Heavy Parachute

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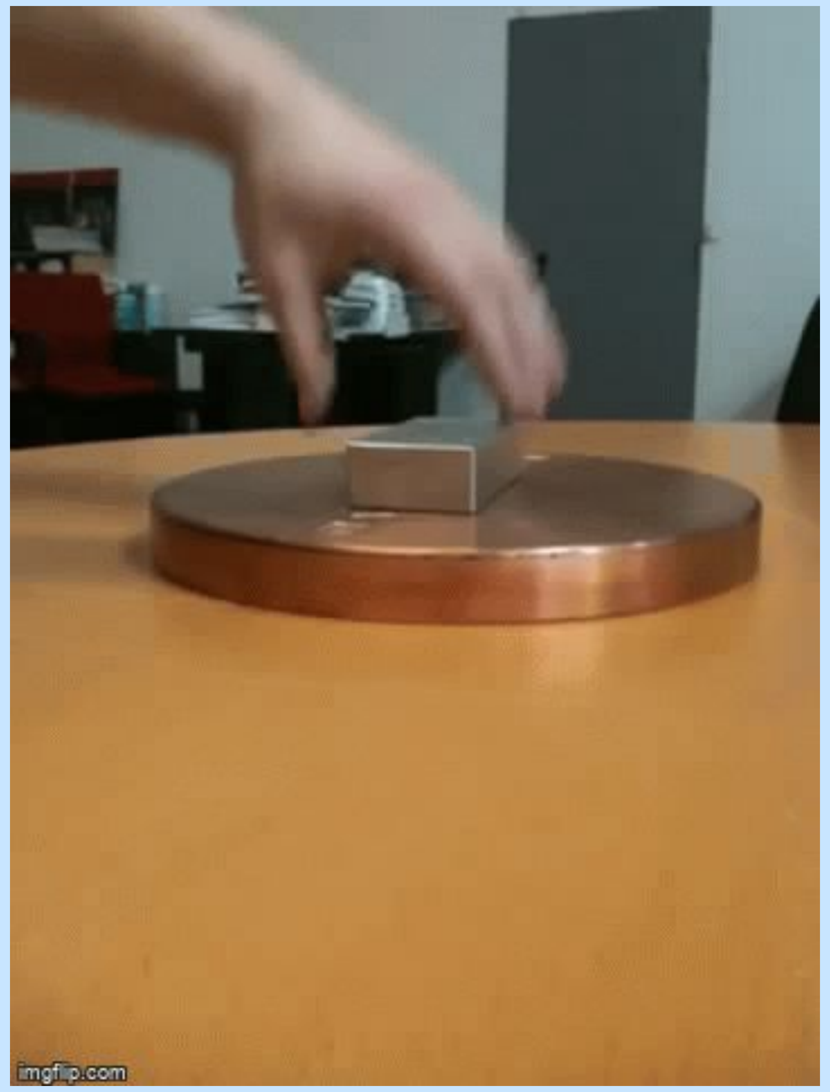
Marcin Kovalevskij

Université de Paris

Problem

"Is it possible to build a magnetic parachute to protect a load from impact when landing on a non-magnetic metallic surface? How should it be built in order to minimize the impact damage? What are the limitations of your parachute?"



source [1]

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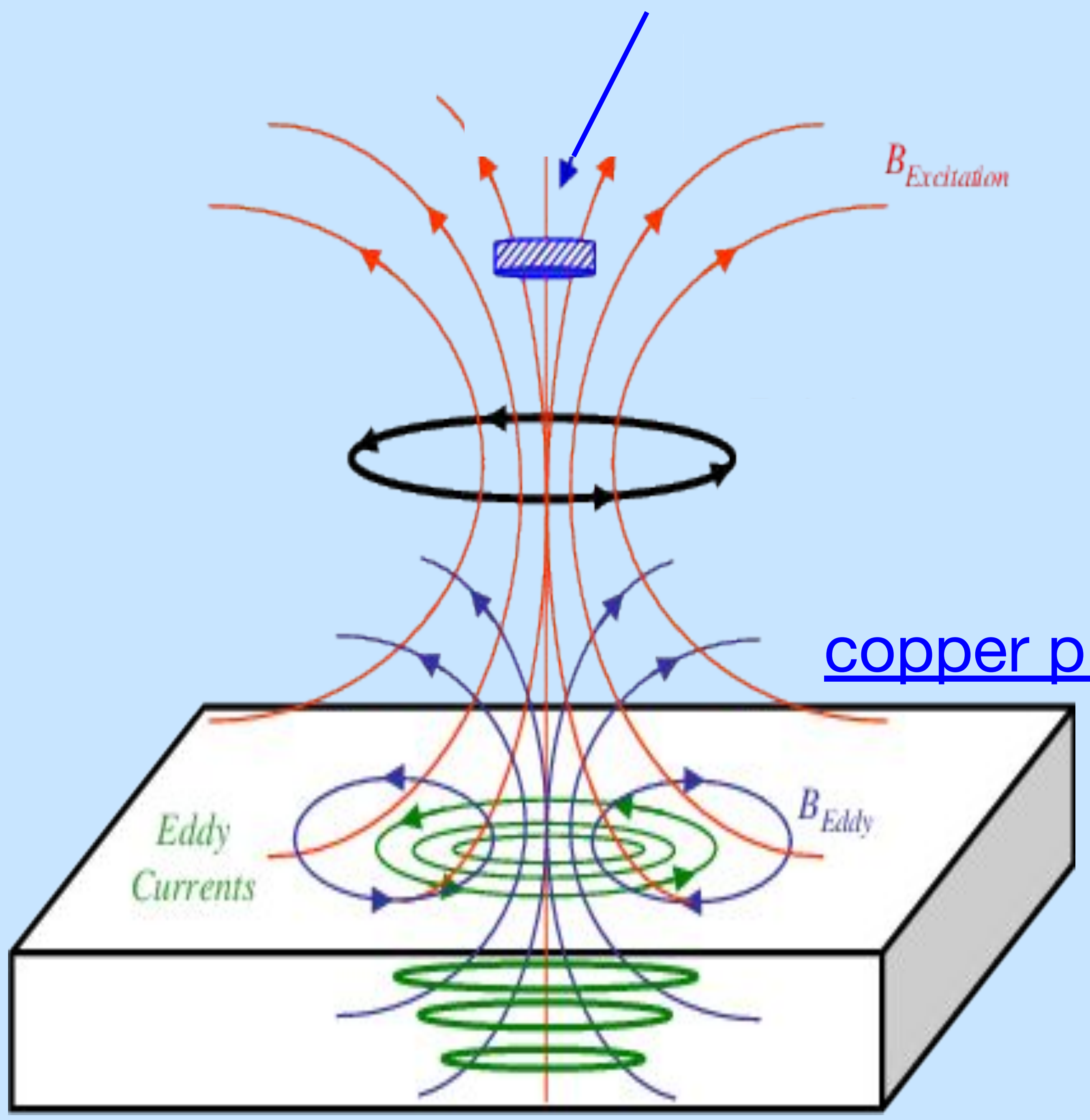
Eddy Currents

