

Surfaces & Interfaces

Lesson 1

MSE 304

Nako Nakatsuka

Nako.Nakatsuka@epfl.ch

September 12th 2025



Outline of Lesson 1

- Information on the **course**
- Introducing the **teaching team**
- Introducing **surface science** – challenges and opportunities
- Why study **surface science**? – applications and Nature



Information on this Class

- All information for this class will be on Moodle
 - I will upload the slides for the Friday lecture by latest Thursday evening
- The class will be taught in a classical way:
 - In-class teaching (in-person attendance required, no recordings)
 - Questions/engagement in class encouraged
 - Annotated slides will be on Moodle



Information on this Class - Schedule

- October 6-12 (Week 5): Student feedback
- October 24: No class (semester break)
- December 19: Last day of class (taught by Postdoc: Dr. Emily Schafer)
- January 12-31: Exam period



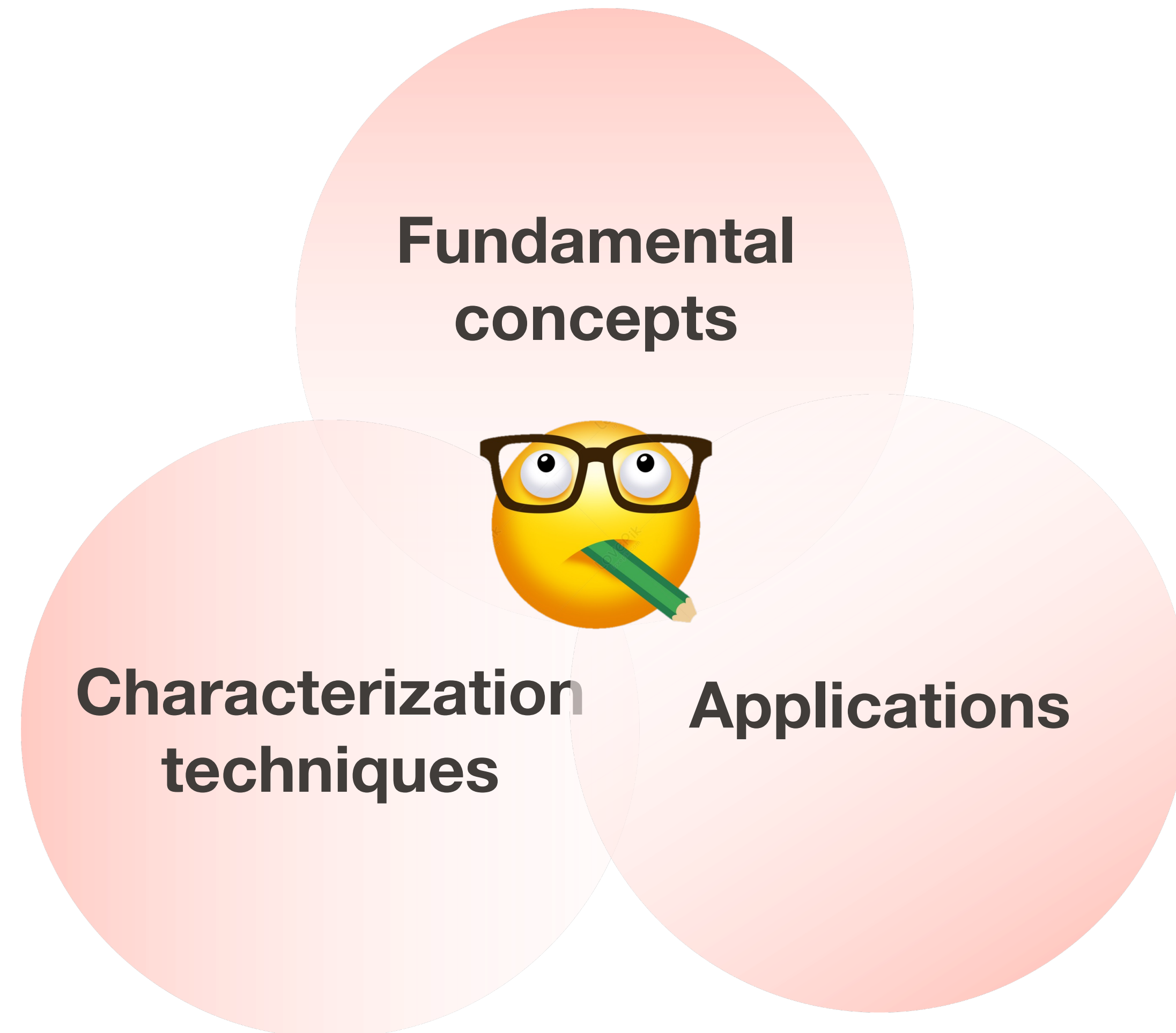
Information on this Class – Final Exam

- There will be a single oral exam
- It will be helpful to get used to answering questions and engaging in class!
- The Exercise Session is designed to help you prepare for the final exam
- The whole class, including the exam, is in English



Learning Goals

Overall goal: By the end of this course, you should understand the key fundamental concepts of surfaces & interfaces. You will be able to critically select techniques to characterize surfaces and explain the role played by surfaces & interfaces in a broad range of phenomena in applied systems.



Plan of the Course: Fundamentals, Characterization, and Applications

1: Intro to Surfaces & Interfaces

2: Surface Energy & Real Surfaces

3: Solid-Solid Interfaces

4: Characterization of Real Surfaces

5: Solid-Liquid Interfaces + Techniques

6: Interfacial Phenomena

7: Charged Solid-Liquid Interfaces

8: Adsorption at Interfaces

9: Surface Chemistry

10: Biological Processes at Surfaces

11: Electronic Properties of Surfaces

12: Thin Film Technologies

13: Biosensor Fundamentals

14: Biosensing applications

Things may be adapted in real time – thank you for your patience!
Midterm feedback (Week 5) – Recap session Week 7?



Information on the Teachers

Prof. Nako Nakatsuka - Lectures

Nako.Nakatsuka@epfl.ch



Teaching Assistants – Exercises

Emie-Kim Ngo Tan

Emie-kim.ngotan@epfl.ch



Lianxin Xu

lianxin.xu@epfl.ch



Emie-kim Ngotan (TA)

Passionate about translating science into real-world therapies.



Pharmacist

Université de
Strasbourg
2011-2019



**Chemical
Engineer**

ENSIC
2016-2019



Scientist

Lonza
Protein formulation
2020-2023



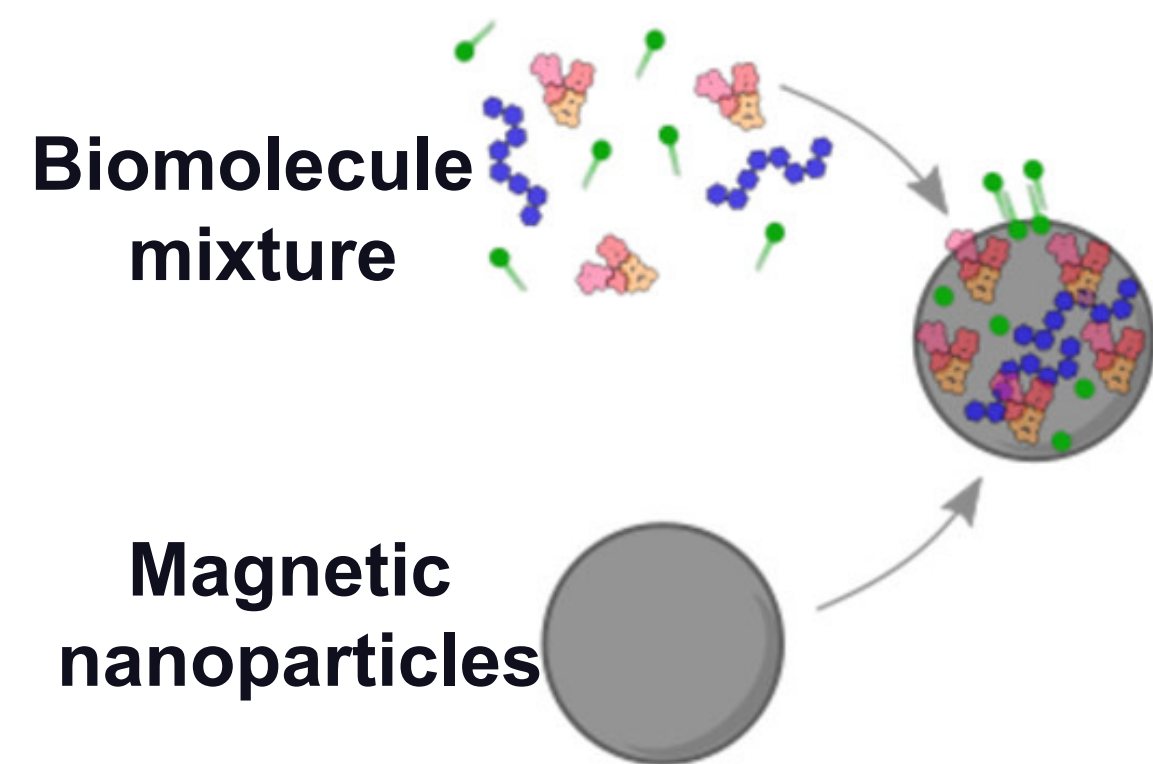
PhD

Pr. Stellacci
mRNA-LNPs
2023-
ongoing

Lianxin Xu (TA)



Chemical Engineering M.Sc.



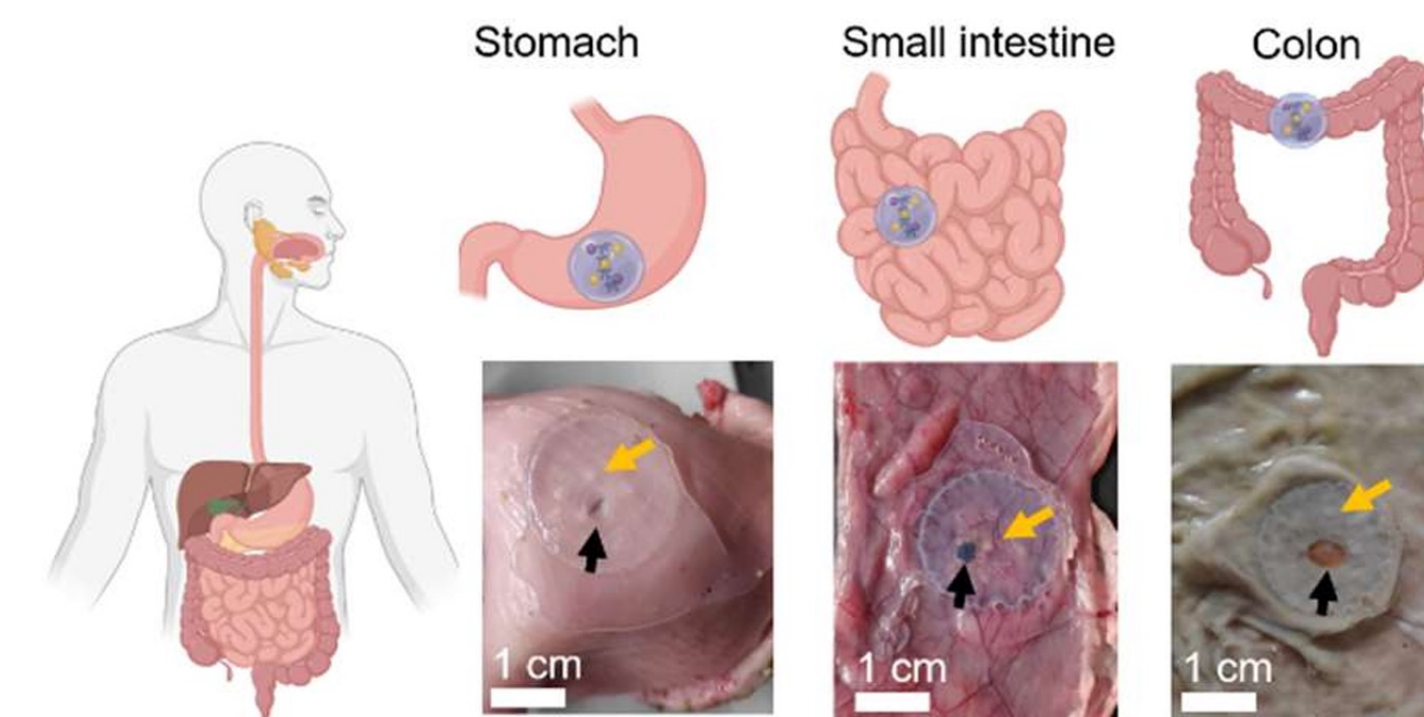
Abarca-Cabrera *et al.*, *ACS Applied Bio Materials*, 2023



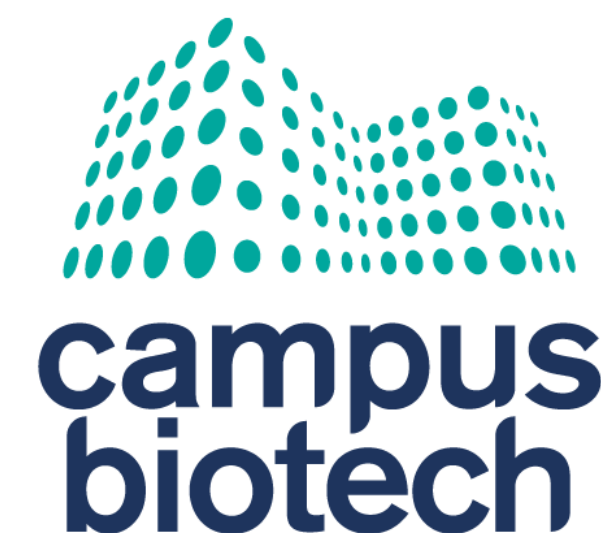
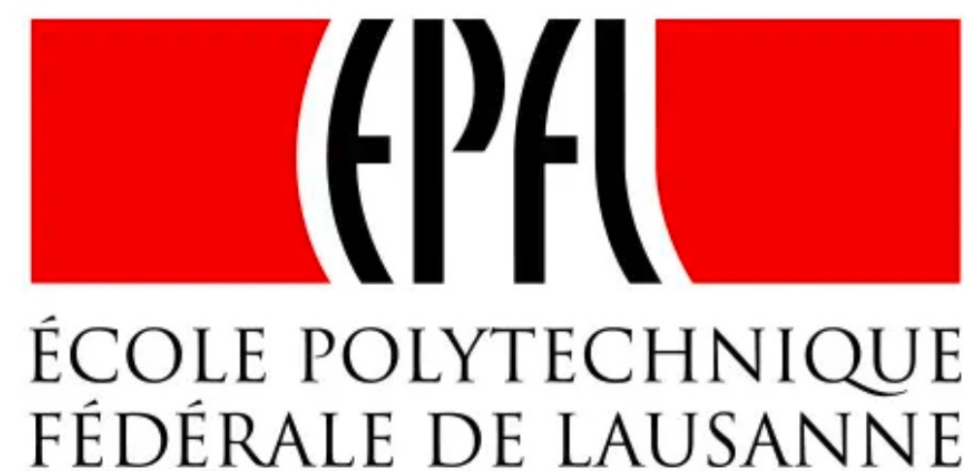
Drug crystal engineering



Tissue engineering

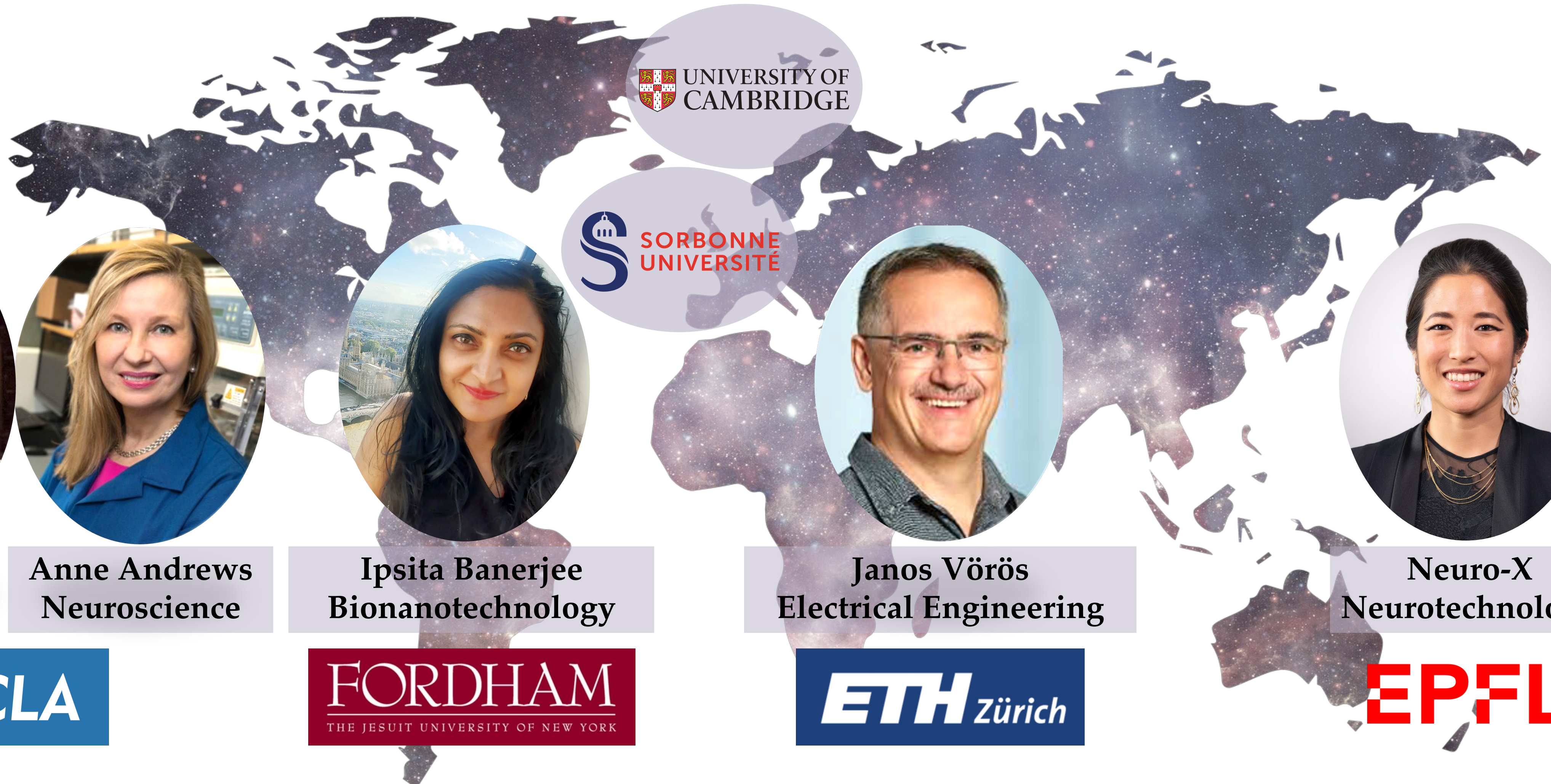


Anthis *et al.*, *Nat Commun*, 2022



lianxin.xu@epfl.ch

My Academic Journey



Paul Weiss
Chemistry



Anne Andrews
Neuroscience



Ipsita Banerjee
Bionanotechnology



Janos Vörös
Electrical Engineering



Neuro-X
Neurotechnology



Laboratory of Chemical Nanotechnology

Campus Biotech, Geneva

Swiss Center of Excellence in Biotechnology focused on:
Neuroscience & Neurotechnology
Digital Health
Global Health

The Campus functions as a giant incubator focused on translation of fundamental science into real solutions that have an impact on society

EPFL

Neuro **X** Institute



**UNIVERSITÉ
DE GENÈVE**

WYSS  CENTER

fb **fondazione
bertarelli**

Laboratory of Chemical Nanotechnology

Harnessing nanoscale chemistry to design technologies to improve human health

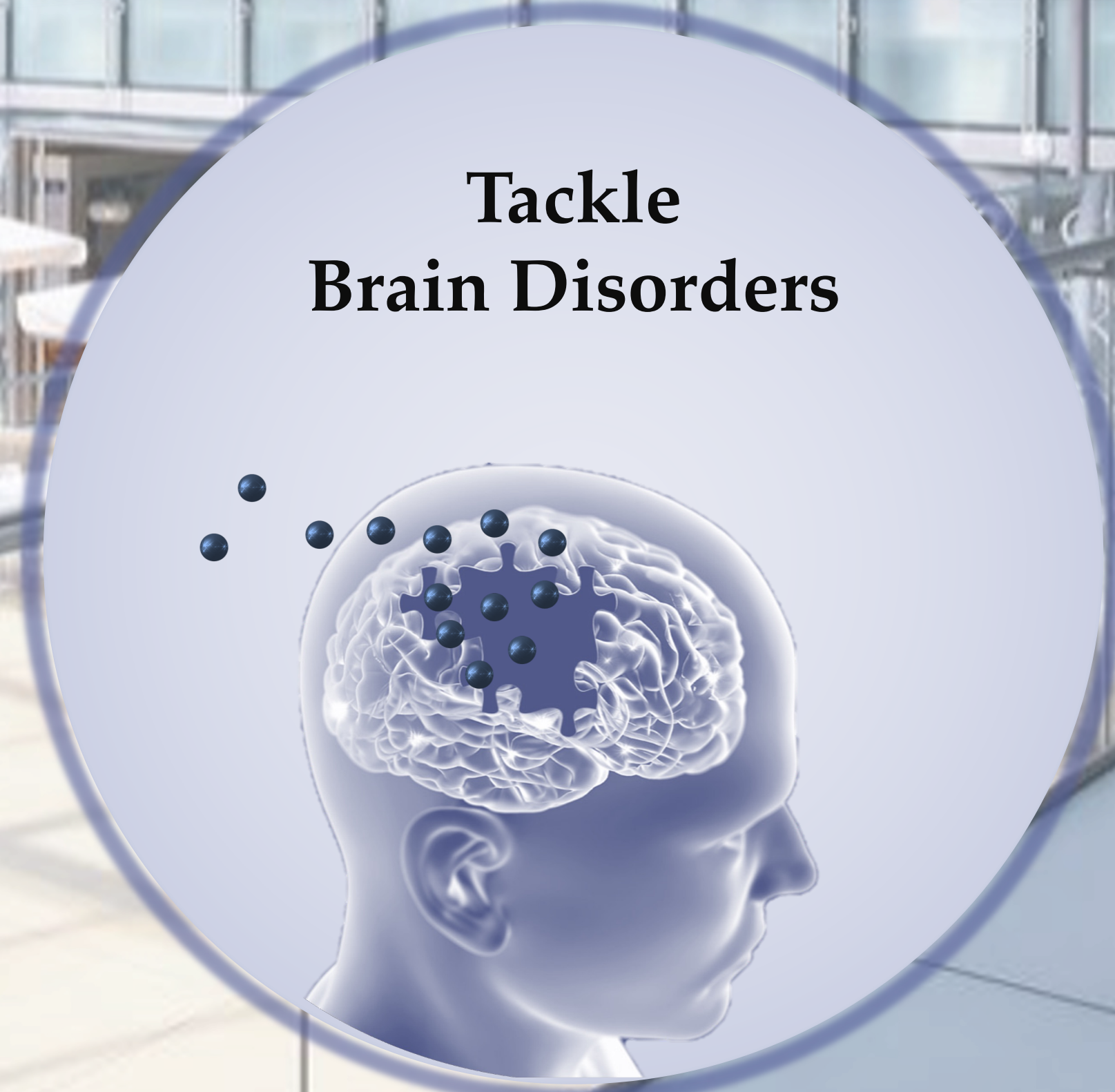
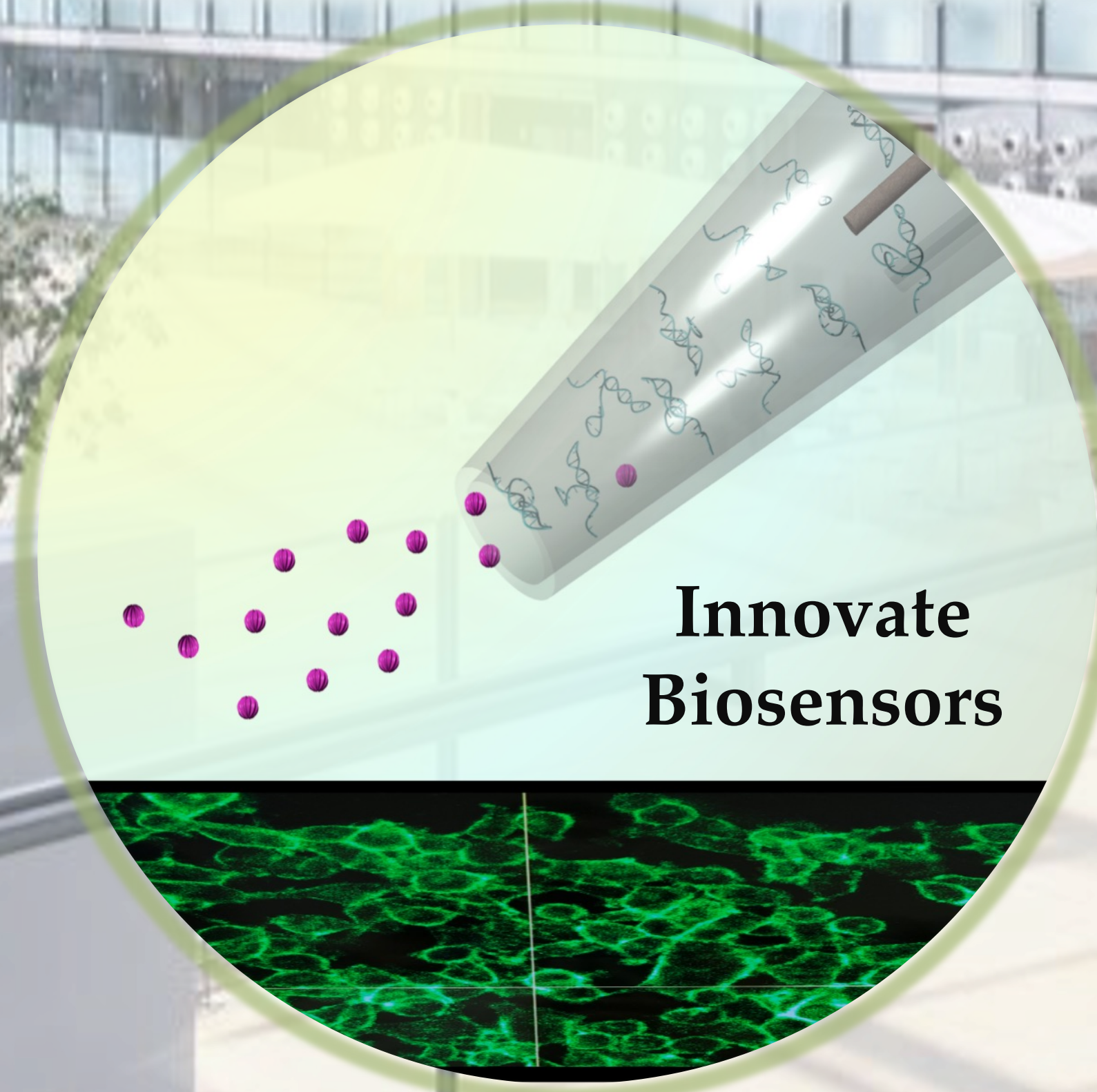
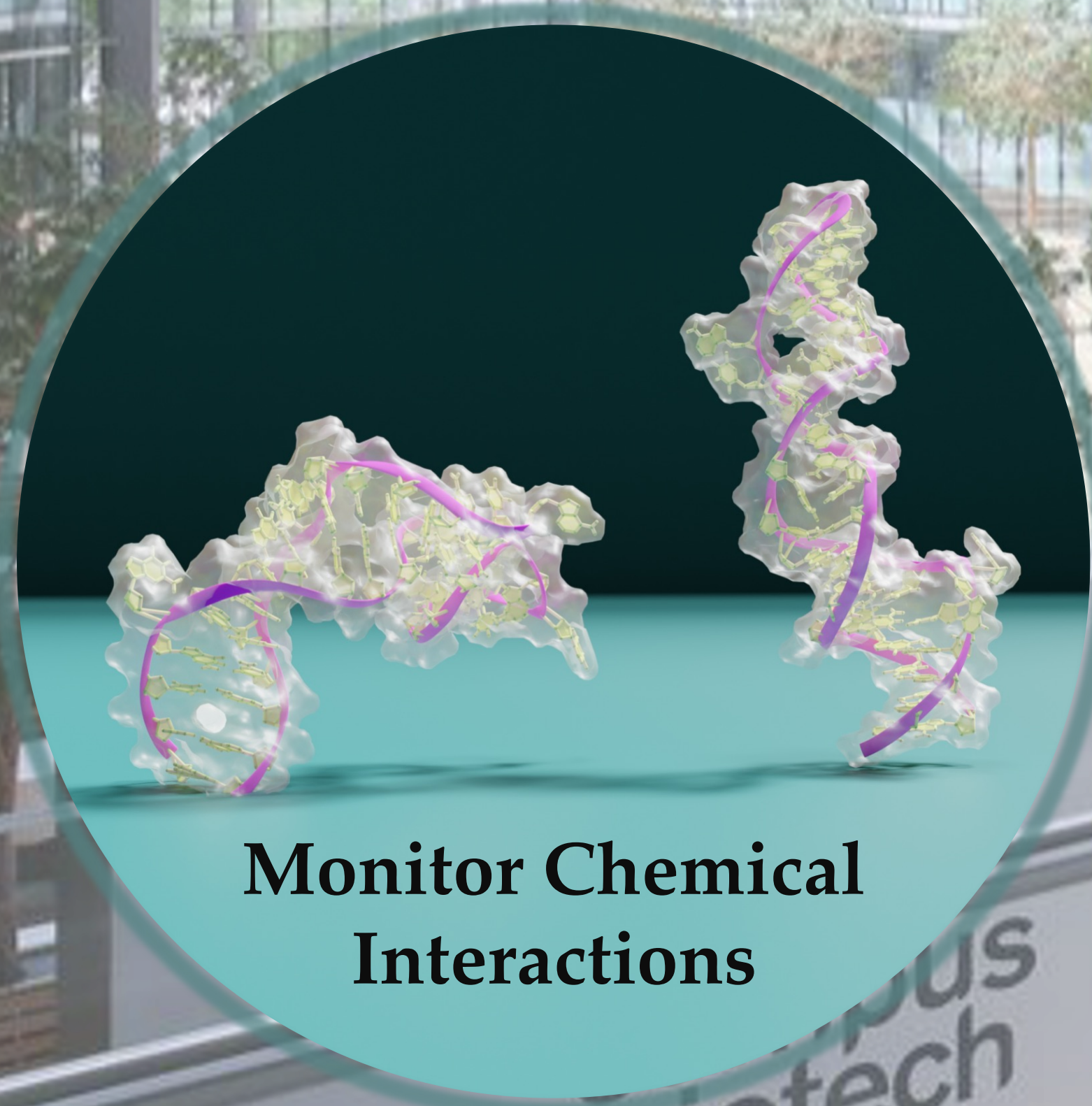
Chemistry



