Plasma Source Development at MPP

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Overview

- Two Plasma Source Candidates: Alkali Metal Sources
- Low ionization Potential

- **Heat Pipe Oven**

WHY BUILT?

- Has been built before

MAIN ISSUE

- The uniformity is not certain

Yet.

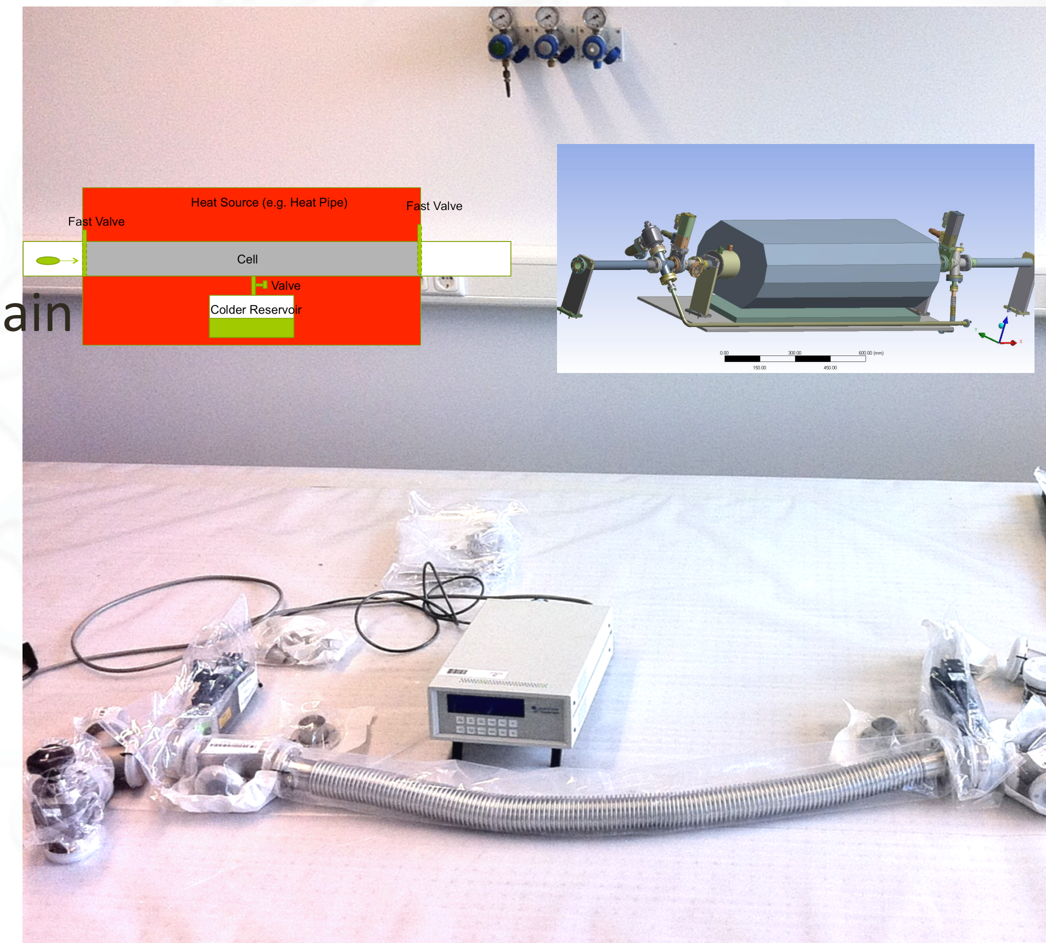
- **Vapor Cell**

WHY?