→ Loops of electric current induced by a changing magnetic field

→ Eddy current creates a B field that opposes the change in the B field that originated it (Lenz's Law)

$$I = \frac{\mathcal{E}}{\mathcal{R}} \qquad \mathcal{E} = -\frac{d\phi}{dt}$$

magnet



copper plate

source [2]

Impact Momentum

From the Newton's 2nd law of motion:

$$\vec{F} = \frac{d\vec{p}}{dt} \approx m\frac{\vec{v}}{\Delta t}$$

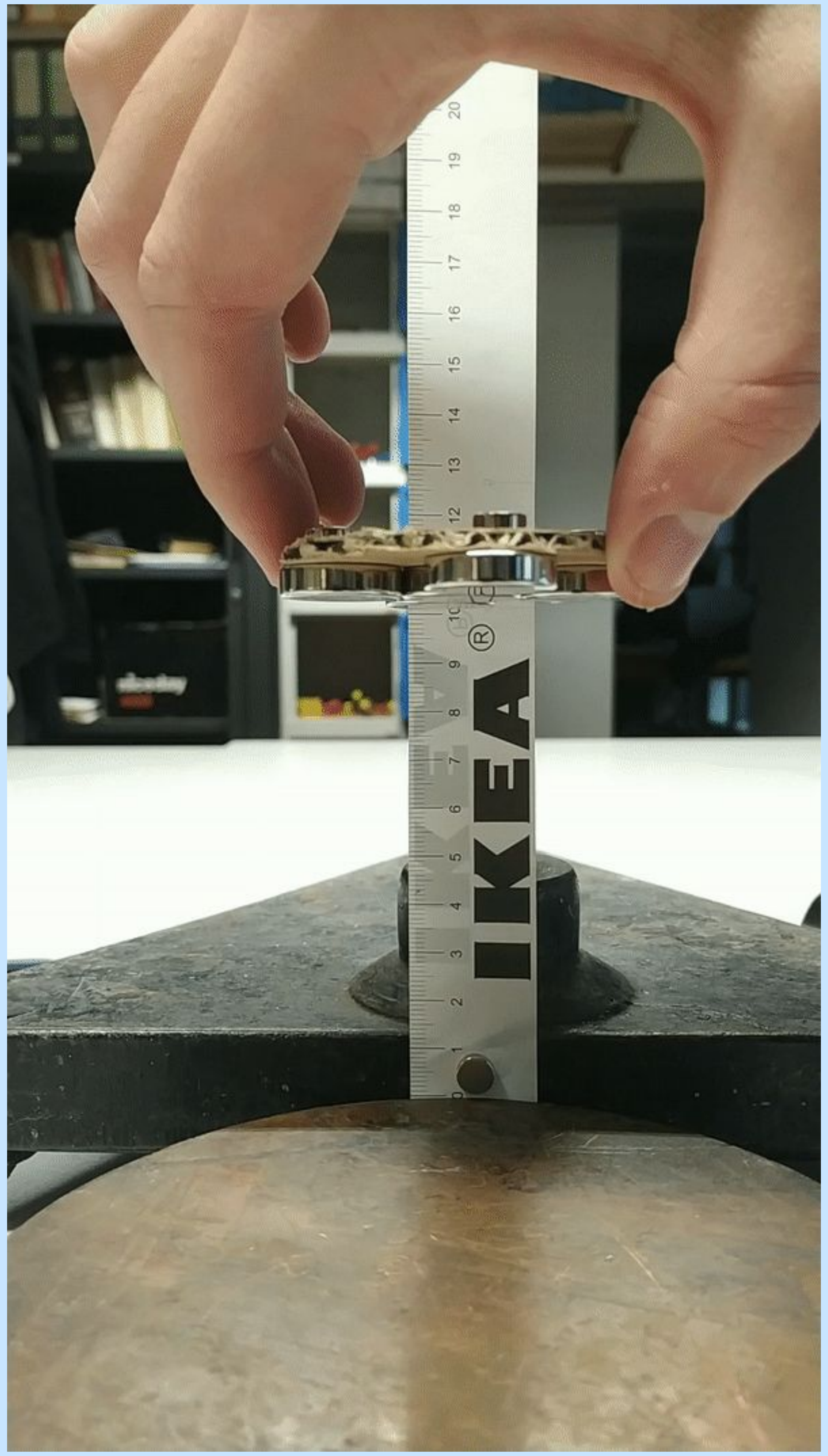
Our goal: increase Δt → minimize impact force

