From superfluid Helium to Bose-Einstein Condensates: Vortex Shedding and Ion Transport

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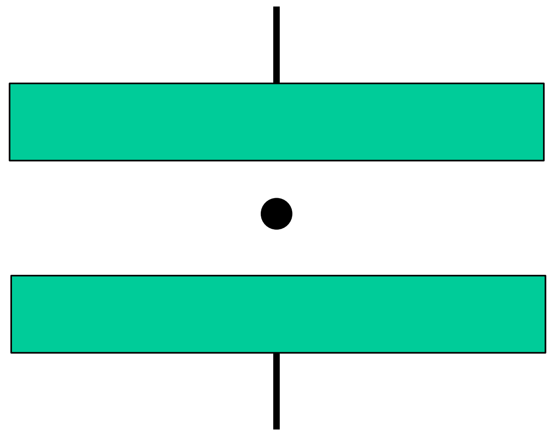
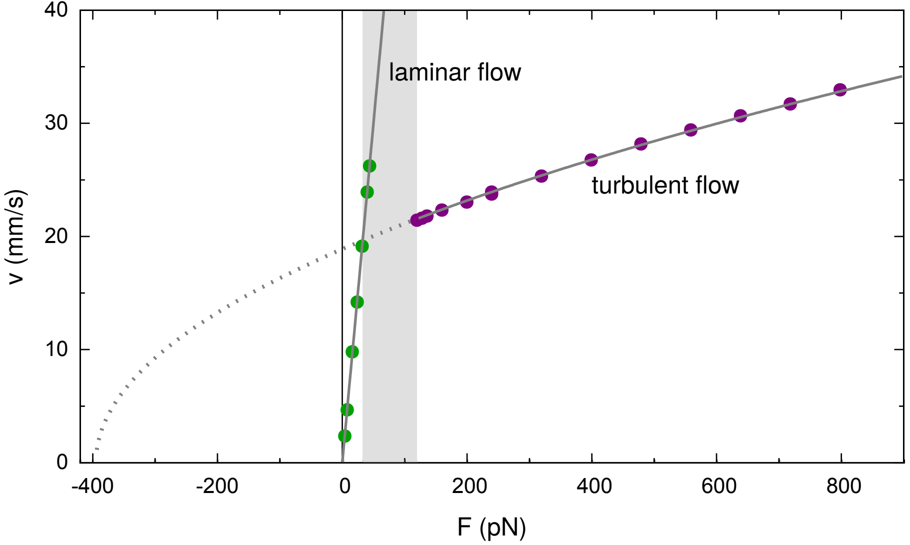
Dedicated to Matti Krusius on the occasion of his 80th birthday