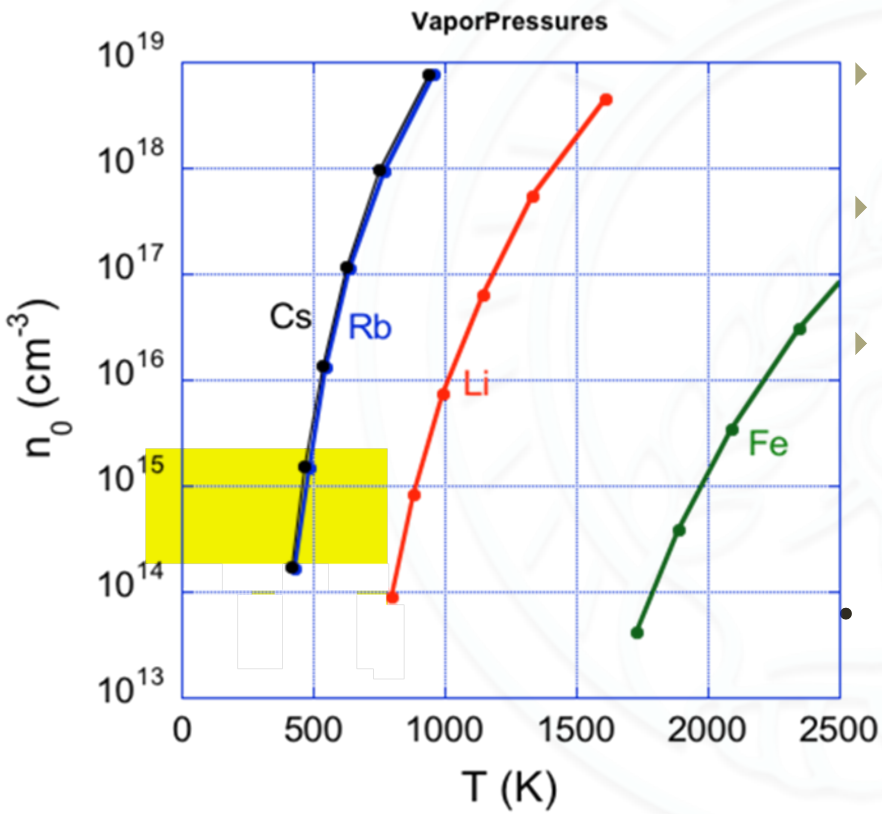
Better uniformity

MAIN ISSUE

- Engineering Challenge



Element of Choice



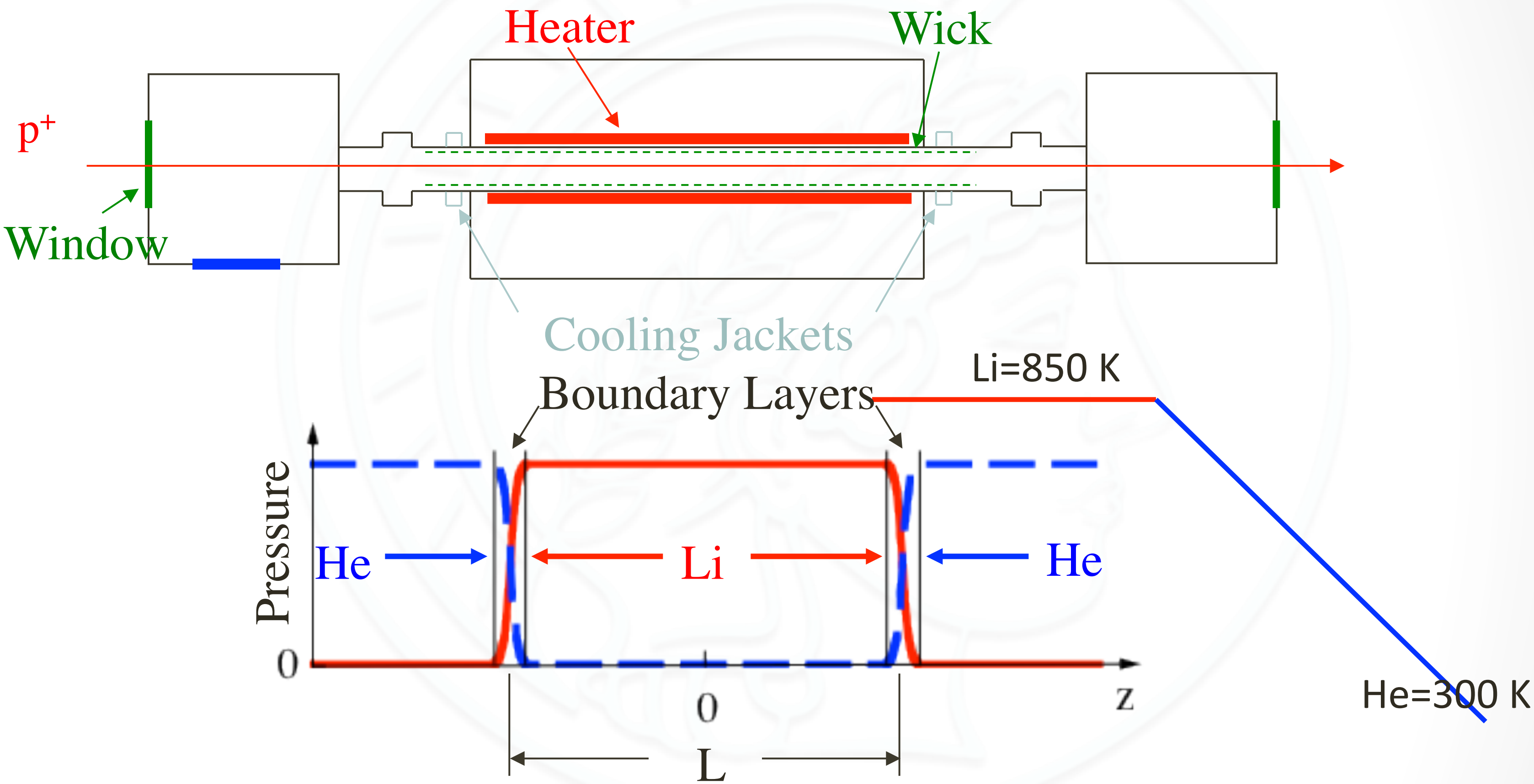
- Li: F=5.45eV, T_{melt}~184°C, T~500-600°C, Z=3, A=7
  light ion
- Rb: F=4.18 eV, T_{melt}~39°C, T~130-200°C, Z=37, A=85
- Cs: F=3.89eV, T_{melt}~28.5°C, T~130-200°C, Z=55, A=133
  liquid at room temperature (needs refrigeration)

- P-T relation Described by Clausius-Clapeyron

$$P = P_i exp(\frac{h}{k_B}(\frac{1}{T_i} - \frac{1}{T}))$$

- Li at SLAC experiments
- Rb or Cs may work better for PDPWA (lower ionization and lower temperature of operation)
- Secondary ionization issues?

