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The Einstein relation generalized to nonequilibrium

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Einstein relation

A. Einstein Ann. Phys. **17,** 549 (1905)

Brownian particle: (colloidal particle)

diffusion and dissipation have the same origin

$$\mu = \frac{1}{k_B T} D$$

$D:$ diffusion coefficient

$\mu:$ mobility

relation generally valid close to equilibrium

non-equilibrium:

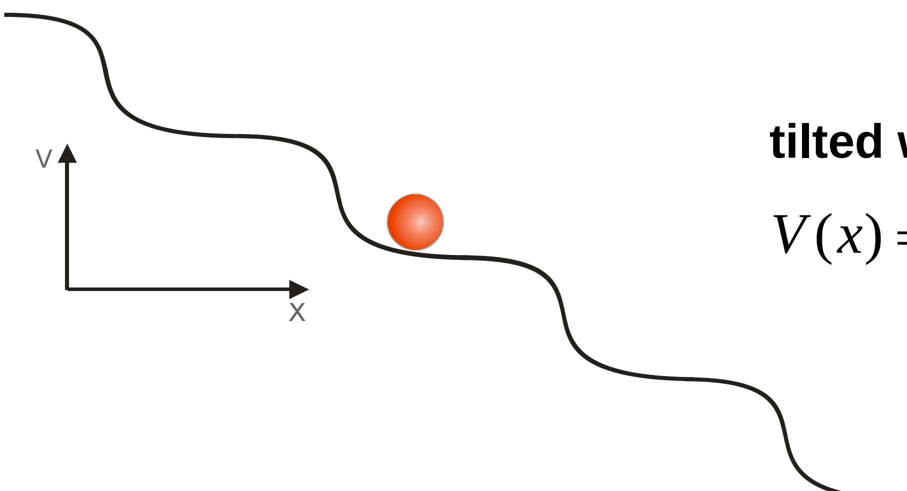
$$\mu \neq \frac{1}{k_B T} D$$

the Einstein relation is violated

NESS

non-equilibrium stationary state NESS:

- most simple non-equilibrium situation
- no time dependence (stationary state)
- stationary probability distribution