Experiment

→ Drop different size magnets from a fixed height

→ Record in slow motion

→ Deduce time to impact Δτ



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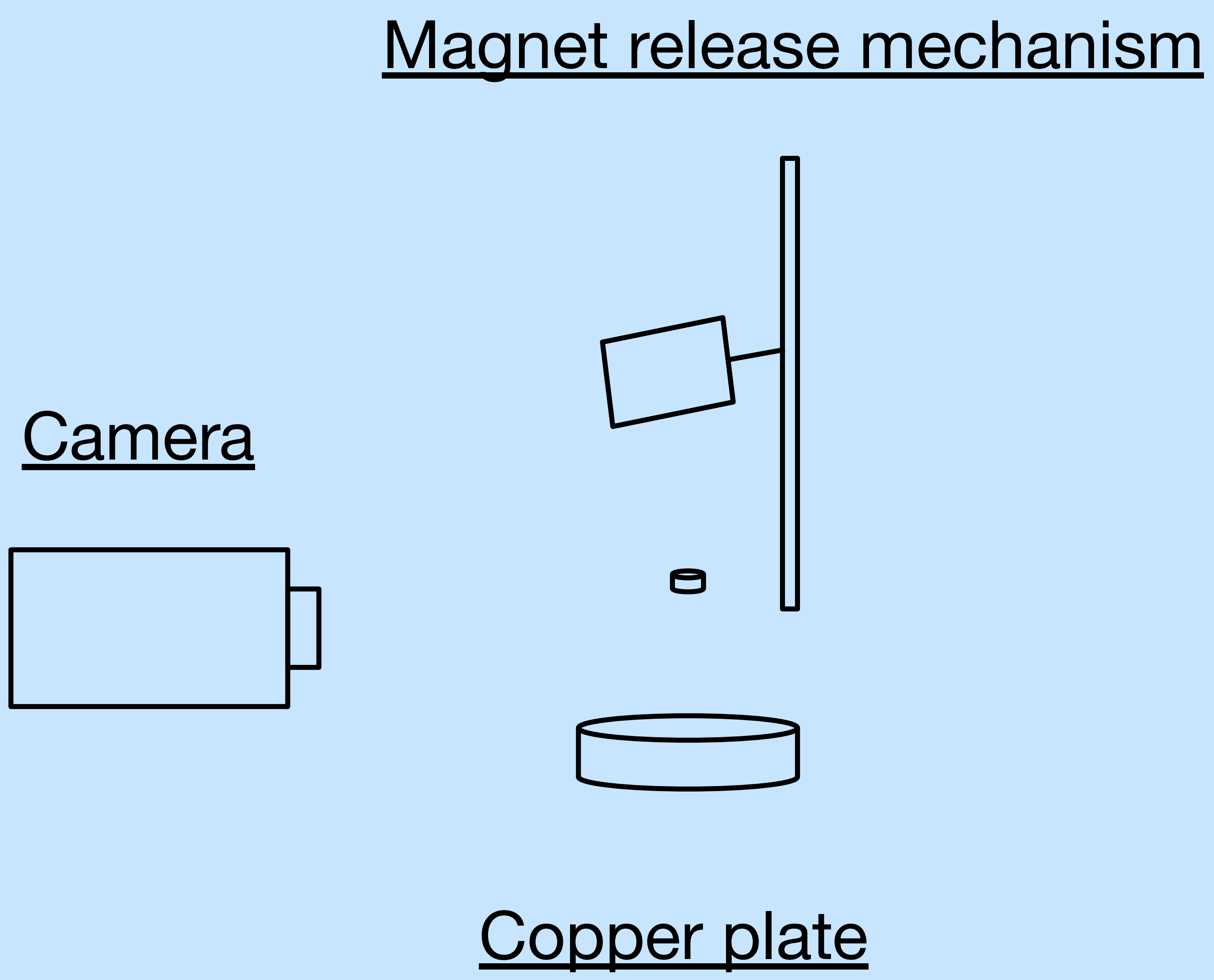
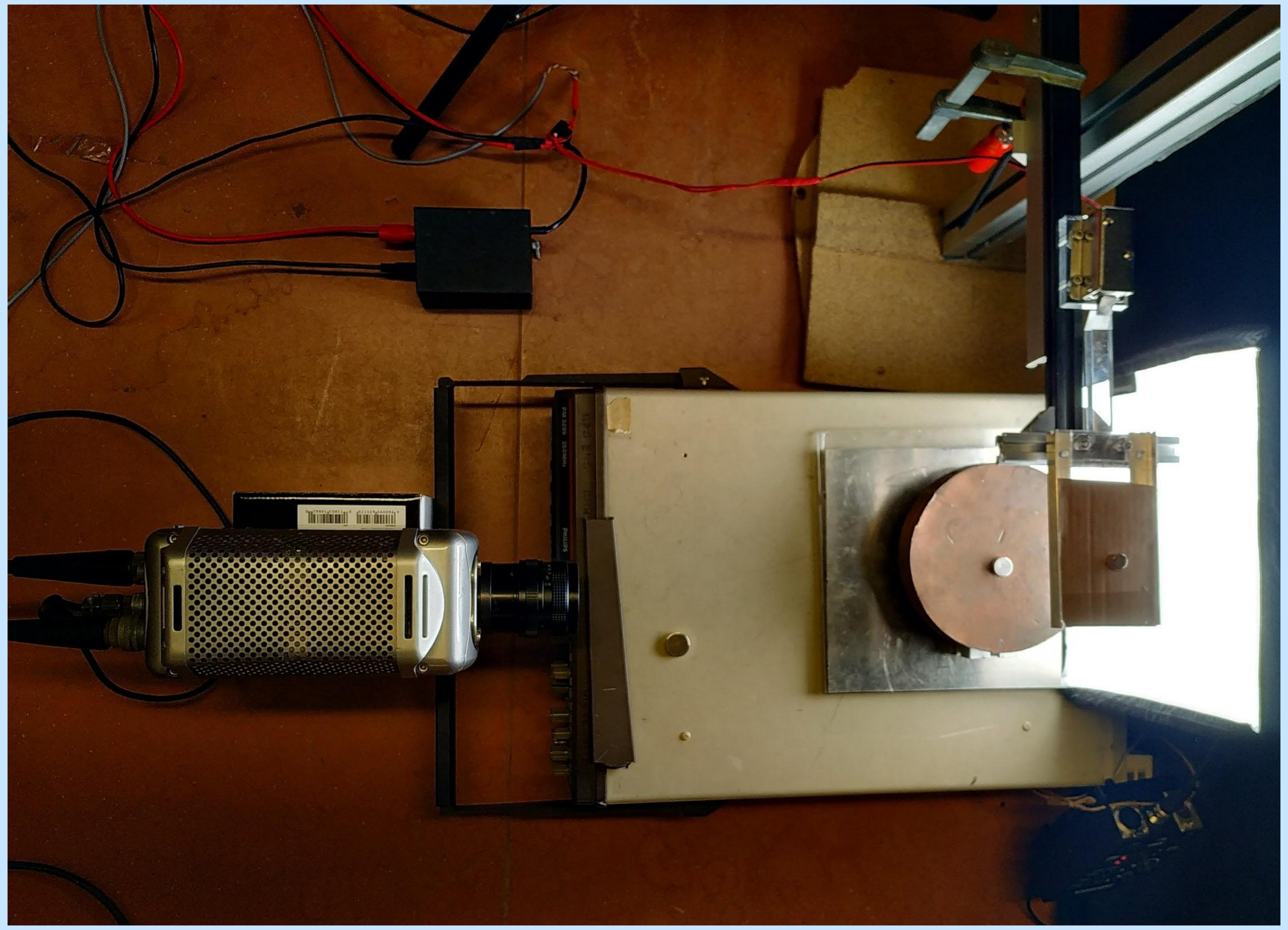
Set up



