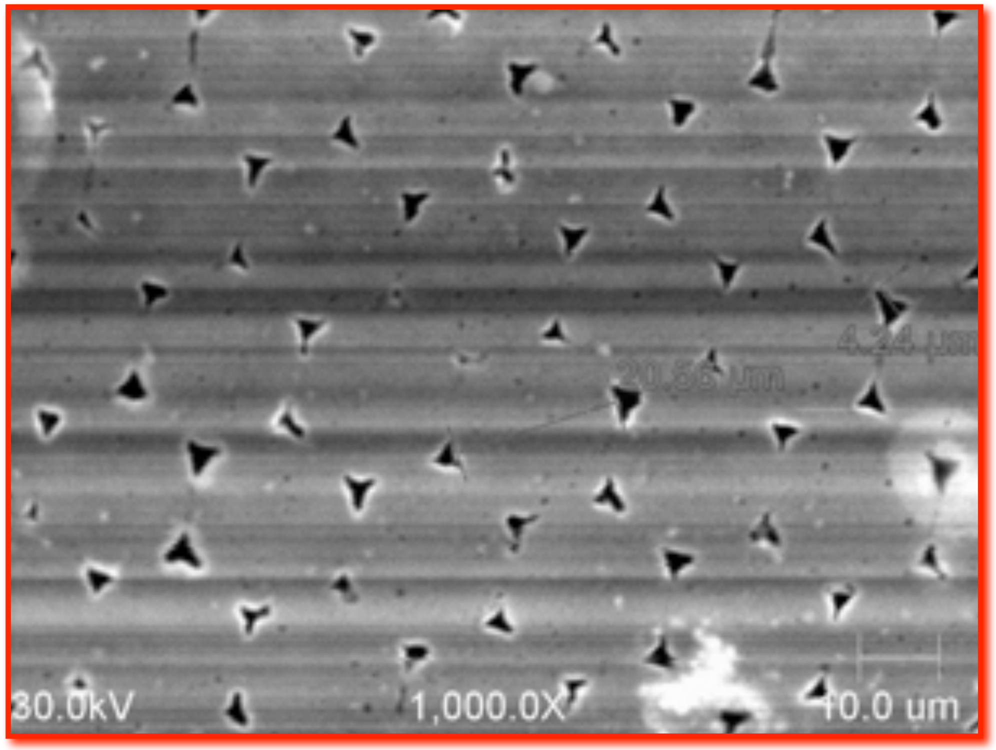
How uniform is the QE for various CPD parameters?

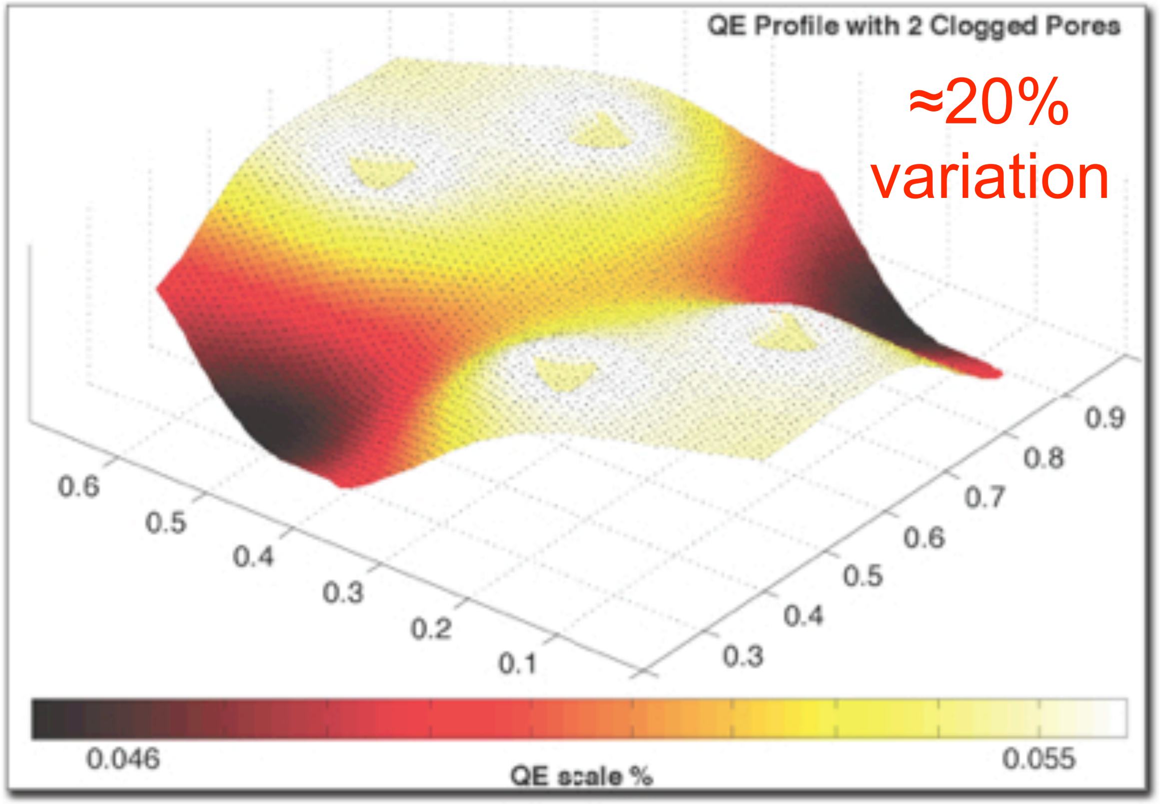
How does CPD parameters such as:
- Temperature
- Pore Size
- Pore Spacing
- Emitter Thickness ,