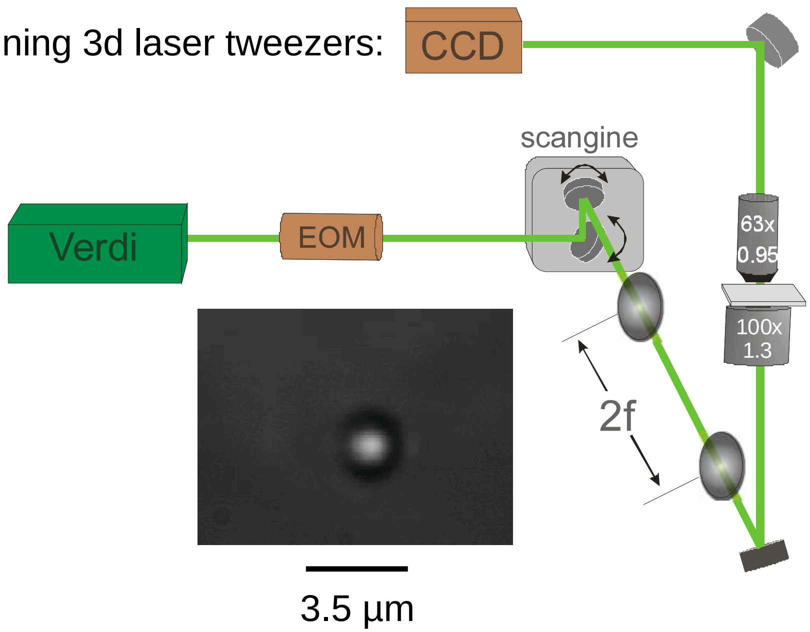
tilted washboard potential

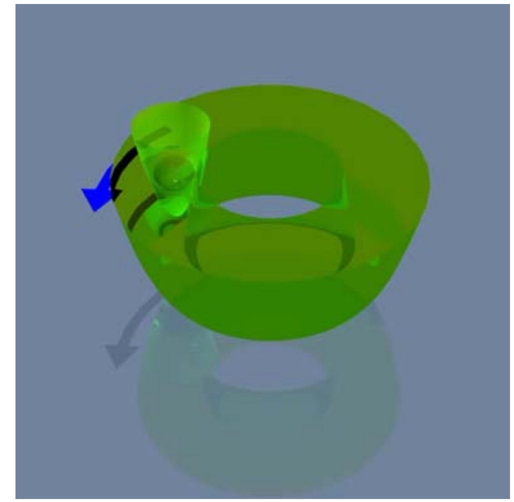
$$V(x) = V_p(x) - f \cdot x$$

$V_p(x)$ periodic potential

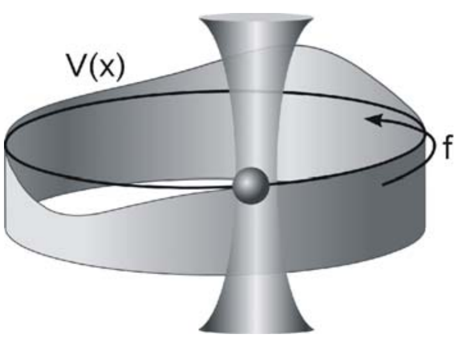
experimental setup

scanning 3d laser tweezers:





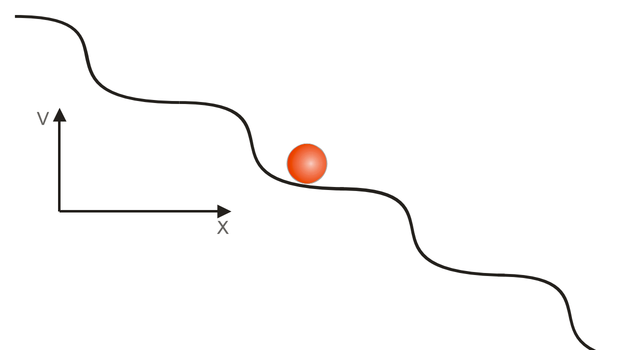
- rotating laser tweezers 570 Hz
- phase-slip regime
- 1d torroidal trap



intensity modulation

↓

additional potential



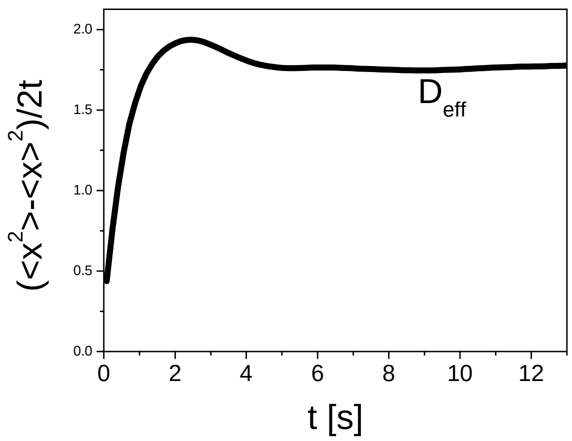
diffusion and mobility

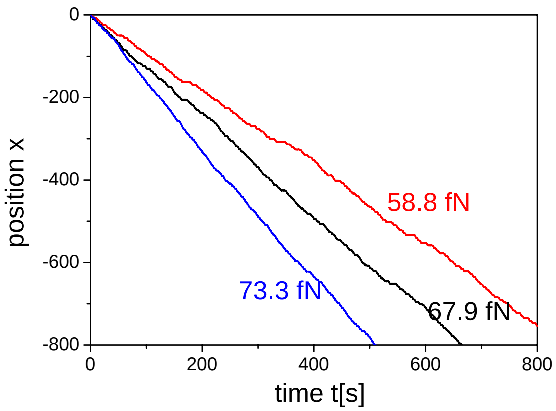
$$D_{eff} = \lim_{t \to \infty} \frac{< x^2(t) > - < x(t) >^2}{2t}$$

$$\mu = \frac{\partial < v >}{\partial f} = \frac{\Delta < v >}{\Delta f}$$

this definition is independent of
the drift velocity and the external driving.