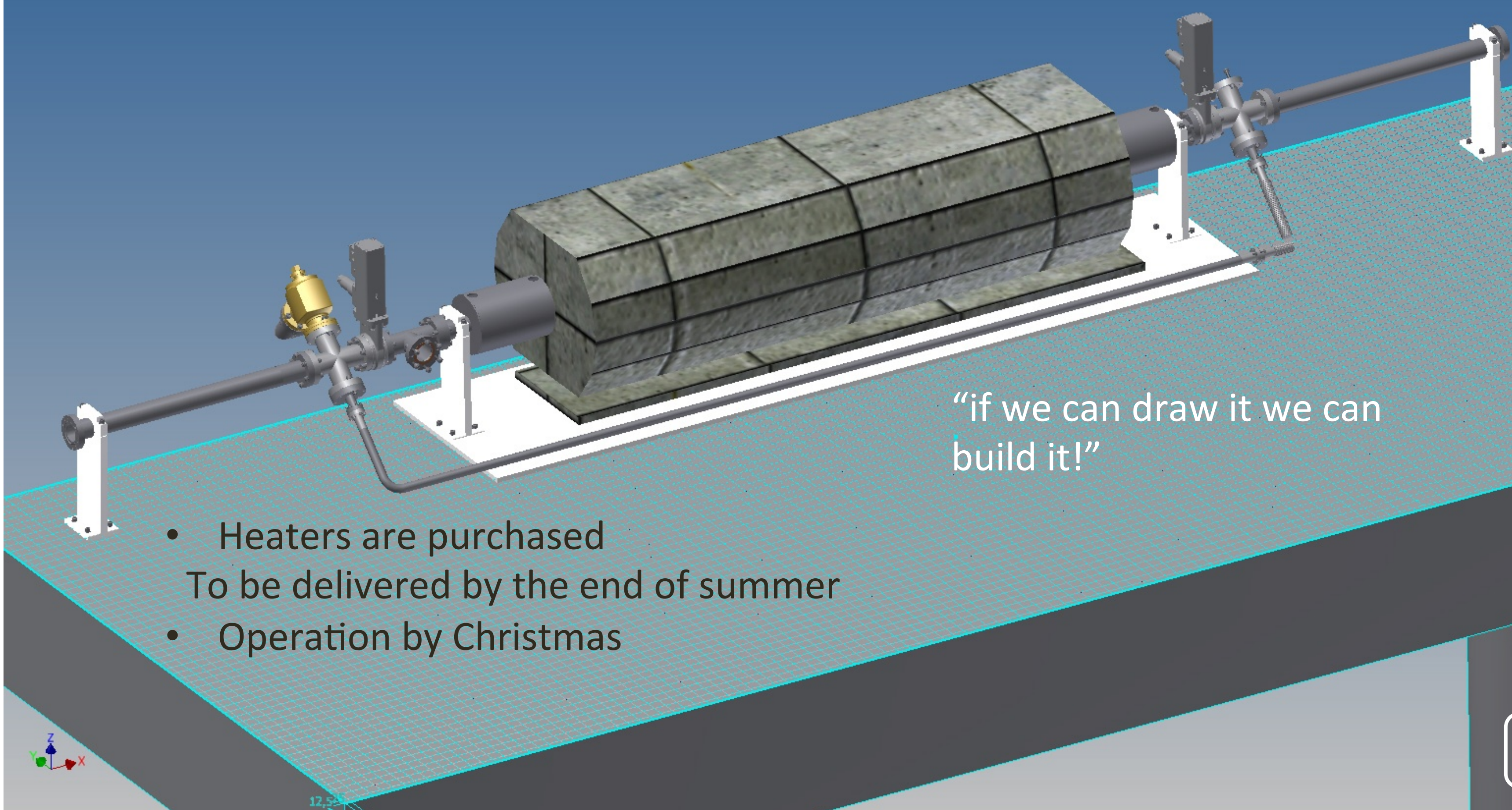
Heat Pipe Oven



Rb(n0=10^{14} cm^{-3}: T=142°C, P=3.3mT)
n0=10^{15} cm^{-3}: T=260°C, P=36 mT)
Li (n0=10^{14} cm^{-3}: T=518°C, P=6.8mT)
n0=10^{15} cm^{-3}: T=611°C, P=76 mT)

Progress with metal vapor source @MPP

- Li/Cs/Rb metal vapor; l=1 m, D=3 cm
- Source in the design/purchasing phase



"if we can draw it we can build it!"

- Heaters are purchased
  To be delivered by the end of summer
- Operation by Christmas

What is Dn/n for heat-pipe oven?