affect CPD performance?

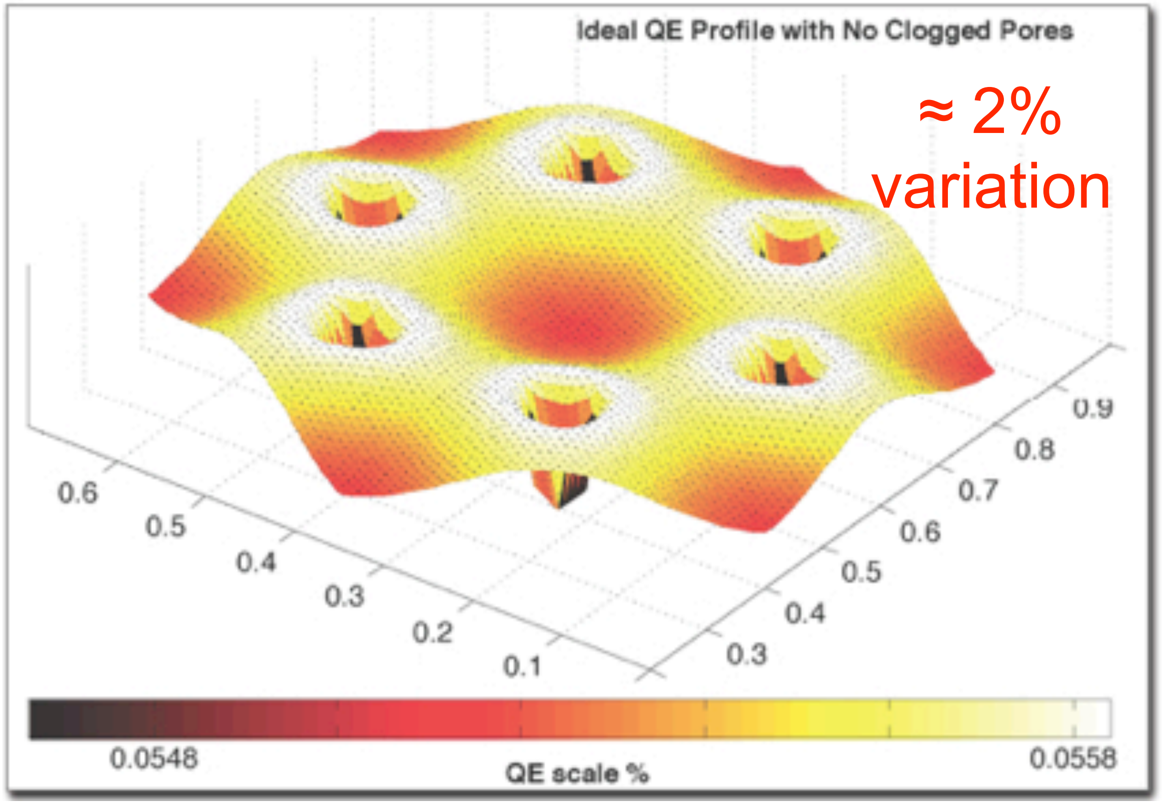
Preliminary Results

CPD Design and Optimization





≈20% variation



≈ 2% variation

Summary and Future Work

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Summary and Future Work

- a model of the surface of a CPD was developed to include evaporation, resupply, and migration of cesium
- The model can successfully predict the surface QE profile of CPD photocathodes
- Run the model to simulate cesium rejuvenation and QE over time at various temperatures
- Use the model for optimization of CPD parameters and diagnostic tool for experiment