Title: Quantum Matter Lecture (230421)

Speakers: Ganapathy Baskaran

Collection: Quantum Matter (2022/2023)

Date: April 21, 2023 - 10:15 AM

URL: https://pirsa.org/23040014

# Condensed matter realization of Qbits

Quantum dots - excitons, electron spins, nuclear spins

Carbon nanotubes – electrons spins (GB)

Topological excitations (Kitaev) –
spinons, holons, Majorana Fermions, fractional charges

Cooper pair box

SQUIDS

Quantum antiferromagnets – Skyrmion
Magnetic molecules – $Mn_{12}$ , $Fe_8$ ….
Majorana Fermions (Kitaev wire, vortices of p-wave supercondutors)

# Quantum Control

We have been always measuring quantum effects even at
Room temperatures !

Specific heat, electrical resistivity
Black body radiation ...
Spectroscopy, Optics, NMR, ESR ..

Avagadro number of atoms/degree of freedom are involved
macroscopic, mesoscopic and nanoscopic materials

We wish to control single or a finite number of
molecules, atoms, electrons, nuclear spins at a time,
manipulate and induce dynamics in limited Hilbert space

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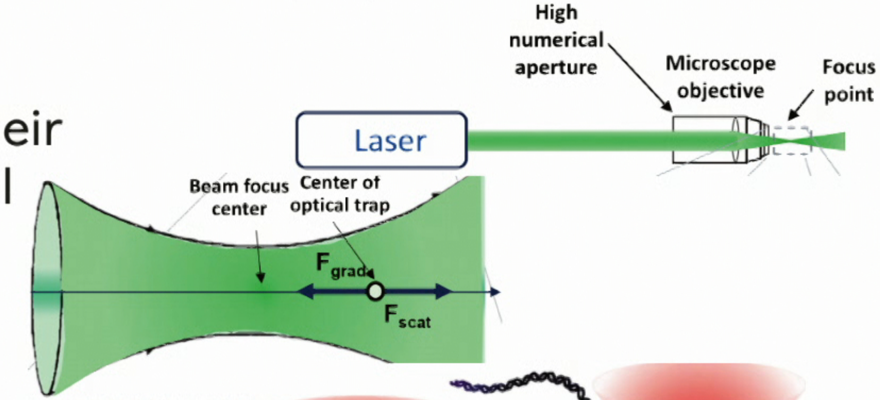
*Quantum dots, ...*

*Use of Laser*

*Optical Tweezers, Optical Traps*
*Laser cooling ...*

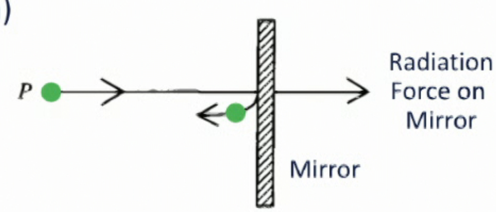
Nobel Lecture 2018 Arthur Ashkin
Bell Laboratories, NJ, USA

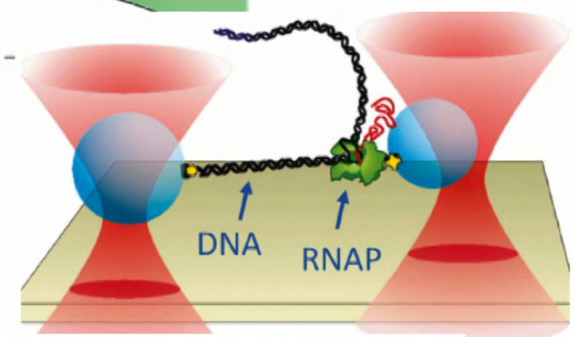
# Optical Tweezers and their Application to Biological Systems




Laser shining on a **reflective** metallic mirror

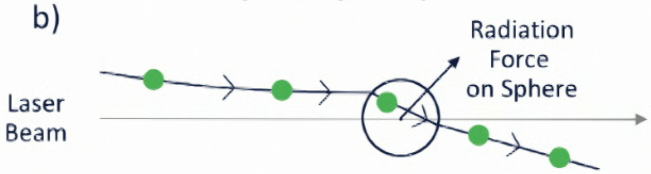
a)

