Contact Mechanics and Elements of Tribology

Foreword

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Outline

- Acquaintance
- Questionnaire
- Course content
- Historical remark
- Complexity
- Notations

Questionnaire

- Please fill in the questionnaire

Message to DMS students :

- Rank all suggested topics[1] for your report in the order of decreasing attractiveness
- Before the lunch one topic will be assigned to everybody
- On Friday (12/02) you will have 10 minutes to present briefly your topic to other students
- If you are not a DMS student but would like to follow, you are welcome
  Basava, Andrei and Paolo will also present rapidly their research projects on 12/02

- By Friday (**19/02**) you will need to send me your report on your topic (≈ 10 pages in Français/English)
- Criteria of evaluation : no plagiarism, scientifically sound report

[1] *or suggest a different one but not related to your master project*

Course content

Lectures :

1. Motivation : industrial applications
2. Contact Mechanics I & II
3. Contact at small scales : surface roughness
4. Computational Contact Mechanics
5. Contact rheology & friction laws
6. Elements of tribology : friction, adhesion, wear
7. Wear and fretting (by Henry Proudhon)
8. Multiphysical problems in contact
9. *Your presentations*

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9. *Your presentations*

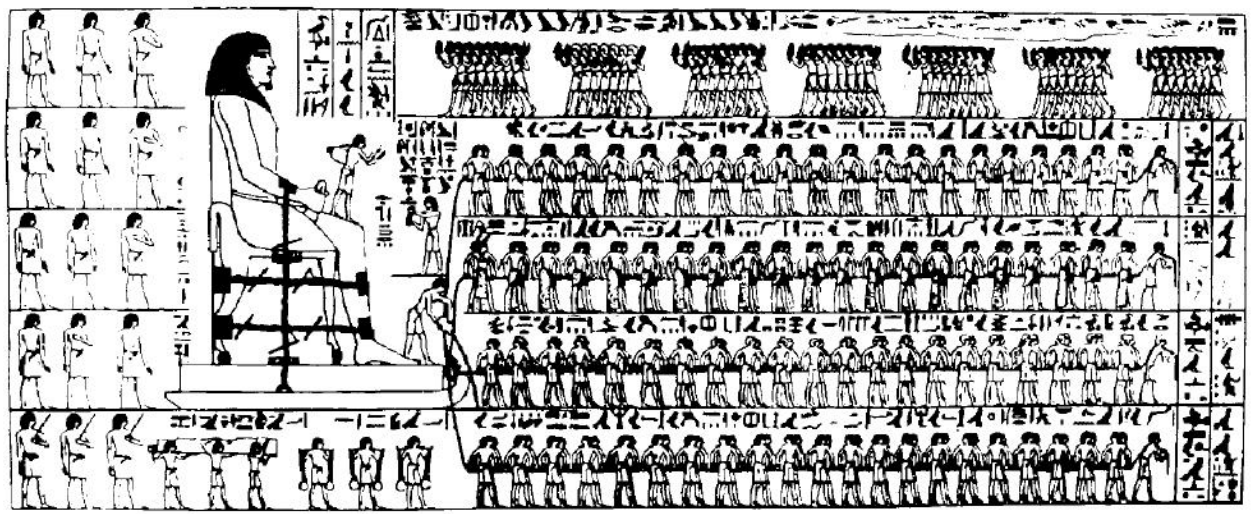
Practice :

1. Chalk and blackboard : Boussinesq, Cerruti, Flamant
2. Chalk and blackboard : Hertz contact
3. Computer : rough contact
4. Computer : frictionless and frictional cylindrical contact
5. Computer : elasto-plastic spherical indentation

Historical remark

Use of friction and overcoming of friction

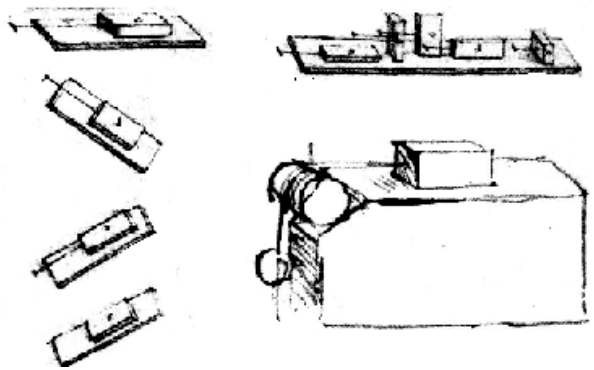
- Frictional heat - lighting of fire **> 40 000 years ago**.
- Ancient Egypt - lubrication of surfaces with oil **> 5 000 years ago**.