Engineering



Neuroscience



biotech

Surfaces & Interfaces in Our Research

Surface chemistry, characterization, and protection in biological systems

Ideal environment (buffer)

Analytes

Aptamers

Sensor material

Transducer

Signal readout

mM
(10^{-3})

pM
(10^{-12})

Laboratory of Chemical Nanotechnology

Driving Innovation with a Multidisciplinary International Team



Nako
Nakatsuka



Jessica
Empain



Emily
Schafer



Annina
Stuber



Ali
Elmorsy



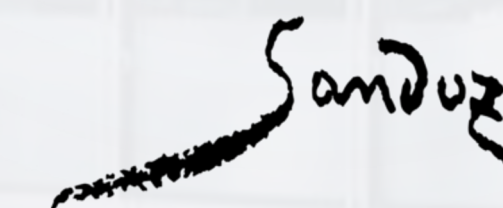
Lianxin
Xu



Sandra Hernandez
Escobar



Alexandra
Banbanaste



FONDATION
PHILANTHROPIQUE
FAMILLE SANDOZ



fondation
PIERRE MERCIER



"la Caixa"



Neuro X Institute

Acknowledgement of Course Inspiration & Support



Prof. Francesco Stellacci



Prof. Lucio Isa



Prof. Nic Spencer

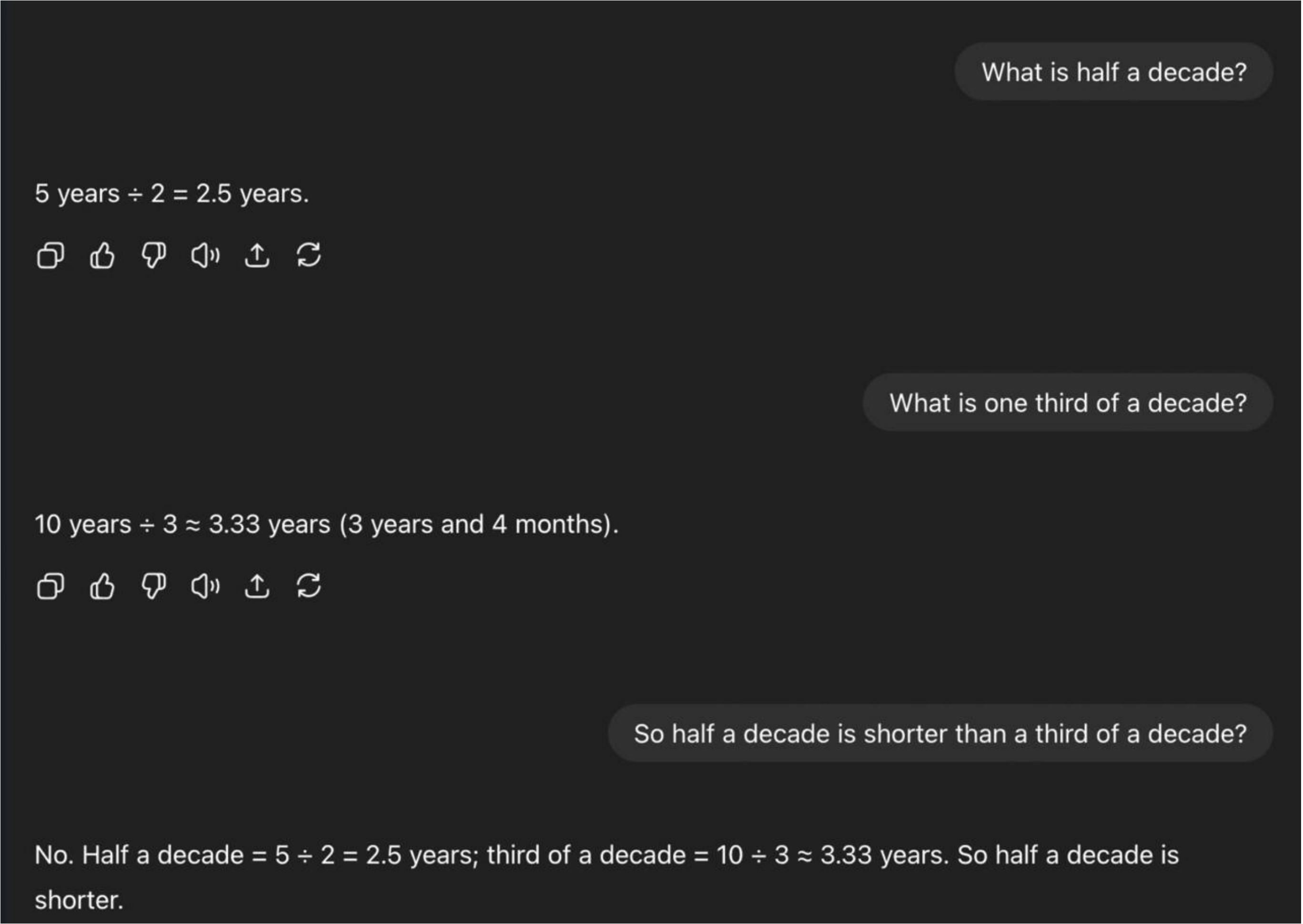
EPFL

ETH zürich



Let's Talk about ChatGPT and AI Tools in General

Use it as a tool to help you understand concepts, but don't rely fully



Source: Werner Seitz - LinkedIn



Engage with the tool to help you to understand concepts but don't take everything it says for face value

We should always critically review the answers AI tools give us



Let's Talk about ChatGPT and AI Tools in General

What AI do students chose ?

Tool	N	%
GPT	387	93%
Coding support (Copilot, cody, phind)	105	25%
Other LLM (Mistral, Sora, Gemini, Bard, Ariya)	30	7%
Writing support (deepl, grammarly)	23	6%
Image processing (midjourney, dall-e, stability, etc.)	31	7%

Source: EPFL Teaching Day 2025



Let's Talk about ChatGPT and AI Tools in General

Positive experiences with AI

- Getting simple explanations for a complex topic
- Getting 24/7 help
- Code to generate plots
- Debugging
- Writing formal letters
- Writing in foreign languages



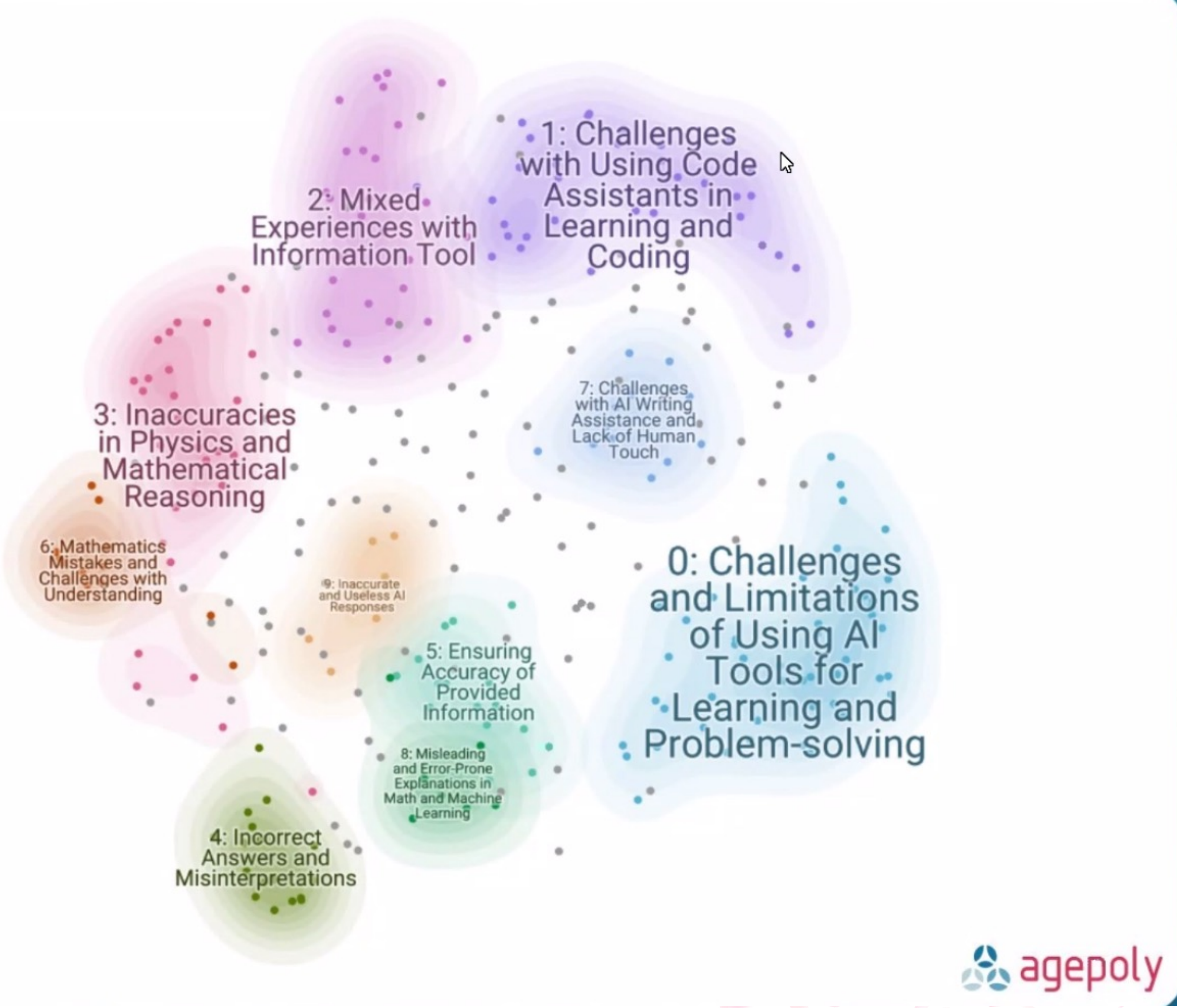
Source: EPFL Teaching Day 2025



Let's Talk about ChatGPT and AI Tools in General

Negative experiences with AI

- Risk of lowering the learning (off-loading too much to AI)
- Risk of getting a wrong answer - mostly in maths and physics.
- Data protection



Source: EPFL Teaching Day 2025



AI at EPFL – How to Be Informed

Information: <http://go.epfl.ch/ai-teaching>

Guidelines: <http://go.epfl.ch/guidelines-ai-ed>

AI/Ed workshops: Sept 18, Sept 30, Oct 16: <http://bookwhen.com/epfl>

Source: EPFL Teaching Day 2025



Surfaces & Interfaces

Continuum Approach

(Classical Thermodynamics)

Surfaces are the terminal limiting planes for objects – they are 2-D complex planes

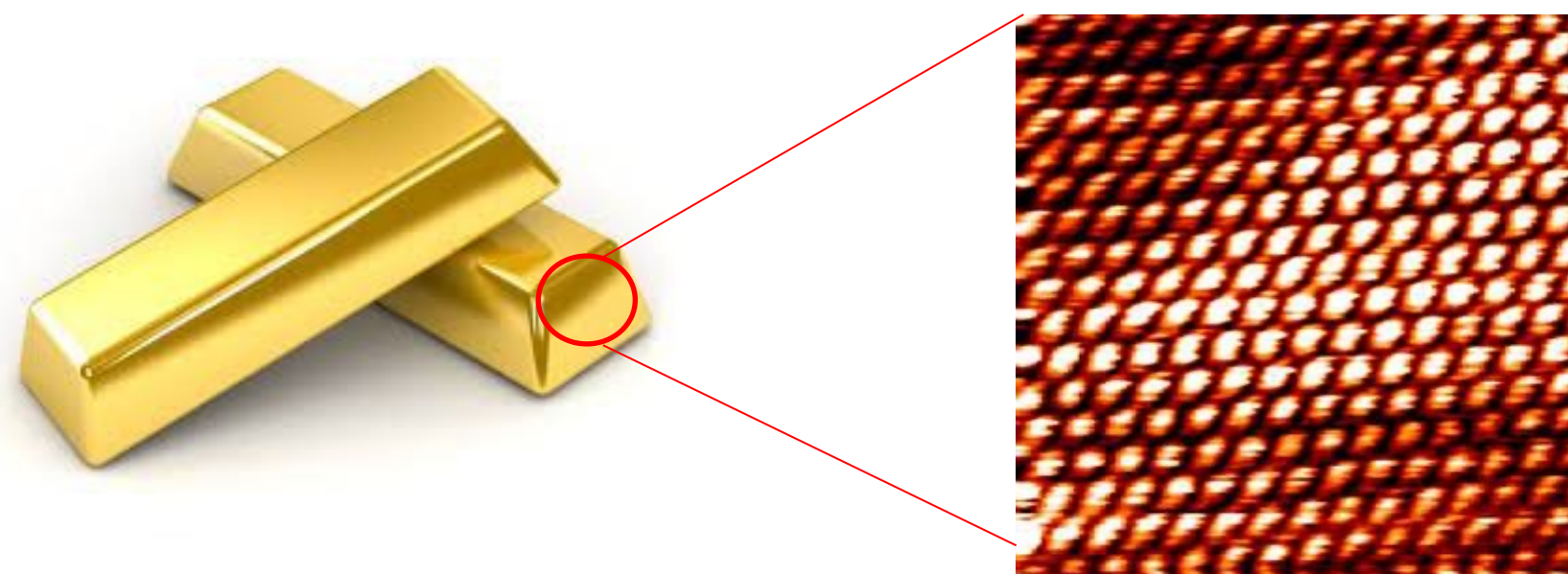
Atomistic Approach

(Statistical Mechanics)

Surfaces are 2-D defects in materials, specifically, they are topological defects containing under-coordinated units

Pure materials

“Interface between a material and nothing (*i.e.*, Ultra-High Vacuum)”



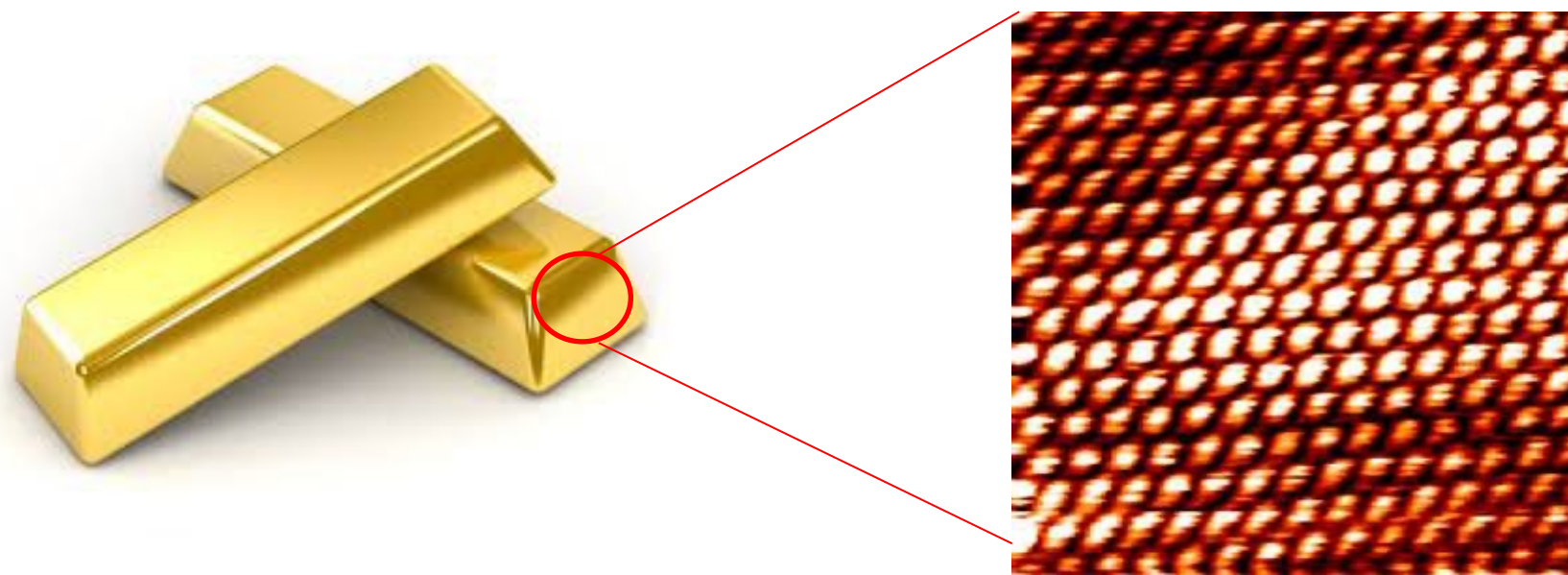
Au(111) by contact-mode AFM

Only solids

Surfaces & Interfaces

Pure materials

“Interface between a material and nothing
(*i.e.*, Ultra-High Vacuum)”



Au(111) by contact-mode AFM

Only solids

Surface of contact between two different materials or two different phases

Solid- Solid
Solid-Liquid
Solid-Gas
Liquid-Liquid
Liquid-Gas

Surfaces & Interfaces



Surface of contact between two different materials or two different phases

- Solid- Solid
- Solid-Liquid
- Solid-Gas
- Liquid-Liquid
- Liquid-Gas

Surfaces & Interfaces

Continuum Approach

(Classical Thermodynamics)

When two surfaces come in atomic contact, they form an interface.

Hence interfaces are topological defects formed by joining two surfaces

Atomistic Approach

(Statistical Mechanics)

Interfaces are topological defects formed by the joining of two surfaces

Surface of contact between two different materials or two different phases

Solid- Solid

Solid-Liquid

Solid-Gas

Liquid-Liquid

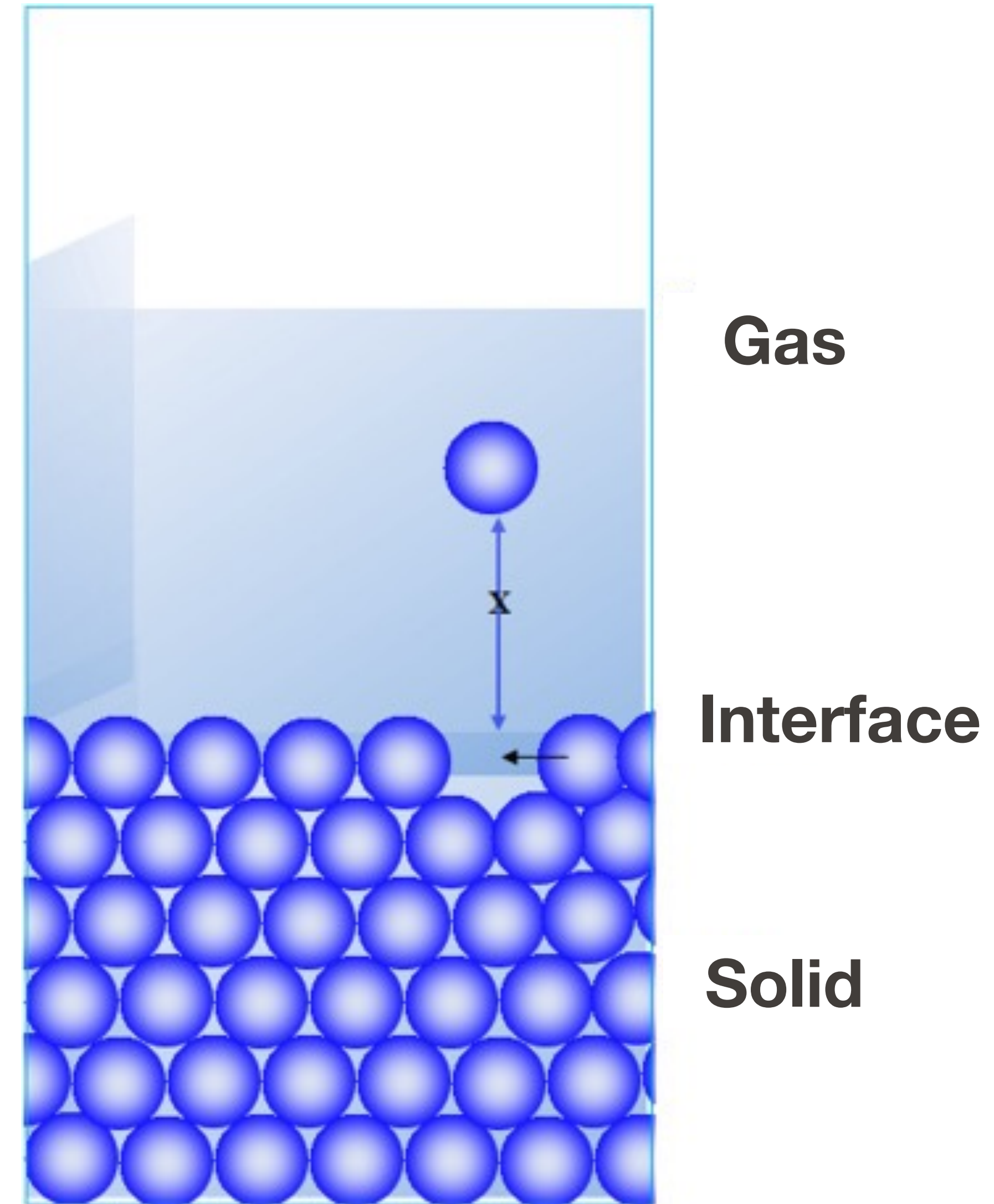
Liquid-Gas

Do Surfaces Exist?

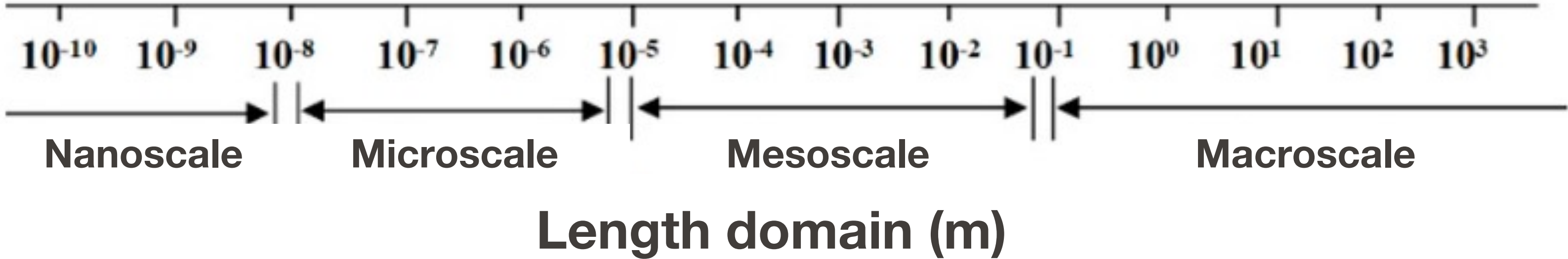
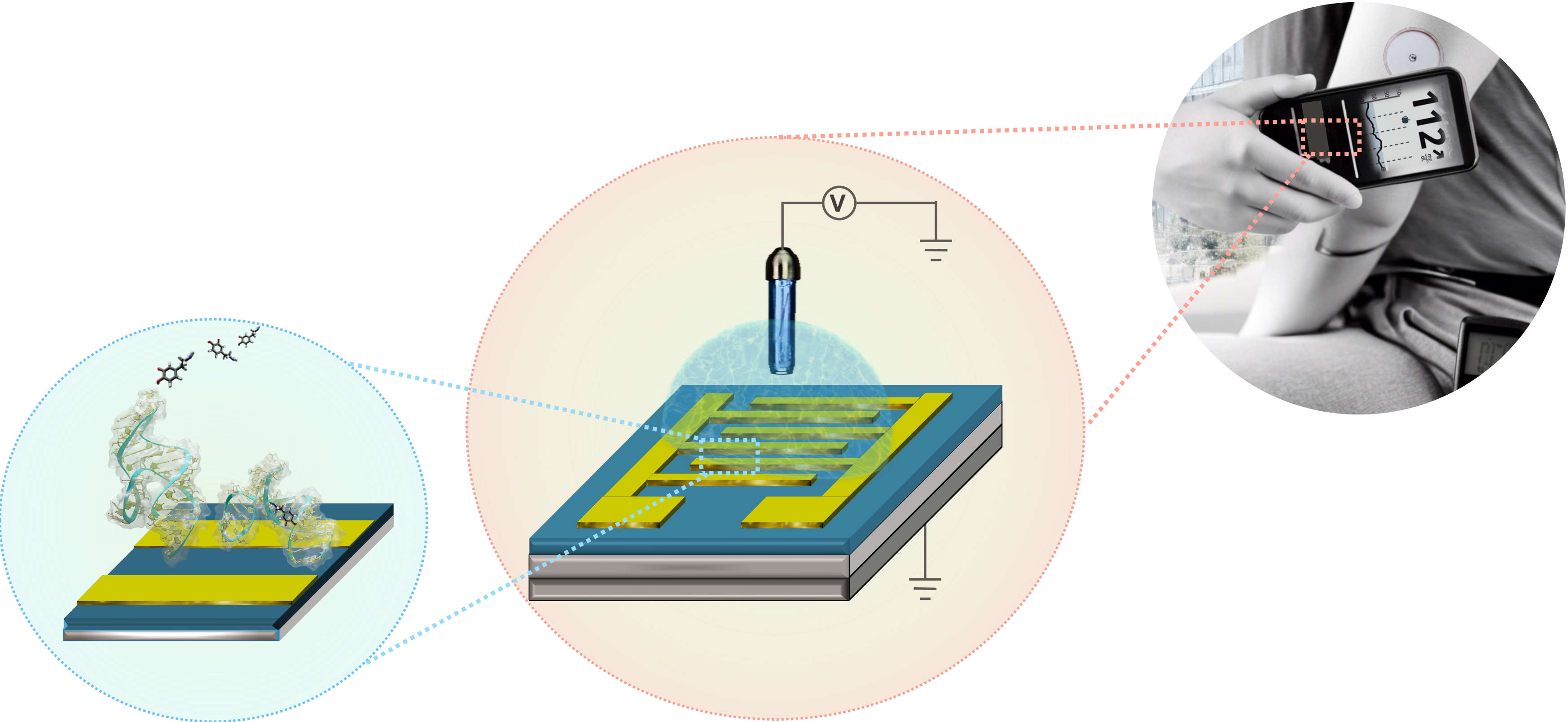
For a surface to exist in Nature,
above it there needs to be nothing

