

# Vibrating Sample Magnetometer

# Theoretical principle

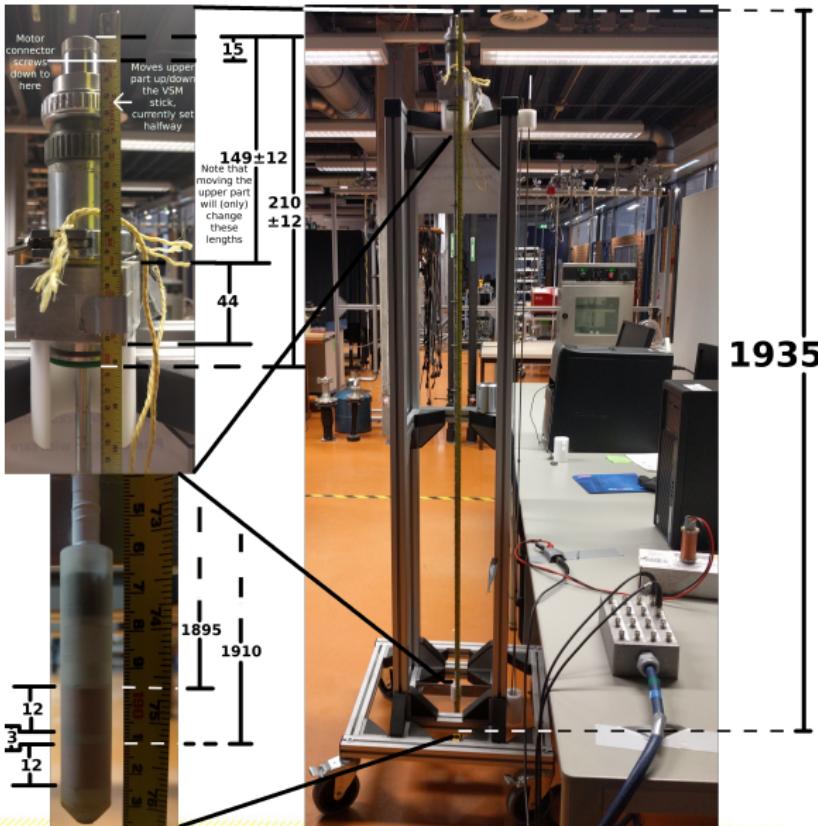
## Faraday's law of induction

$$V = -\frac{d\phi_B}{dt} \quad (1)$$

$$\phi_B = \iint_S \vec{B}(\vec{r}, t) \cdot d\vec{A} = BS \quad (2)$$

## Magnetization

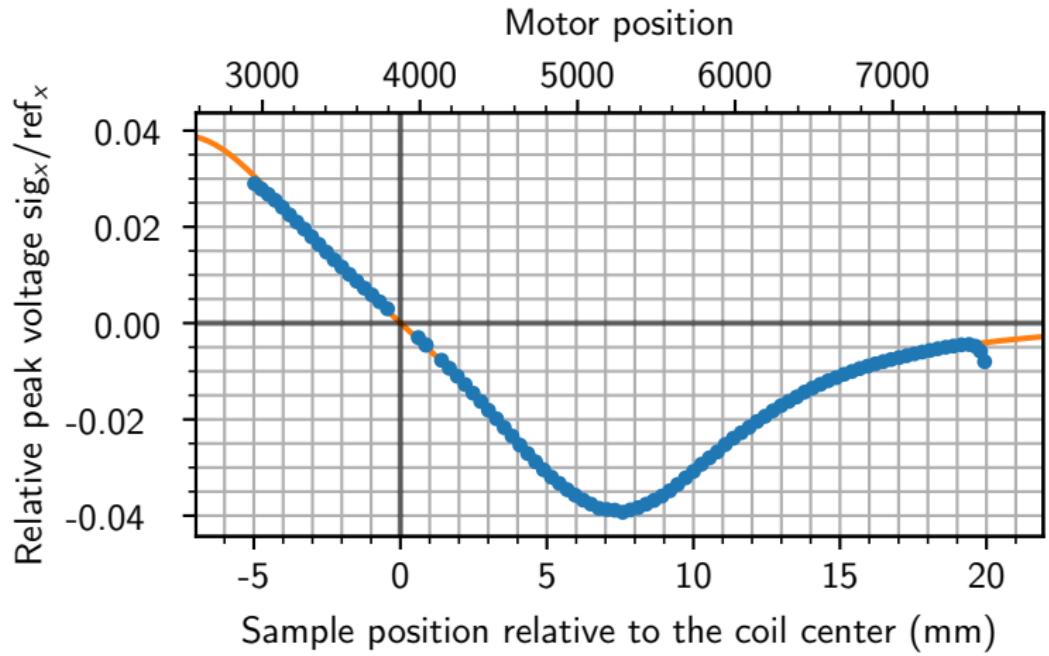
- **Paramagnetism:** Magnetic moment of unpaired electrons
- **Diamagnetism:** Lorentz force on electrons in orbitals