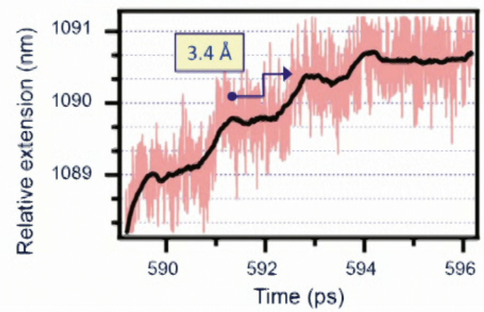



(Slightly focused) laser shining on a **transparent** glass sphere

b)



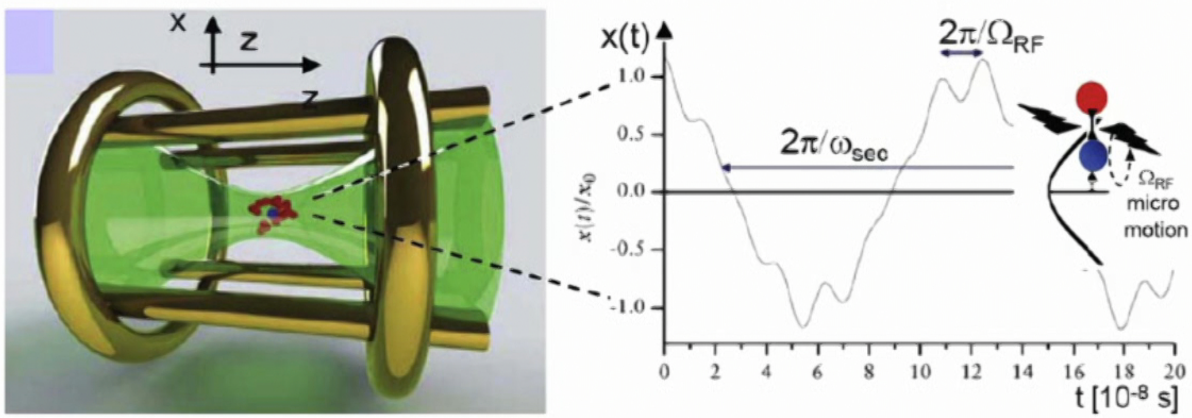



# Laser Cooling

The Royal Swedish Academy of Sciences has decided to award **the 1997 Nobel Prize in Physics** jointly to

Professor **Steven Chu**, Stanford University, Stanford, California, USA,
Professor **Claude Cohen-Tannoudji**, Collège de France and École Normale Supérieure, Paris, France, and
Dr. **William D. Phillips**, National Institute of Standards and Technology, Gaithersburg, Maryland, USA,

J. Phys. B: At. Mol. Opt. Phys. **50** (2017) 102001



## Rydberg Atoms

Simulations: Roger Melko and Collaborators (PI, U Waterloo)

https://mikomma-de.translate.goog/fh/atom/rydbrev.htm?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=de&_x_tr_sch=http

C S Adams , J D Pritchard and J P Shaffer

Rydberg atom quantum technologies

J. Phys. B: At. Mol. Opt. Phys. **53** (2020) 012002

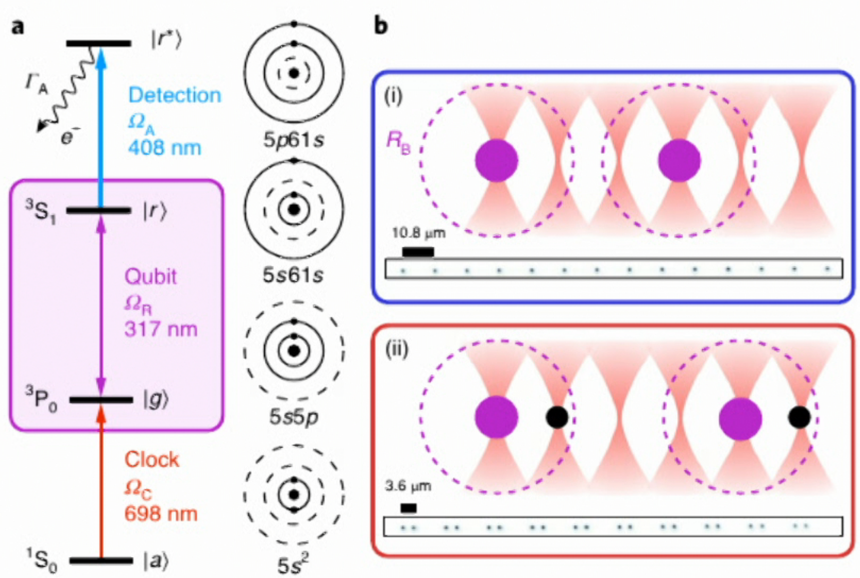
**Table 1.** Alkali atom principal quantum number ($n$) scaling of the most important properties of Rydberg states. The $n$ dependence results from the characteristics of the Rydberg atom wavefunctions, as described in the text.