If this exists, it's a rare event

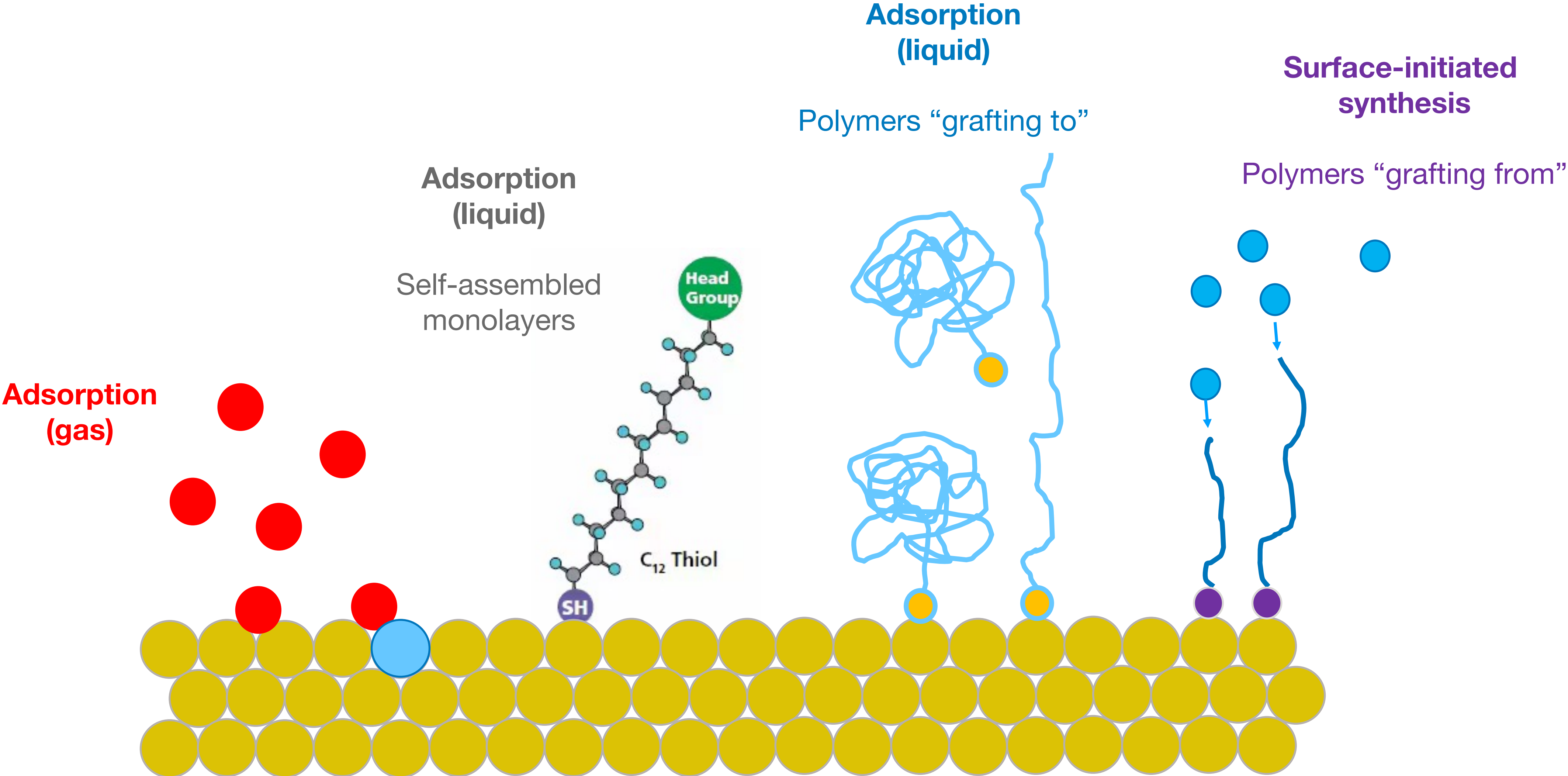
This class will mostly be about
interfaces – where a material ends,
something else begins



Surfaces & Interfaces at Different Length Scales



Modifications of Solid Surfaces



Surfaces & Interfaces

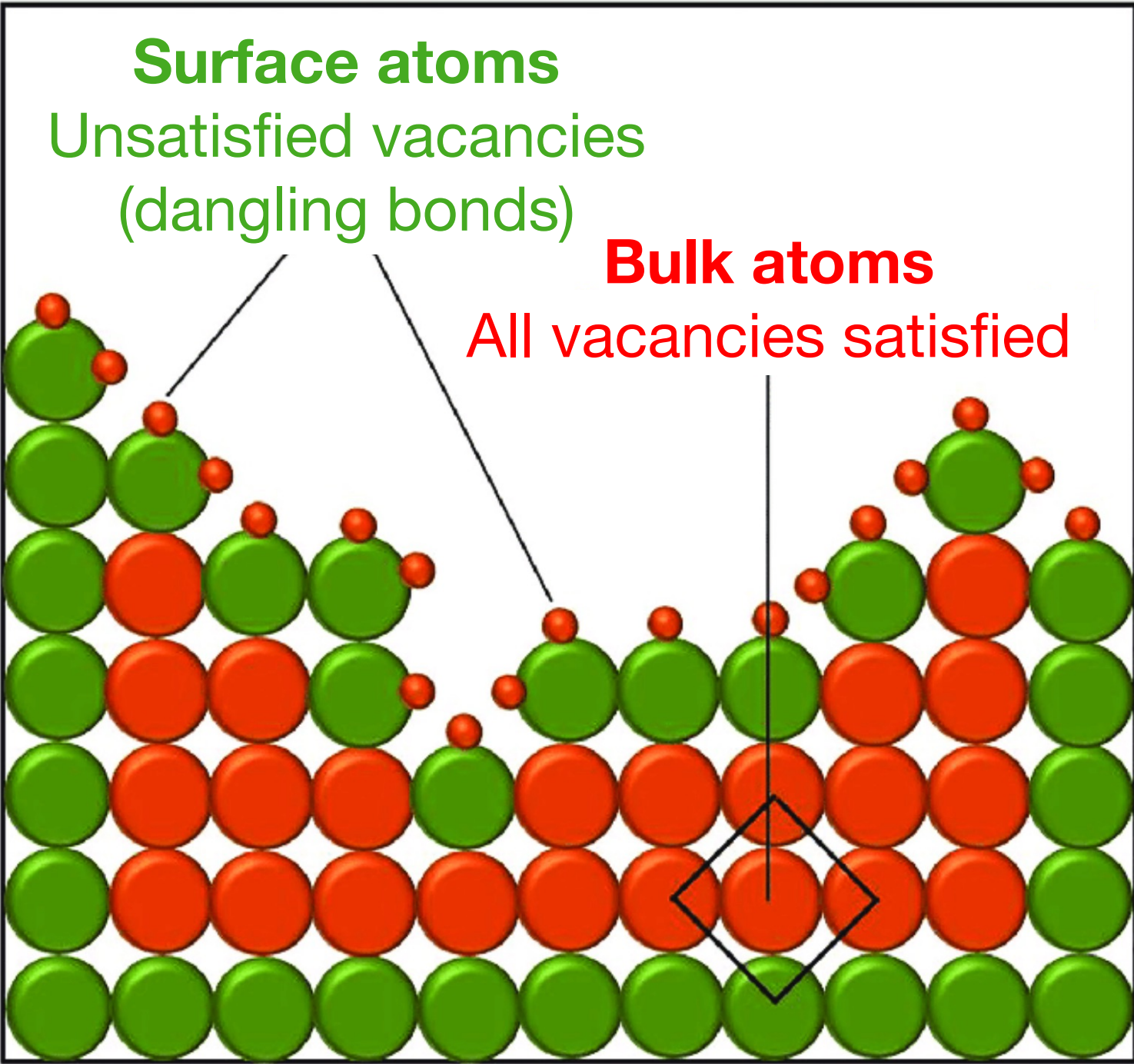


Wolfgang Pauli

God made solids, but surfaces were the work of the Devil



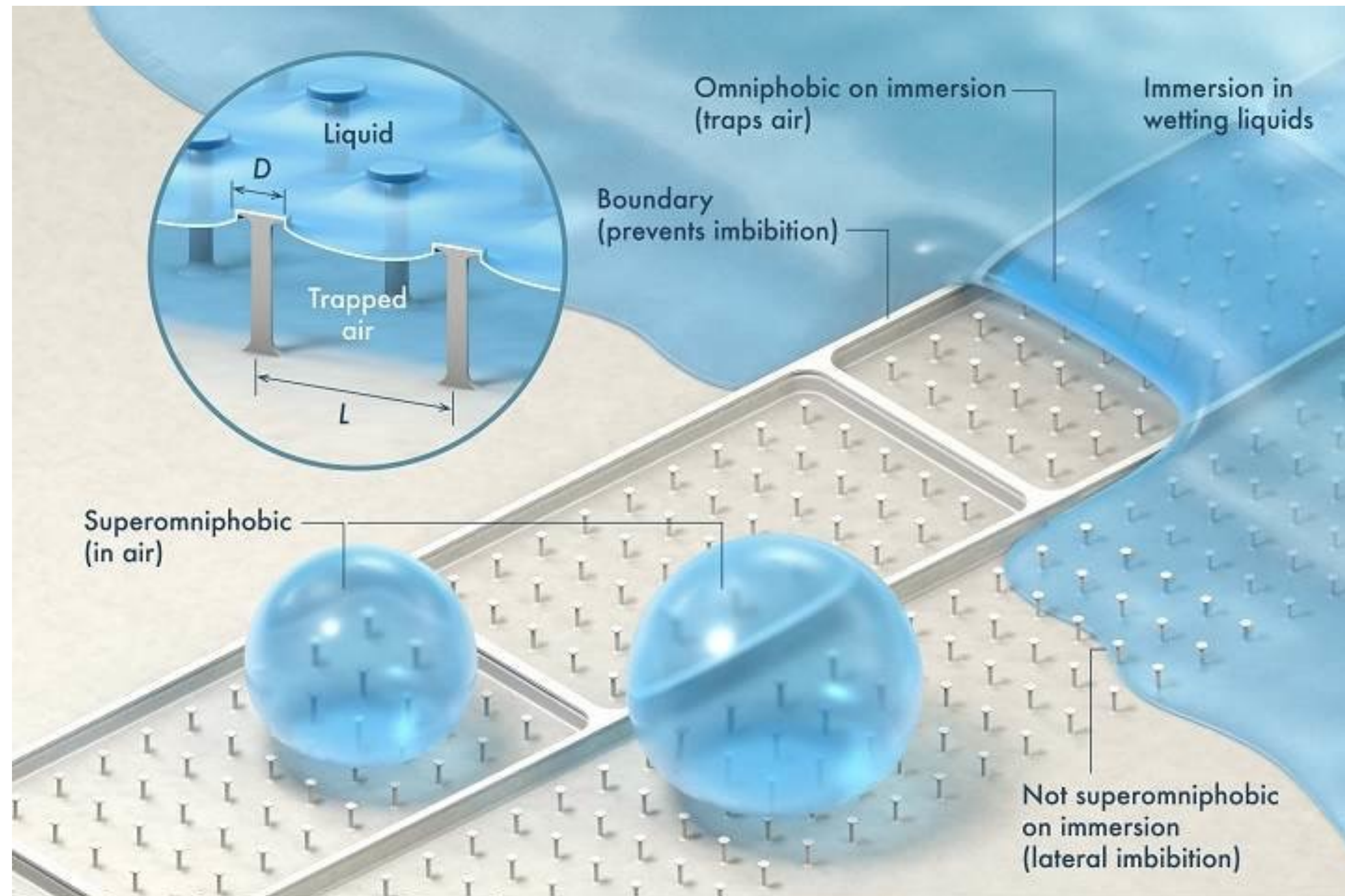
Nobel Prize in Physics 1945



Surfaces looked messy, unpredictable, and plagued with complications that resisted neat theory

What is Surface Science?

Surface Science studies the structure, properties, and the phenomena that happen at surfaces and interfaces.

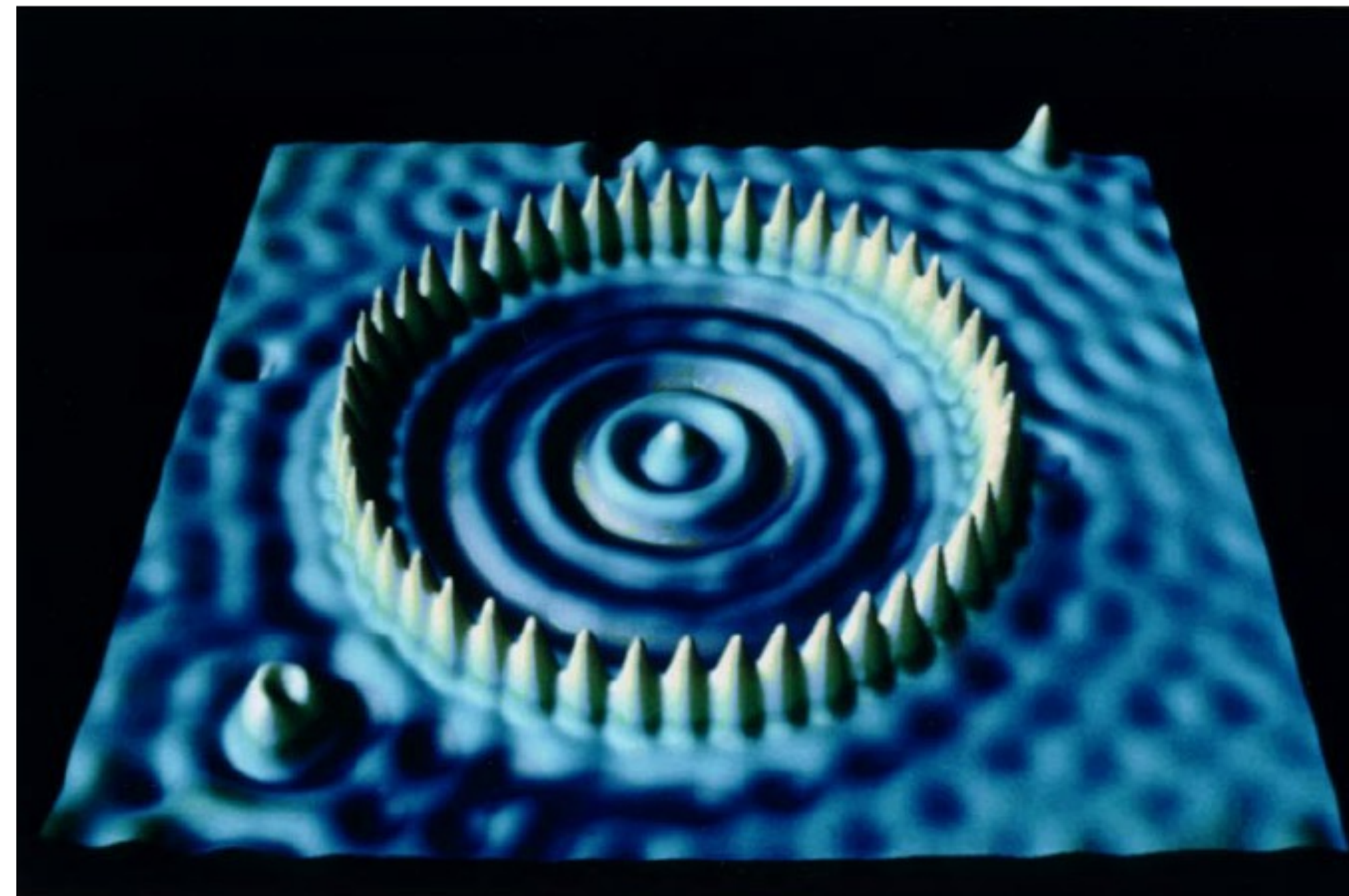


What is Surface Science?

Surface Science is part of **thermodynamics** that tries to understand and characterize surface and interfacial phenomena – the behavior of atoms, electrons, and adsorbates at surfaces

Quantum mechanical component to surface science – can't be explained by classical physics

- Scanning tunneling microscopy (STM) – quantum tunneling of electrons



STM image of 48 iron atoms on copper
in a 12.4 nm diameter ring

D. Eigler, IBM Research Center

But Careful...

Surface Science is *not* a mature field

Why Wolfgang Pauli perceived it as the work of the Devil

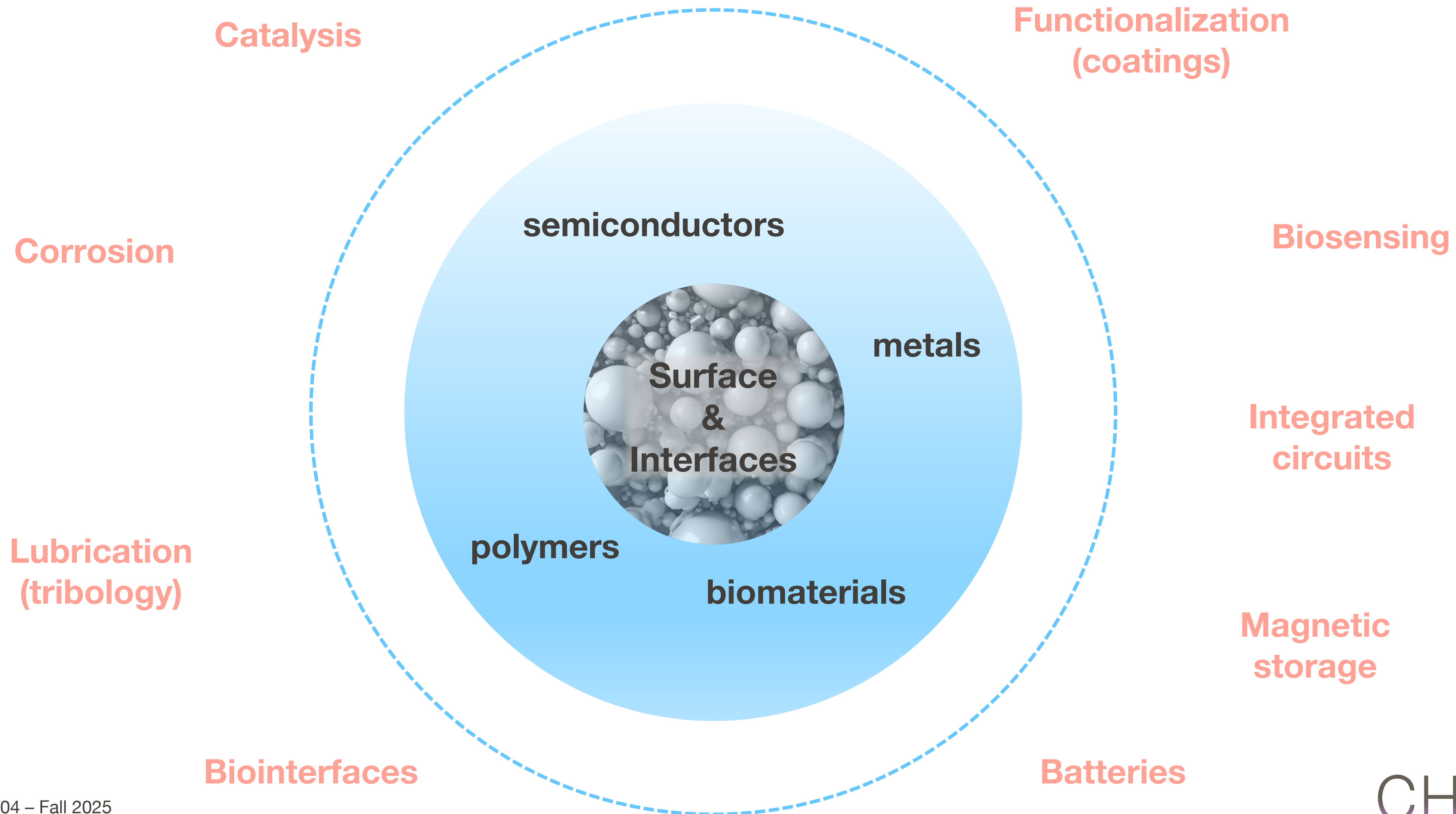
This class will leave lots of holes, not for pitfalls of the instructor, but because of the state of the field



Prof. Francesco Stellacci

Why Should We Study Surface Science??

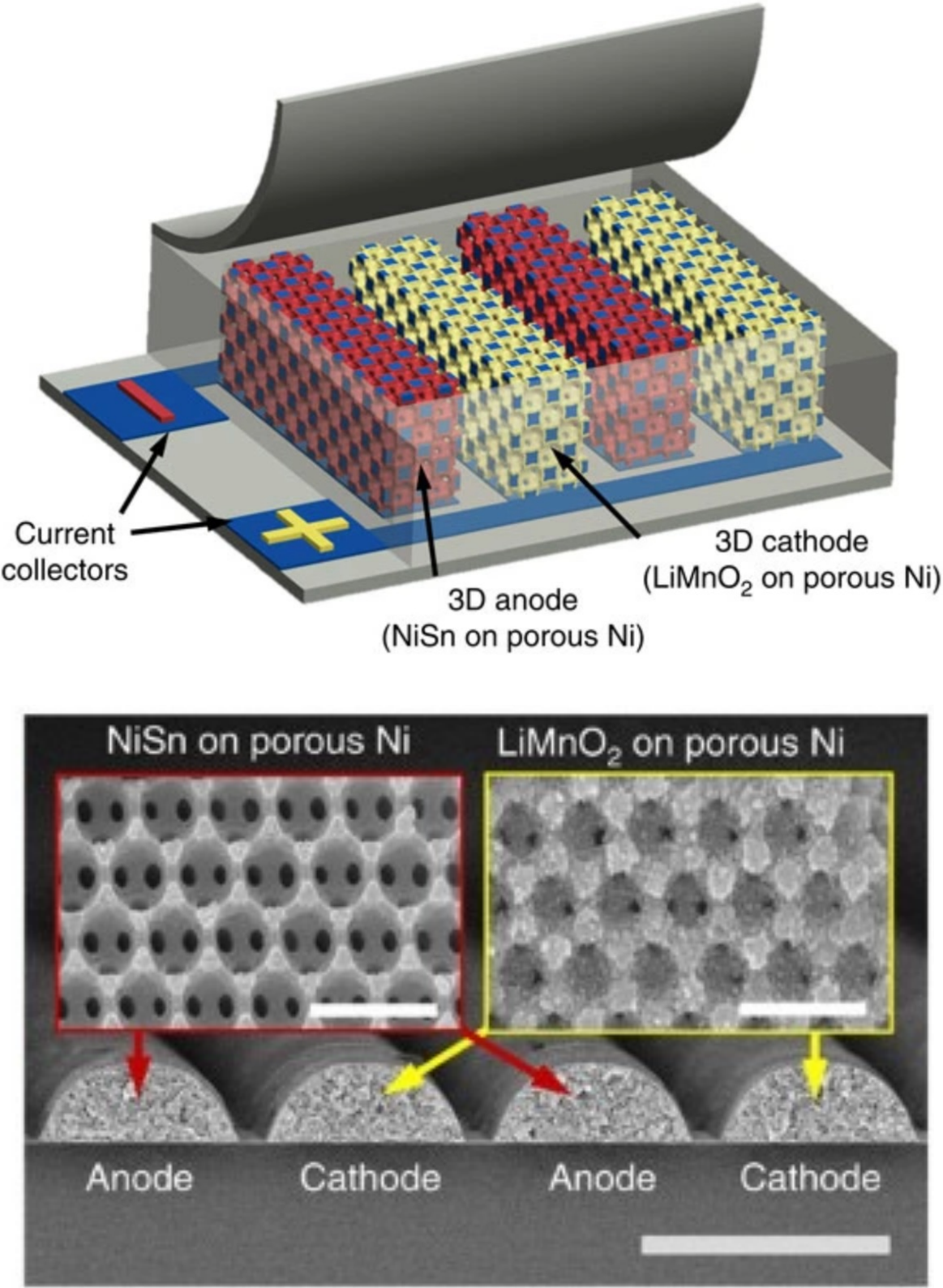
Diverse applications in our lives



Why Study Surfaces & Interfaces?

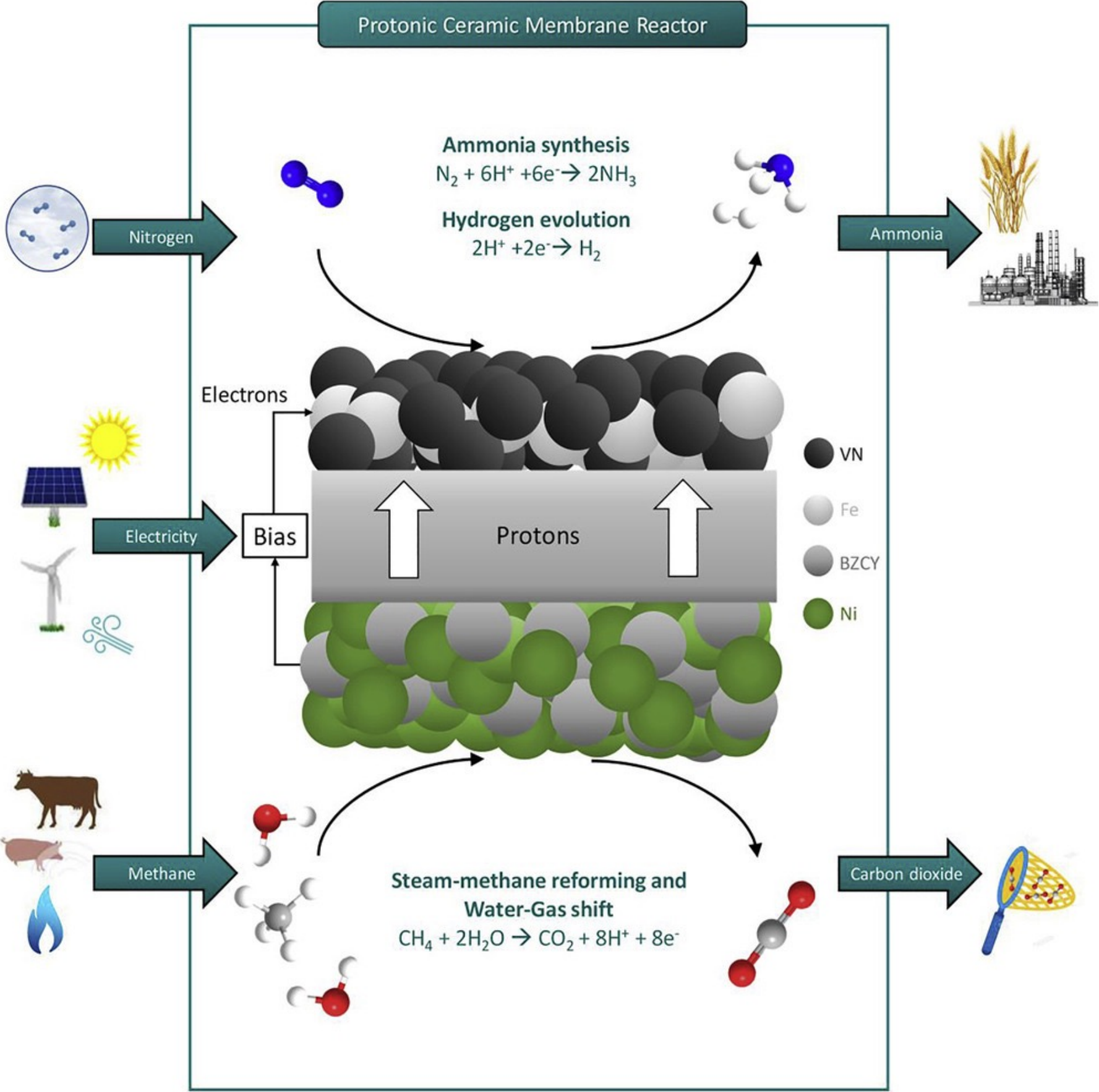
The efficiency of all (electro)chemical reactions that take place at a surface scales with the available surface area

Porous electrodes for lithium-ion batteries



Pikul et al. | *Nature Communications* | 2013

Haber & Bosch Process



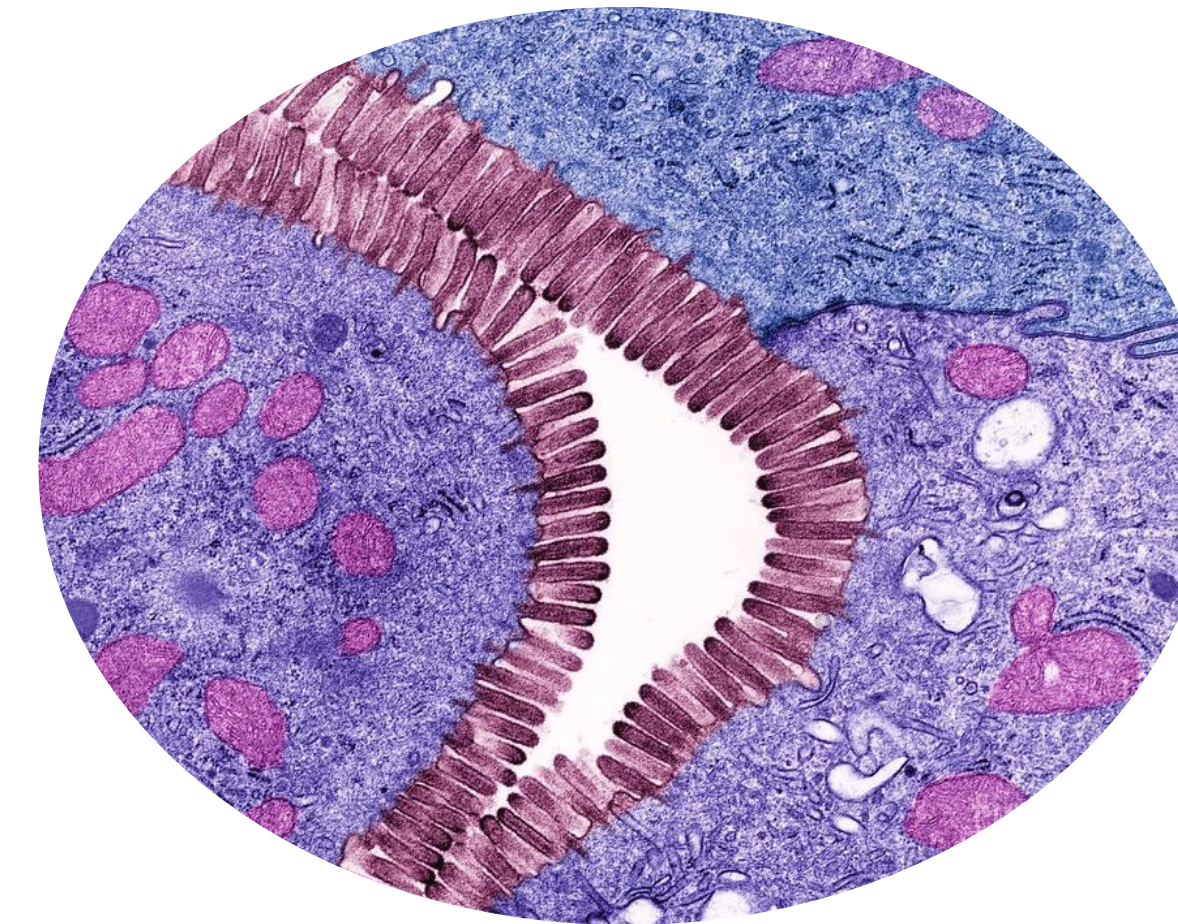
Kyriakou et al. | *Joule* | 2020

Surfaces & Interfaces in Nature

Specific surface area = ratio of area (A) to volume (V)
Nature harnesses high A/V materials

