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Hydrodynamic Instabilities in LIquid Metal BAtteries

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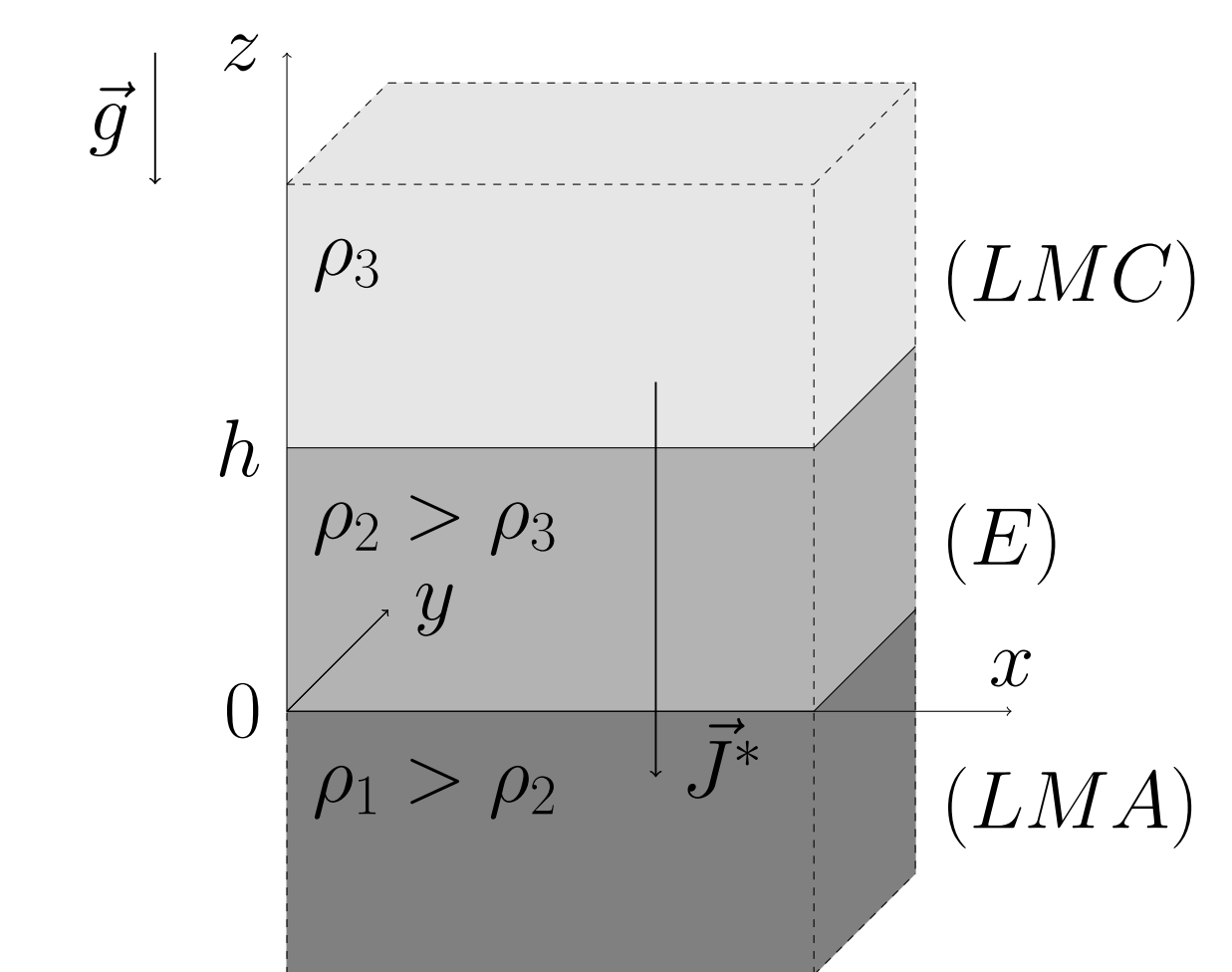
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Introduction

- Increase in the production of renewable energies \Rightarrow energy storage = the major challenge \Rightarrow the proposed solutions = Liquid Metal Batteries (LMBs) [1].
- LMB = system of 3 superimposed fluid layers: a molten salt electrolyte (E) sandwiched between two metal electrodes, (LMC) and (LMA) + a strong vertical electric current \vec{J}^* .
- Avantages = long lifetime + low cost use \Rightarrow ideal for stationary applications.
- Difficulties = complex system involving several hydrodynamic phenomena such as metal pad roll instability, thermal convection, Taylor instabilities, electro-vortex flows, etc. \Rightarrow risk of short circuit + need for thermal efficiency improvement [2].