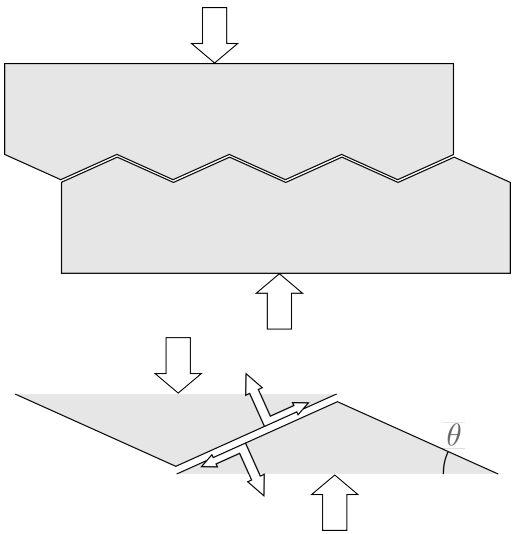
Historical remark

First scientific studies on contact and friction

- **Leonardo da Vinci** [1452-1519]
  first friction laws and many other tribological topics
- **Isaac Newton** [1687]
  Newton's third law for bodies interaction
- **Guillaume Amontons** [1699]
  rediscovered friction laws
- **Leonhard Euler** [1707-1783]
  roughness theory of friction



From Leonardo da Vinci's notebook

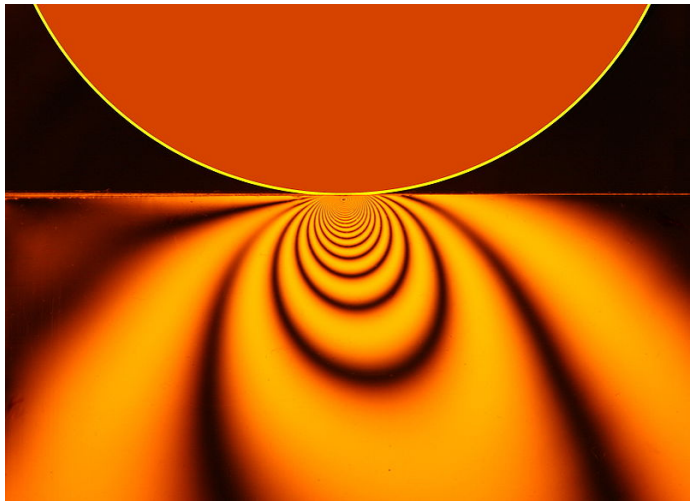


Roughness theory of friction

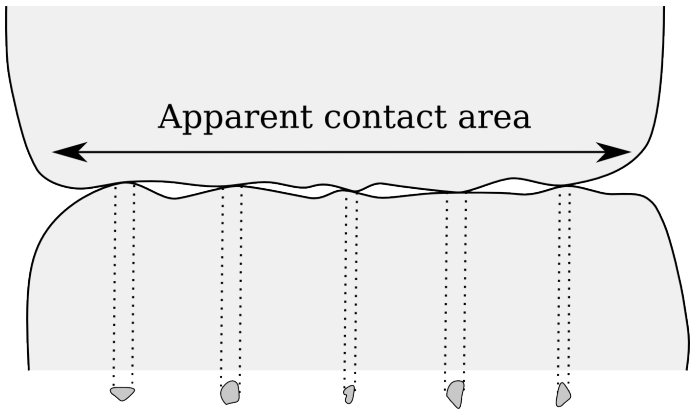
Historical remark

First scientific studies on contact and friction

- **Charles-Augustin de Coulomb** [1789]
  friction independence on sliding velocity and roughness, the influence of the time of repose
- **Heinrich Hertz** [1881-1882]
  the first study on contact of deformable solids
- **Holm** [1938],
  Ernst and Merchant [1940],
  Bowden and Tabor [1942]
  difference between apparent and real contact areas, adhesion theory.