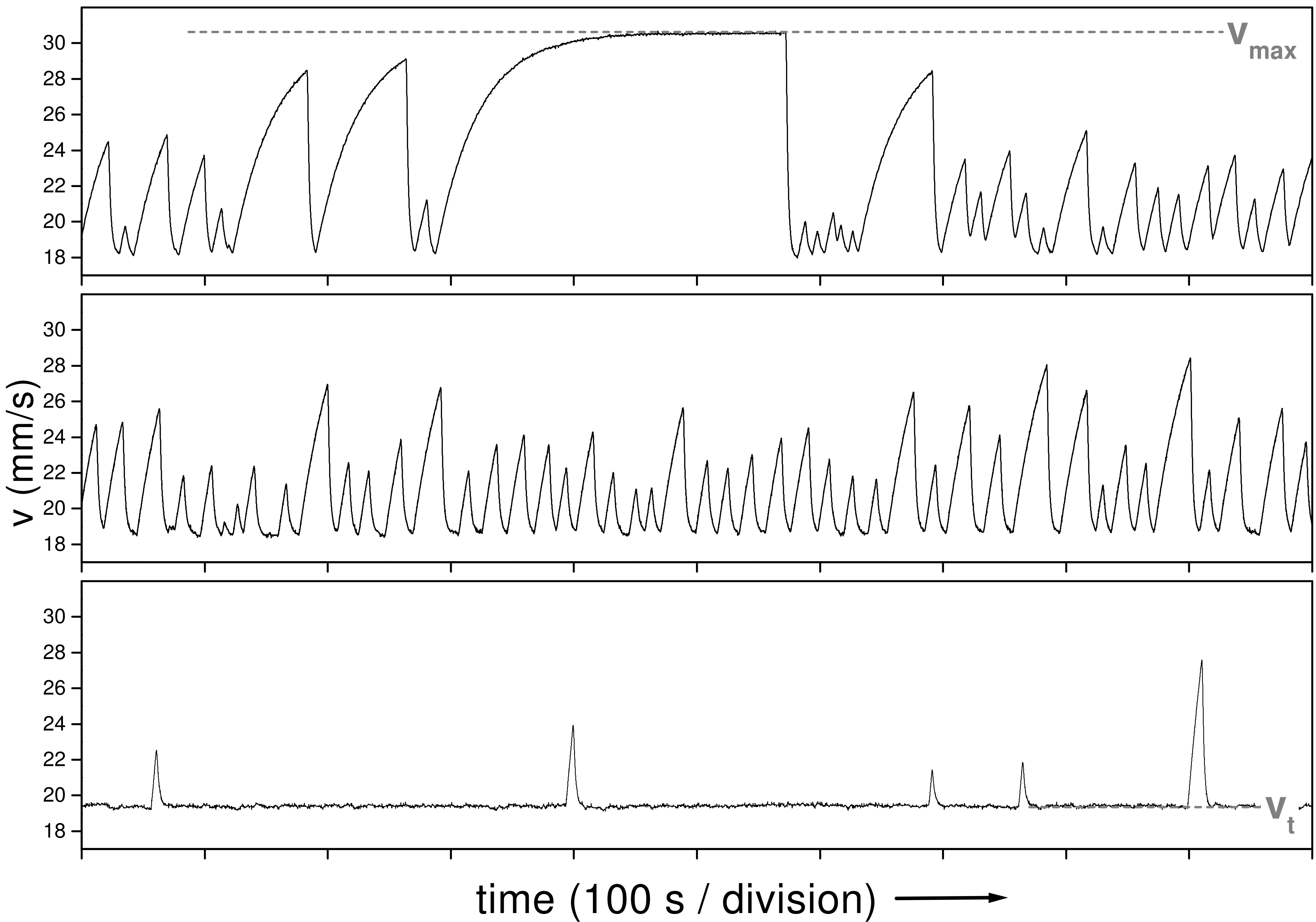
Nb capacitor: spacing 1 mm, diameter 4mm

permanent magnet: spherical, radius 0.1 mm,
electric charge ca. 1 pC

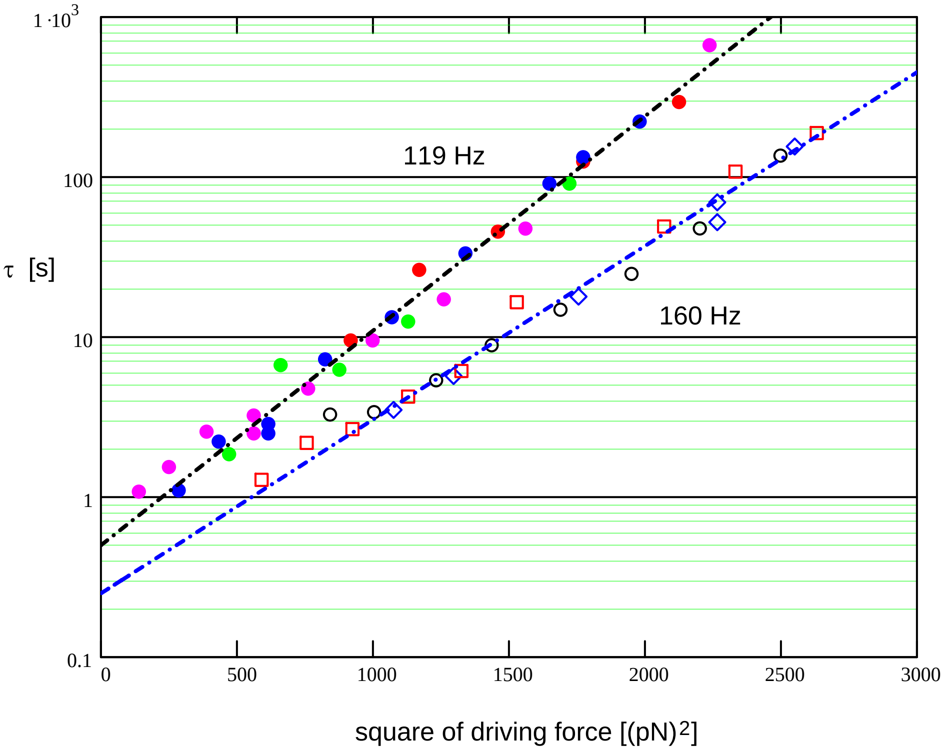
driving force: $F = q\,U_{ac} / d$
induced current: $I = q\,v / d$
oscillation amplitude 50 nm to 50 µm



laminar flow
turbulent flow
v (mm/s)
F (pN)
0
10
20
30
40
-400
-200
0
200
400
600
800



v (mm/s)
30
28
26
24
22
20
18
v_{max}
v_t
time (100 s / division)