The Brain

- 86 billion neurons
- 100 trillion synapses
- Neural connectivity
- Efficient metabolism



Microvilli (small intestine)

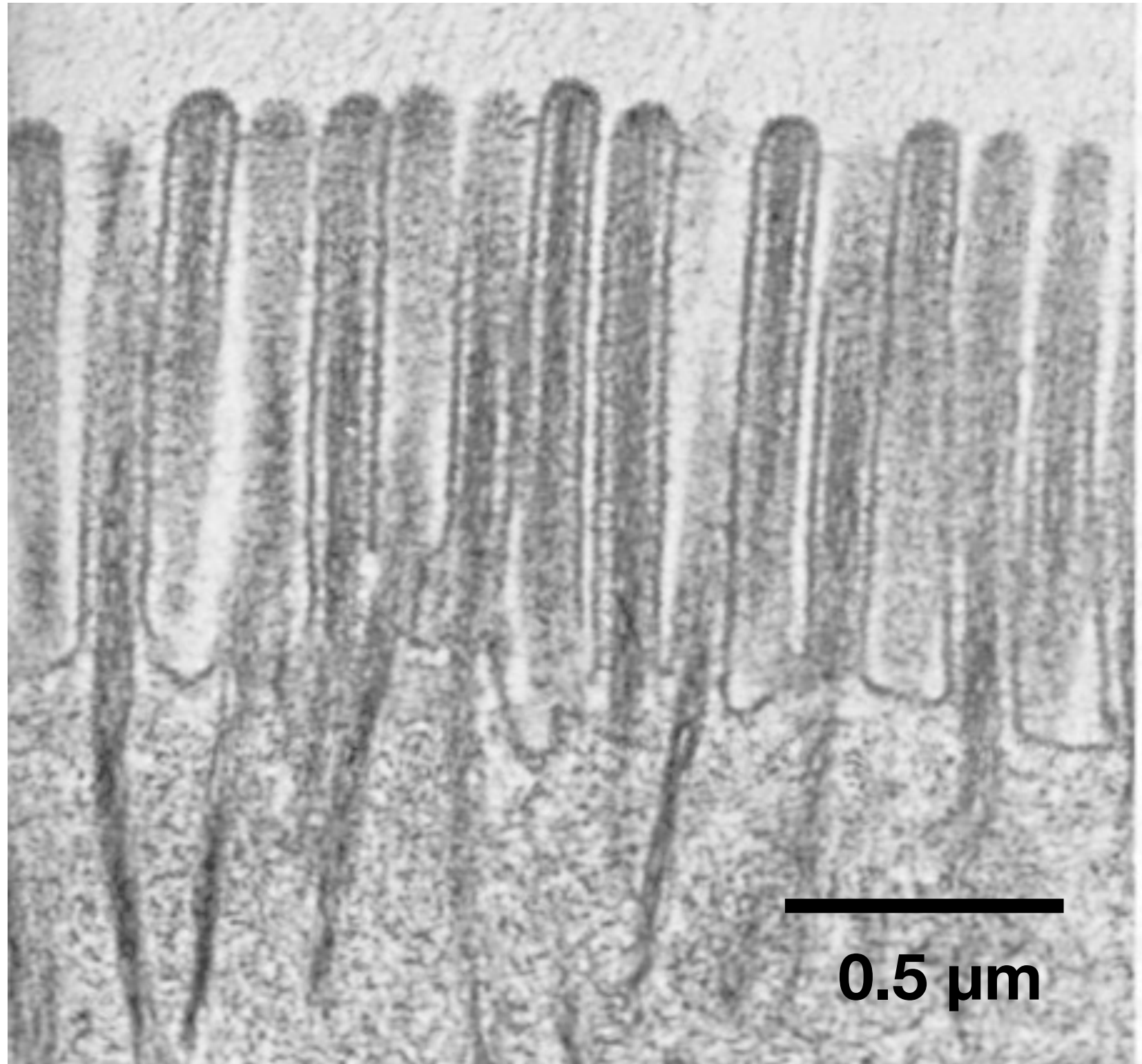
- Absorption & exchange
- Efficient interactions
- Cell-environment interfaces for biochemical reactions

Chemical reactions often take place at interfaces

Materials with high A/V play an important role in several artificial surfaces & interfaces
(e.g. catalysts)

High Area to Volume in Microvilli Enables Digestion

Question: How long would it take to digest a sandwich without microvilli?



$$A = \pi \cdot d \cdot h$$

Diameter (d) = $0.1 \mu\text{m} = 1 \times 10^{-7} \text{ m}$
Length (h) = $1 \mu\text{m} = 1 \times 10^{-6} \text{ m}$

$$A = \pi \cdot (1 \times 10^{-7} \text{ m}) \cdot (1 \times 10^{-6} \text{ m}) = 3.14 \times 10^{-13} \text{ m}^2$$

Assume microvilli covers most intestinal surface ~ 1000 microvilli/ μm^2

Total microvilli on 1 cm^2 surface:

$$1 \text{ cm}^2 = 10^8 \mu\text{m}^2 \Rightarrow 10^8 \times 1000 = 10^{11} \text{ microvilli}$$

$$\text{Total Surface Area} = 10^{11} \times 3.14 \times 10^{-13} \text{ m}^2 = 31.4 \text{ m}^2$$

$$\text{Ratio} = \frac{31.4 \text{ m}^2}{10^{-4} \text{ m}^2} = 314,000$$

With microvilli
Without microvilli (flat surface)

So if on average, it takes someone 4 h to digest a sandwich WITH microvilli...

it would take **1,256,000 hours \approx 143 years** WITHOUT microvilli!!!

How Does a Gecko Stick on a Wall?



1. Their hands and feet excrete sticky materials (goo)
2. Their hands and feet have tiny hooks
3. Their hands and feet are like tiny suction cups
4. None of the above

How Does a Gecko Stick on a Wall?




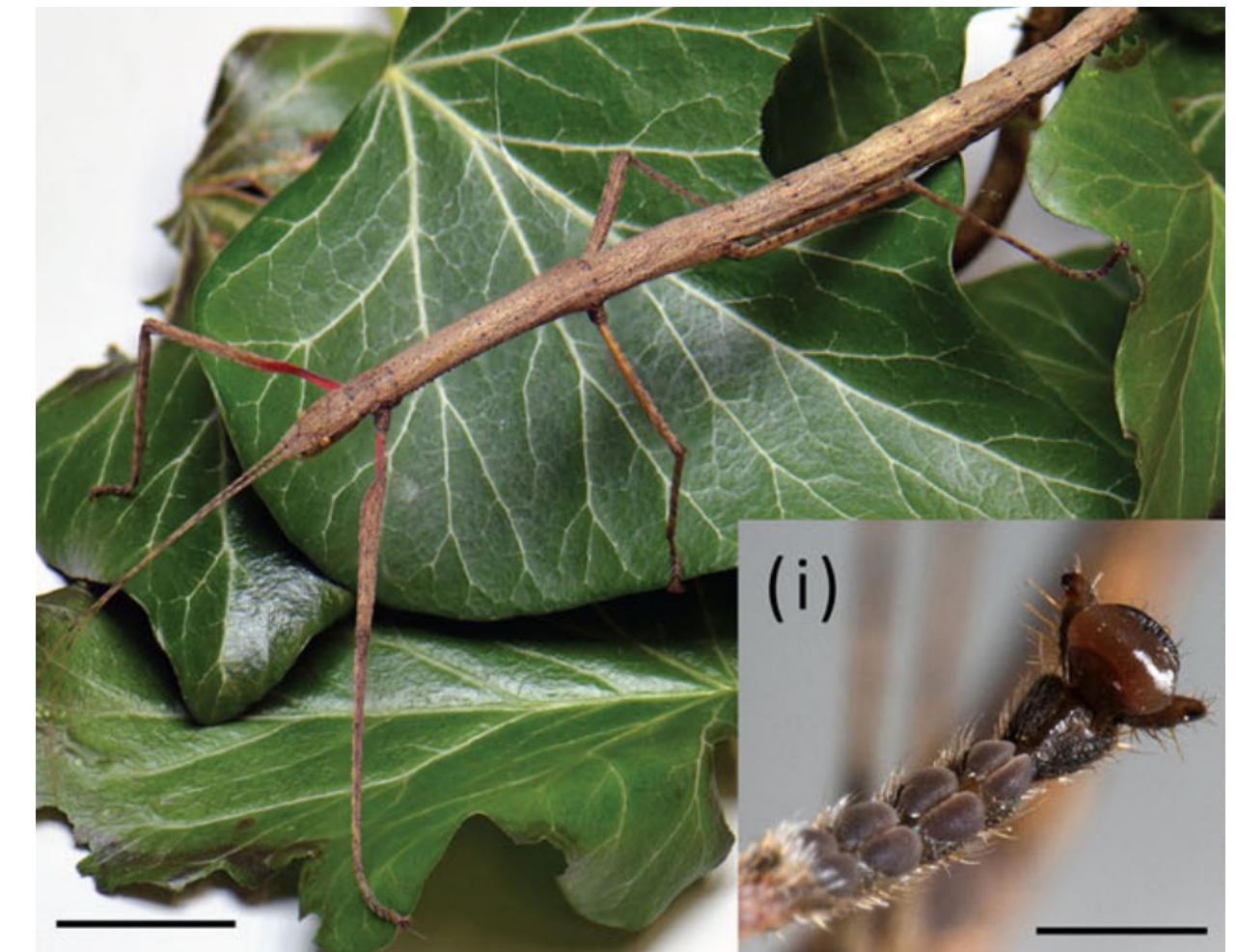
Hypothesis 1: Capillary forces for adhesion (like insects) – condensation of water from atmosphere forming a monolayer of water molecules/insects secreting liquid from their feet can cause significant capillary attraction

ORIGINAL ARTICLE

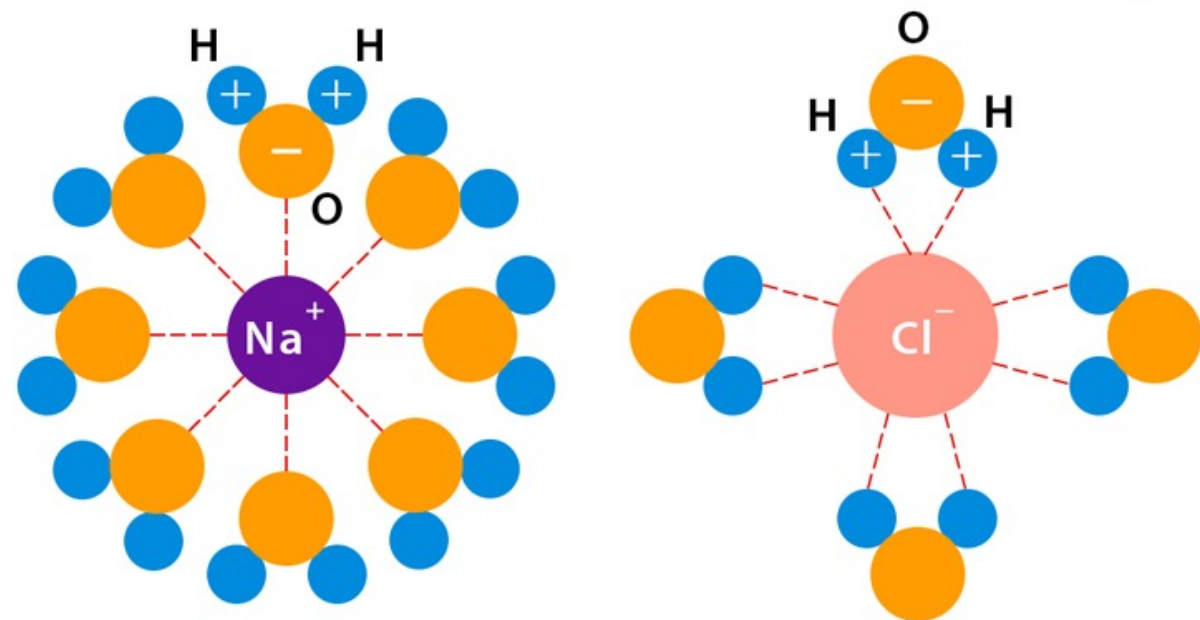
ANNALS OF THE NEW YORK
ACADEMY OF SCIENCES

Capillary adhesion of stick insects

Guillermo J. Amador¹  | Brett Klaassen van Oorschot¹  | Uddalok Sen² |
Benjamin Karman³ | Rutger Leenders¹

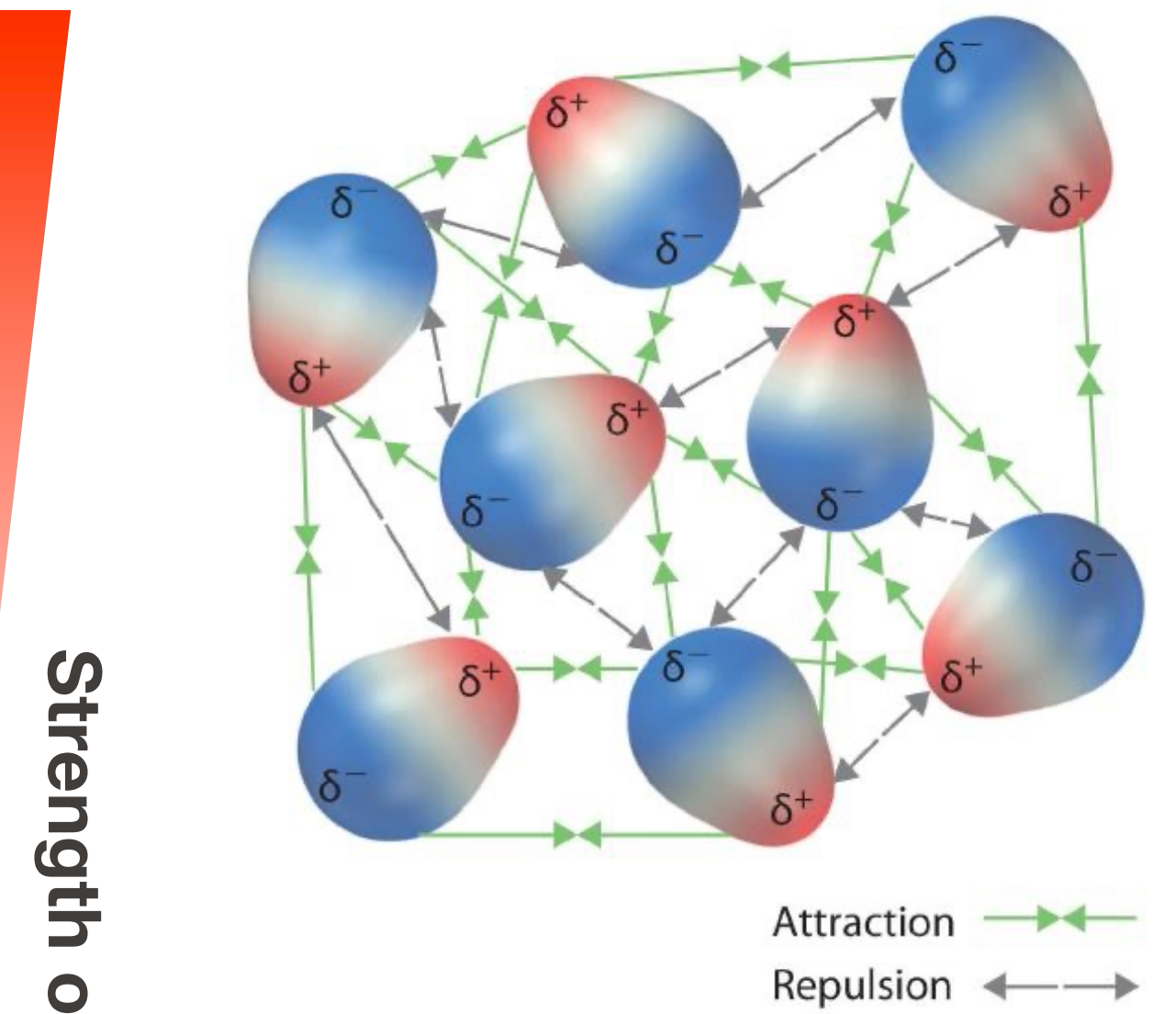


Different Forms of Intermolecular Interactions/Forces



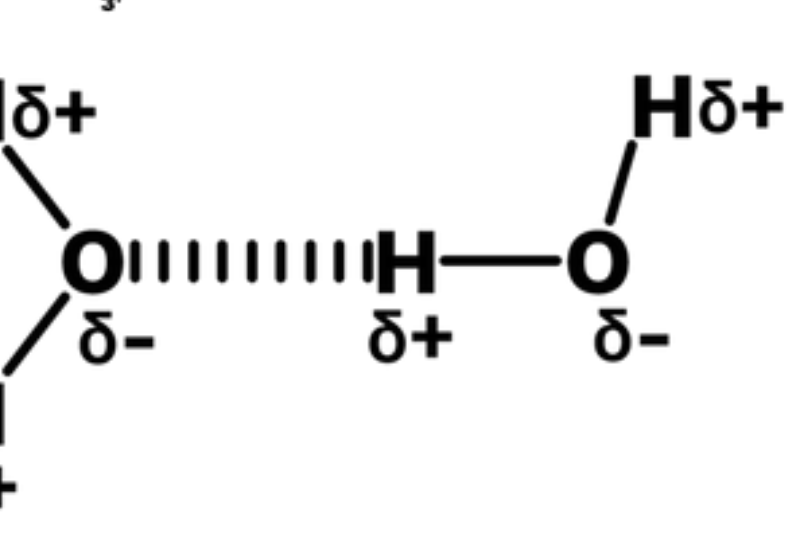
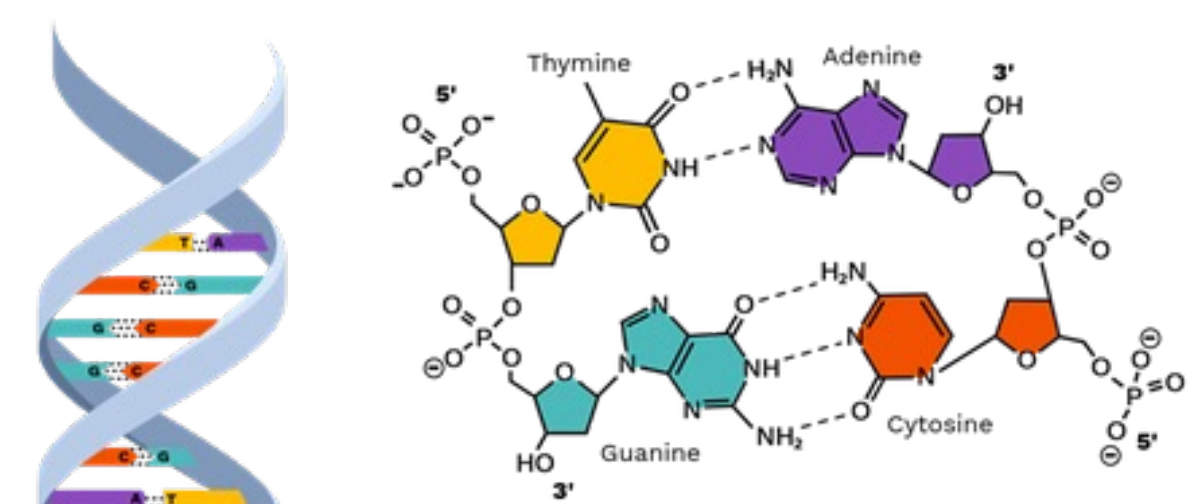
Ion-dipole

Intermolecular Forces	Formed by attraction between:
Ion-dipole	Ion + polar molecule
Hydrogen bond	Molecules with H, N, O, F atoms
Dipole-dipole	Two polar molecules
Ion-induced dipole	Ion + nonpolar molecule
Dipole-induced dipole	Polar + Nonpolar molecule
Van der Waals forces	Two nonpolar molecules

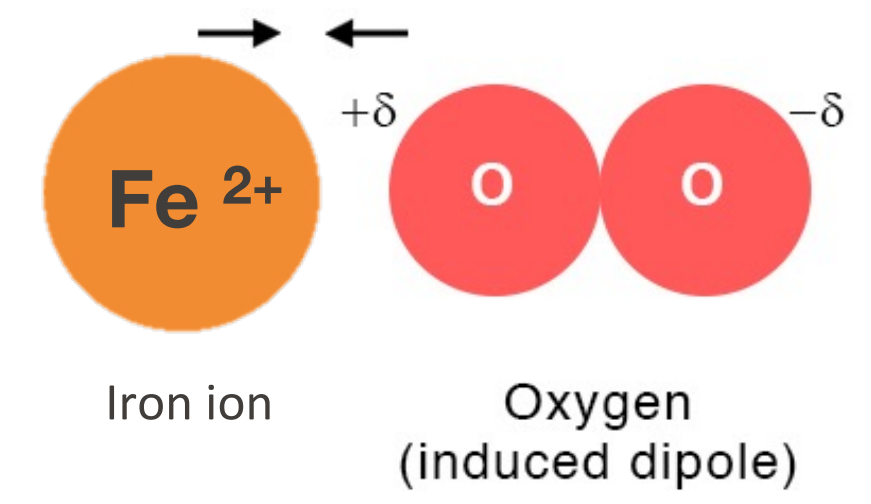


Strength of force

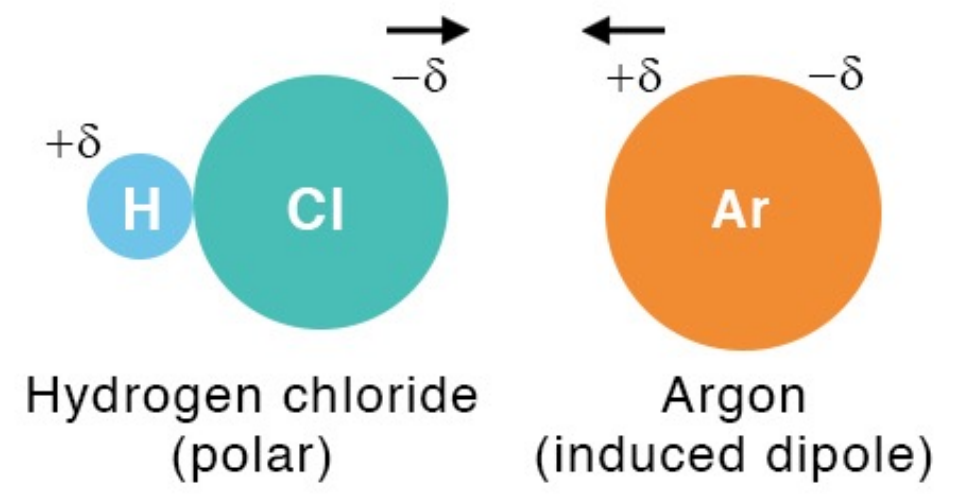
Dipole-dipole



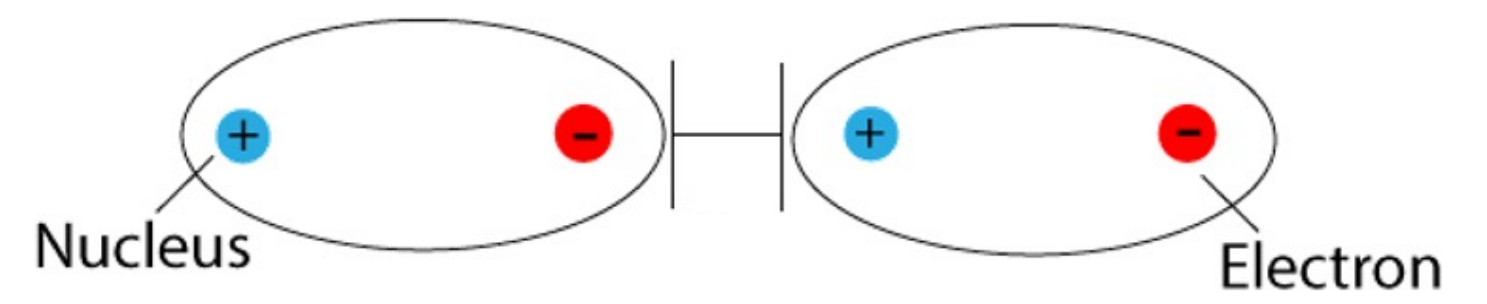
H-bond



Ion-induced dipole



Dipole-induced dipole



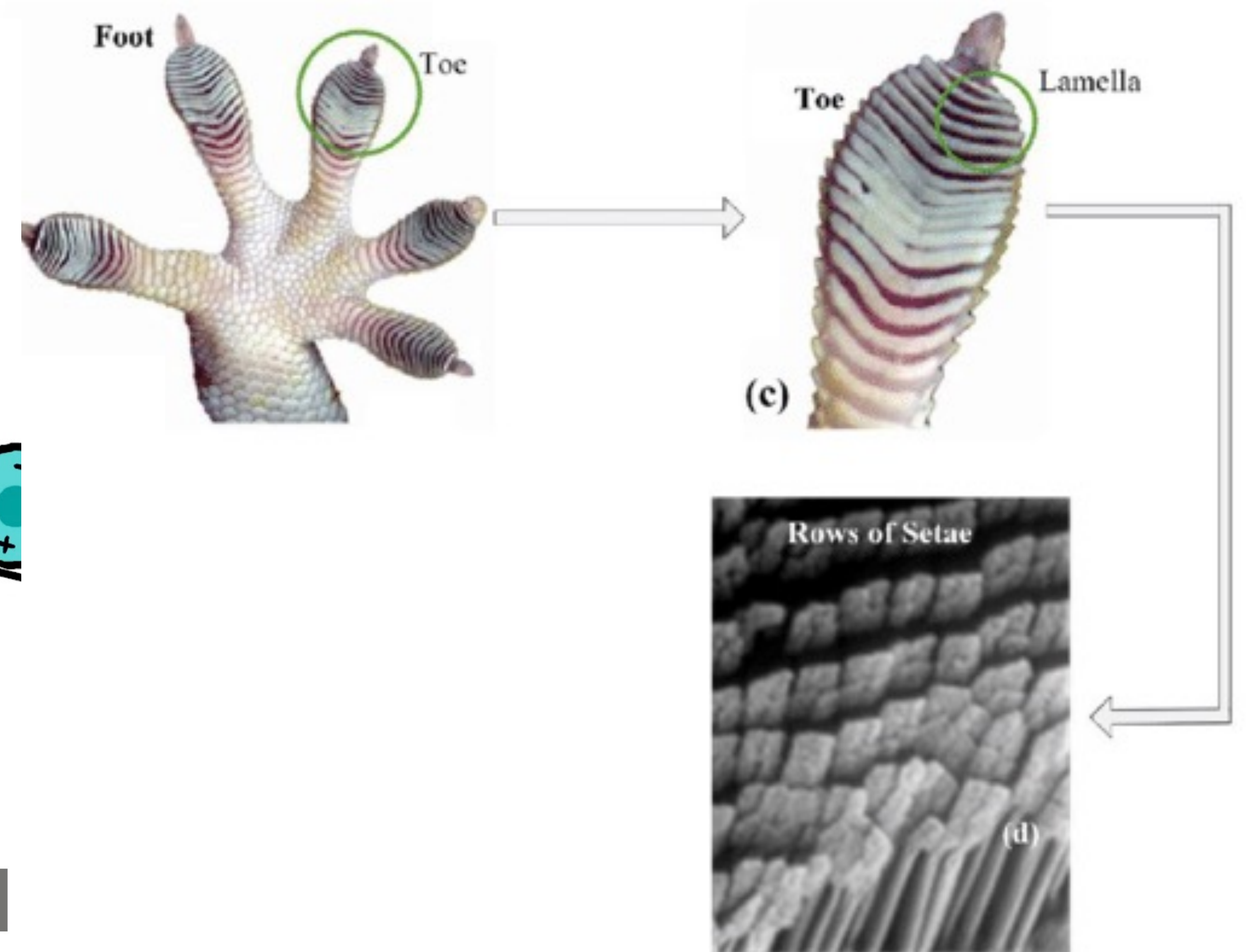
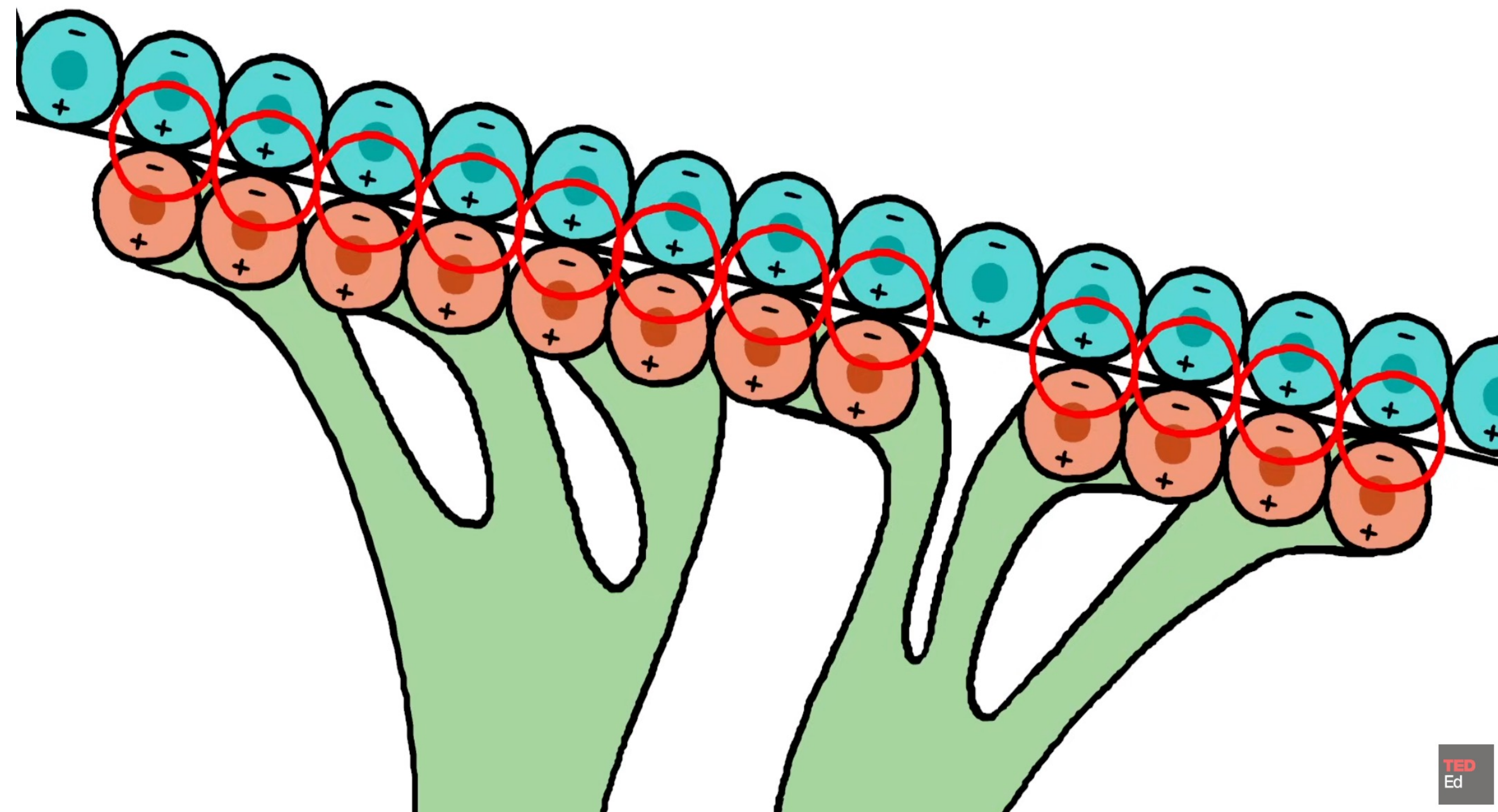
Van der Waals forces

The toes of geckos are hydrophobic and not charged...