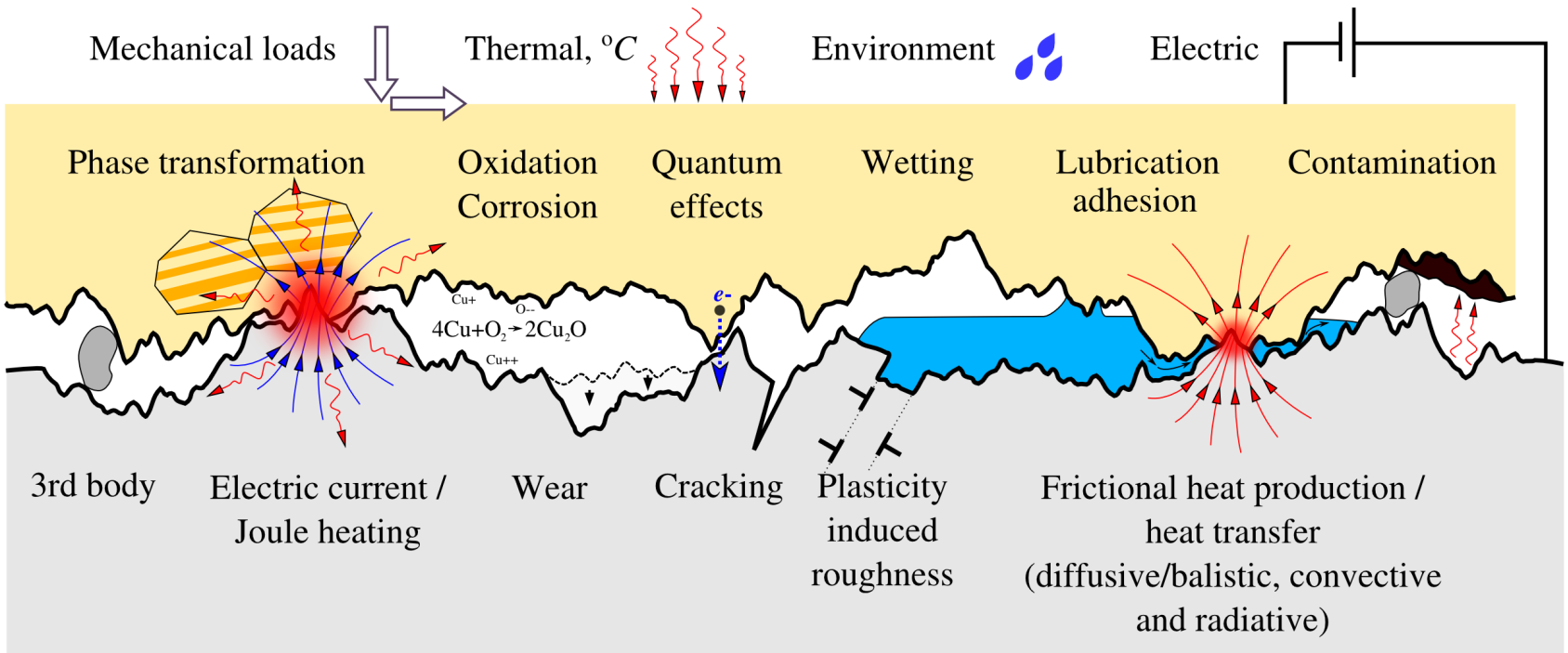
Photoelasticity analysis of Hertz contact problem
(fringes correspond to max shear stresses)



Apparent and real areas of contact

Complexity

- **Zoom on the contact interface**
- Between different heterogeneous materials with specific rough surfaces
- Under various loads



Involved physical phenomena

Primary phenomena (atomic/electronic interactions)

1. Contact (non-penetration)
2. Friction (tangential resistance)
3. Adhesion (resistance to tension)
4. Surface energy
5. Quantum effects (tunneling, Casimir effect)