1 ·10^3
100
10
1
0.1
τ [s]
119 Hz
160 Hz
0
500
1000
1500
2000
2500
3000
square of driving force [(pN)2]

The mean lifetimes $\boldsymbol{\tau}$

are found to grow rapidly with increasing drive, namely as

$$\boldsymbol{\tau(F) = \tau_0\ \exp[(F/F_1)^2]},$$

where for 119 Hz F_1=18 pN and τ_0=0.5 s,
and for 160 Hz F_1=20 pN and τ_0=0.25 s.

$$n = \frac{F}{F_1} = \frac{(8/3\pi)\gamma(v^2 - v_c^2)}{1.3\,\rho\,\kappa\,R\,\sqrt{\kappa\omega}} = \frac{\Delta v}{v_1}\left(1 + \frac{\Delta v}{2v_c}\right) \tag{8}$$

where $v_1 = 0.48\kappa/R$ and $v_c = 2.8\sqrt{\kappa\omega}$

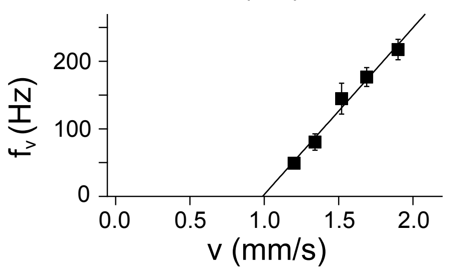
The shedding frequency

$$\boldsymbol{f_v = 2\, f\, n = \frac{2\, f}{v_1} \cdot \Delta v = a\ \cdot \Delta v}$$

where
$a = 0.60\ \mu\text{m}^{-1}$ at 119 Hz and
$a = 0.80\ \mu\text{m}^{-1}$ at 160 Hz.

$1/a = v_1/2f$ is a relevant length scale.

What happens if $f \rightarrow 0$ for steady flow? Then the relevant length scale will be the size R of the sphere!



200
100
0
0.0
0.5
1.0
1.5
2.0
f_v (Hz)
v (mm/s)

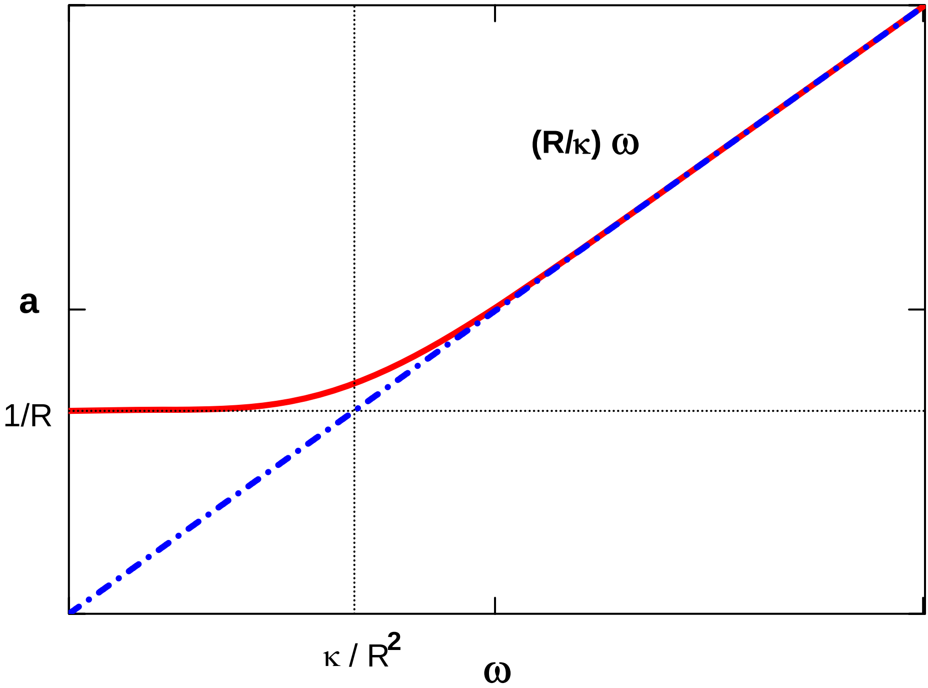
Woo Jin Kwon et al., Phys. Rev. A **92**, 033613 (2015) find

in a BEC of ^{23}Na atoms:

$a = 0.25\ \mu\text{m}^{-1}$.