- Except for the short boundaries ISOTHERMAL system (T constant)(orders of magnitude higher thermal conductivity than comparable size metals)
  - Boundary length independent of heating power (on the order of several He-Li mean free path)

$l = \frac{1}{\sqrt{2}\sigma_c n}$ l =1=1/(5x10^{14} x2.5x10^{-15})= 0.6 cm

- 1-D analytic estimates quoted : 0.005 ^{o}C/cm* (for 1 m, 0.005 % in T)
- Thermocouple measurements quoted :1 ^{o}C 1000 ^{o}C (0.1 % in T) from the center to the condenser**
- For an ideal gas Dn/n =DT/T (pv=nkT)
- Not true for vapor $P = P_i exp(\frac{h}{k_B}(\frac{1}{T_i} - \frac{1}{T}))$

Because of steep vapor-pressure curve Dn/n is larger than DT/T

- Simulations

$$l = \frac{1}{\sqrt{2}\sigma_c n}; K_n = \frac{l}{D} \approx 0.2 \quad ; D = 3cm$$

free-molecular flow $Kn > 1.0$;
transition flow $0.01 < Kn < 1.0$;
continuum flow $Kn < 0.01$.

Transition & molecular Flow Regime

- Not fluid
- Can't use Navier Stokes
- Wall collsions are important

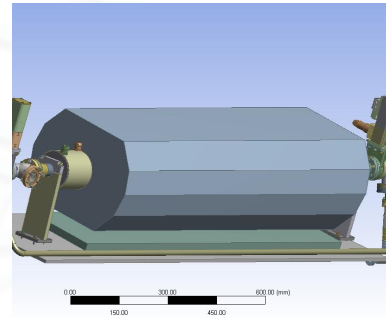
- Difficult to measure DT/T with accuracy better than 0.1 %
- Quartz tuning forks?

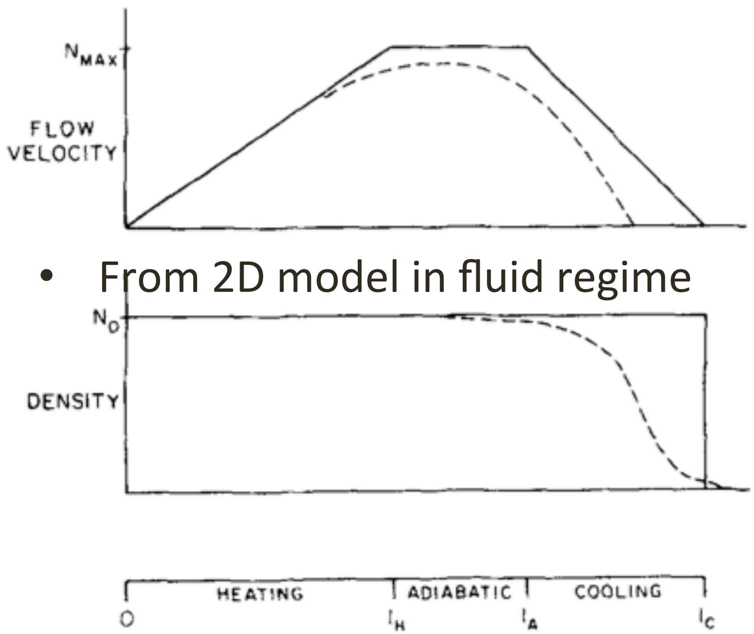
*G. M. Grover, T. P. Cotter, and G. F. Erickson, Journal of Applied Physics 35, 1990 (1964),
**C.R. and Vidal, in Atomic, Molecular, and Optical Physics: Atoms and Molecules, (Academic Press, 1996), vol. 29, Part B of Experimental Methods in the Physical Sciences, pp. 67 -83

Quantifying Density Uniformity Challenge at Low Pressure

(Li 850 K n=5x10^{14} cm^{-3} P~0.05 Torr ~6 Pa)

- Density uniformity depends on flow





- From 2D model in fluid regime

FIG. 4. Velocity and density profiles: solid line—ideal heat pipe, no diffusion, $\beta = 1$; dashed line—ideal heat pipe with diffusion, $\beta = 1$.

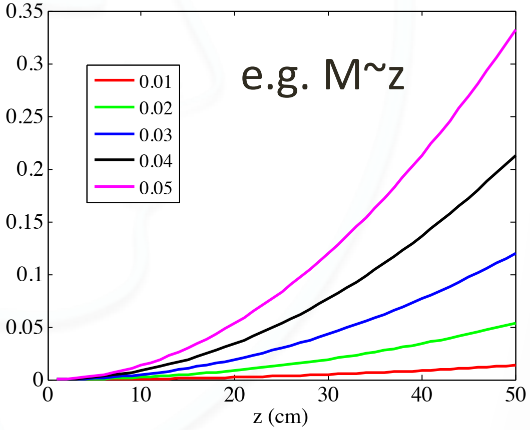
- For the densities we have We don't know. ?