measuring drift velocity for different driving forces

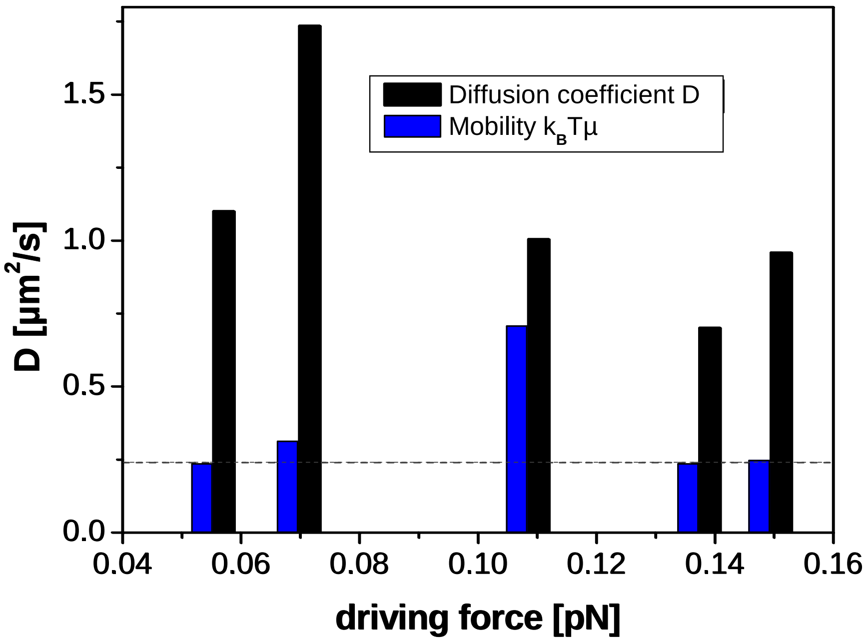




test of ER

$$\mu \neq \frac{1}{k_B T} D \quad ?$$

Einstein relation is violated



$$D_0 = 0.24 \mu m^2 / s$$

enhancement

giant diffusion

peak

P. Reimann, PRL **87**, 391 (2001)
S. Lee, PRL **96**, 10601, (2006)

Can we quantify the violation of ER ?

restoring einstein relation

T. Speck, U. Seifert, Europhys. Lett. 74, 391 (2006)

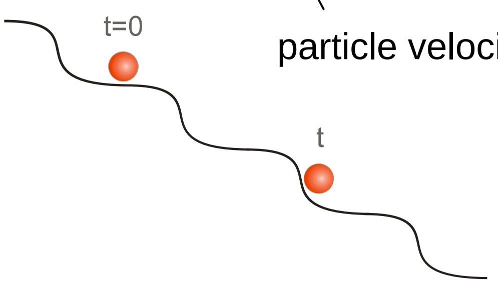
$$D = kT\mu + \int_0^\infty d\tau I(\tau)$$