How Geckos Stick on der Waals

Revealing the lizards' secret, engineers aim to make wall-walking robots

27 AUG 2002 · BY BEN SHOUSE



Adhesion strength from subdividing each toe into 2 billion microstructures → maximize contact area → increase cumulative van der Waals interactions with the surface

Wang et al., *J. Bionic. Eng.*, 18, 1011, 2021

Semiconductor Material Led to Evidence of Interactions

RESEARCH ARTICLE | BIOLOGICAL SCIENCES | ✓

PNAS

Evidence for van der Waals adhesion in gecko setae

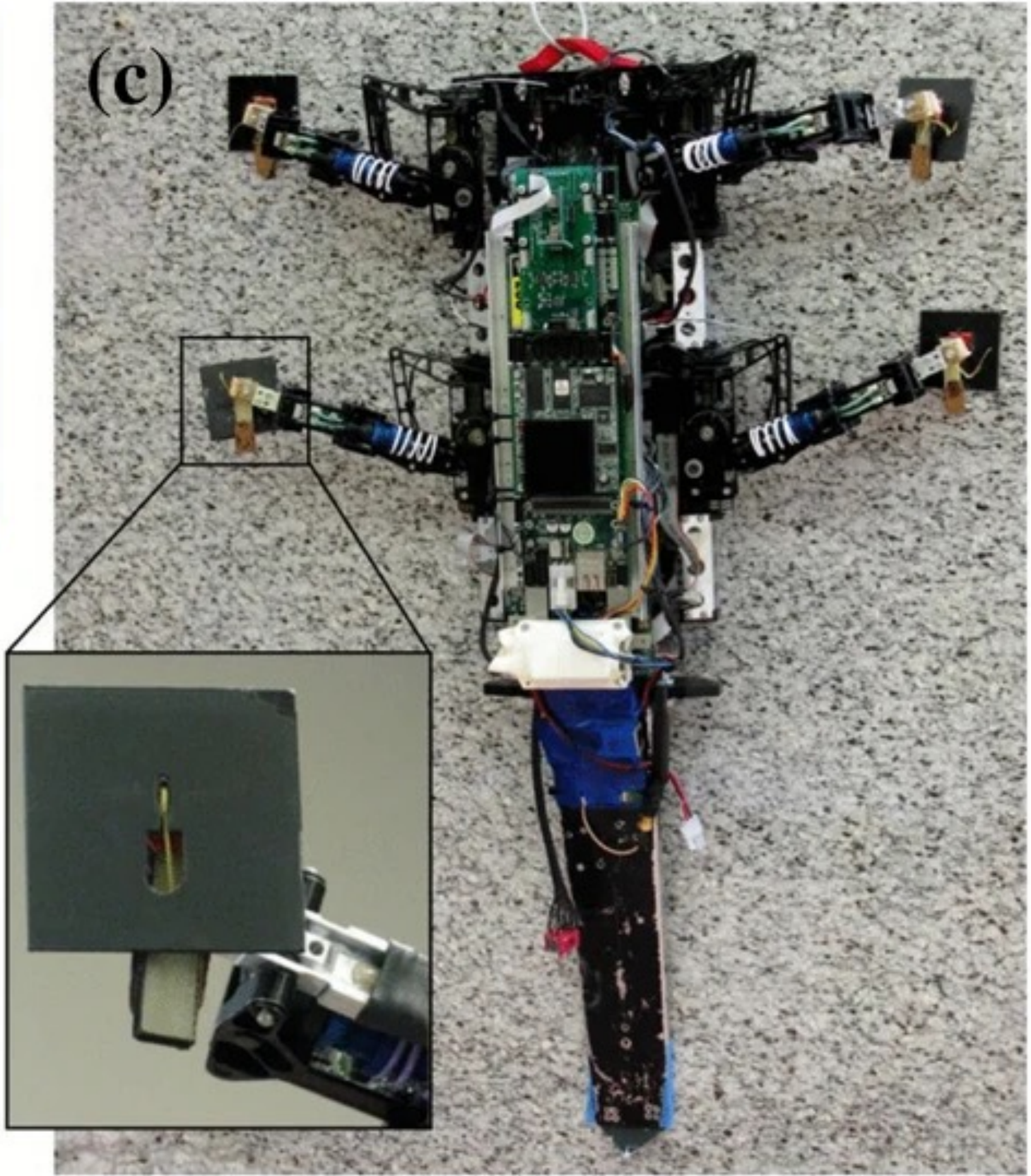
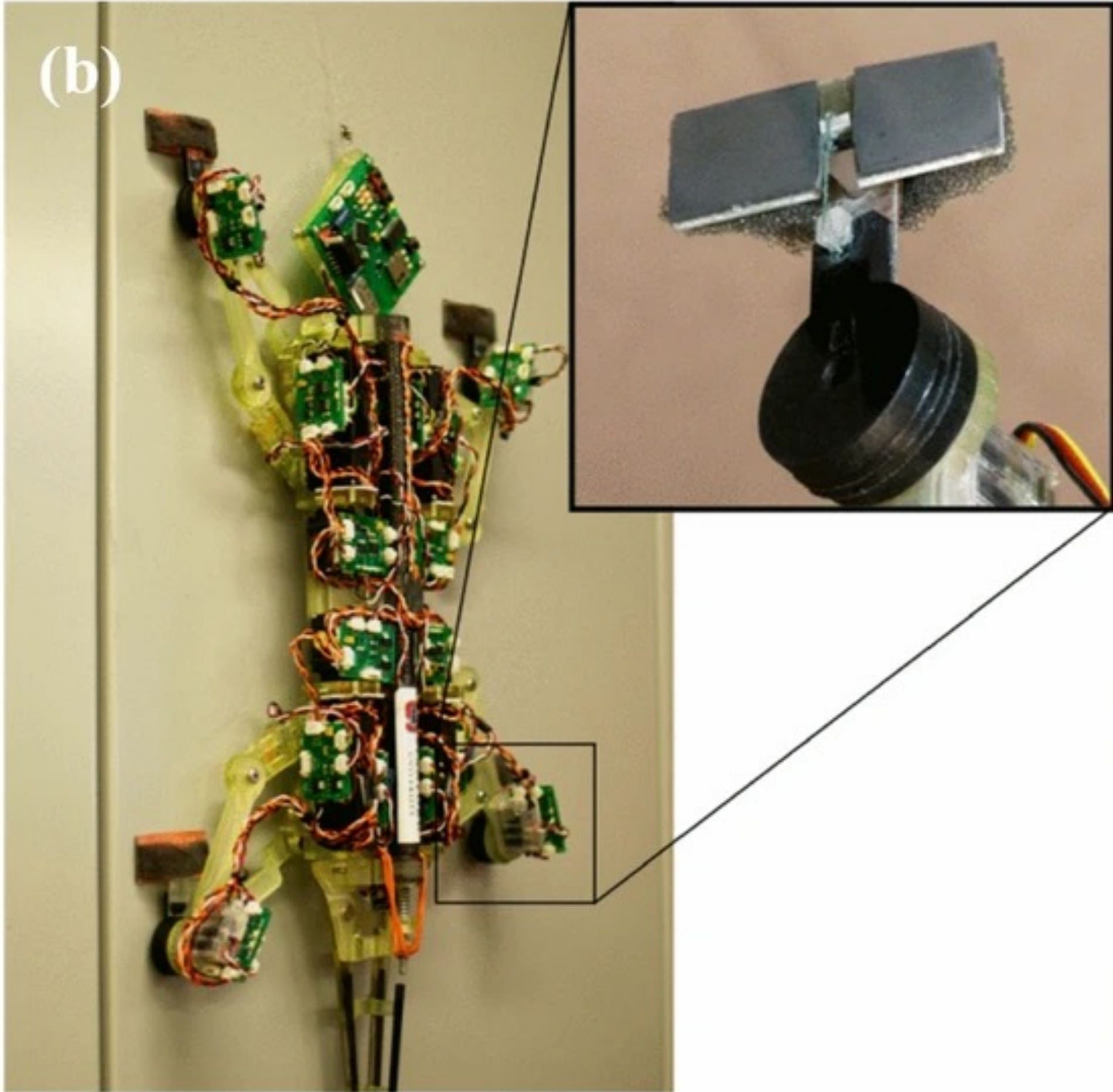
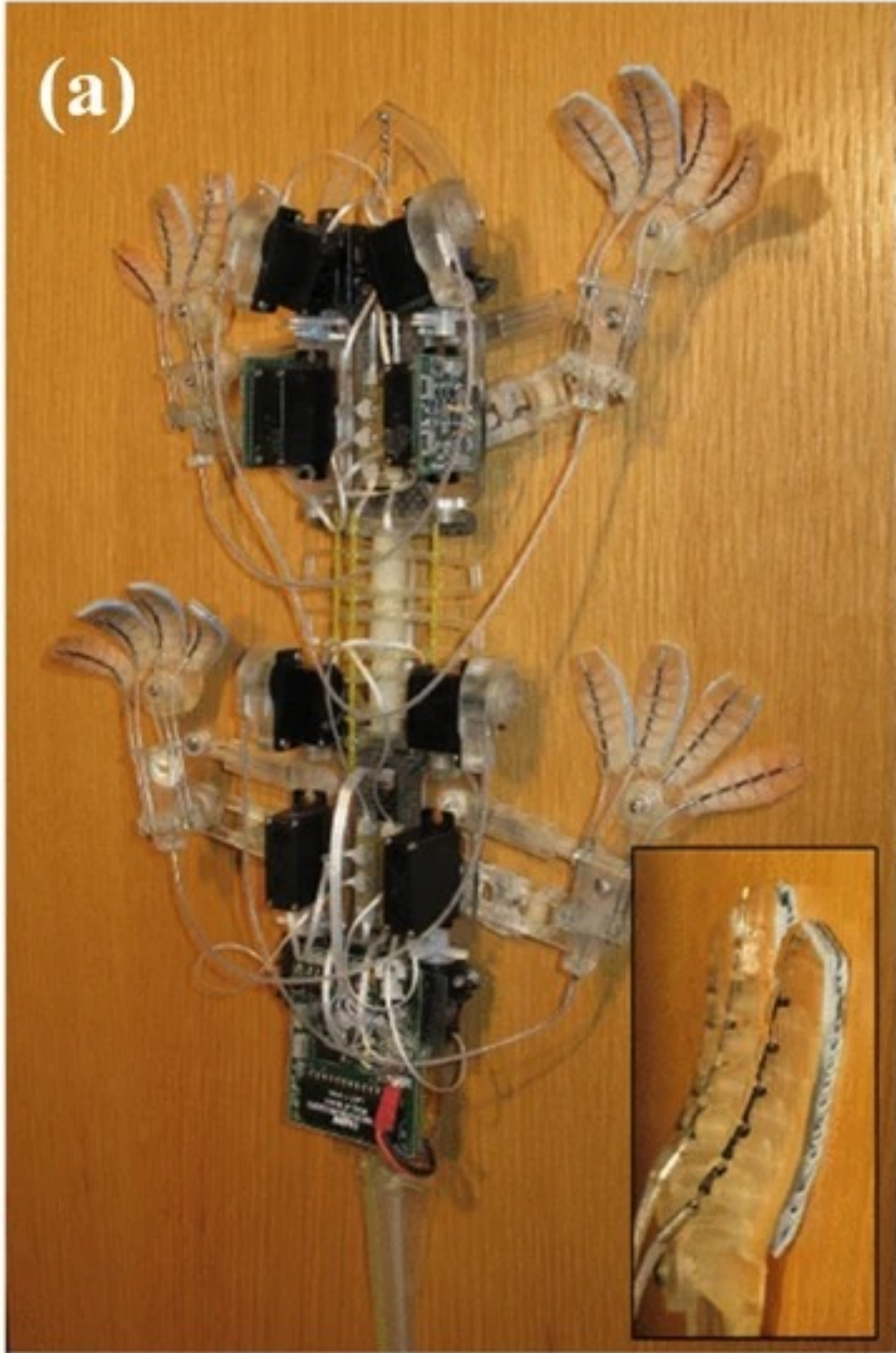
Kellar Autumn, Metin Sitti, Yiching A. Liang, Anne M. Peattie, Wendy R. Hansen, Simon Sponberg, Thomas W. Kenny, Ronald Fearing, Jacob N. Israelachvili, and Robert J. Full -6 [Authors Info & Affiliations](#)

August 27, 2002 | 99 (19) 12252-12256 | <https://doi.org/10.1073/pnas.192252799>



Gecko adhering to molecularly smooth hydrophobic gallium arsenide semiconductor demonstrates mechanism of adhesion is van der Waals force

Wall-Climbing Robots Inspired by this Knowledge



Wang et al. | *J. Bionic. Eng.* | 2021

Key Takeaways

Surface science is *not* a mature field

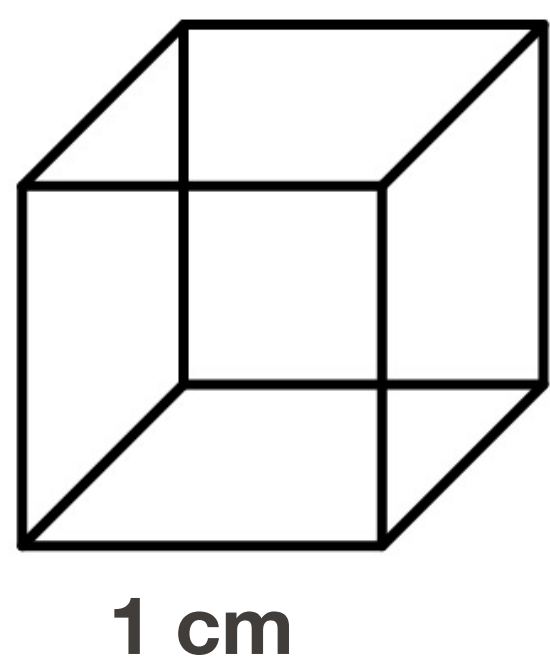
Studying surface science is important for diverse applications

Surfaces and interfaces play a key role in Nature

Nature can inspire research projects

Challenges of Studying Surface Science

1. Surface science needs its own field and special tools



Number of atoms in
a 1 cm^3 cube

Bulk atoms = 10^{23}

Surface atoms = 10^{15}



Weak signal – bulk dominates the signal from most characterization techniques

Surface sensitivity required – surface-specific (XPS, STM, AFM) or surface-enhanced (SERS)

Surfaces are dynamic – surface atoms have weaker bonds = higher mobility

Challenges of Studying Surface Science

2. A freshly cleaned surface remains clean for a very short time interval

Average molecular velocity

$$v_{\text{avg}} = \sqrt{\frac{8RT}{\pi M}}$$

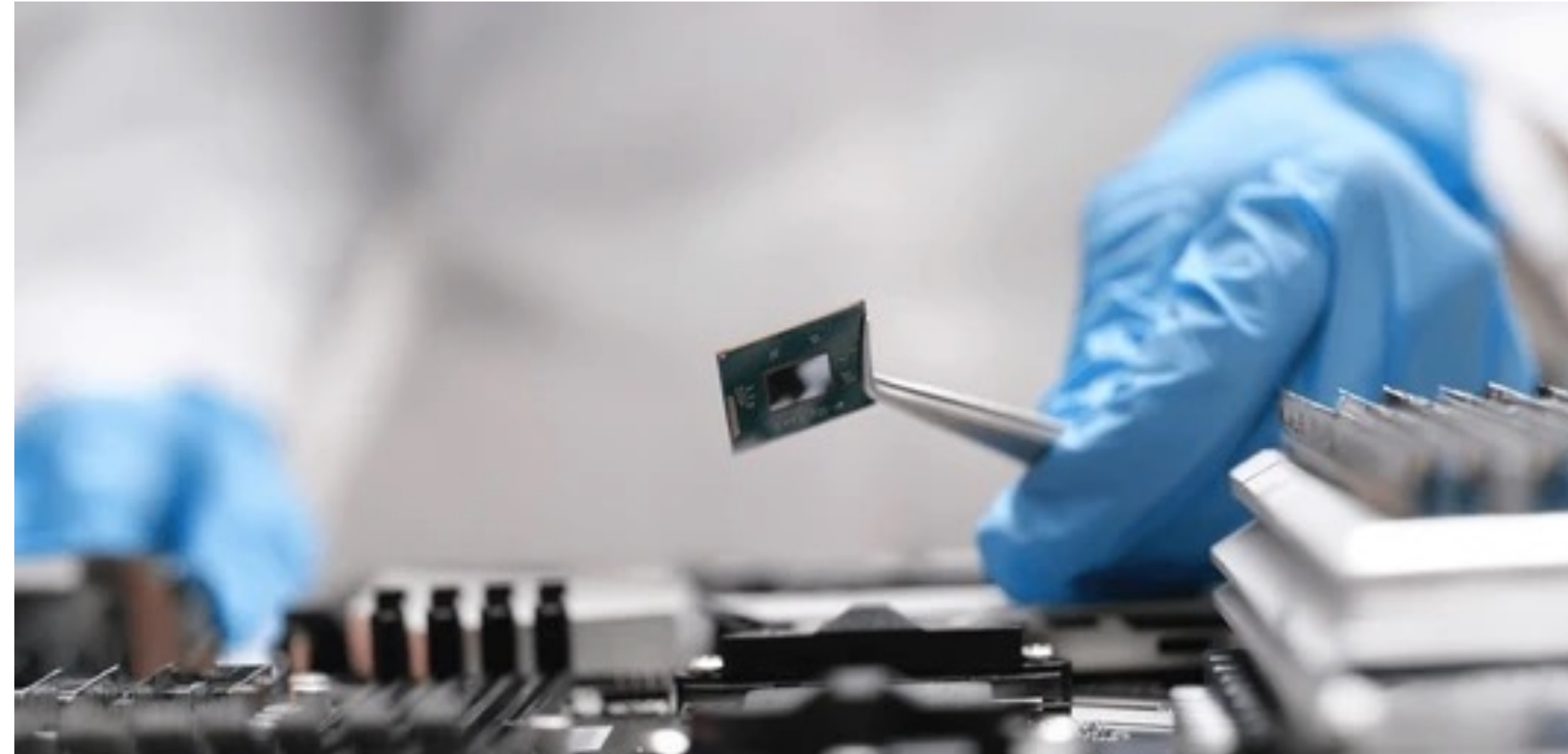
At 20 °C:

$$v_{\text{avg}} = \mathbf{472 \text{ m/s}}$$
 for N₂



Challenges of Studying Surface Science

2. A freshly cleaned surface remains clean for a very short time interval



The number of molecules that hit the sample surface per unit time (impact frequency) and unit area is calculated as follows:

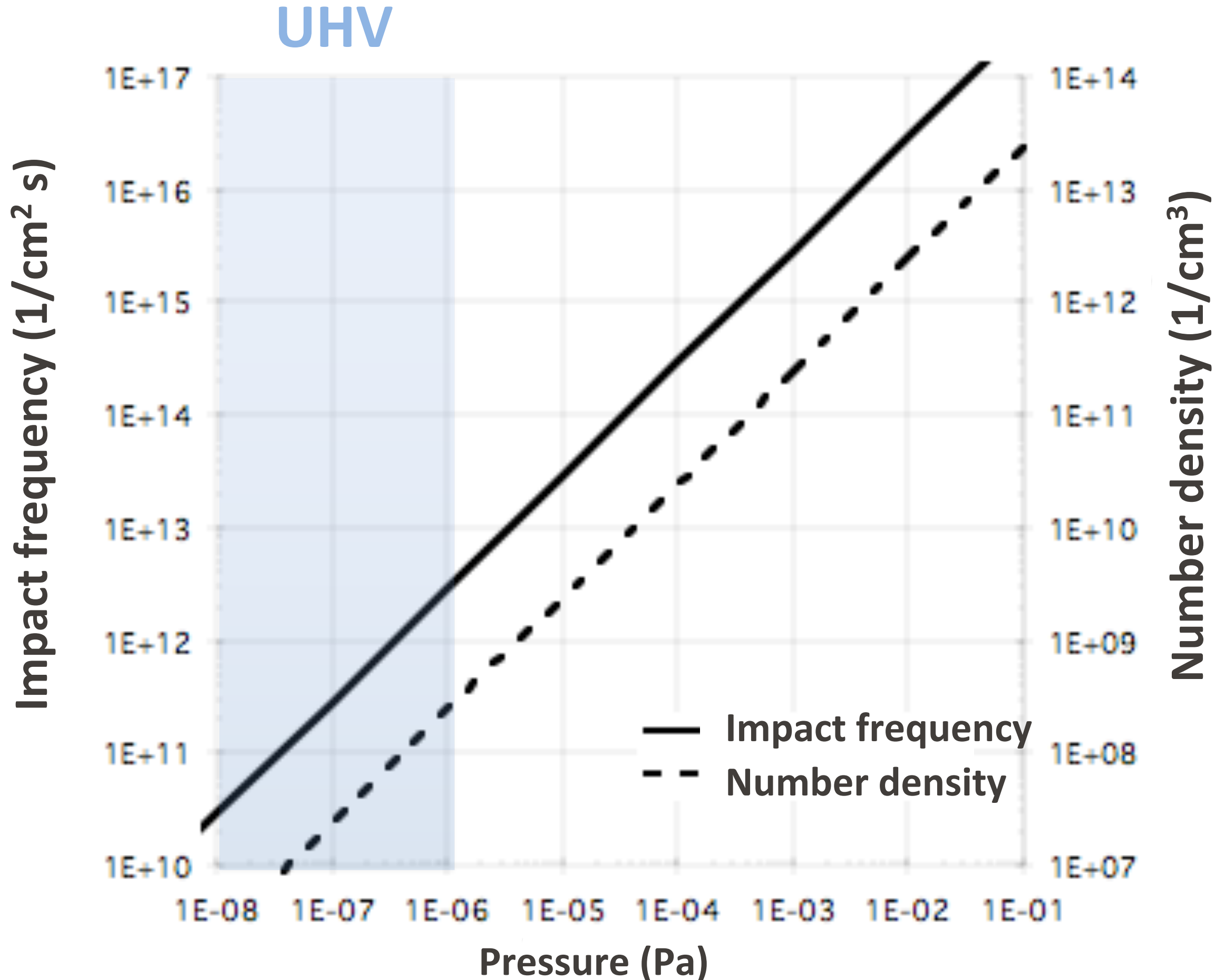
$$\dot{n}_s \approx 2.7 \times 10^{22} \frac{P}{\sqrt{MT}} \text{ cm}^{-2} \text{ s}^{-1}$$

P: pressure
M: molecular weight
T: Temperature

Each atom of a 1 cm² metal surface is hit **~100 million times/s by a gas particle**
(at atmospheric pressure)

Ultra High Vacuum (UHV) Needed for Ultra Clean Surfaces

The number of impacts per second per cm² can only be decreased by pressure reduction



1 Pa is about the pressure exerted by a CHF 100 note on a table!

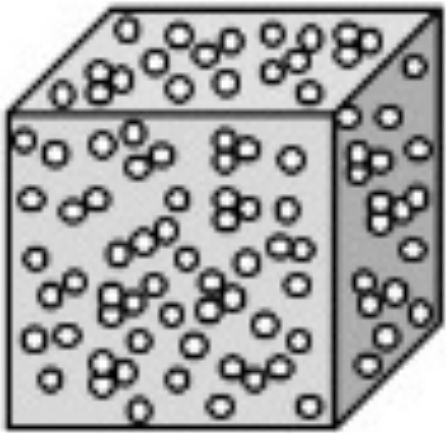


1 standard atmosphere = 101,325 Pa

Impact frequency/unit area and number density as a function of the pressure for an ideal gas

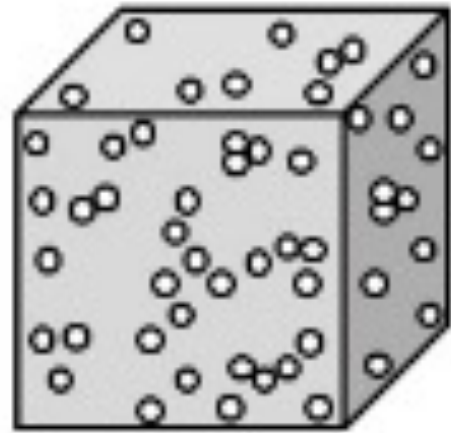
Vacuum Levels Significantly Impacts Monolayer Formation

Rough Vacuum
1 atm – 10^{-3} Torr



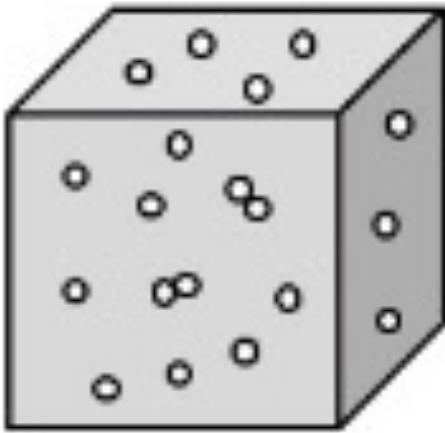
1×10^{-3} Torr
 10^{13} atoms/cm³

High Vacuum
 10^{-3} Torr - 10^{-8} Torr



1×10^{-6} Torr
 10^{10} atoms/cm³

Ultra High Vacuum
 10^{-8} Torr - 10^{-12} Torr

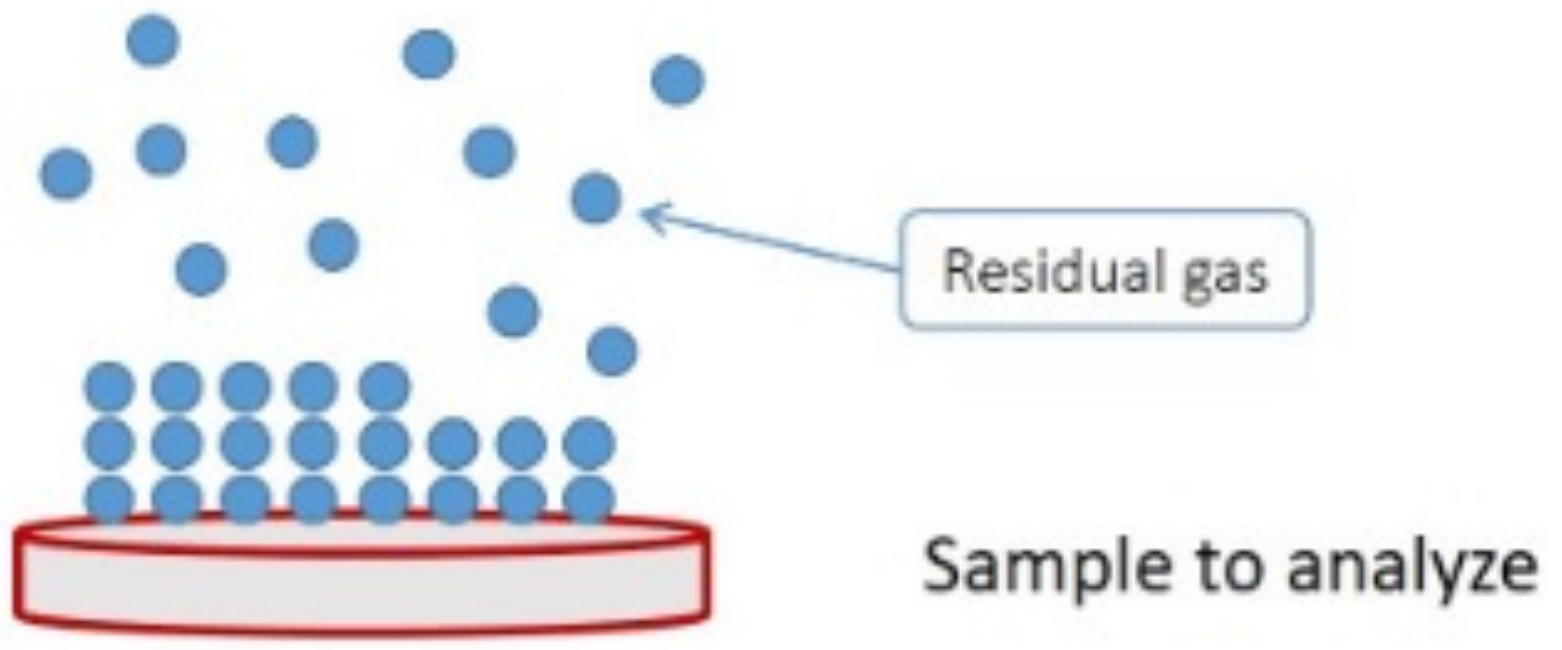


1×10^{-11} Torr
 10^5 atoms/cm³

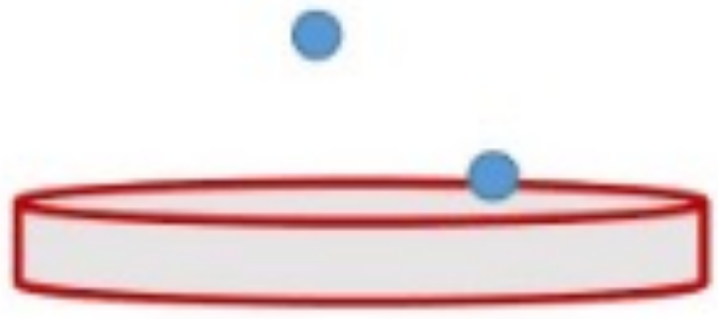
1 residual gas monolayer every 4 SECONDS