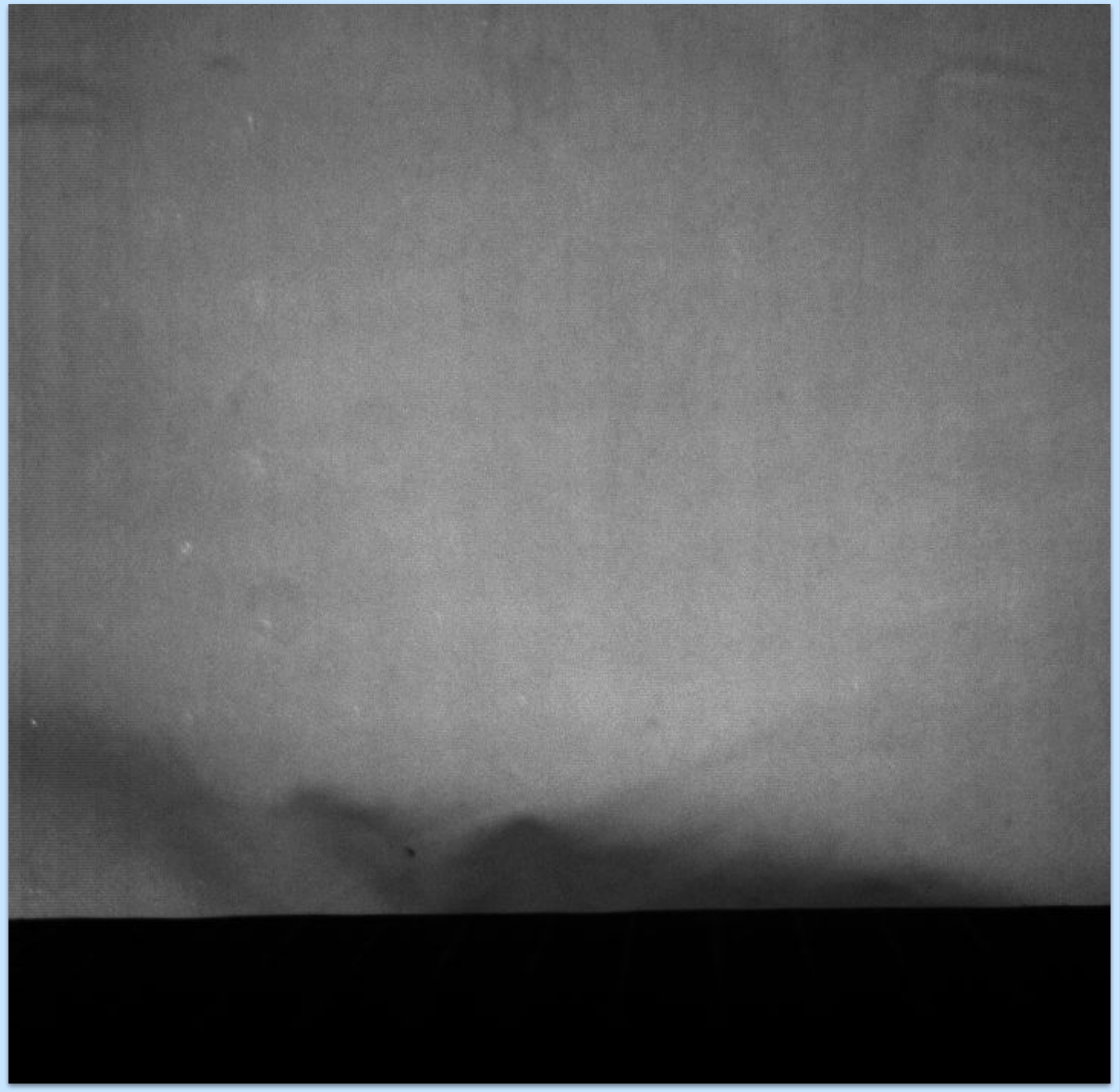


Tested magnets

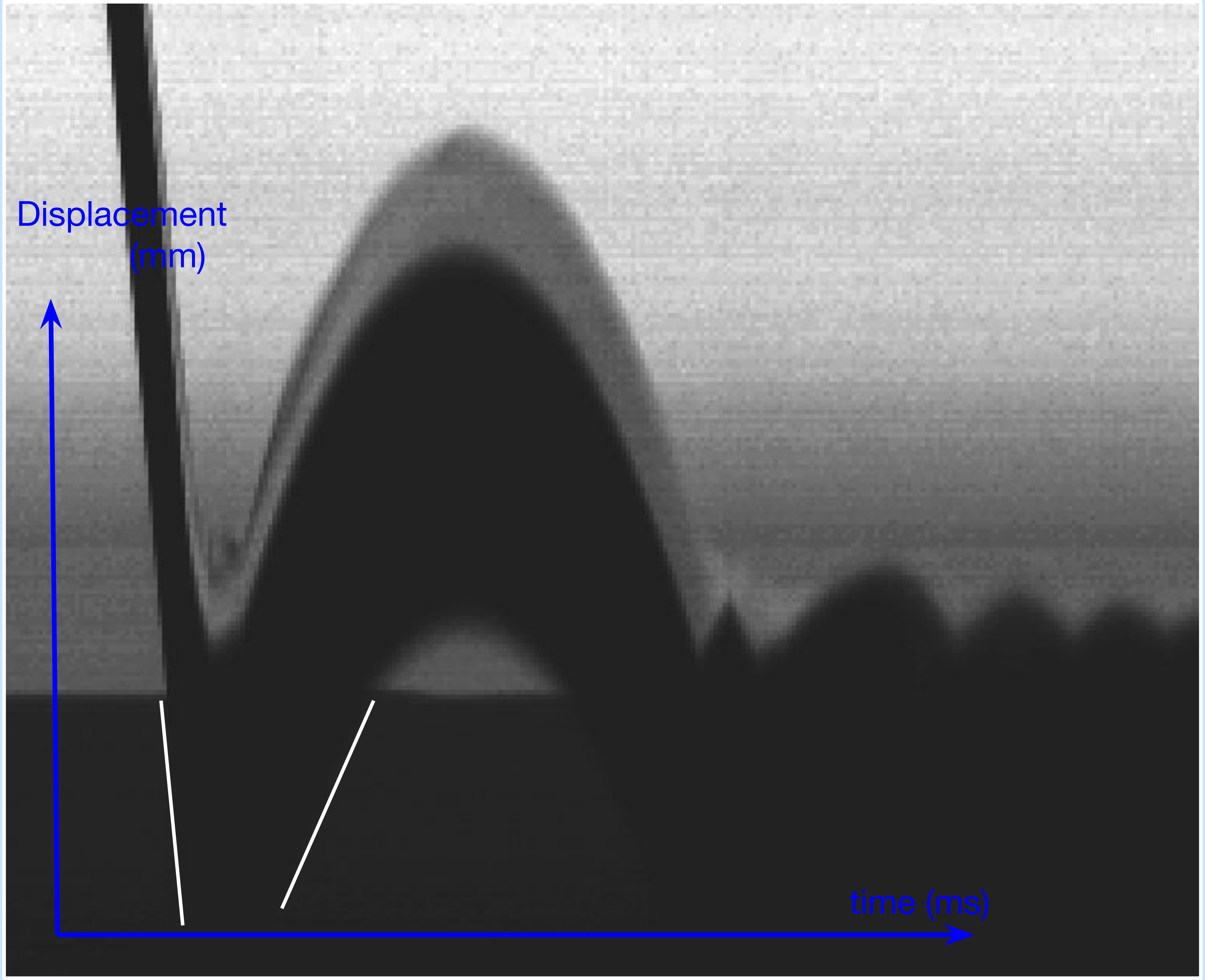
diameter x height

8   mm x 3   mm
15 mm x 8   mm
20 mm x 5   mm