*L. A. Melton and P. H. Wine J. Appl. Phys. 51, 4059 (1980);

1D Model energy and pressure balance shows*

- $g_{max} = \sqrt{\frac{1+\gamma}{\gamma} A(\frac{\epsilon_t D}{d^2})} \quad \alpha \ M = \frac{v_{flow}}{c}$ where $\quad A = 4\sigma (T_0^4 - T_r^4) \frac{(2kT_0 m)^{1/2}}{l_A P_0}$
  - $A \propto P_0^{\frac{9\kappa}{2}-1}$ where $\kappa = \frac{kT_0}{l_A}$
- For our parameters $A \propto P_0^{-0.8}$
  - The lower the pressure the more flow we have and more Non-uniformity

$$\frac{n}{n_0} = \frac{1+\frac{1}{2}M^2(\gamma-1)}{1+\gamma M^2}$$



- Low pressure could cause issues
- We need to look more carefully

*C. Vidal J. Appl. Phys. 44 2225 (1973)

Simulations

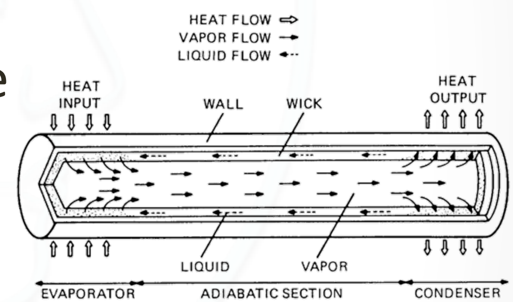
- ANSYS FLUENT

Does not strictly apply in molecular regime however in short term could be used as a guide and cross check for molecular codes in

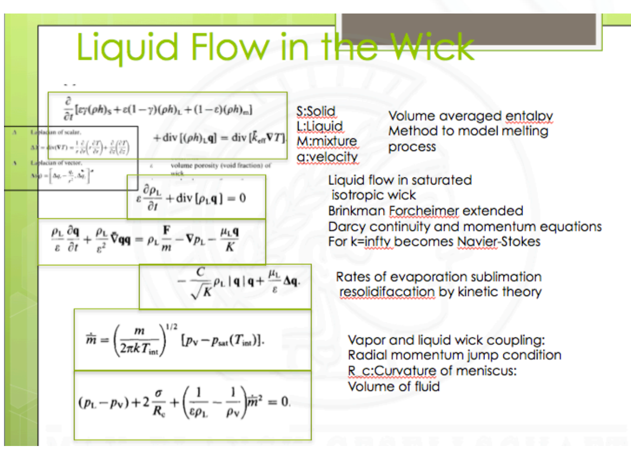
- Simulating all the coupled process especially

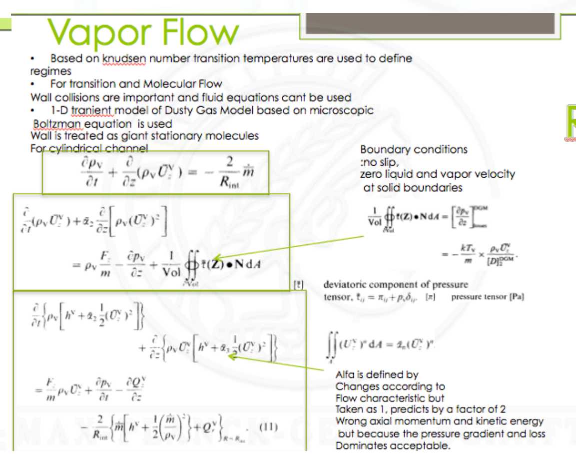
in this regime requires highly sophisticated code and a long term Project

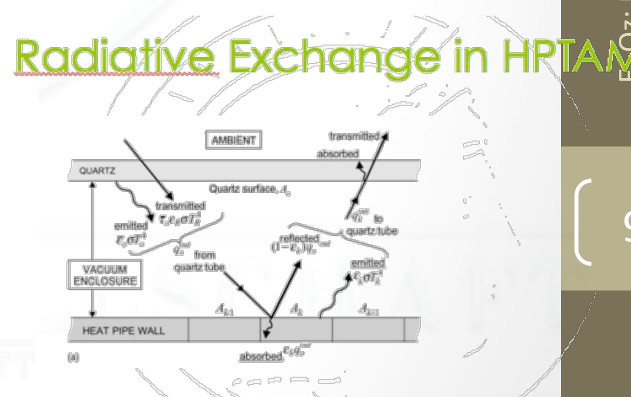
- In contact with experts to collaborate



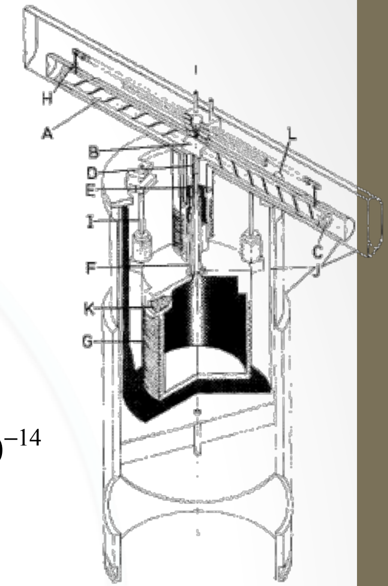
URE 2.1. Illustration and Principle of Operation of a Conventional Heat Pipe.