1 residual gas monolayer every 4 DAYS

High Vacuum



UHV



VAC COAT

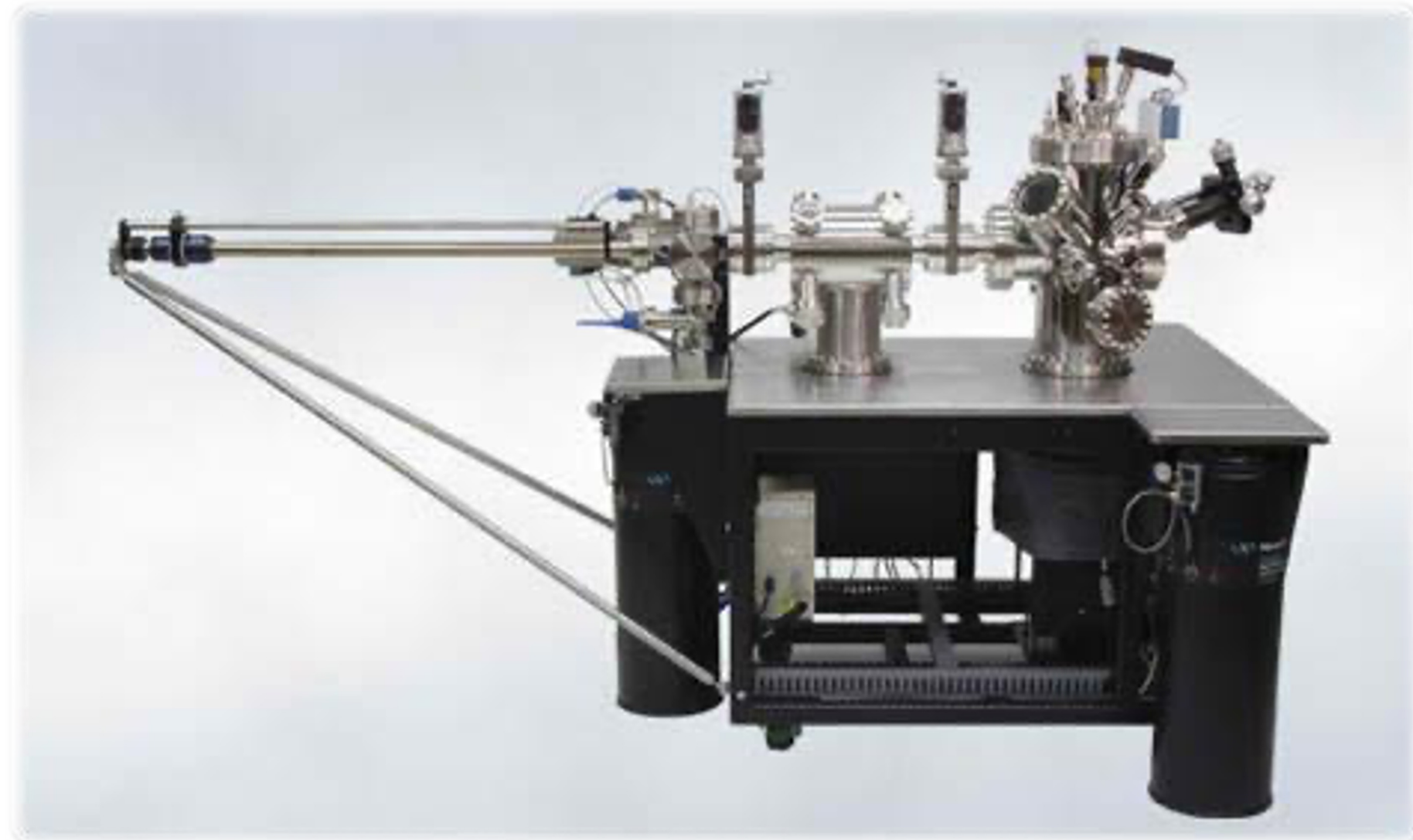
CHEMNA

Why Do We Need Ultra-High Vacuum?

Instrumentation

Ion and electron beam instruments

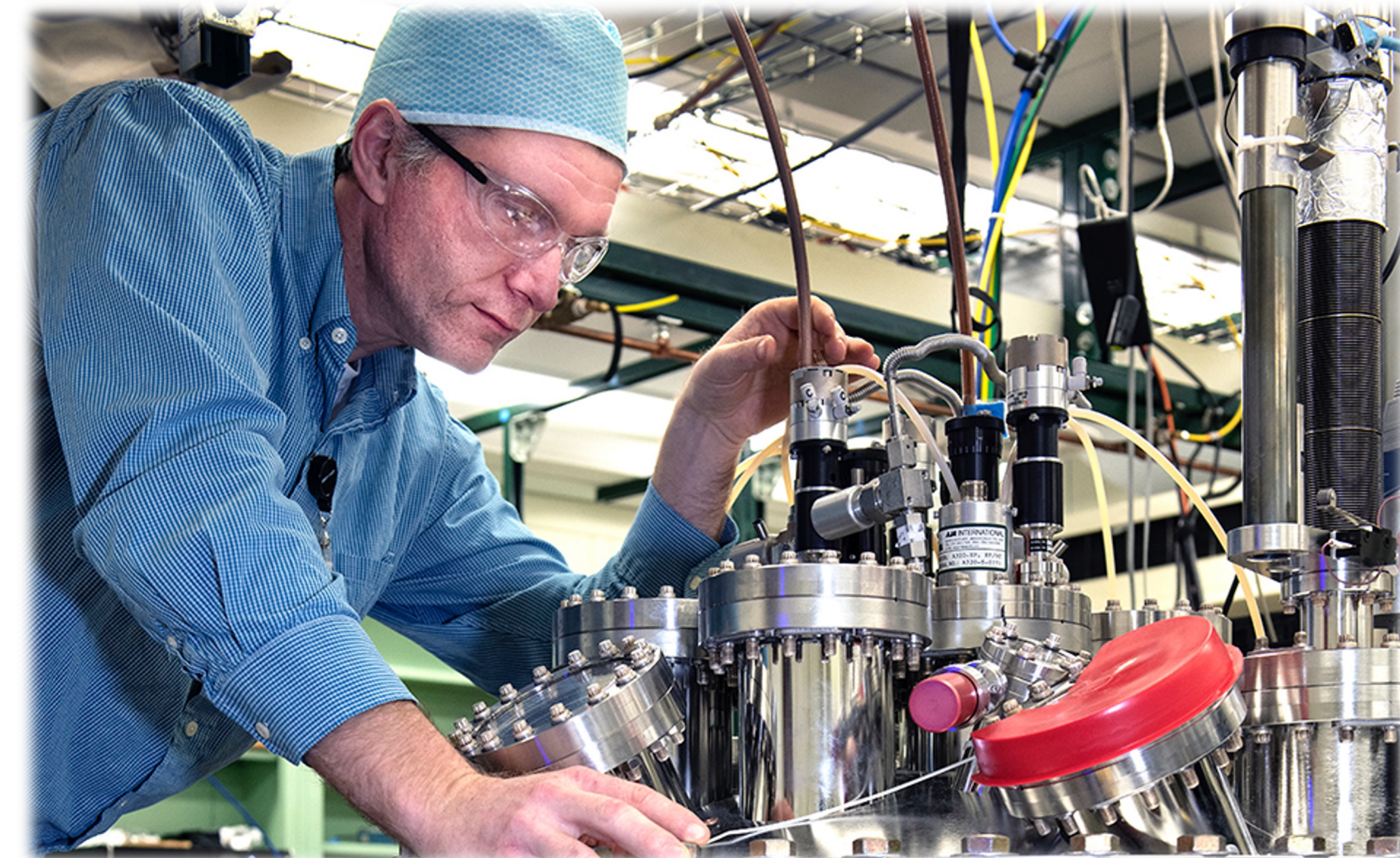
Need low pressure to avoid collisions with gas molecules



Depositions

Chamber atmosphere can affect surface of specimen

Gas in chamber can adsorb onto surface



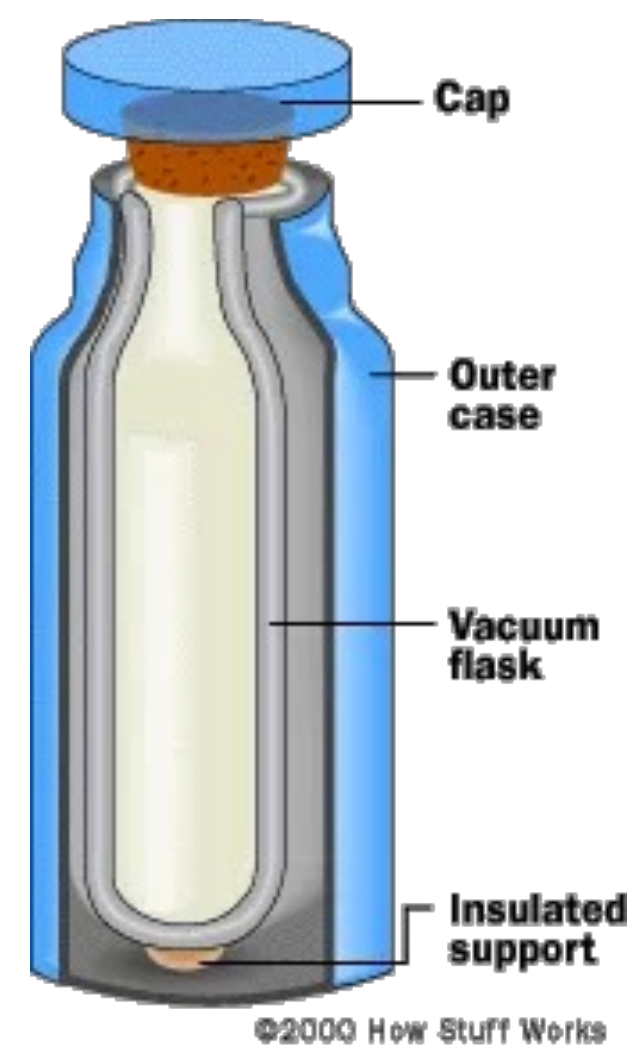
NIST

CHEM\$NA

Ultra High Vacuum (UHV) Applications

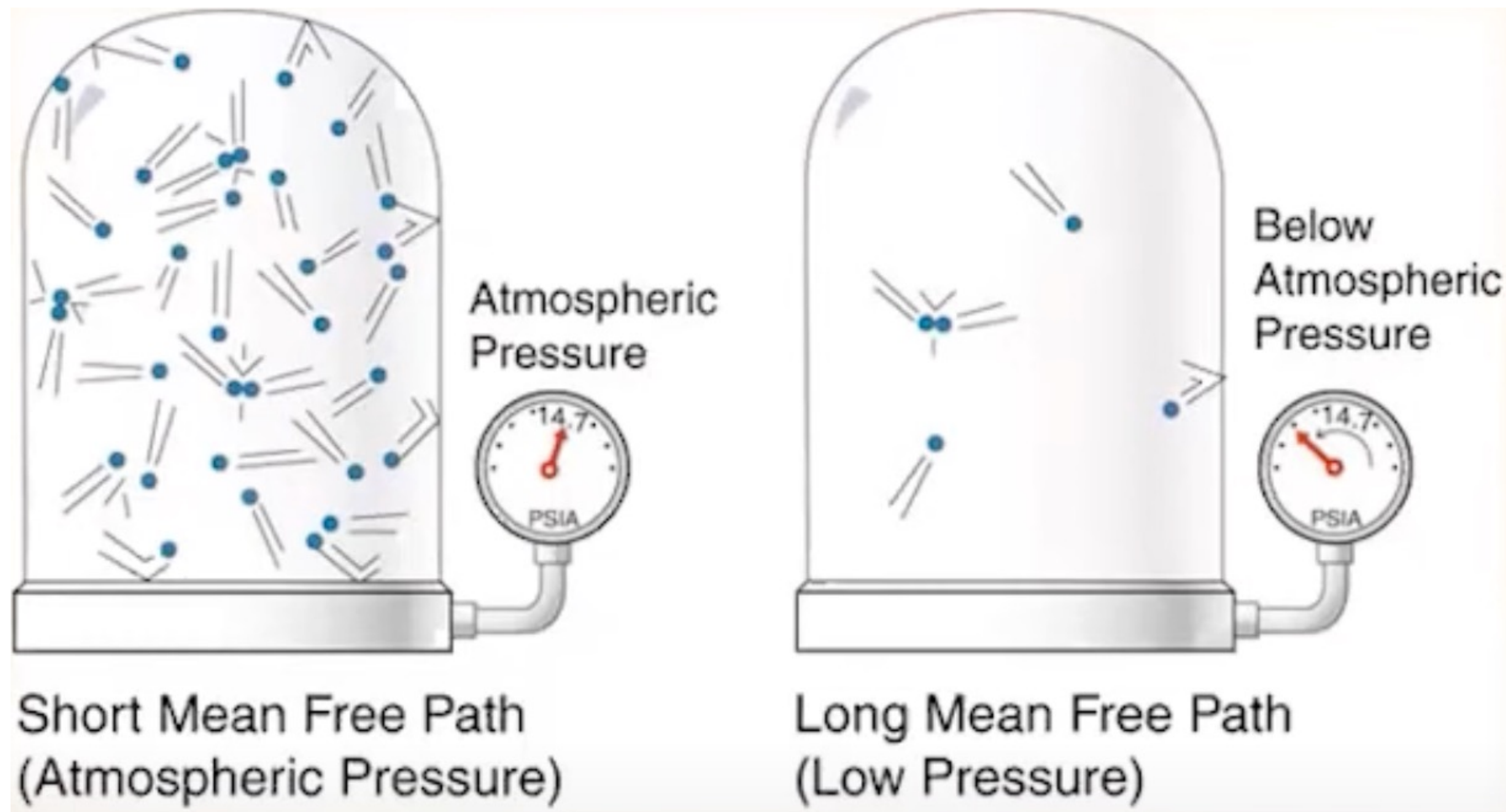
Latin word “**vacuus**”: free or empty (space without air or matter)

Vacuum	Pressure (Torr)	Mean Free Path	Molecules/cm ³
Vacuum cleaner	600	70 nm	10 ¹⁹
Thermos bottle	10 ⁻² – 10 ⁻⁴	0.01 – 1 m	10 ¹⁴ – 10 ¹²
Vacuum tube	10 ⁻⁷ – 10 ⁻¹⁰	1-1000 km	10 ⁶ – 10 ⁴
Surface analysis chamber	10 ⁻⁹ – 10 ⁻¹¹	100-10,000 km	10 ⁷ – 10 ⁵
Moon surface	10 ⁻¹¹	10,000 km	4 x 10 ⁵
Interstellar space	10 ⁻¹⁷	Unimaginable	1



Why Do We Need Ultra-High Vacuum?

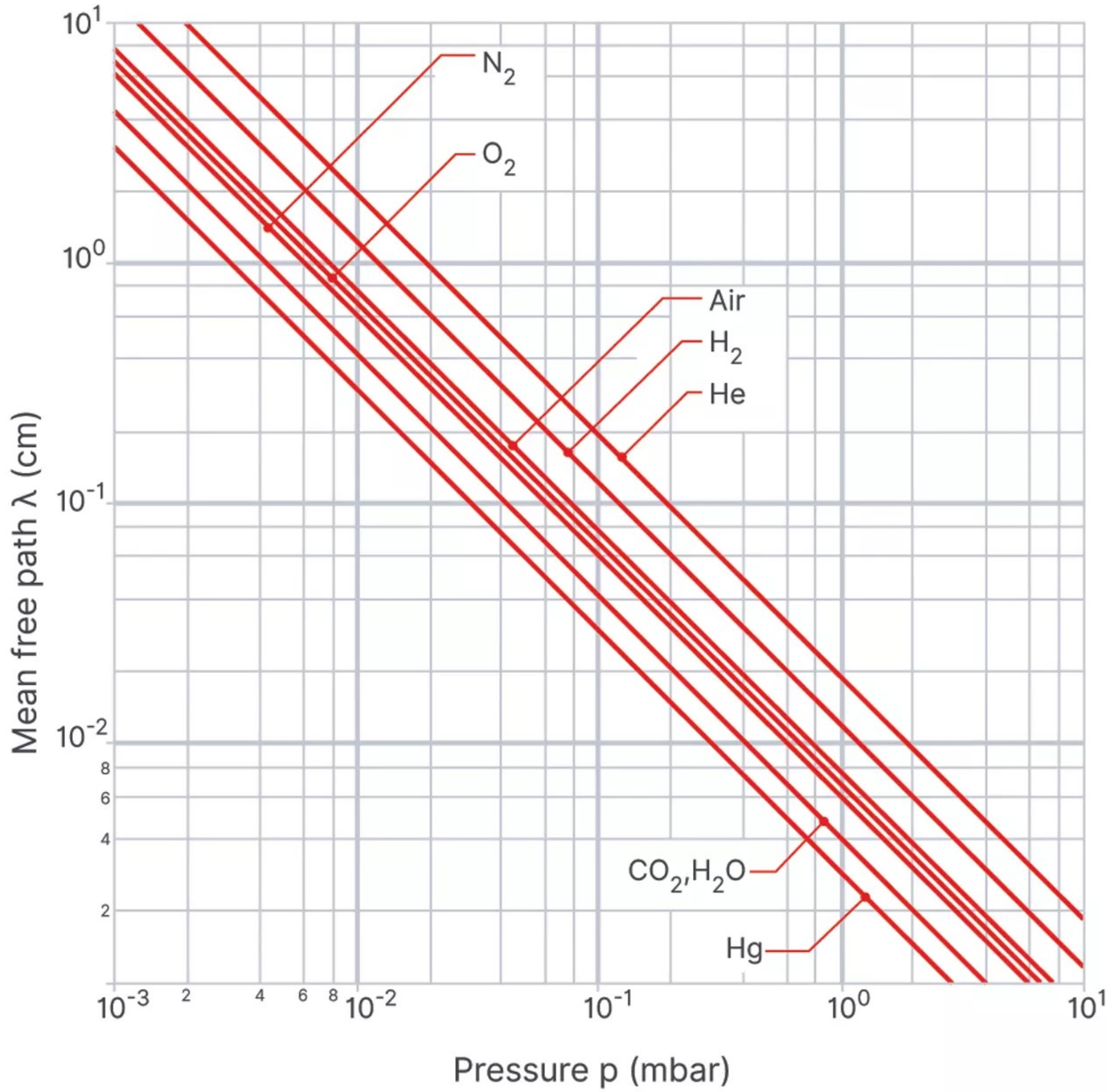
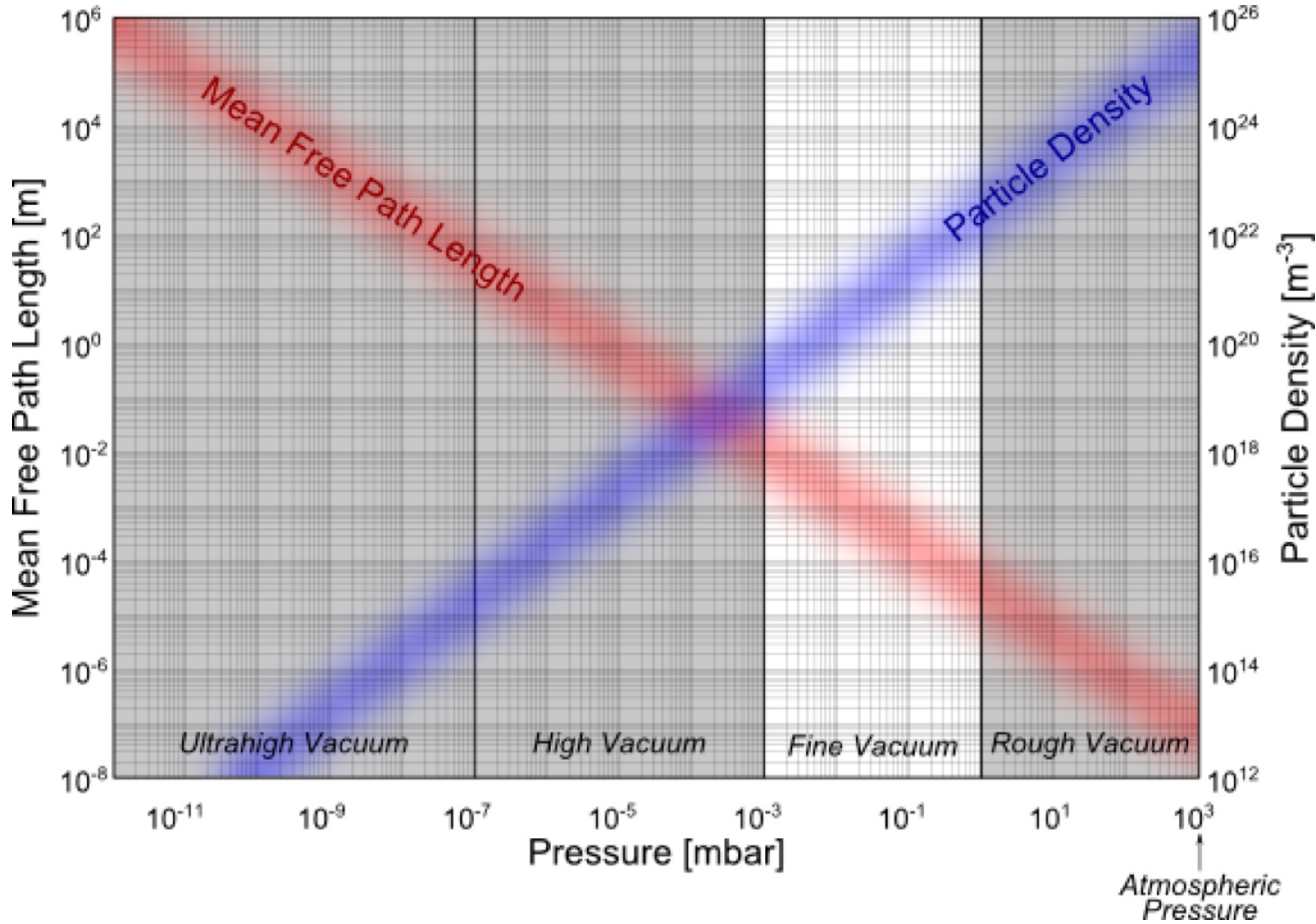
Lower pressure to decrease the mean free path – the average distance a particle travels before undergoing a significant collision with another particle



$$\Lambda = \frac{k_B T}{\sqrt{2} \pi d^2 p}$$

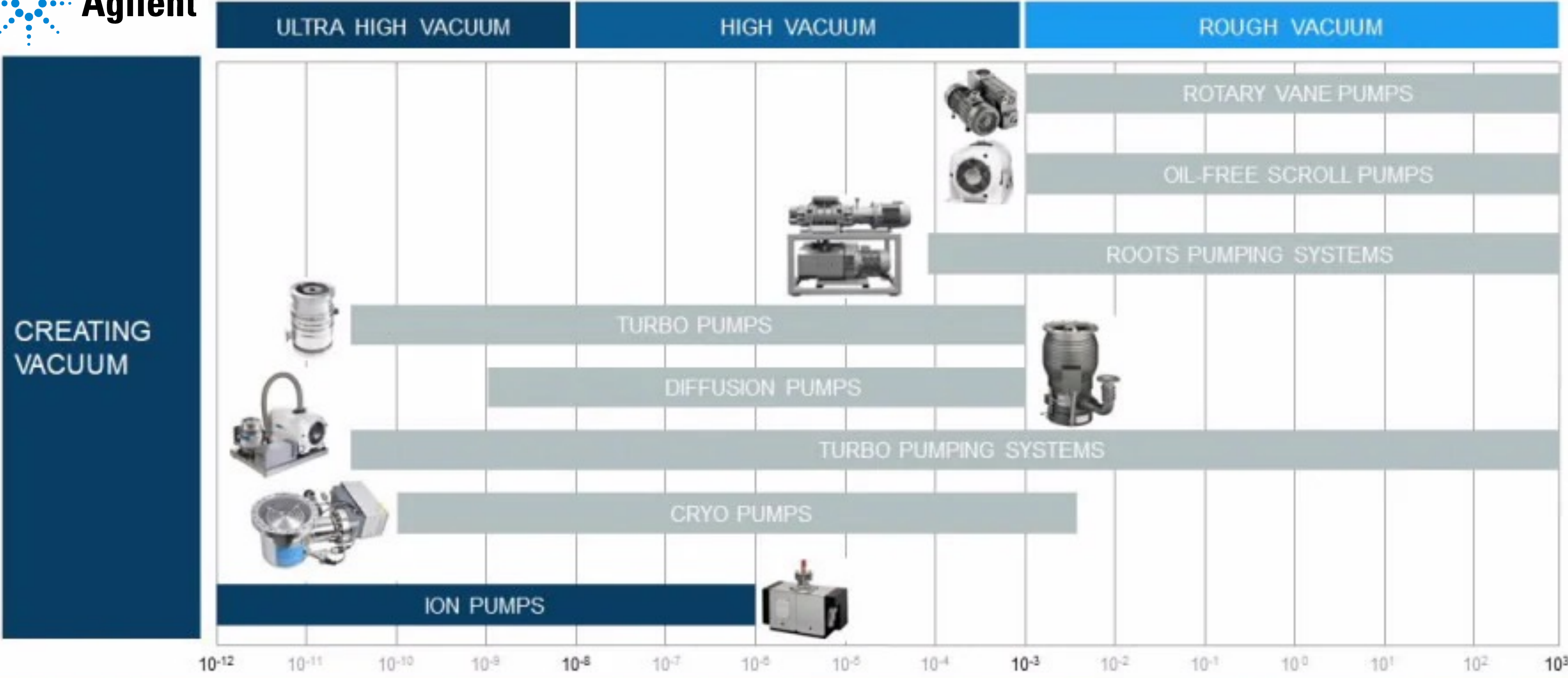
Λ : mean free path
 k_B : Boltzmann's constant
 T : Temperature
 d : diameter of particle
 p : pressure

How To Achieve Ultra High Vacuum (UHV)



How To Achieve Ultra High Vacuum (UHV) - Pumps

Final vacuum level $\begin{cases} \rightarrow \text{Type of pumps used} \\ \rightarrow \text{Degassing rate of the chamber materials} \end{cases}$



Pumps do not work over wide pressure range

How To Achieve Ultra High Vacuum (UHV)