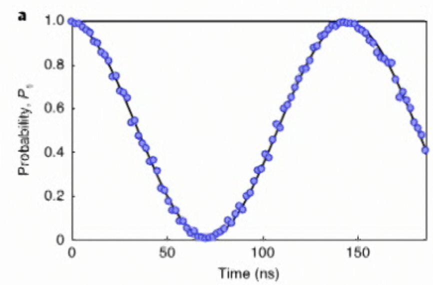
| Property | Quantity | Scaling |
|---|---|---|
| Energy levels | $E_n$ | $n^{-2}$ |
| Level spacing | $\Delta E_n$ | $n^{-3}$ |
| Radius | $\langle r \rangle$ | $n^2$ |
| Transition dipole moment ground to Rydberg states | $\lvert\langle n\ell\rvert - er\lvert g\rangle\rvert$ | $n^{-3/2}$ |
| Radiative lifetime | $\tau$ | $n^3$ |
| Transition dipole moment for adjacent Rydberg states | $\lvert\langle n\ell\rvert - er\lvert n\ell'\rangle\rvert$ | $n^2$ |
| Resonant dipole–dipole interaction coefficient | $C_3$ | $n^4$ |
| polarisability | $\alpha$ | $n^7$ |
| van der Waals interaction coefficient | $C_6$ | $n^{11}$ |

# High-fidelity entanglement and detection of alkaline-earth Rydberg atoms

Ivaylo S. Madjarov[1,4], Jacob P. Covey[1,4], Adam L. Shaw[1], Joonhee Choi[1], Anant Kale[1], Alexandre Cooper[1,3], Hannes Pichler[1], Vladimir Schkolnik[2], Jason R. Williams[2] and Manuel Endres

NATURE PHYSICS | VOL 16 | AUGUST 2020 | 857




Rabi oscillations

## ION TRAPS

A charged particle, such as an ion, feels a force from an electric field.

Earnshaw's theorem states that it is not possible to confine an ion in an electrostatic field.