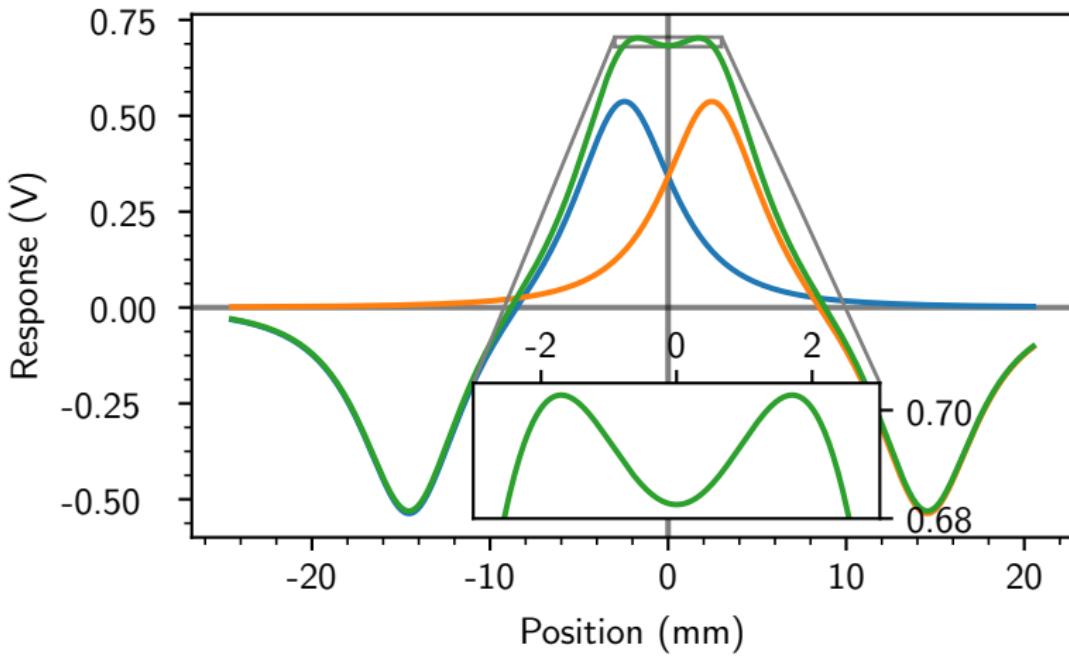


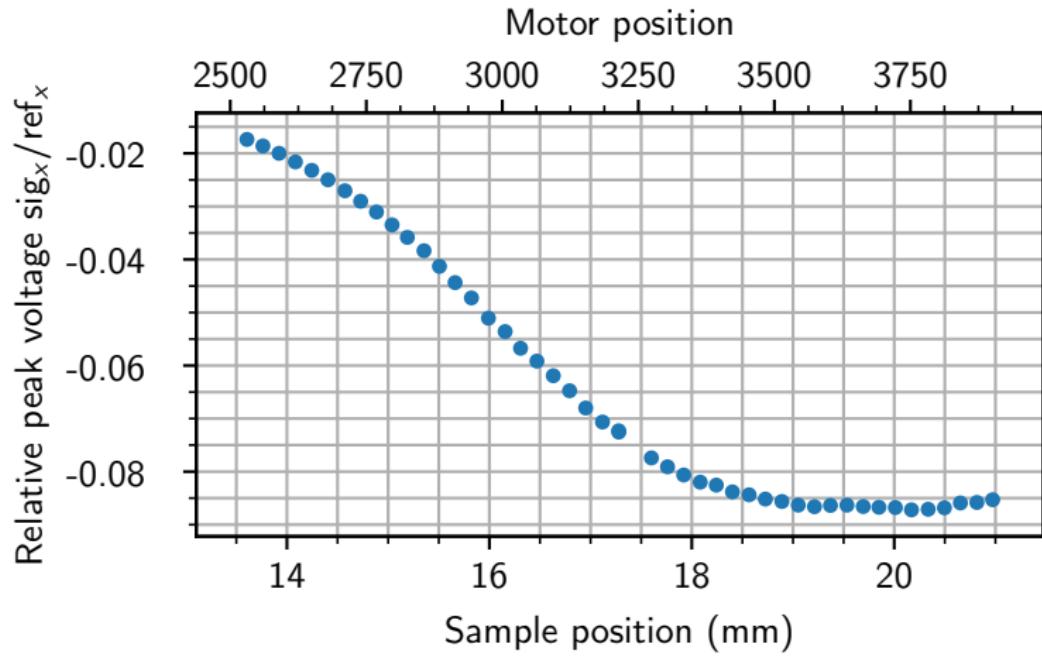
# Theoretical principle

## VSM Induction

$$\begin{aligned} V(z) = & -NASI\mu_0 \frac{f\pi}{\sqrt{2}} \left[ \ln \left( r_2 + \sqrt{r_2^2 + (z-L)^2} \right) - \ln \left( r_1 + \sqrt{r_1^2 + (z-L)^2} \right) + \right. \\ & (z-L)^2 \left( \frac{1}{r_2 \sqrt{r_2^2 + (z-L)^2} + r_2^2 + (z-L)^2} - \frac{1}{r_1 \sqrt{r_1^2 + (z-L)^2} + r_1^2 + (z-L)^2} \right) + \\ & \ln \left( r_1 + \sqrt{r_1^2 + z^2} \right) - \ln \left( r_2 + \sqrt{r_2^2 + z^2} \right) + \\ & \left. z^2 \left( \frac{1}{r_1 \sqrt{r_1^2 + z^2} + r_1^2 + z^2} - \frac{1}{r_2 \sqrt{r_2^2 + z^2} + r_2^2 + z^2} \right) \right] \end{aligned} \quad (3)$$