30 mm x 10 mm

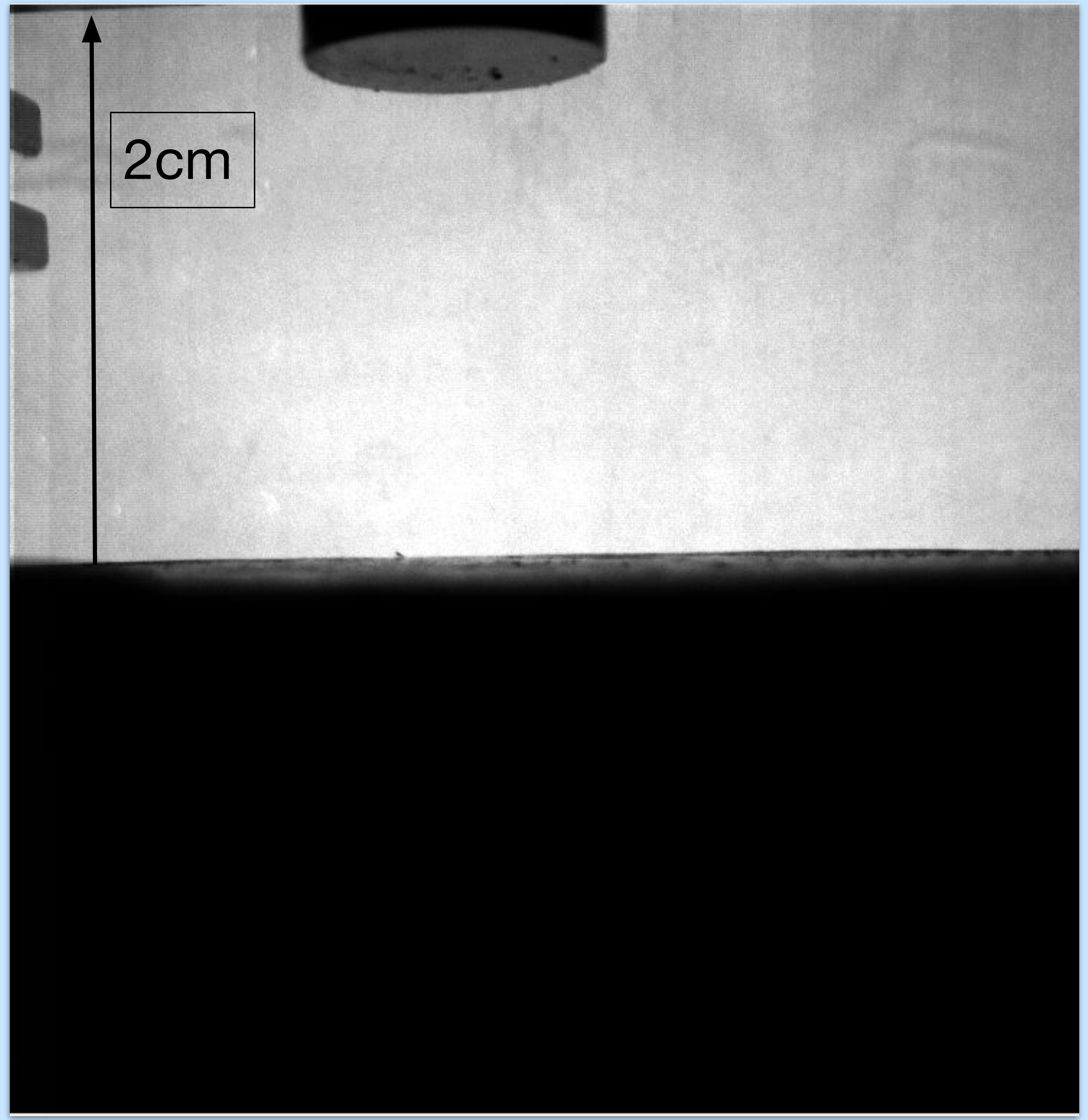
Experience - Non Conductive



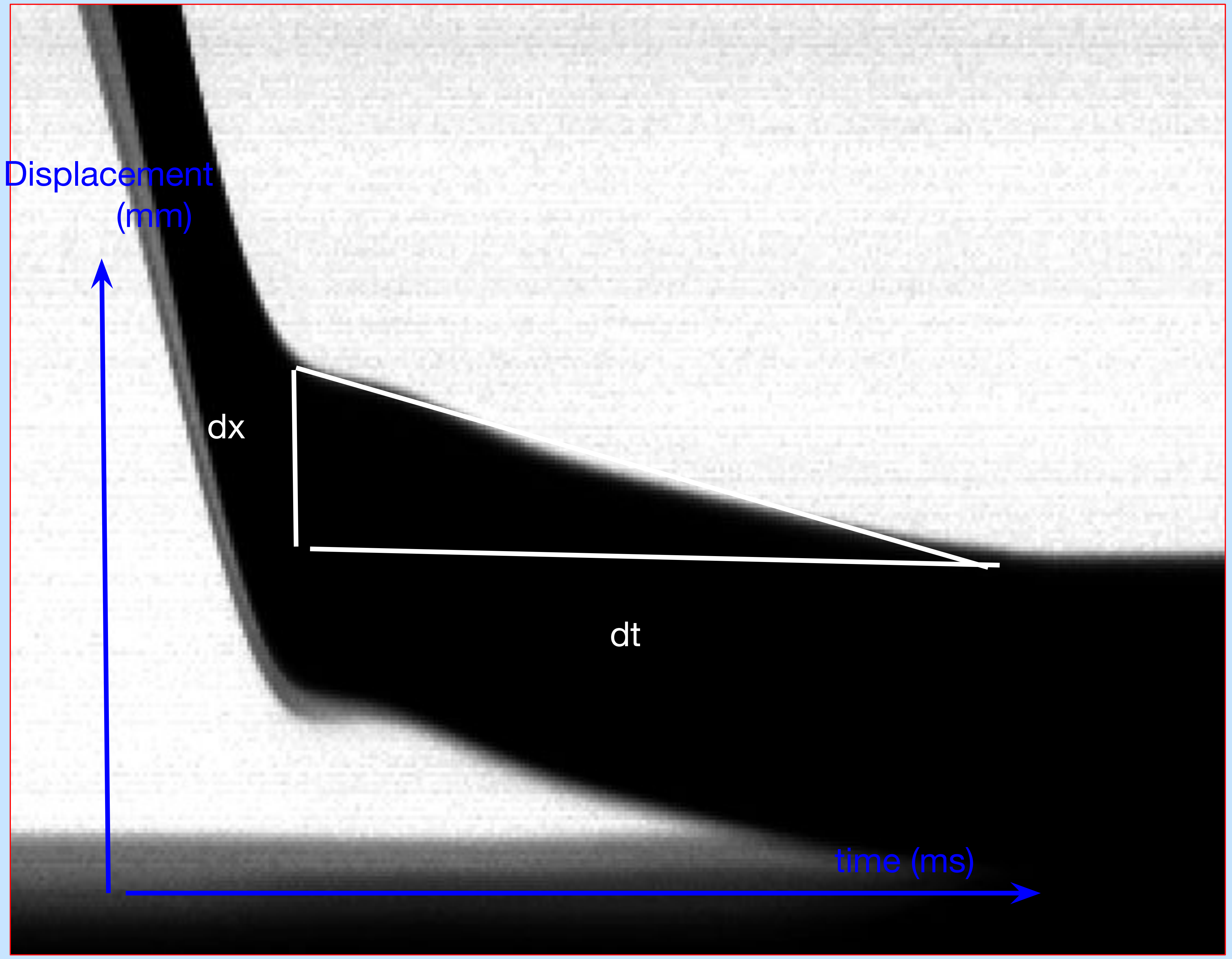
Space vs time transform