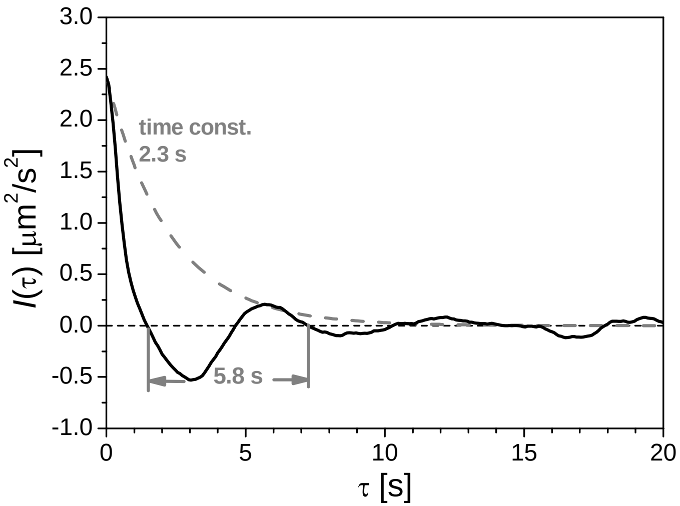
violation function

$$I(t) = < v_s(x(0))\dot{x}(t) > - < v >^2$$

average local velocity

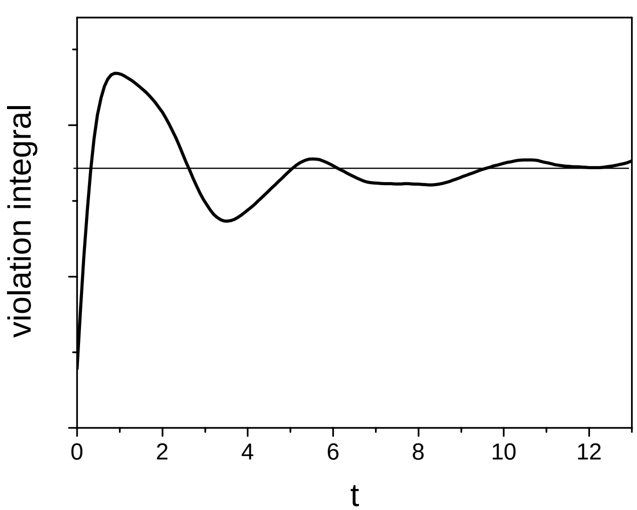
particle velocity





Integration

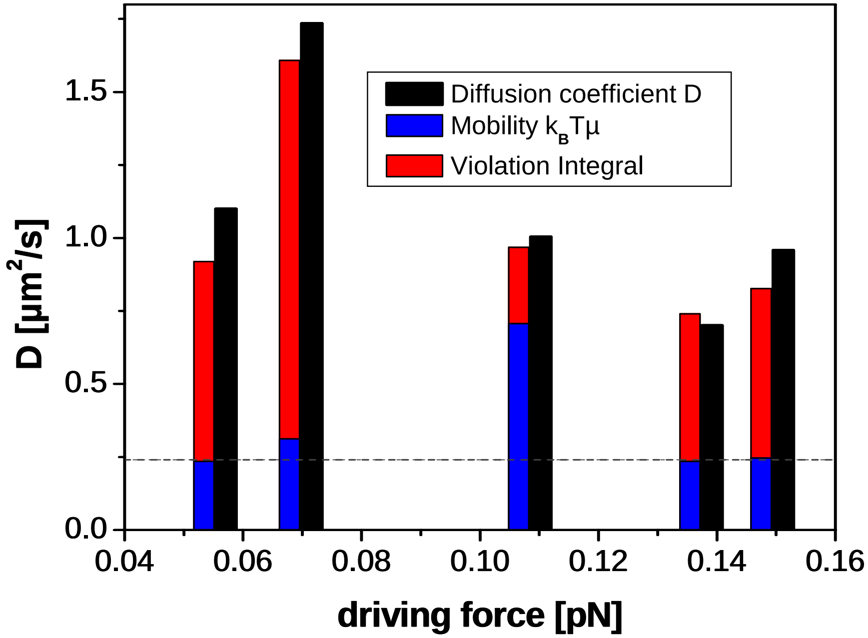
$$\int_0^t I(\tau)d\tau$$



restoring the ER

$$D_{eff} = kT\mu + \int_0^\infty d\tau I(\tau)$$

good agreement



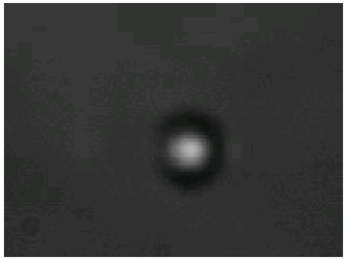
violation contributes substantially to D

beyond linear response

D and µ structures are understood

Blickle et al, submitted

summary and outlook



realization of NESS using laser tweezers

test an extened Einstein relation

Langevin approach is suitable to describe colloids in non-equilibrium

general test of fluctuation dissipation theorem

time dependend processes

Thank you for your attention !!