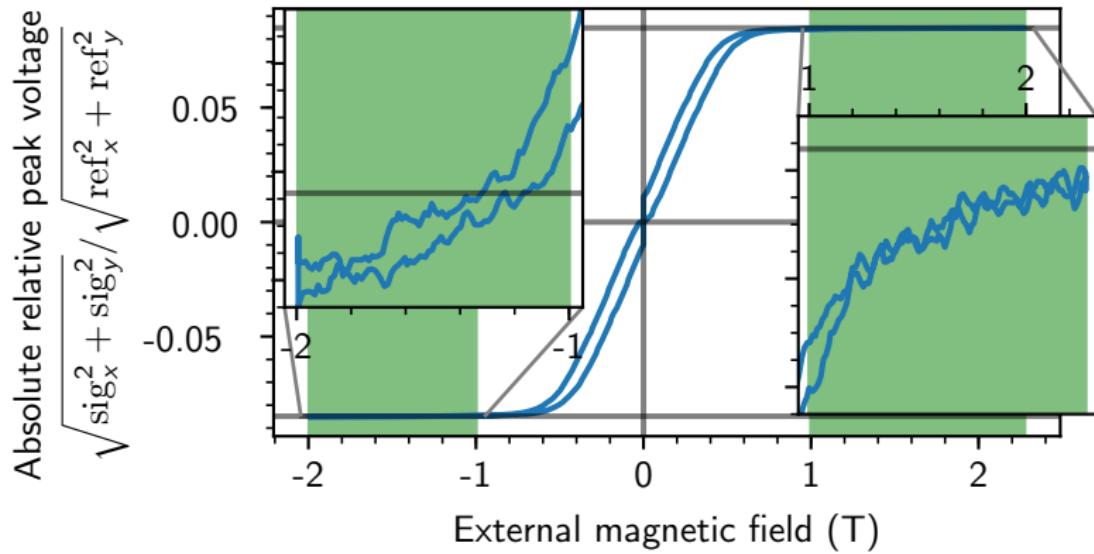




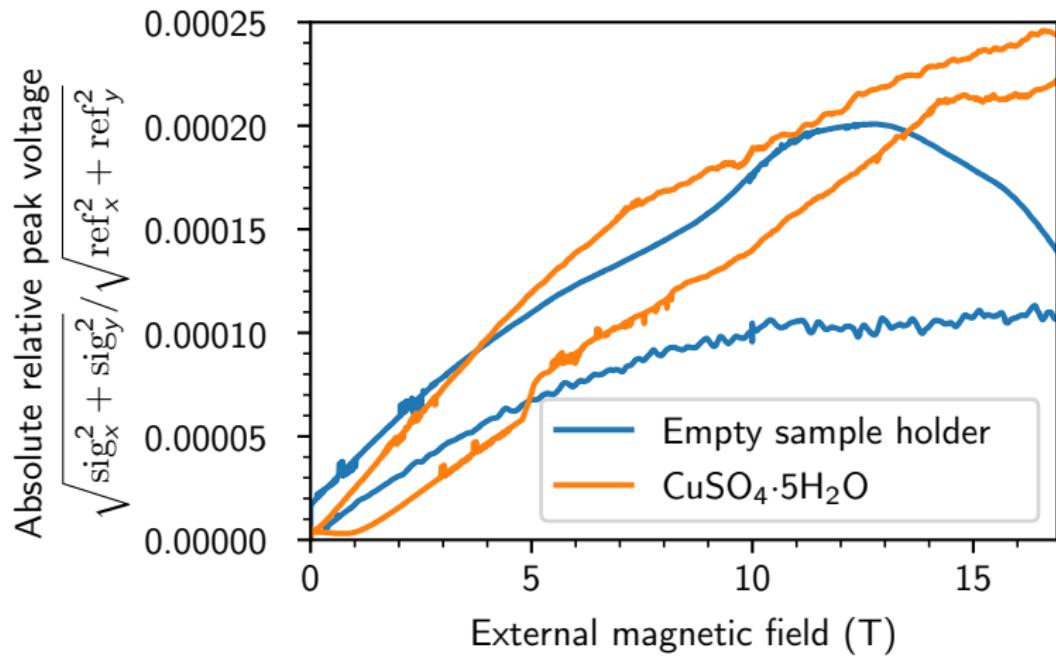
## Nickel (Room Temperature)

$$(58.57 \pm 0.03) \text{ emu/g} \implies (2.489 \pm 0.002) \text{ emu} \implies c = (29.34 \pm 0.06) \text{ emu}$$

Average of absolute value in  
shaded area:  $0.084839 \pm 0.000153$



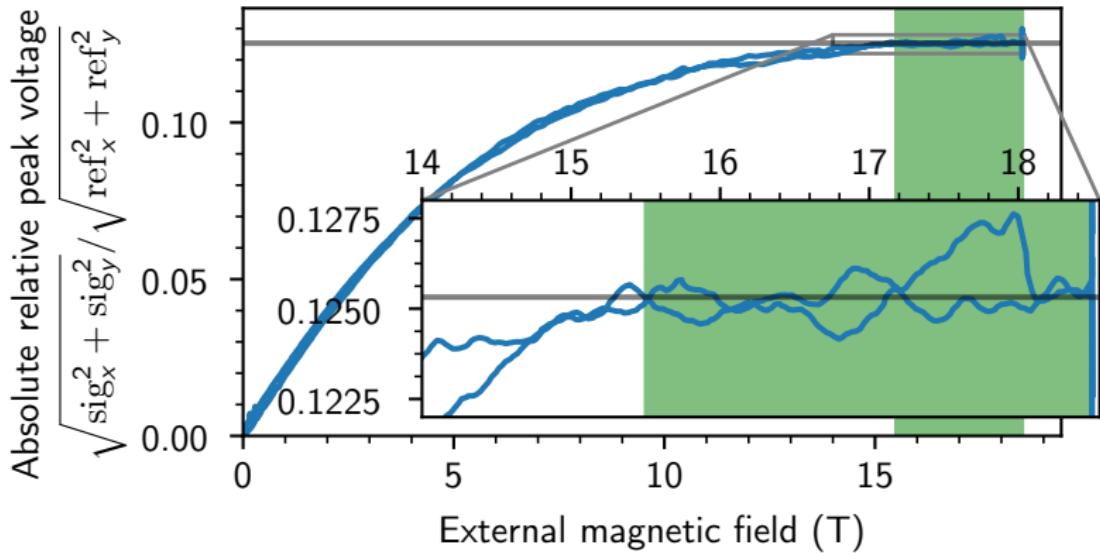
# $\text{CuSO}_4 \cdot 5 \text{H}_2\text{O}$ (Room Temperature)



# $\text{CuSO}_4 \cdot 5 \text{H}_2\text{O}$ (4K)

$$c = (29.34 \pm 0.06) \text{ emu} \implies (3.67 \pm 0.04) \text{ emu} \implies (25.7 \pm 0.3) \text{ emu/g}$$

Average of absolute value in  
shaded area:  $0.125318 \pm 0.001352$



## Sanity Check

- Paramagnetic Cu<sup>2+</sup> ions: Spin 1/2
- $2\sqrt{s(s+1)} = \sqrt{3} \mu_B$
- CuSO<sub>4</sub>·5H<sub>2</sub>O: 249.684 u
- $\implies 39 \text{ emu/g}$
- Diamagnetic contributions of H<sub>2</sub>O and SO<sub>4</sub><sup>2-</sup>