What is a Vapor Cell?

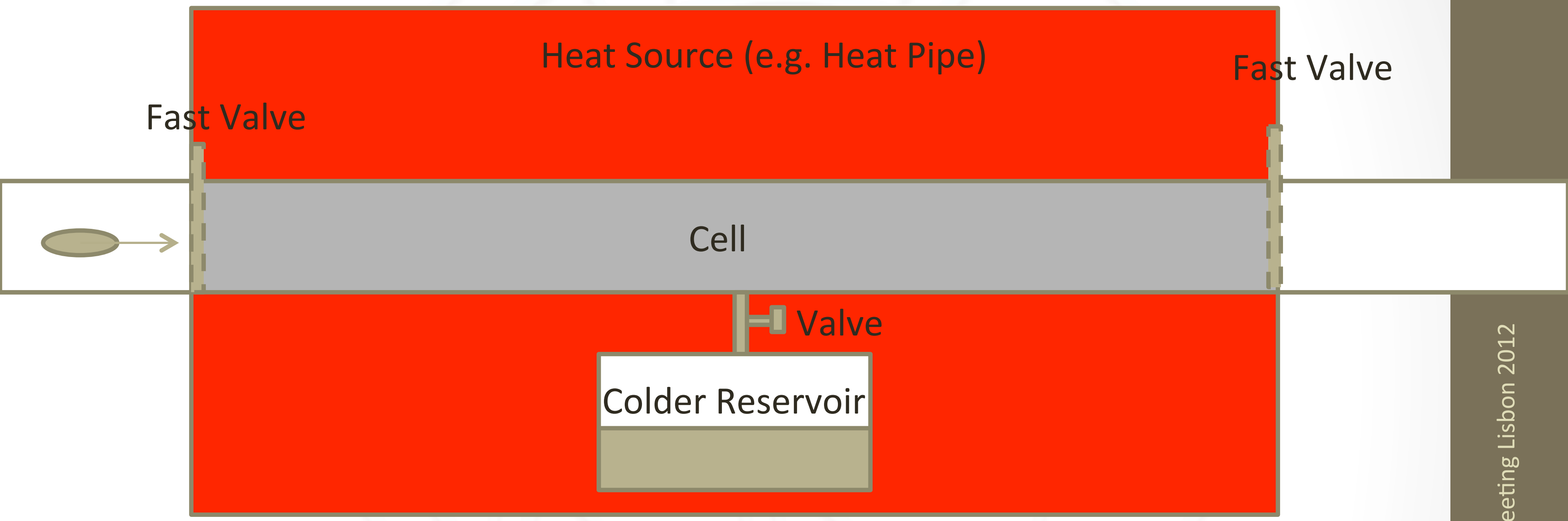


- No buffer gas, no wick, no liquid
- Just the vapor as the ideal gas
- DT/T=Dn/n $<(\Delta T)^2>=\frac{kT}{C_v}$
- Why don't people do it?
- Alkali metals are extremely corrosive, hard to confine, blacken glass, quartz

  Requires special sealing, special materials especially for windows, high failure rate
- Literature: Vapor cells with separate liquid reservoir (coldest point) or random condensation
  - No report on just gas : liquid provides density control
  - Supply of vapor compensate for leaks
  - Heated windows to prevent condensation on window which can be very problematic.

$$\frac{\sqrt{<(\Delta T)^2)>}}{T}=\sqrt{\frac{k}{C_v T}}\sim 10^{-14}$$

Sketch:Vapor Cell



- Two key factor: corrosion resistance and even compression of seal for a range of temperatures (0-700 C) (mathing thermal expansion coefficients)
- Fast Valves?
- Chose of element (Rb, Li, Cs)?

Back of the envelope calculations tolerance on valve opening

Speed of sound
In Lithium or Rubidium

$c = \sqrt{\frac{5kT}{3M}}$ for Li =850 K c ~ 1300 m/s, for Rb=500 K c ~ 285 m/s.

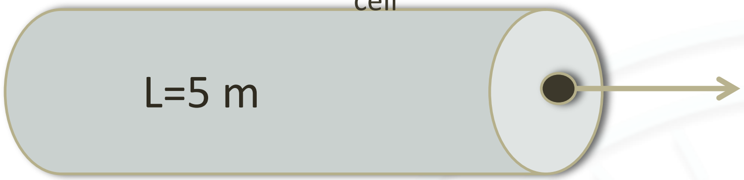
In Steel

$c = \sqrt{\frac{Y}{\rho}}$ where Y is the young's modulus for steel Y=200 GPa; $\rho = 8000 kg / m^3$

c ~5000 m/s.

for a 10 μs opening time this would be a distance of 5 cm in steel, 0.3 cm in Rb and 1.3 cm in Li.