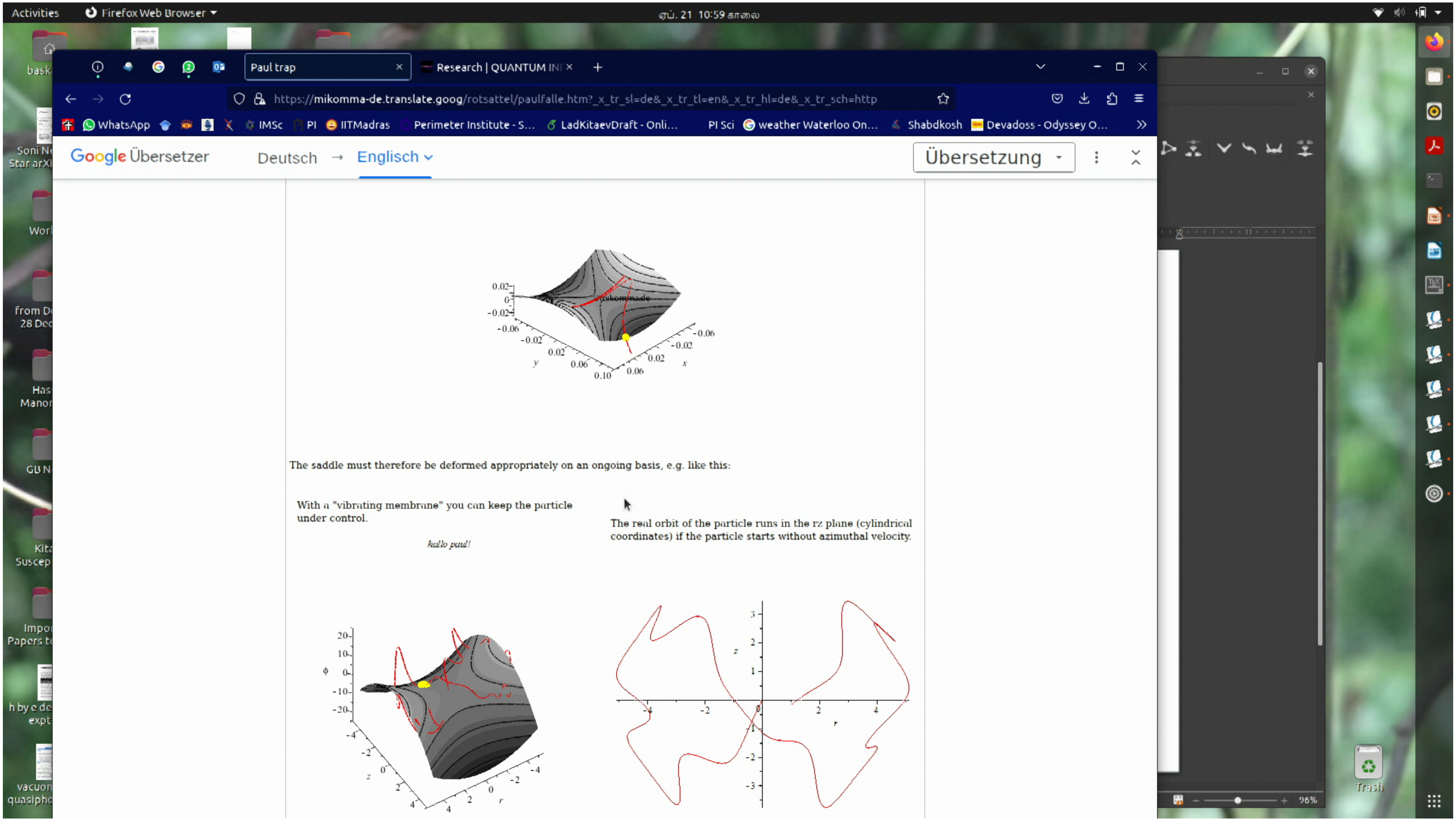
There are ways of working around this theorem by using combinations of static magnetic and electric fields.