Experience - Conductive



Space vs time transform



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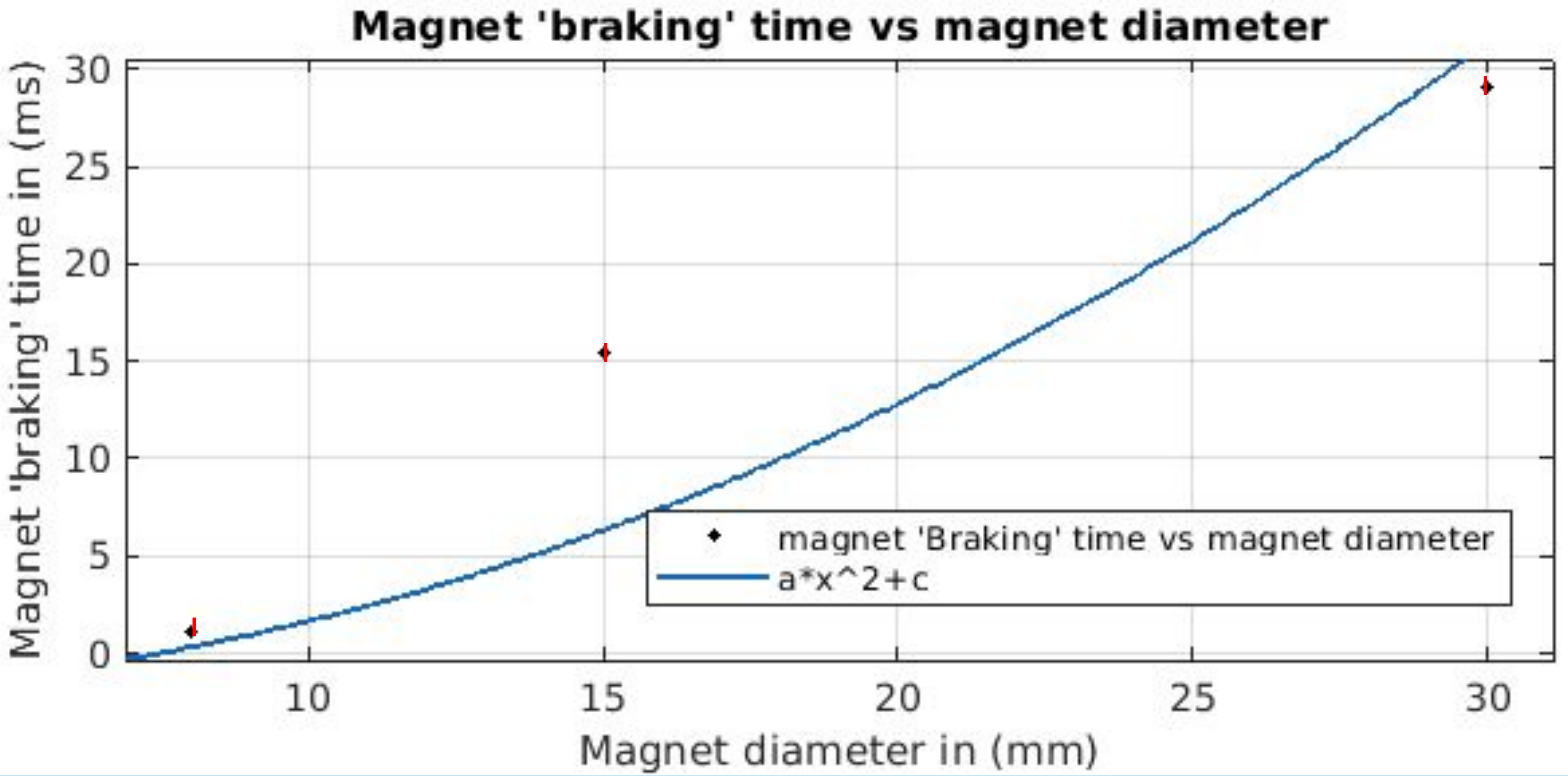
Results