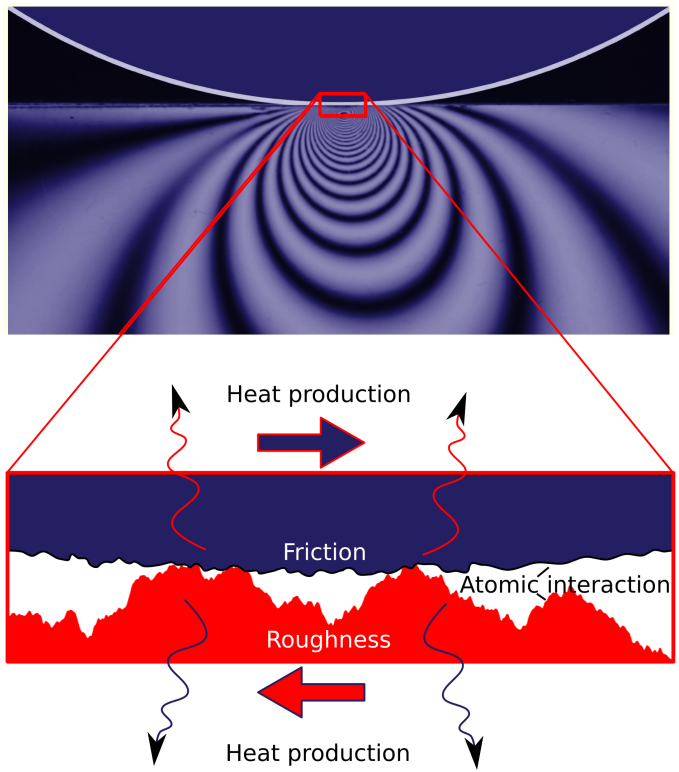
Secondary phenomena

1. Wear
2. Lubrication (fluid-structure interaction)
3. Environmental effects (oxidation)
4. Aging, diffusion
5. Heat production
6. Heat and electricity transfer

Contact complexity : physics and mathematics

Particular difficulties related to contact problems :
multiphysical aspects, mathematical aspects

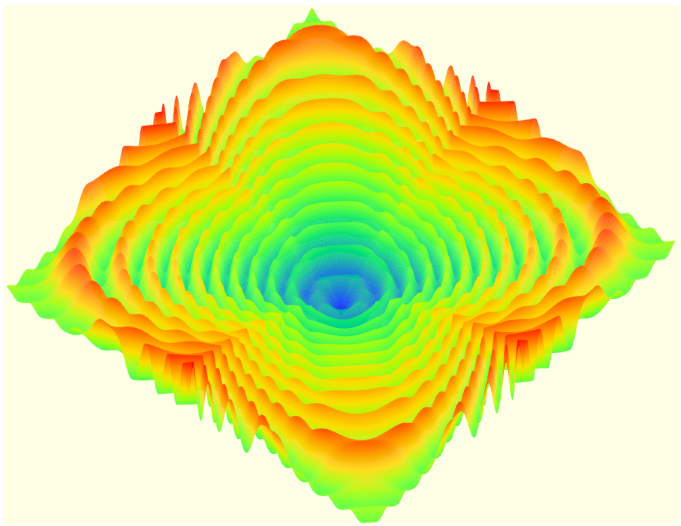
- Fractality of surfaces
- Interface chemistry
- Hardly accessible contact interface
- Generation and diffusion of heat
- Multiscale and multiphysical nature of friction



Contact complexity : physics and mathematics

Particular difficulties related to contact problems :
multiphysical aspects, **mathematical aspects**

- One of the most hard problems in mechanics
- Lack of standard optimization problem
- Non-convexity and non-differentiability
- Non-continuous character
- Bad scalability



Notations

Vectors and tensors

- a, α scalars
- $\underline{b}$ vectors
- $\underline{\underline{C}}, \underline{\underline{\beta}}$ 2nd order tensors
- $\overset{4}{\underline{\underline{D}}}$ 4th order tensors
- $\nabla \underline{a} = \underline{\underline{B}}$ gradient operator
- $\nabla \times \underline{a} = \underline{\underline{B}}$ rotor operator
- $\underline{a} \cdot \underline{b} = c$ scalar (dot) product
- $\underline{a} \times \underline{b} = \underline{c}$ vector (cross) product
- $\underline{a} \otimes \underline{b} = \underline{\underline{C}}$ tensor product
- $\underline{\underline{A}}^T$ transposition
- $\nabla \cdot \underline{a} = c$ divergence operator
- $\underline{\underline{I}} = \underline{e}_i \otimes \underline{e}_i$ unitary 2nd order tensor

Mechanics

- $\underline{\underline{\sigma}}$ Cauchy stress tensor
- g, g_n gap, normal gap
- ϵ penalty parameter
- $\lambda, \lambda_n, \lambda_t$ lagrange multipliers
- $\sigma_n = (\underline{\underline{\sigma}} \cdot \underline{n}) \cdot \underline{n}$ contact pressure
- $\underline{\underline{\varepsilon}}$ Small strain tensor
- $\underset{\sim}{\xi}$ position vector in parent space
- $\underline{n}$ outward unit normal vector
- $\frac{\partial \underline{\underline{\varrho}}}{\partial \xi_1}, \frac{\partial \underline{\underline{\varrho}}}{\partial \xi_2}$ surface tangent vectors
- f Coefficient of friction

☺ Welcome to CMET course !