Metal pad roll instability

Rayleigh-Marangoni convection

Sele mechanism

Energy analysis

Base state and Marginal stability

Eigenfunctions

Assumptions:

- Isothermal conditions
- $\sigma_1 \gg \sigma_2$
- Viscosities disregarded
- Surface tension disregarded
- $\eta(t=0) = \alpha_x x$
- (2) \sim plane capacitor
- $\vec{B} = \vec{B}^* = B_z^* \vec{e}_z$
- Linear behaviour

Mechanical energy theorem:

$$\frac{dE_c}{dt} = -\frac{dE_p}{dt} + \mathcal{P}_{non\ conservative\ forces}$$

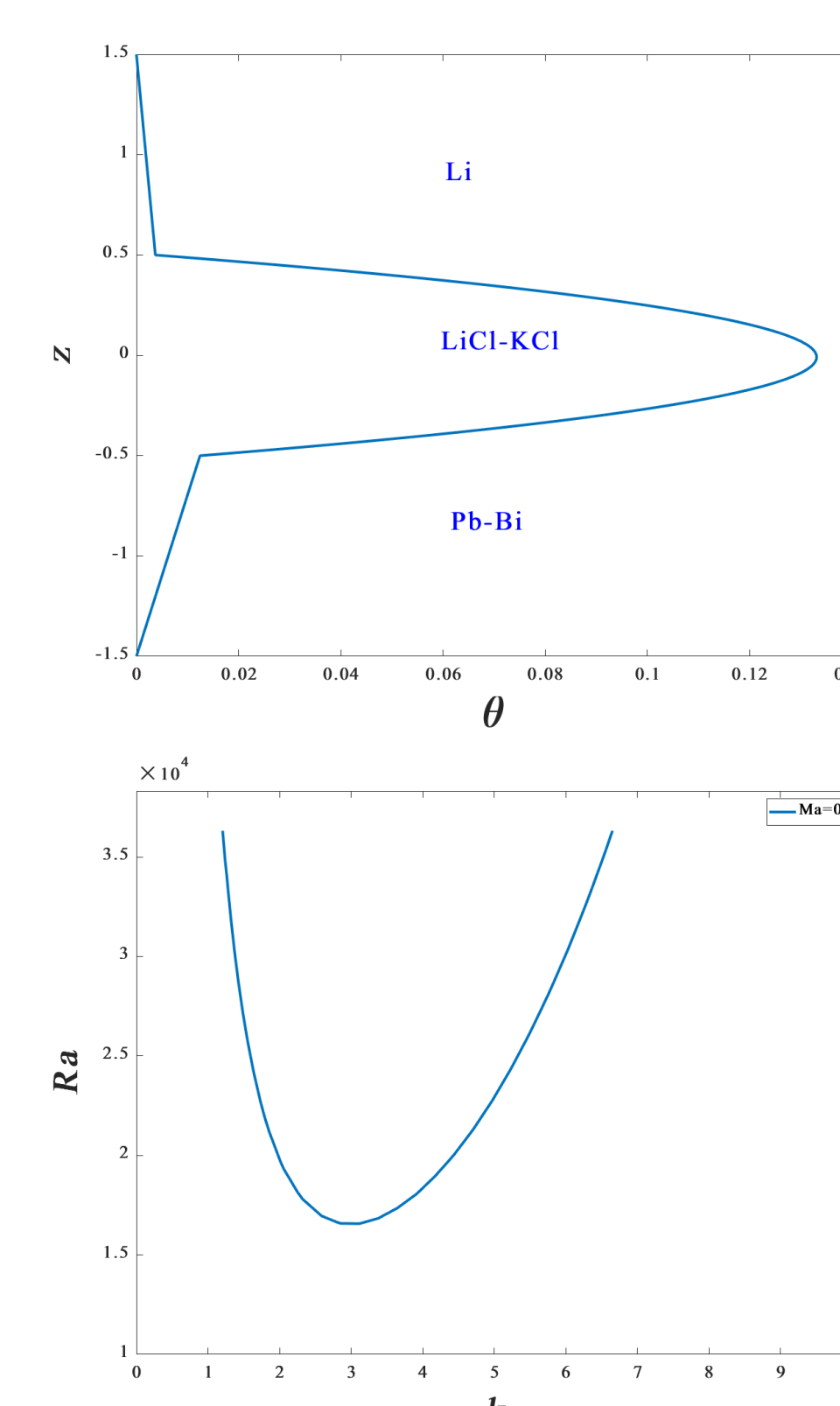
Condition for instability:

$$\frac{dE_c}{dt} > 0$$

Instability criterion

$$\beta = \frac{J^* B_z^* l_x l_y}{g(\rho_1 - \rho_2) h_1 h_2} > \beta_{cr} = 12 \quad [3].$$

- Not as effective improvements made about this criterion [4].
- Need for a more general criterion \Rightarrow compare to our infinite inviscid model inspired by [5] \Rightarrow better understand this interfacial instability.