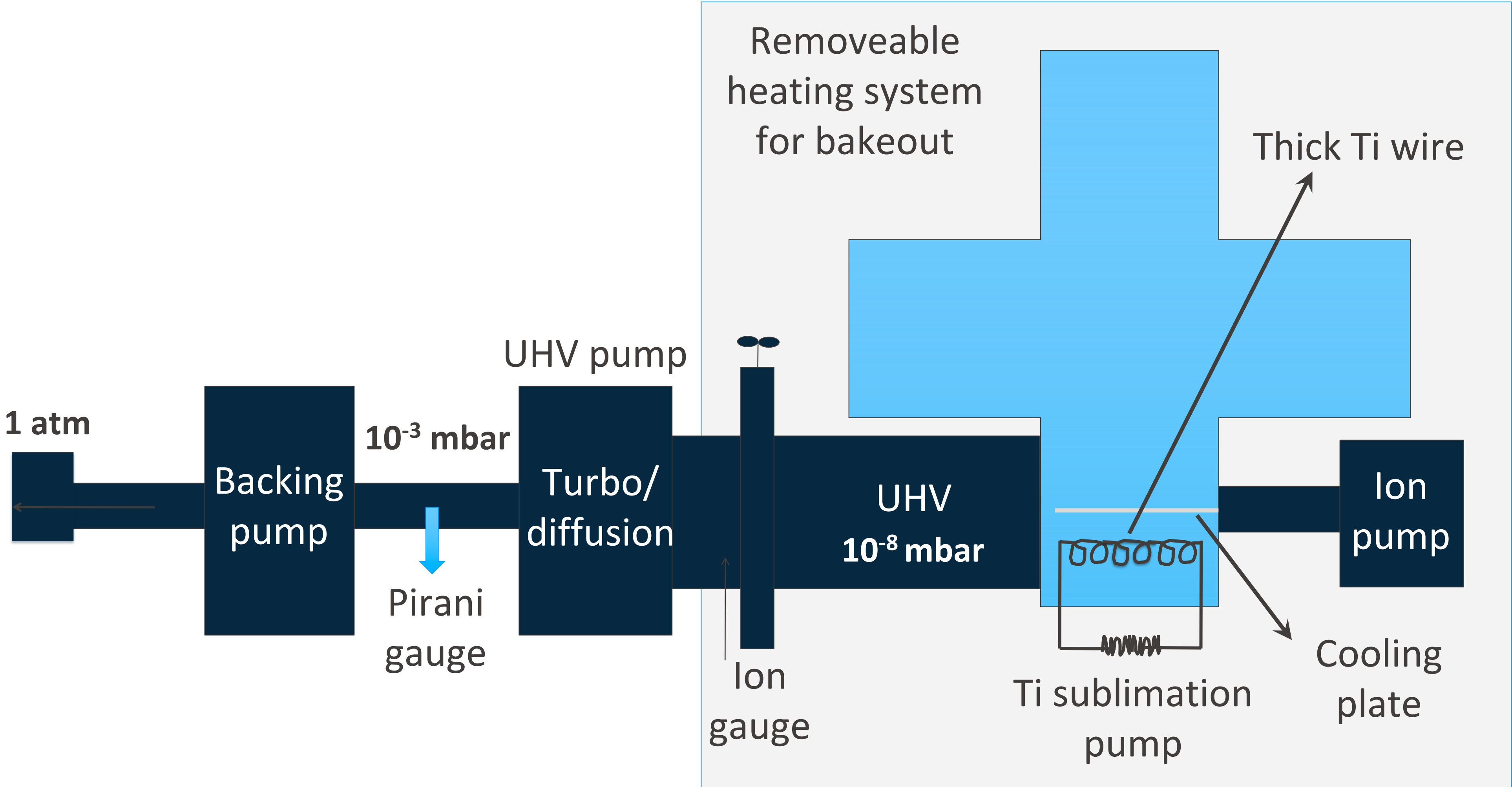
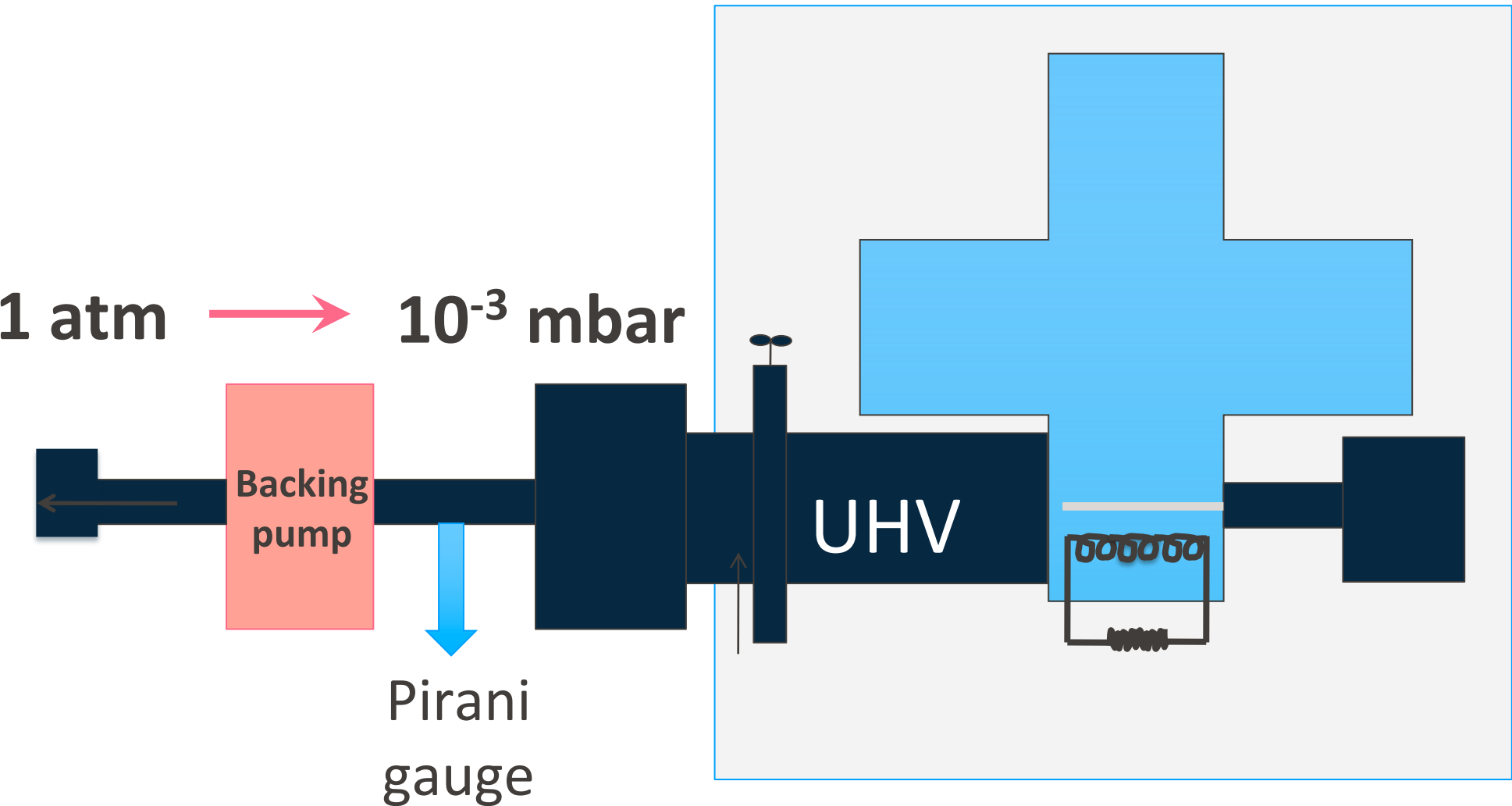


Image: Nic Spencer

Stage 1: Backing pump (“Backs Up” the Primary Pumps)



Reduce pressure to a workable level from atmospheric P

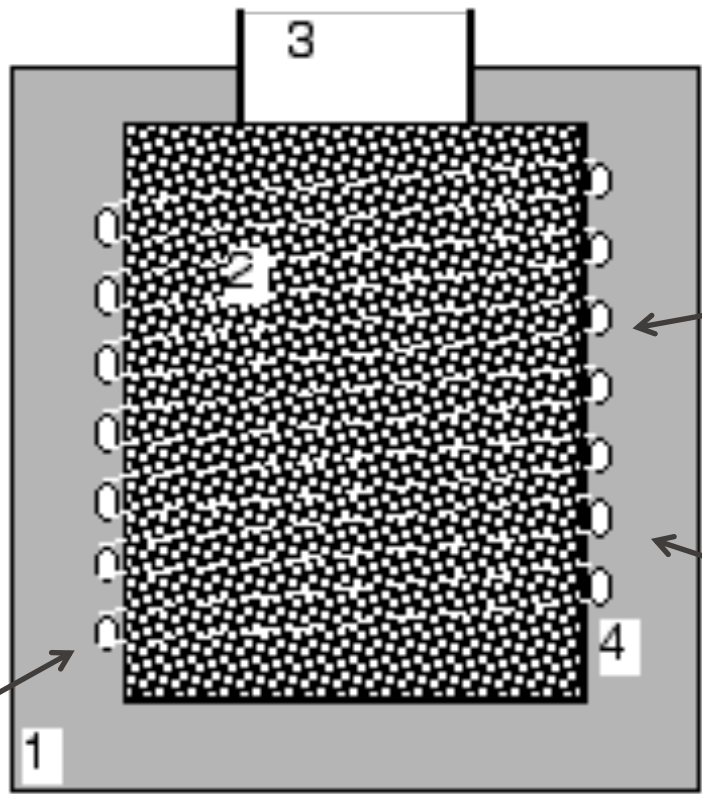
Discharge gas molecules

Prevent backflow

**Sorption pump:
molecular sieve**

Cooling with liquid nitrogen to adsorb gases

Connection to the vacuum chamber

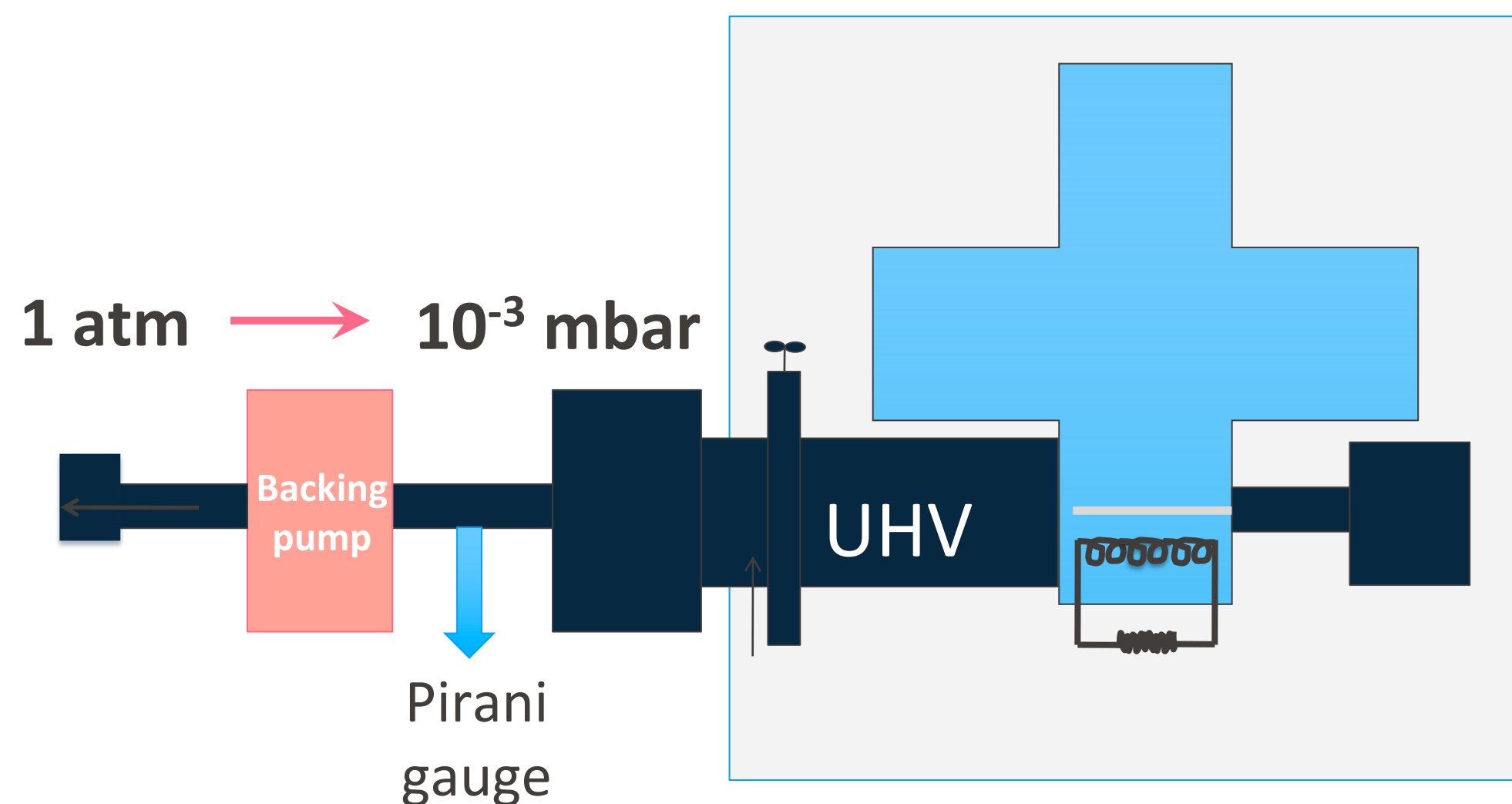


Molecular sieve traps gas molecules

Heating to release trapped gas molecules – regeneration

Image: Wikipedia

How to Measure the Pressure? Pirani Gauge



If $P > 10^{-3}$ mbar (low-mid vacuum) pressure can be measured by thermal conductivity (hot wire in a gas)

$$\lambda = A \cdot n \cdot c \cdot \Lambda \cdot \frac{c_v}{N_L}$$

λ : heat conductivity

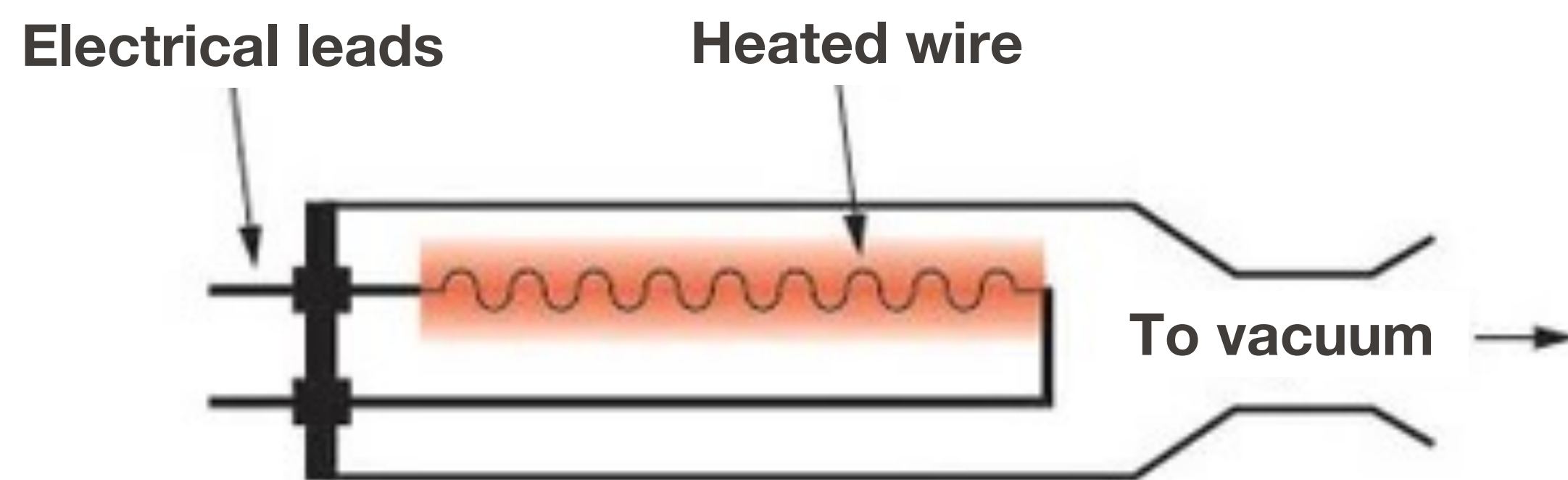
A : structure factor (geometry dependent constant)

n : number of molecules per unit volume in m⁻³

c : medium speed of the particles in m/s

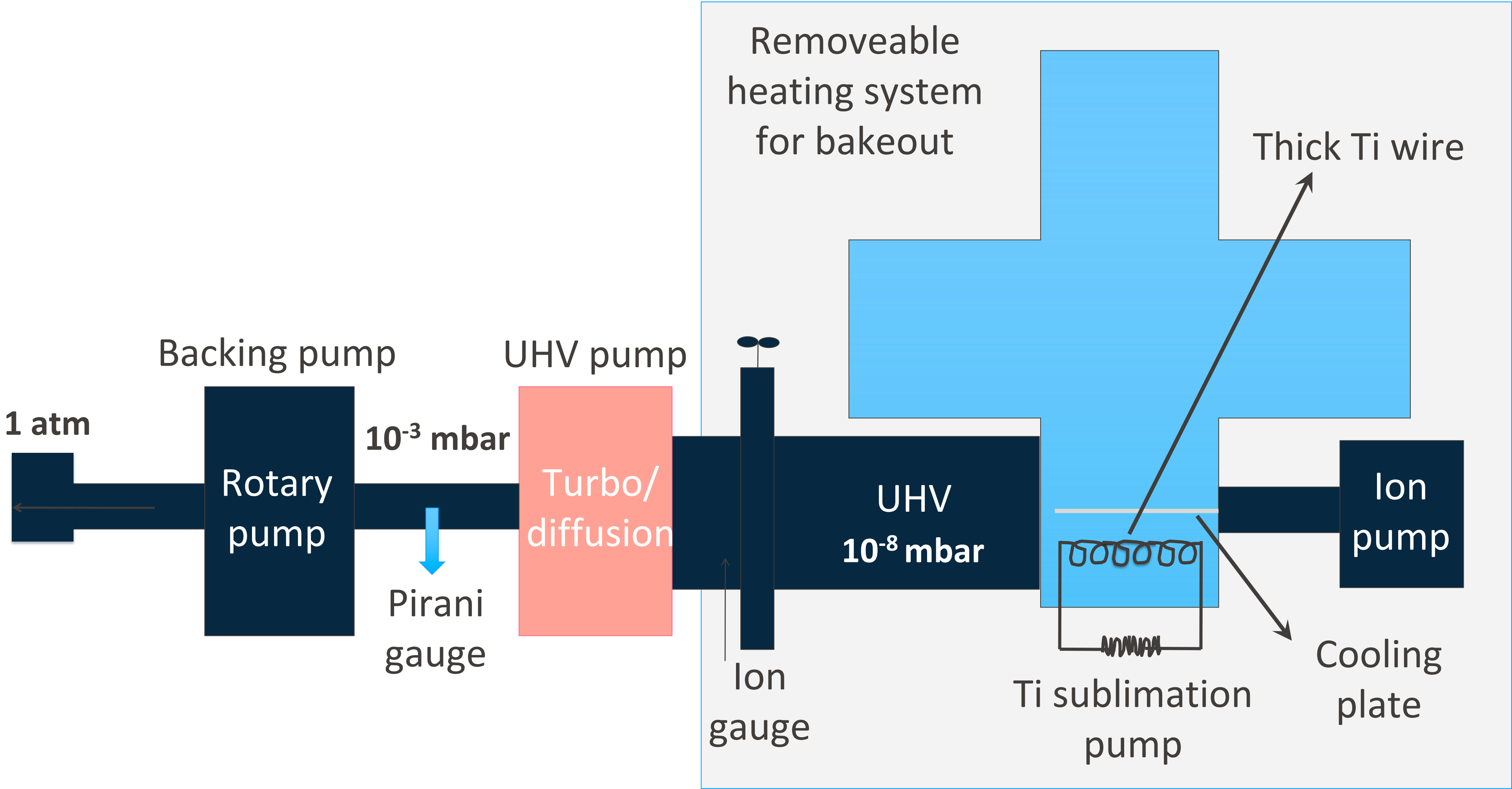
Λ : mean free path

c_v : molecular thermal capacity



Pressure is calculated by combining thermal conductivity and ideal gas law: $n = \frac{p}{k_B T}$

How To Achieve Ultra High Vacuum (UHV)

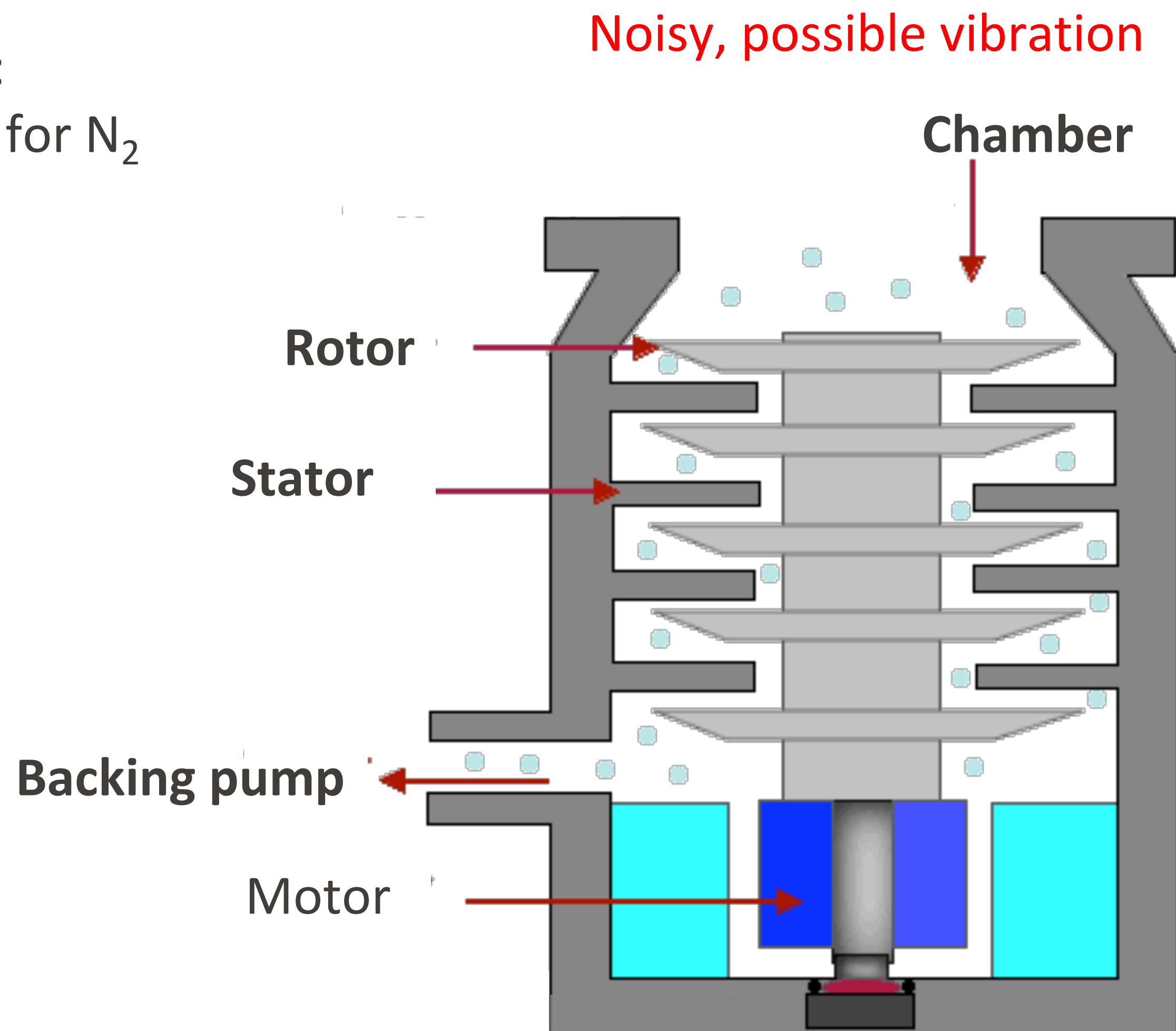


Stage 2: Turbo Molecular Pump

Gas molecules in the pump are given a desired orientation by impacts with a rotating turbine

The rotor speed needs to be comparable to the thermal speed of the molecules

At 20 °C:
 $V_{\text{avg}} = 472 \text{ m/s}$ for N_2



Roger Federer
Precision

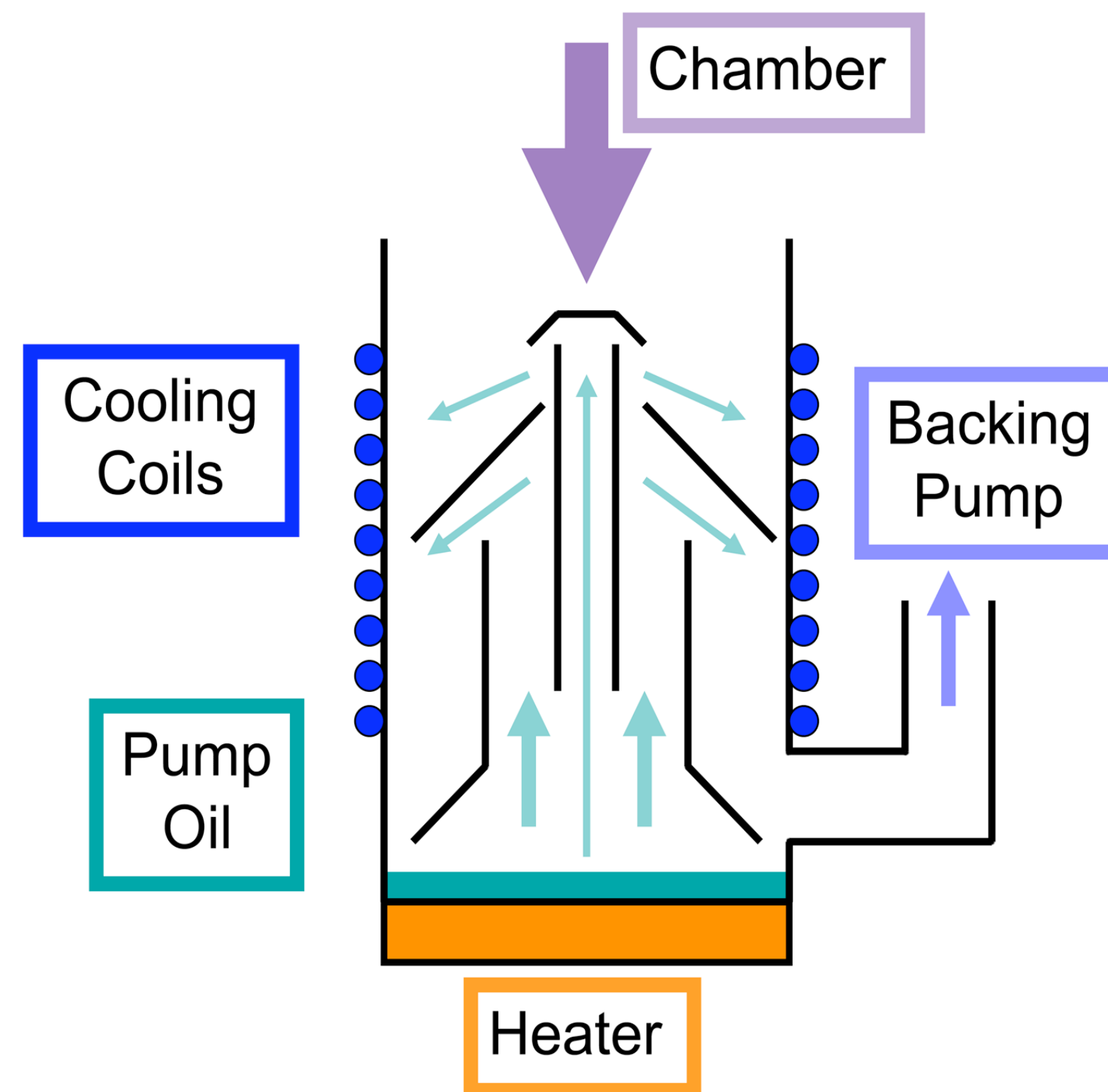
Stage 2: Diffusion Pump

Gas molecules in the pump are given a desired orientation by impacts with a supersonic vapor jet of oil molecules

Polyphenyl esters are used for their low vapor pressure at room temperature

Cheap and effective for all gases

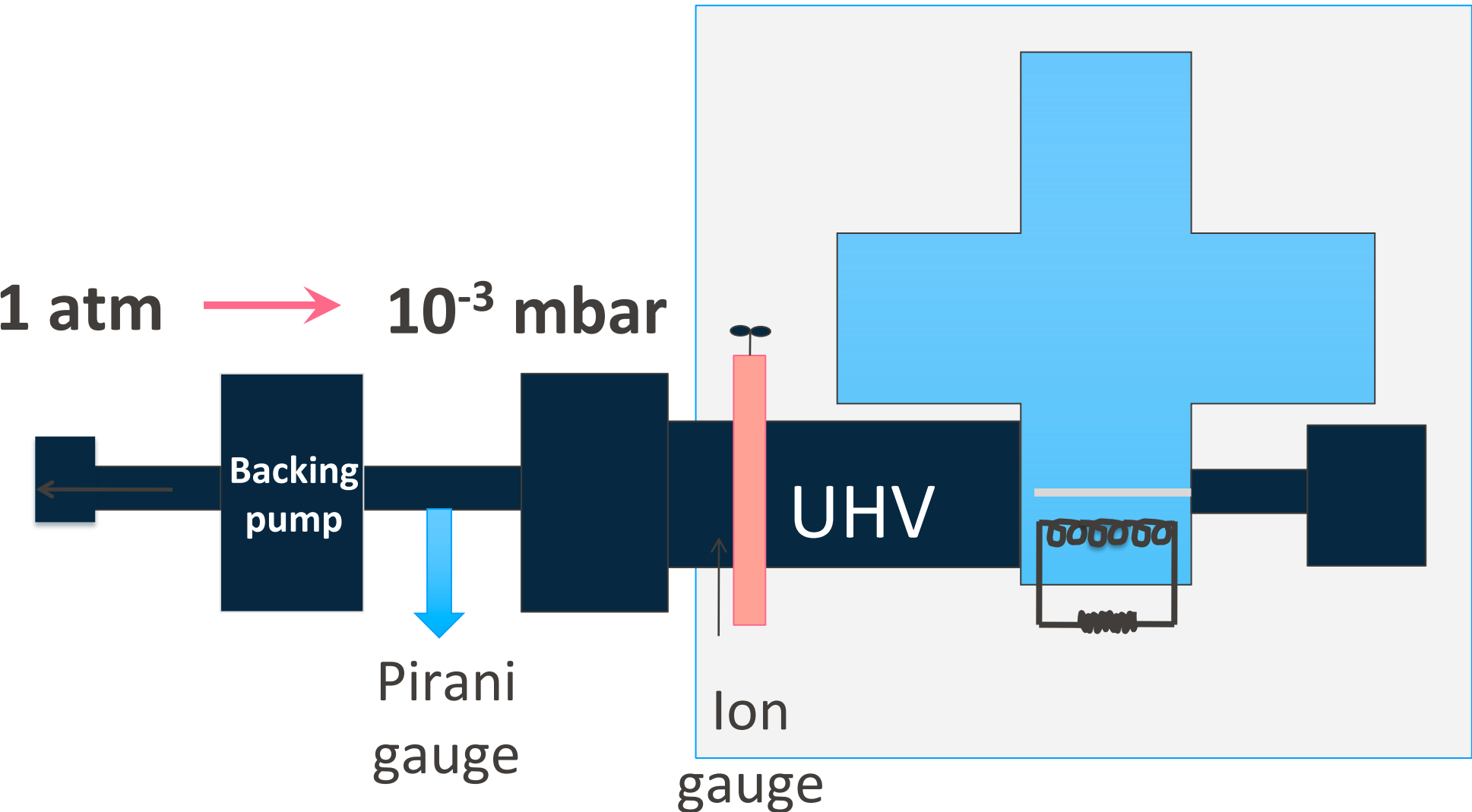
Needs a cooling system and consumes significant energy