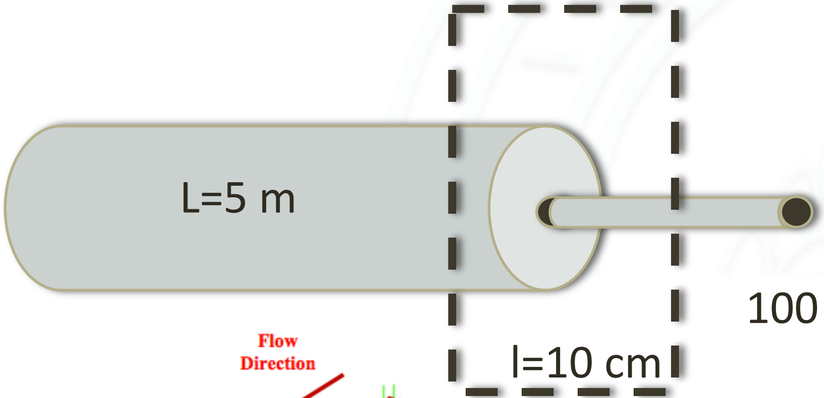
D_{cell}=3 cm



$$\Gamma = \frac{nc\pi r^2}{4}$$

r_{hole}=2 mm
n=5x10^{14}cm^{-3}

$$\Gamma = 2x10^{18}$$ Atoms/s



$$\Gamma = 10^{15}$$ Molecular flow with long narrow tube

100 ms opening $\frac{dV}{V}$ =0.2 %

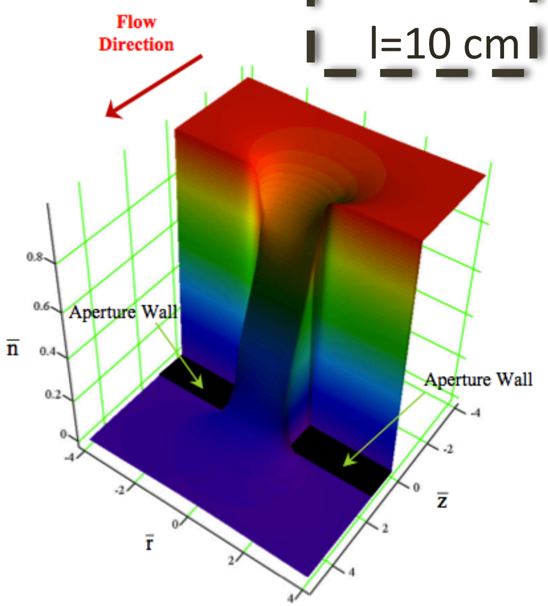
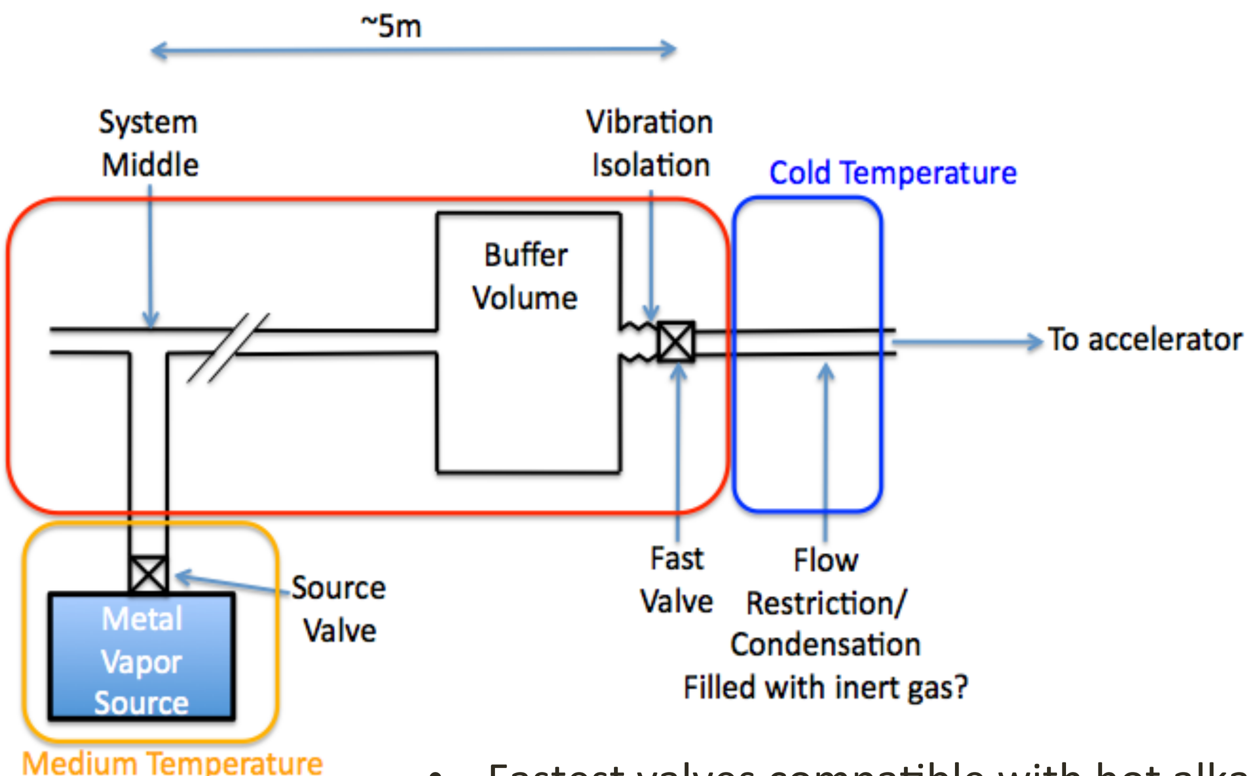