dt ≈ 0.5 ms

a = 0.037 ± 0.030
c = -2 ms
R-square: 0.7785

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Magnetic Diffusion

From magnetic diffusion equation: $$\frac{\partial \vec{B}}{\partial t} - \kappa \nabla^2 \vec{B} = \vec{0}$$

we identify diffusion constant: $$\kappa = \frac{1}{\sigma \mu_0}$$

σ_cu = 6.10^7 S/m
µ0 = 4.π.10^-7 kg.m A−2.s−2

Time needed for diffusion over a distance D (magnet diameter) to happen is:

$$\boxed{\tau \approx \frac{D^2}{\kappa}}$$

Numerical application:

Diameter:	Time:
D = 2 cm	τ = 30 ms
D = 3 cm	τ = 67 ms

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Motion

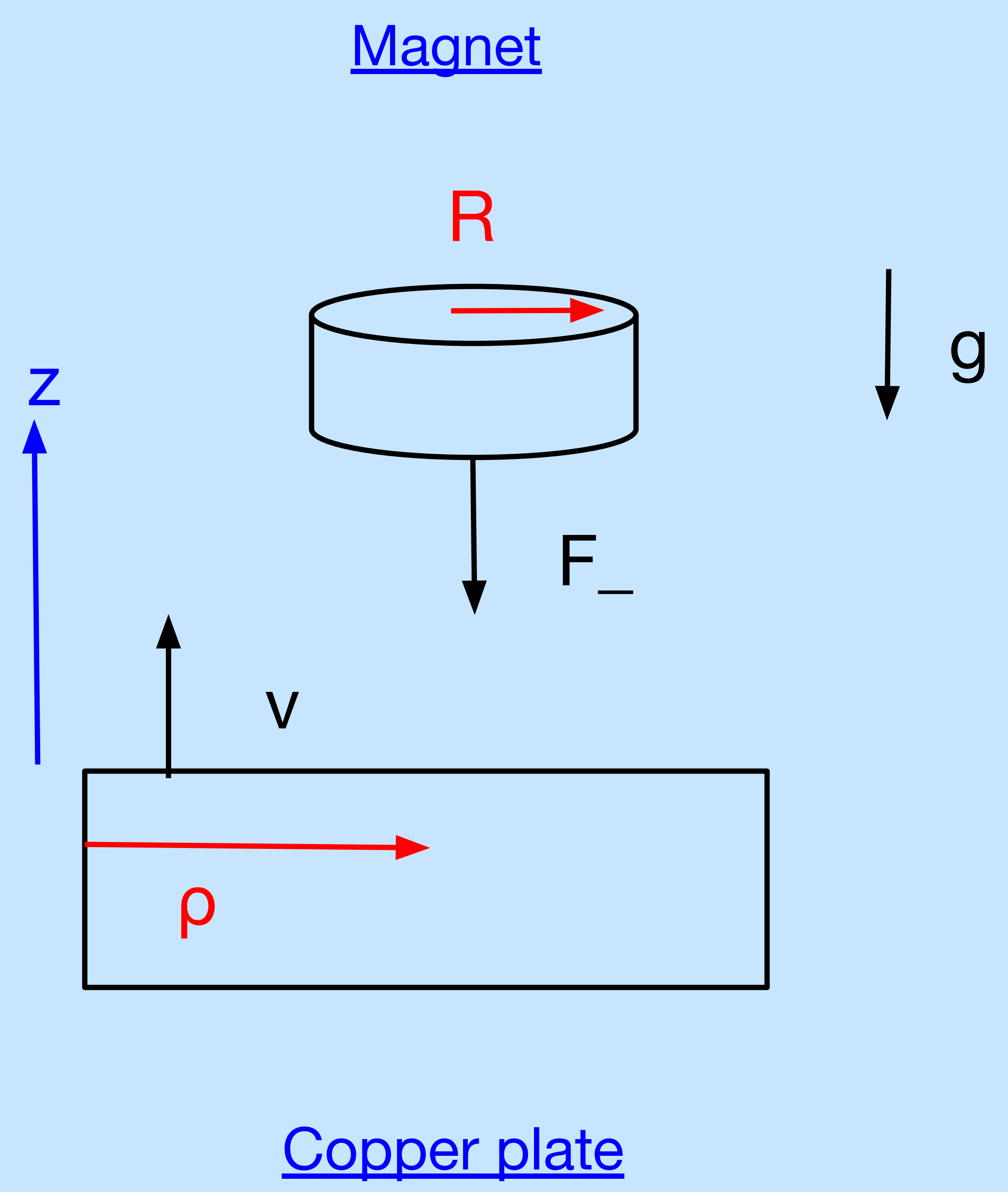
Model the motion of a copper plate subjected to the magnetic field of the magnet :

$$m\vec{a} = \vec{F}(z) + m\vec{g} \quad \Rightarrow \quad \boxed{\ddot{z} = cst\,\frac{z^2}{(\rho^2+z^2)^5}\,\dot{z} + g}$$