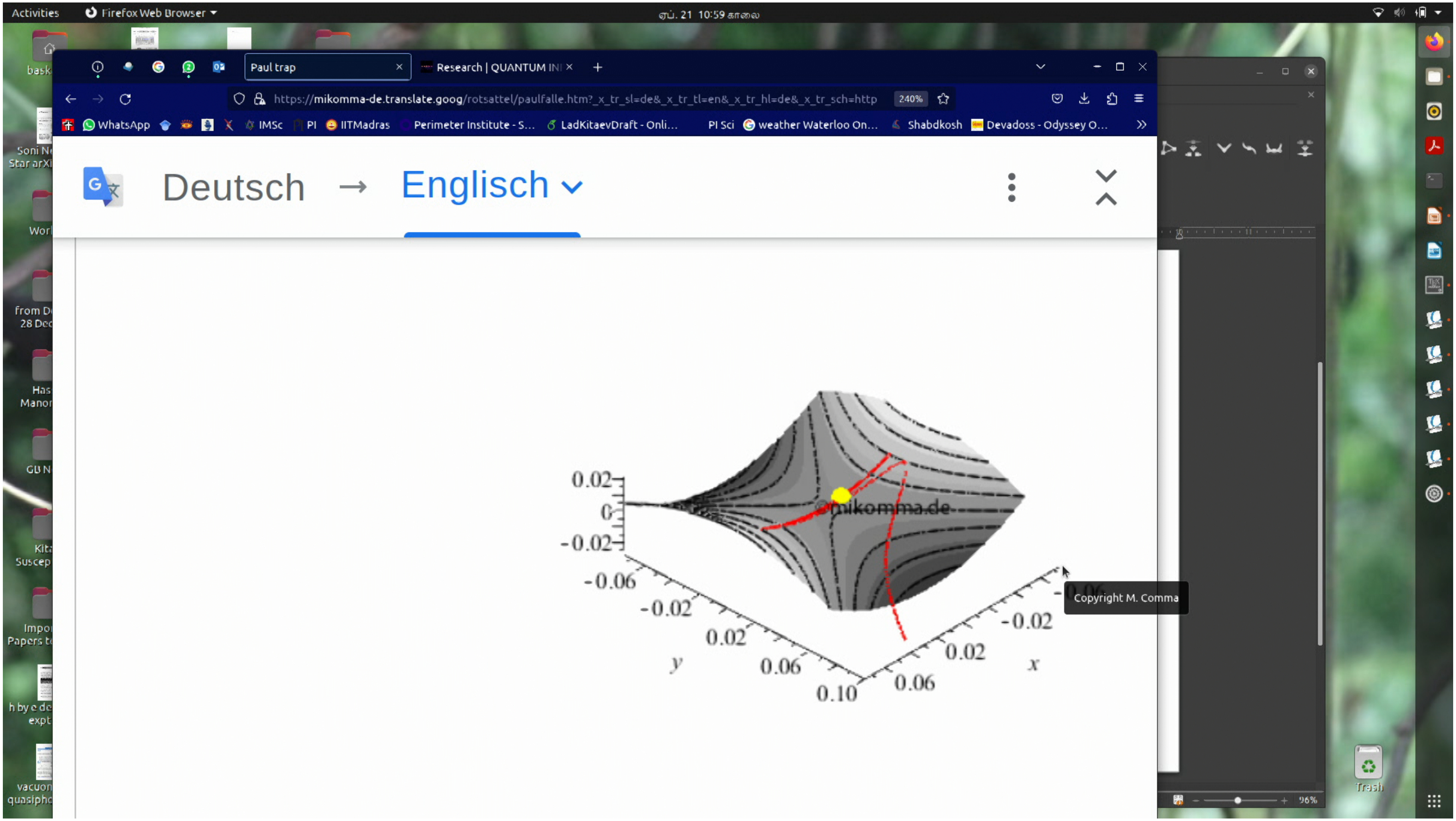
The force on the ion is given by $$M\ddot{\mathbf{r}} = e\mathbf{E}_0 \cos(\Omega t)$$

Assuming that the ion has zero initial velocity, the velocity and displacement as

$$\dot{\mathbf{r}} = \frac{e\mathbf{E}_0}{M\Omega} \sin(\Omega t)$$

$$\mathbf{r} = \mathbf{r}_0 - \frac{e\mathbf{E}_0}{M\Omega^2} \cos(\Omega t)$$


Paul trap
Research | QUANTUM IN
https://mikomma-de.translate.goog/rotsattel/paulfalle.htm?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=de&_x_tr_sch=http
Google Übersetzer
Deutsch → Englisch
Übersetzung
The saddle must therefore be deformed appropriately on an ongoing basis, e.g. like this:
With a "vibrating membrane" you can keep the particle under control.
hallo paul!
The real orbit of the particle runs in the rz plane (cylindrical coordinates) if the particle starts without azimuthal velocity.


Activities
Firefox Web Browser
Paul trap
Research | QUANTUM IN
https://mikomma-de.translate.goog/rotsattel/paulfalle.htm?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=de&_x_tr_sch=http
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x
@mikomma.de
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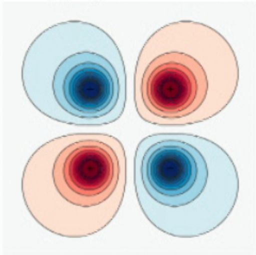
Trash

**Paul trap** uses an oscillating quadrupole field to trap ions radially and a static potential to confine ions axially. The quadrupole field is realized by four parallel electrodes laying in the -axis positioned at the corners of a square in the -plane.