From the width of the laser beam $2R = 9.1\,\mu\text{m}$ we have

$a \simeq 1/R = 0.22\ \mu\text{m}^{-1}$.



(R/κ) ω
a
1/R
κ / R2
ω

The Strouhal number

$$Sr \equiv f_v 2R/v$$

$$f_v = a\Delta v = \Delta v/R$$

$$Sr = 2\,\Delta v/v$$

In Helium for $v \geq v_c$:

$$n(\Delta v) = \frac{F}{F_1} = \frac{(8/3\pi)\gamma(v^2 - v_c^2)}{1.3\,\rho\,\kappa\,R\sqrt{\kappa\omega}} = \frac{\Delta v}{v_1}\left(1 + \frac{\Delta v}{2v_c}\right)$$

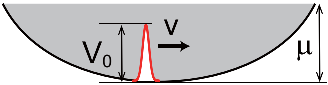
$$f_v(\Delta v) = 2fn(\Delta v)$$

$$Sr = \frac{2f}{v1}\left(1 + \frac{\Delta v}{2v_c}\right)\frac{2R\,\Delta v}{v}$$

$$Re_s = \Delta v\,2R/\kappa$$

$$Sr = Re_s(2\,R\omega/\pi v)(1 + Re_s v_1/v_c),\ \ (v \geq v_c) \qquad (9)$$

(a)



Ions in superfluid helium ^{4}He and ^{3}He:

Structure, mobility, critical velocity, vorticity,

trapping in vortices, ions at the free surface of liquid helium, etc.

PHYSICAL REVIEW LETTERS **126,** 033401 (2021)

Editors' Suggestion Featured in Physics

Transport of a Single Cold Ion Immersed in a Bose-Einstein Condensate

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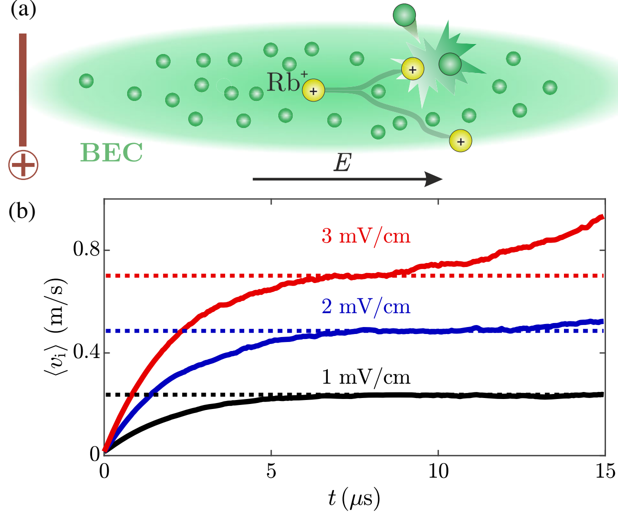
We investigate transport dynamics of a single low-energy ionic impurity in a Bose-Einstein condensate. The impurity is implanted into the condensate starting from a single Rydberg excitation, which is ionized by a sequence of fast electric field pulses aiming to minimize the ion's initial kinetic energy. Using a small electric bias field, we study the subsequent collisional dynamics of the impurity subject to an external force. The fast ion-atom collision rate, stemming from the dense degenerate host gas and the large ion-atom scattering cross section, allow us to study a regime of frequent collisions of the impurity within only tens of microseconds. Comparison of our measurements with stochastic trajectory simulations based on sequential Langevin collisions indicate diffusive transport properties of the impurity and allows us to measure its mobility. Our results open a novel path to study dynamics of charged quantum impurities in ultracold matter.

DOI: 10.1103/PhysRevLett.126.033401



(a)
Rb+
BEC
E
(b)
3 mV/cm
2 mV/cm
1 mV/cm
0.8
0.4
0
0
5
10
15
⟨v_i⟩ (m/s)
t (μs)

Literature:

Shin's Group: New J. Phys. 24, 083020(2022) and

arXiv:2210.04403v1 [cond-mat.quant-gas] 10 Oct 2022

Pfau's Group: PRL 126, 033401 (2021)

WS:

JLTP Online first, doi.org/10.1007/s10909-022-02716-w

and

arXiv:2204.11256 v4 [cond-mat.other] 20 August 2022

Matti, thank you for half a century of pleasant co-operation and personal friendship!