- In the base state $\vec{V} = 0$ \Rightarrow only temperature profile exists. Figure : The temperature profile in the conduction state.

- Linear stability problem \Rightarrow eigenvalue resolution $\vec{A}\vec{\Psi} = s\vec{B}\vec{\Psi}$ with $s = \sigma + i\omega$ the complex growth rate. Figure : Marginal stability curve for $\sigma = 0$.

Critical parameters

| | |
|---------------------------|---------------------------|
| $Ma = 0$ | $Ma = 1000$ |
| $Pr = 7.26$ | $Pr = 7.26$ |
| $Ra_c = 1.65 \times 10^4$ | $Ra_c = 1.63 \times 10^4$ |
| $k_c = 2.99$ | $k_c = 2.97$ |

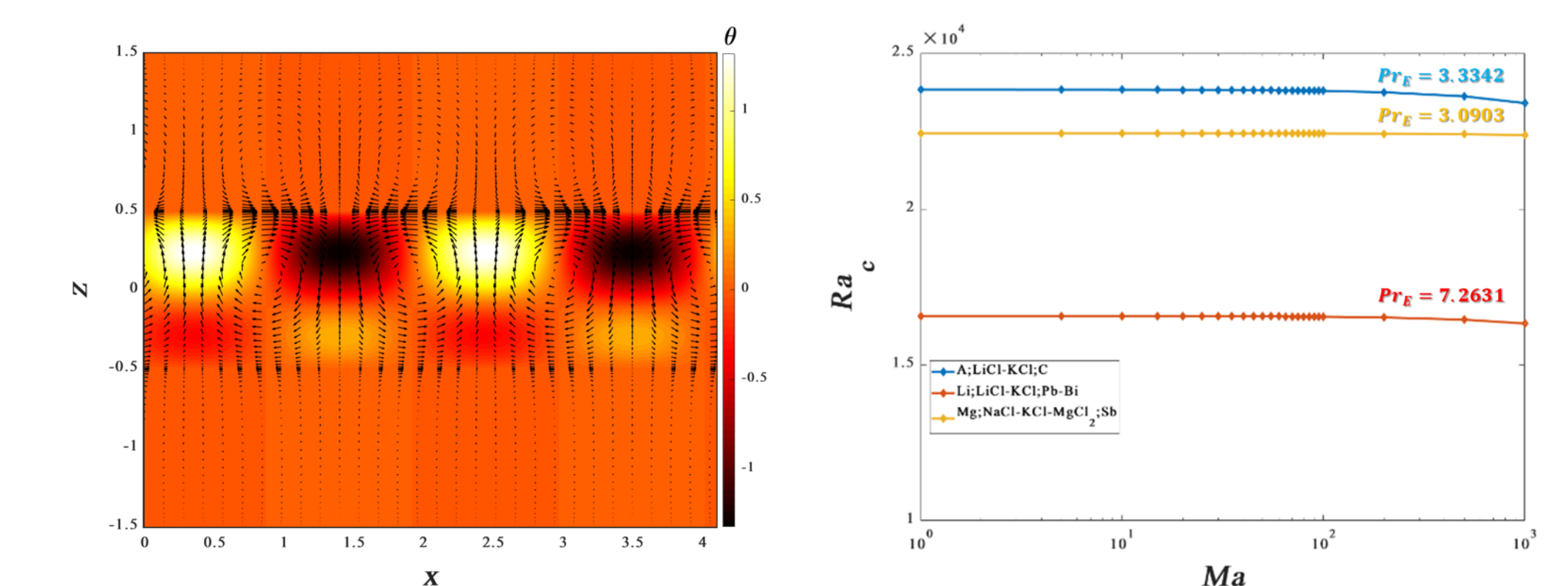


Figure : The Eigenfunctions of the battery around the critical limit at $Ma = 0$ and the variation of the threshold as a function of Ma for 3 different batteries [6-8].