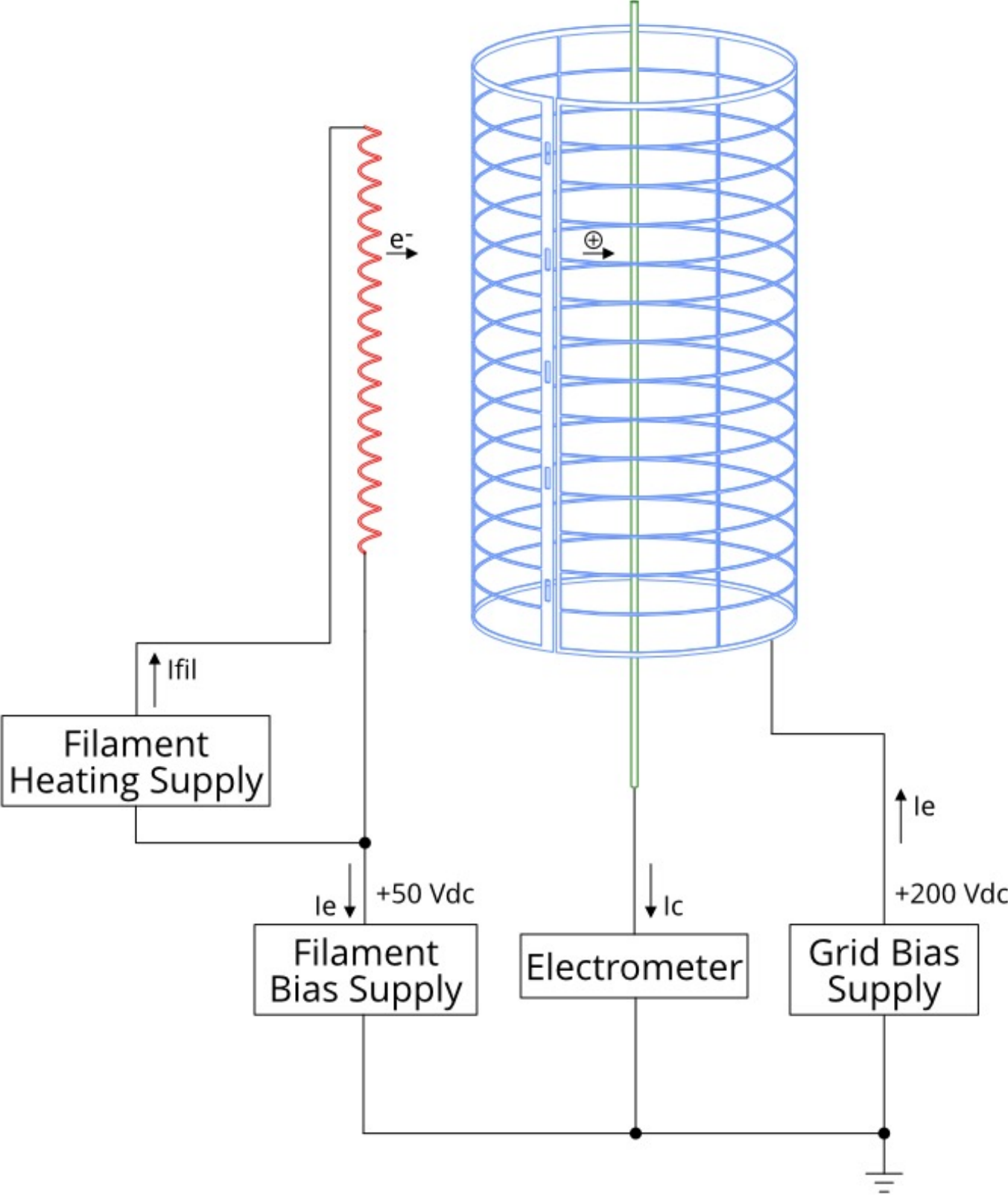
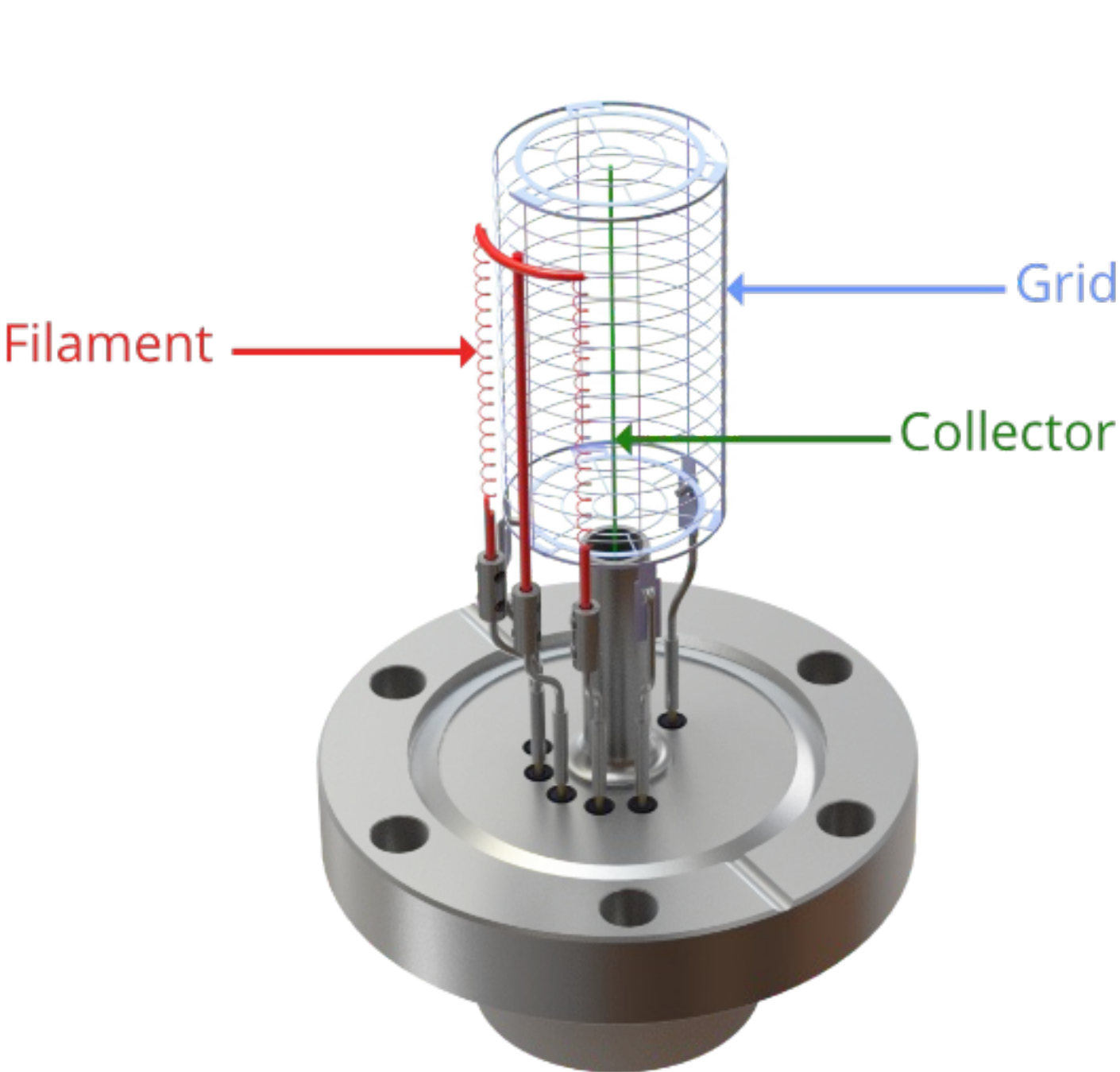
Raphael Nadal
Raw power

Image: Wikipedia

How to Measure the Pressure? Ion Gauge



If $P < 10^{-3}$ mbar pressure is measured by ion gauges



Electrons accelerated between a cathode and anode ionize gas
 Ions are attracted by the **anodic collector**

Anode current is proportional to the pressure:
$$P = \frac{I_c}{(s \times I_e)}$$

I_c : current at collector electrode (\propto number of ions generated)
 s : gauge sensitivity (constant)
 I_e : electron emission current (constant)

Maintaining Ultra High Vacuum (UHV)

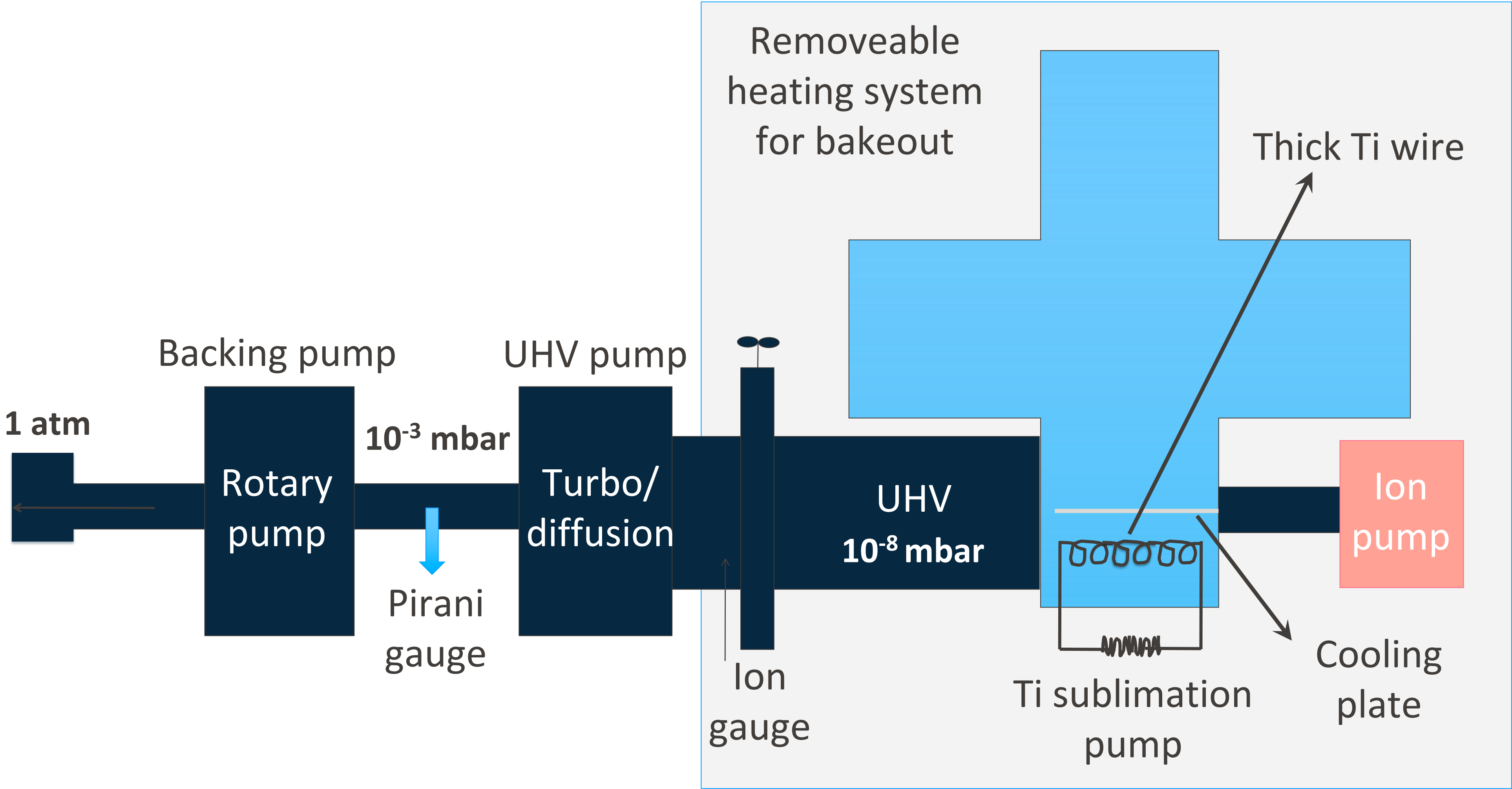


Image: Nic Spencer

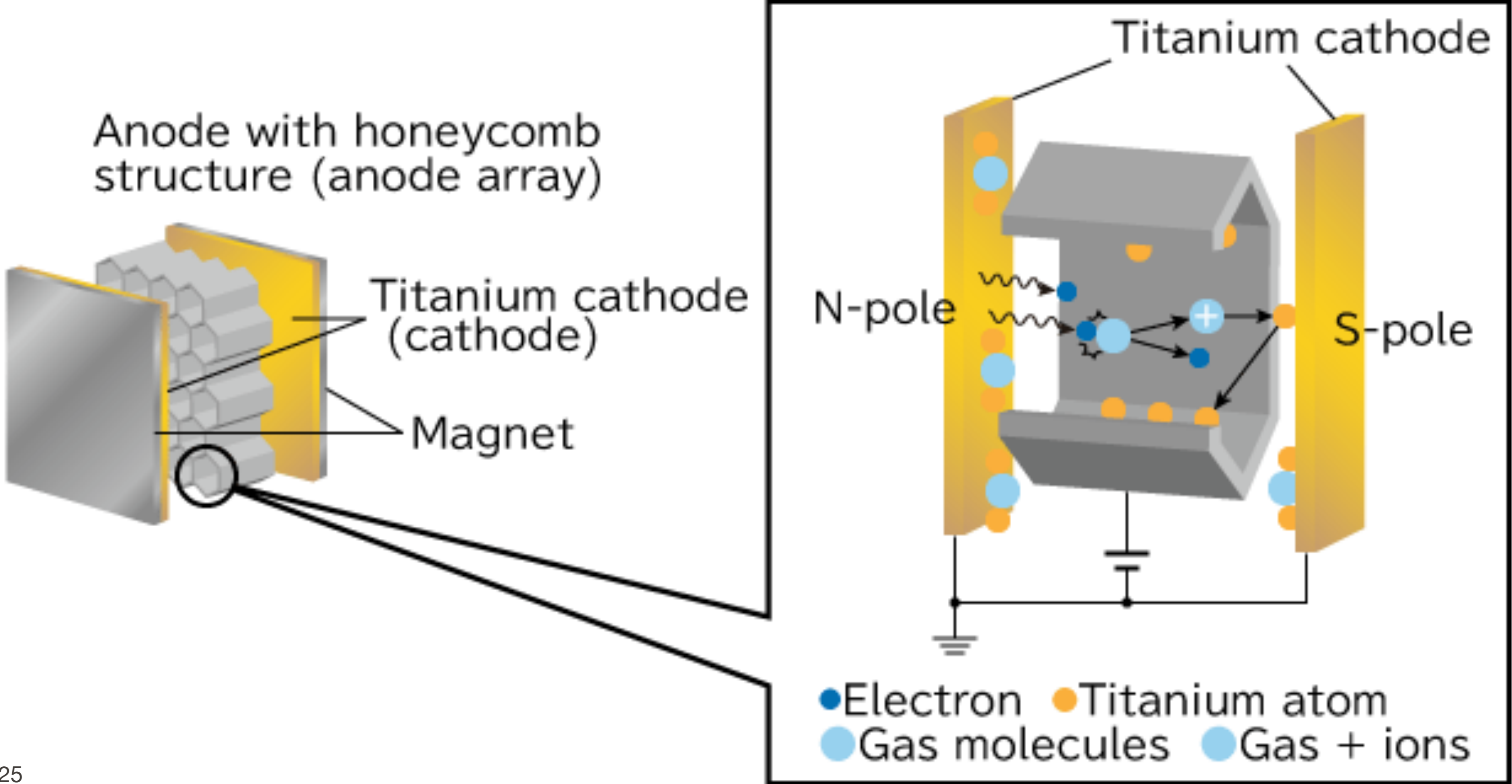
Stage 3: Ion Pump

Ionizes gases and employs a strong magnetic field to accelerate them onto a solid titanium electrode

Sputtering of Ti occurs

Ti atoms produced react with gas molecules (oxygen, hydrogen, CO, CO₂), which chemisorb to the surface

Not very suitable for noble gases or large amounts of gas



How To Achieve Ultra High Vacuum (UHV) – Baking Out

UHV chambers are heated overnight (150-200 °C) to increase the desorption gas rate of species adsorbed on chamber walls

Probability of desorption of a particle per second: $\nu = \nu_0 e^{-E_{ads}/kT}$

ν_0 : intrinsic vibration/attempt frequency of adsorbed molecule to leave surface

E_{ads} : binding energy of molecule to the surface

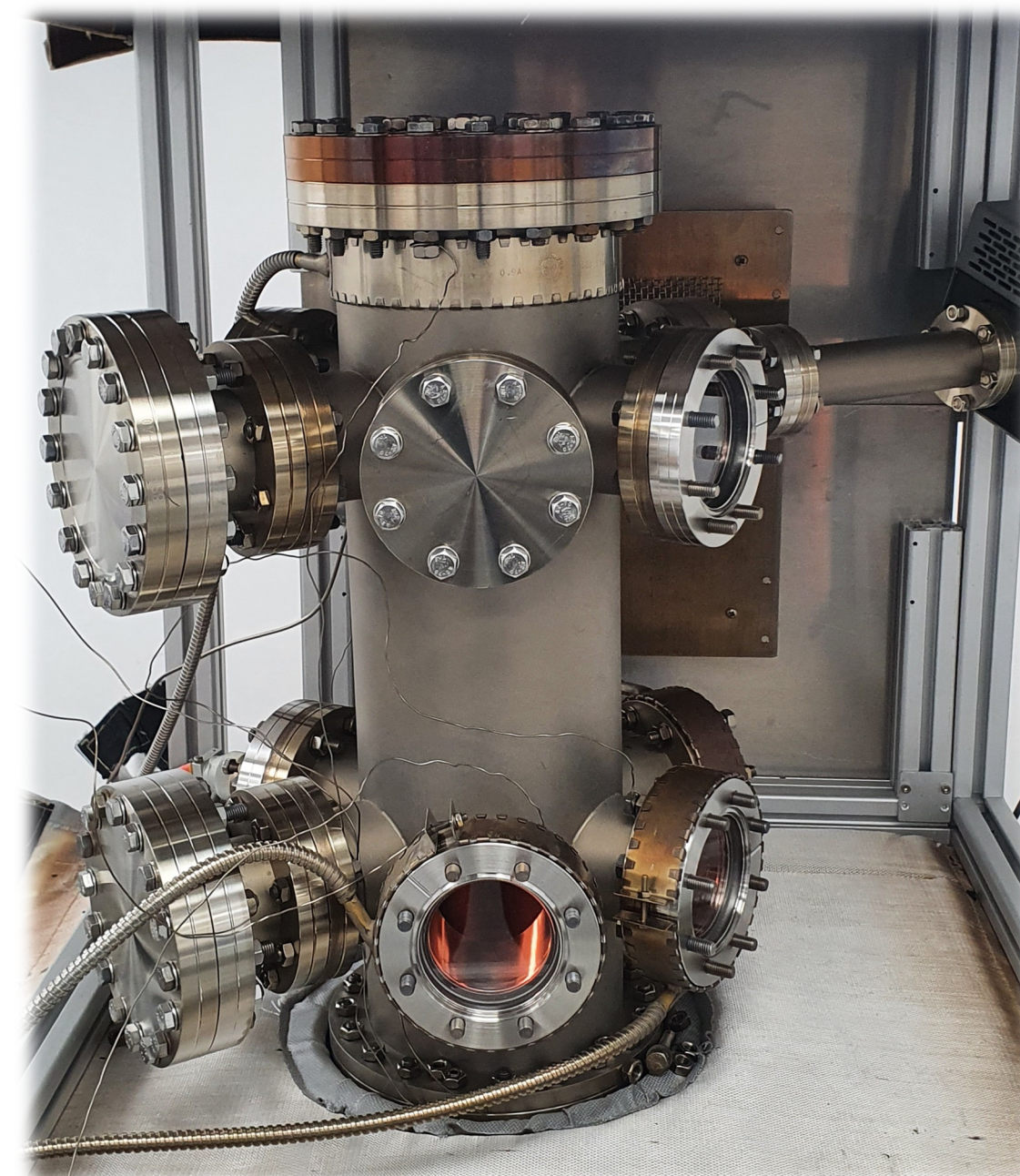
k : Boltzmann's constant

T : Absolute temperature of surface during bake-out

For H₂O on stainless steel, increasing T (300K to 500K), increases the desorption probability by several orders of magnitude

Before heating: adsorbed and residual gases are mainly H₂O molecules

After heating: CO, H₂ and CH₄ are present



Requirements for Construction Materials of UHV Chamber @ 200 °C

- 1) Mechanically and thermally stable
- 2) Low vapor pressure

Polymeric materials: cannot be used as construction materials (high VP, permeability/trapping water, thermal, mechanical, and chemical instability) (apart from Viton and PTFE)

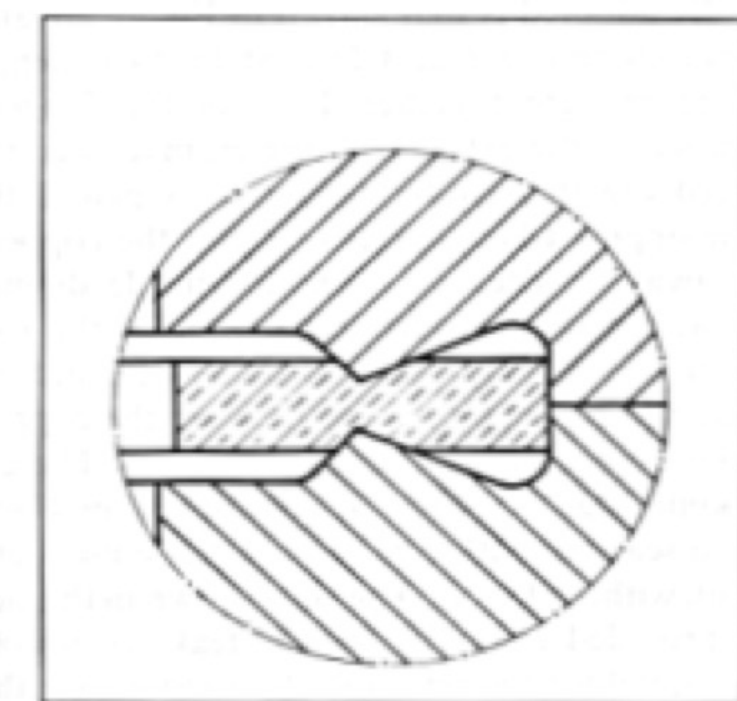
Zinc alloys or galvanized steel: cannot be used as construction materials (high vapor pressure of zinc)

Ta, W, Mo: used to make sample holders (too expensive and difficult to machine to be used for the chamber)

Stainless steel: suitable to make chamber

Oxide ceramics: suitable to make electrical insulators

Cu: usually used to make gaskets



(b)
Cu gasket seal

Requirements for Construction Geometry

- 1) Large diameter tubing to connect pumps
- 2) Bends should be avoided

Thin pipes and cracks cannot be evacuated in finite time



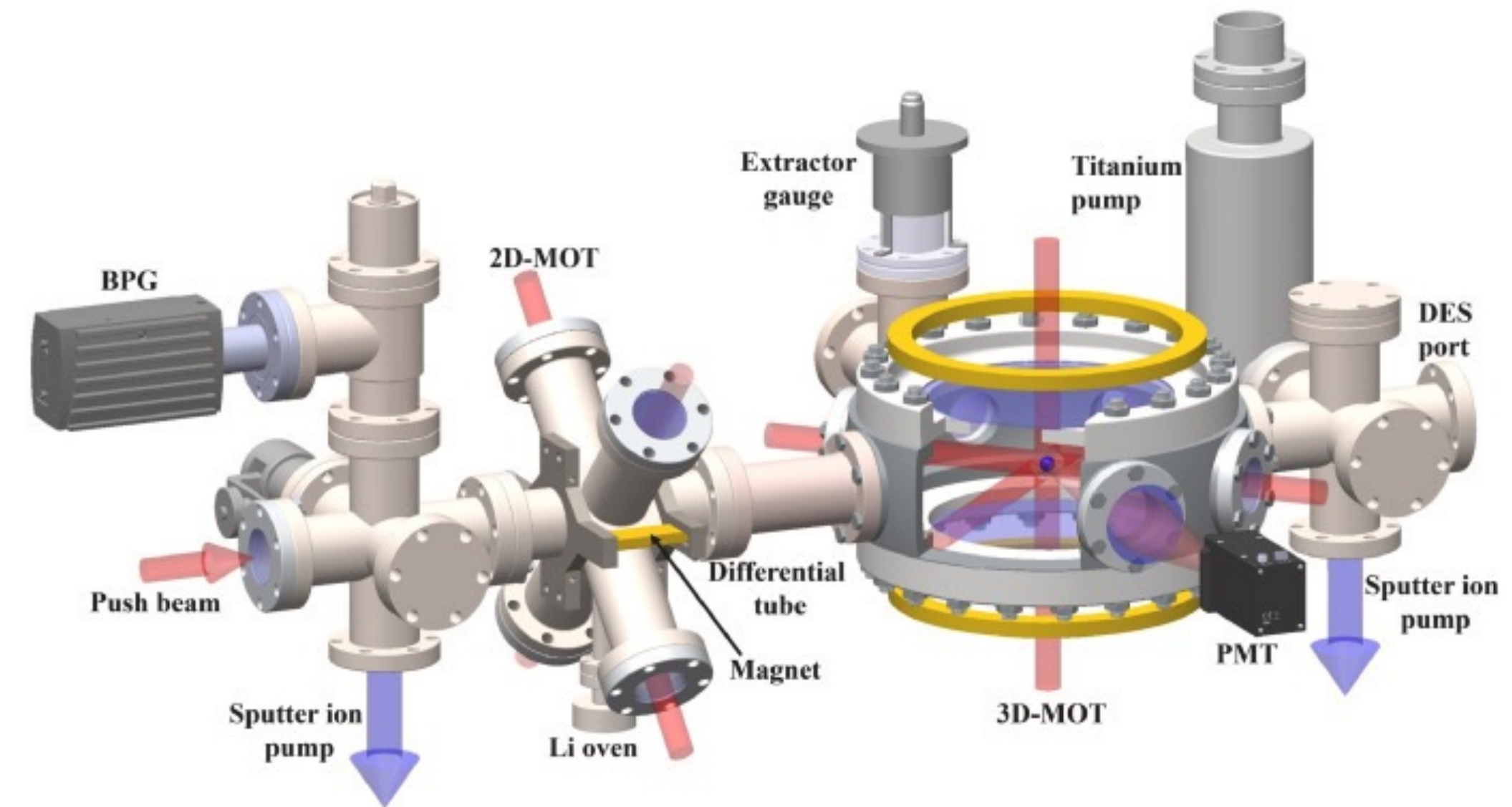
At RTP, the mean free path of gas molecules is on the order of meters



Molecules move back and forth between the walls without collisions



Low probability that a molecule leaves the chamber through a thin pipe



Sun et al. | *Vacuum* | 2024

Pumping velocity $\propto r^4$
(r = radius of the
connecting pipe)

Key Takeaways

UHV conditions are necessary to obtain clean surfaces

Increase mean free path of molecules = decrease collisions with surfaces

UHV conditions are challenging to obtain (complex instrumentation)

Keeping surfaces clean is very challenging

Summary of Today's Class

- Information on the **course**
- Introducing **surface science** – challenges and opportunities
- Why study **surface science**? – applications and Nature
- Basics and applications of **ultra high vacuum (UHV)**



Prof. Nako Nakatsuka
nako.nakatsuka@epfl.ch

EPFL
Laboratory of Chemical Nanotechnology
Campus Biotech
Chemin des Mines 9
1202, Geneva

<https://www.epfl.ch/labs/chemina/>