Figure 20.—Particle density surrounding a cylindrical aperture with a thickness-to-radius ratio of 1.25.

*Gas flux and density surrounding a cylindrical aperture in the free molecular flow regime, George C Soulas; NASA Glenn Research Center.

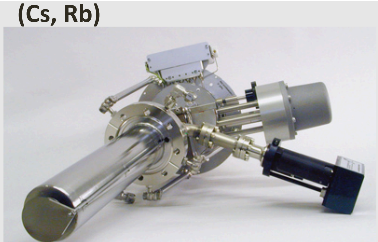
NASA technical memorandum, 216970. 2011

Vapor Cell



- Fastest valves compatible with hot alkali metal vapor?
- What is the density perturbation? (Simulations)
- How to provide uniform temperature?

(Cs, Rb)



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Concentric heat pipe

THE REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 42, NUMBER 12 DECEMBER 1971

Heat Pipe Oven Applications. I. Isothermal Heater of Well Defined Temperature. II. Production of Metal Vapor–Gas Mixtures

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National Bureau of Standards, Boulder, Colorado 80302

(Received 30 July 1971)

A concentric heat pipe oven is described, which serves as an oven with a highly homogeneous temperature distribution as required by such applications as crystal growing, thermal treatment of materials, and radiation standards. The design is simpler than conventional ovens with similar temperature stability and homogeneity. The temperature control is replaced by a pressure control. This device is used in a modification of the heat pipe oven that generates homogeneous mixtures of a vapor (such as a metal vapor) and an inert gas at well defined total pressure, partial pressure, temperature, and optical path length. All the features of the previously described heat pipe oven are maintained with the additional option that allows quantitative total and partial pressure r pressure curves.

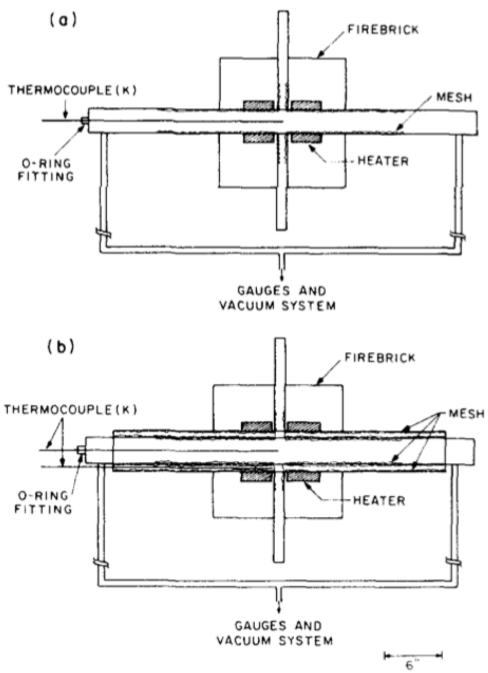

FIG. 1. Heat pipe used in experimental studies. (a) Simple heat pipe, (b) concentric heat pipe.

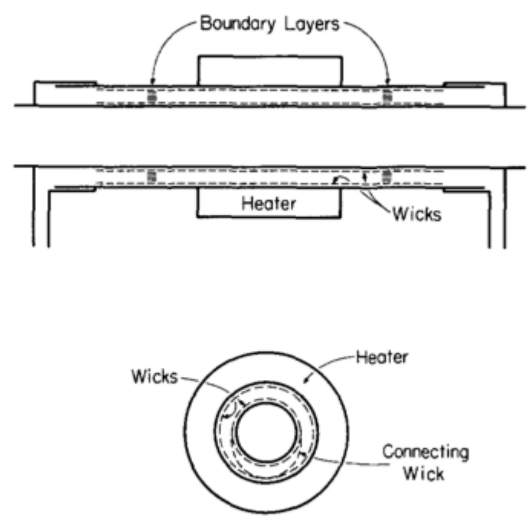

FIG. 1. Schematic diagram of the concentric heat pipe oven which serves as the isothermal heater of well defined temperature.

*L. A. Melton and P. H. Wine J. Appl. Phys. 51, 4059 (1980);

PLANS AND FUTURE WORK

- Finish 1-m long heat-pipe
- Design and test vapor cell
- Study ideal heat pipe case with numerical simulations
- Characterize neutral temperature and density profiles in both systems with various diagnostics
- Characterize plasma density profile in both systems with various diagnostics

Thank you for listening. Any questions?