- High working temperatures \Rightarrow inevitable thermal convection.
- Joule's volumetric heating \Rightarrow vortices displaced from the center of the electrolyte.
- Upper layer = thermally unstable region and lower electrode = thermally stable region. \Rightarrow stronger vortices in the upper electrode.
- No effect of surface tension on threshold of convection.

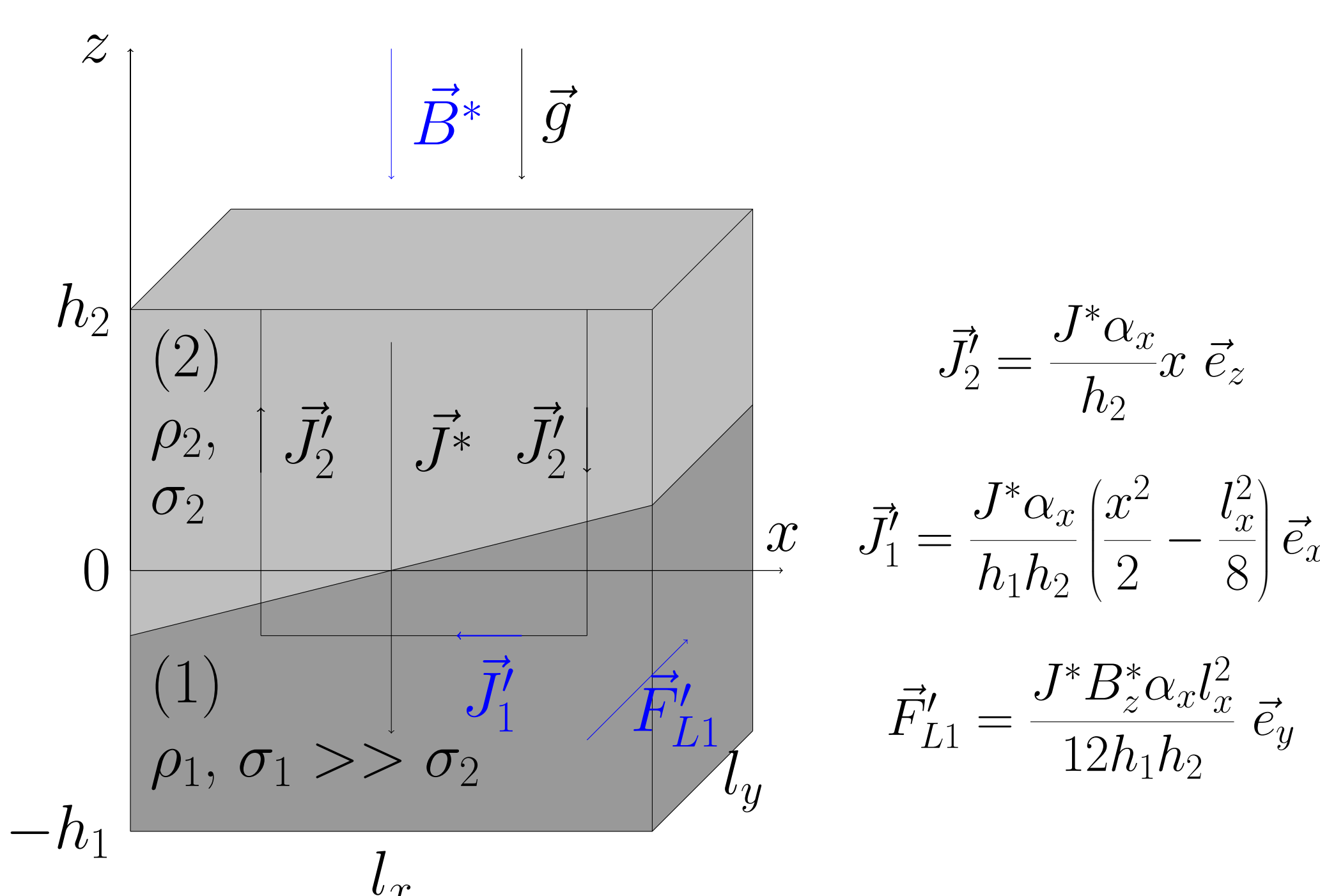


Figure : Forces in the cell.

Conclusions and perspectives

References

- Energy principle used to better understand the cell geometry effect on the shape of the instability.
- Perform numerical simulations to validate the general criterion.
- Linear stability code developed and validated for a non isothermal 3-layer case.
- Conduct an energy analysis to better understand the thermal instabilities in the system.

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