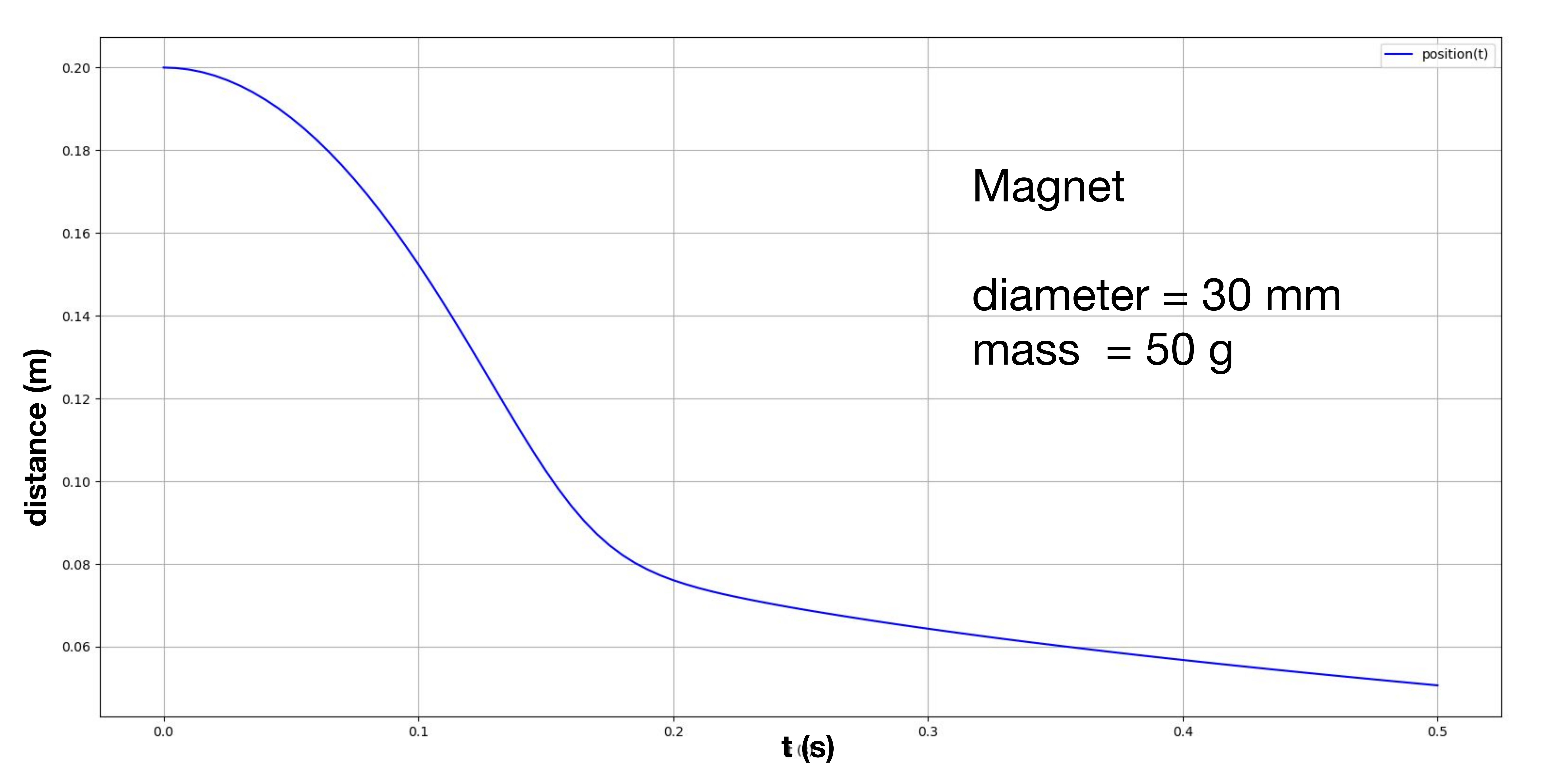
where $$\vec{F}(z) = -2\pi R^3 \boxed{\sigma\, B_\rho^2(z)}\, \dot{z}\,\vec{e}_z$$

Electric conductivity of a plate

$$B_\rho(z) = \frac{3\mu z\rho}{(\rho^2+z^2)^{5/2}}$$ ← magnetic dipole approximation



Motion - Numerical Solution



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Conclusion

→ x^2 relation between 'braking' time and magnet diameter

→ Falling from high altitudes requires larger magnets to observe the effects, yet physics remain the same, heavy parachute could be scaled

→ Theory and experience gives the same order of magnitude of the 'braking' time

→ <u>Limitations</u>: model doesn't take into the account possible magnet rebound with the plate, magnetic dipole approximation doesn't holds when magnets is at distance of magnet diameter from the plate

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Credits

+ Lucas Barbier, student in Physics, helped with the theory
+ Adrian Daeer, Michael Berhanu, Hugo Roussille, team leaders
+ Wladimir Toutain - Technician - Université de Paris
+ Oune-Saysavanh Souramasing - Engineer MSC, Université de Paris, machine shop

Bibliography and references

[1] - https://www.youtube.com/watch?v=Yu1uRvErM80, [accessed 4 Feb, 2021]

[2] -Low-frequency nondestructive analysis of cracks in multilayer structures using a scanning magnetic microscope - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Representation-of-the-mechanism-of-the-eddy-current-generation-in-an-unflawed-conducting_fig2_230764801 [accessed 4 Feb, 2021]

[3] - https://en.wikipedia.org/wiki/Magnetic_diffusion

[4] - Magnet fall inside a conductive pipe: motion and the role of the pipe wall thickness , G Donoso, C L Ladera and P Mart´ ınDepartamento de F´ısica, Universidad Sim´ on Bol´ ıvar, Apdo. 89000, Caracas 1080, Venezuela, 2009, Eur. J. Phys. 30 855 (http://iopscience.iop.org/0143-0807/30/4/018)

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