Electrodes diagonally opposite each other are connected and an a.c.voltage is applied. Along the -axis, an analysis of the radial symmetry yields a potential

$$\nabla^2 \phi = 0. \qquad \phi = \alpha + \beta(x^2 - y^2)$$

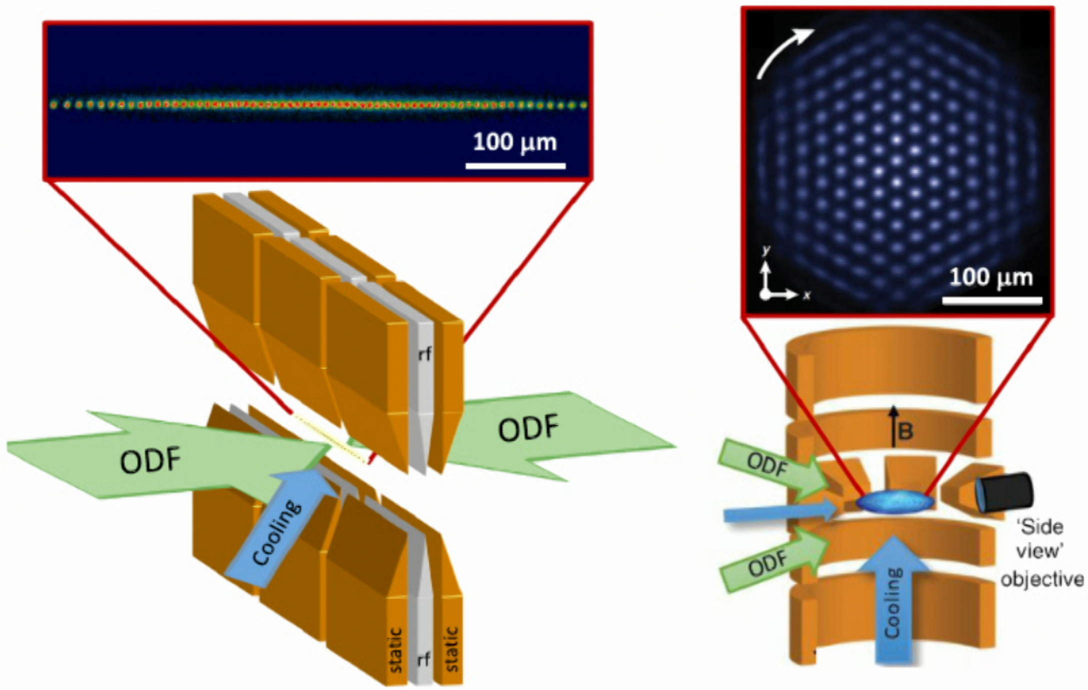


$$\phi = \phi_0 + \frac{V_0}{2r_0^2}\cos(\Omega t)(x^2 - y^2) \qquad \mathbf{E} = -\frac{V_0}{r_0^2}\cos(\Omega t)(x\hat{\mathbf{e}}_x - y\hat{\mathbf{e}}_y)$$

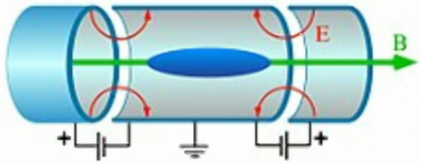
$$\tau = \Omega t/2 \qquad \frac{d^2 x_i}{d\tau^2} = -\frac{4eV_0}{Mr_0^2\Omega^2}\cos(2\tau)x_i$$

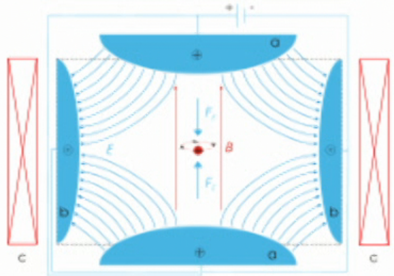
Mathieu equation

Programmable quantum simulations of spin systems with trapped ions
C. Monroe, ... R. Islam, ..., C. Senko
Reviews of Modern Physics, **93**, 025001-1 (2021)



# Penning Trap

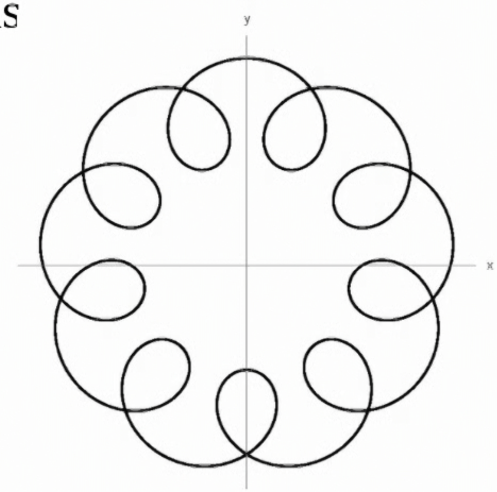


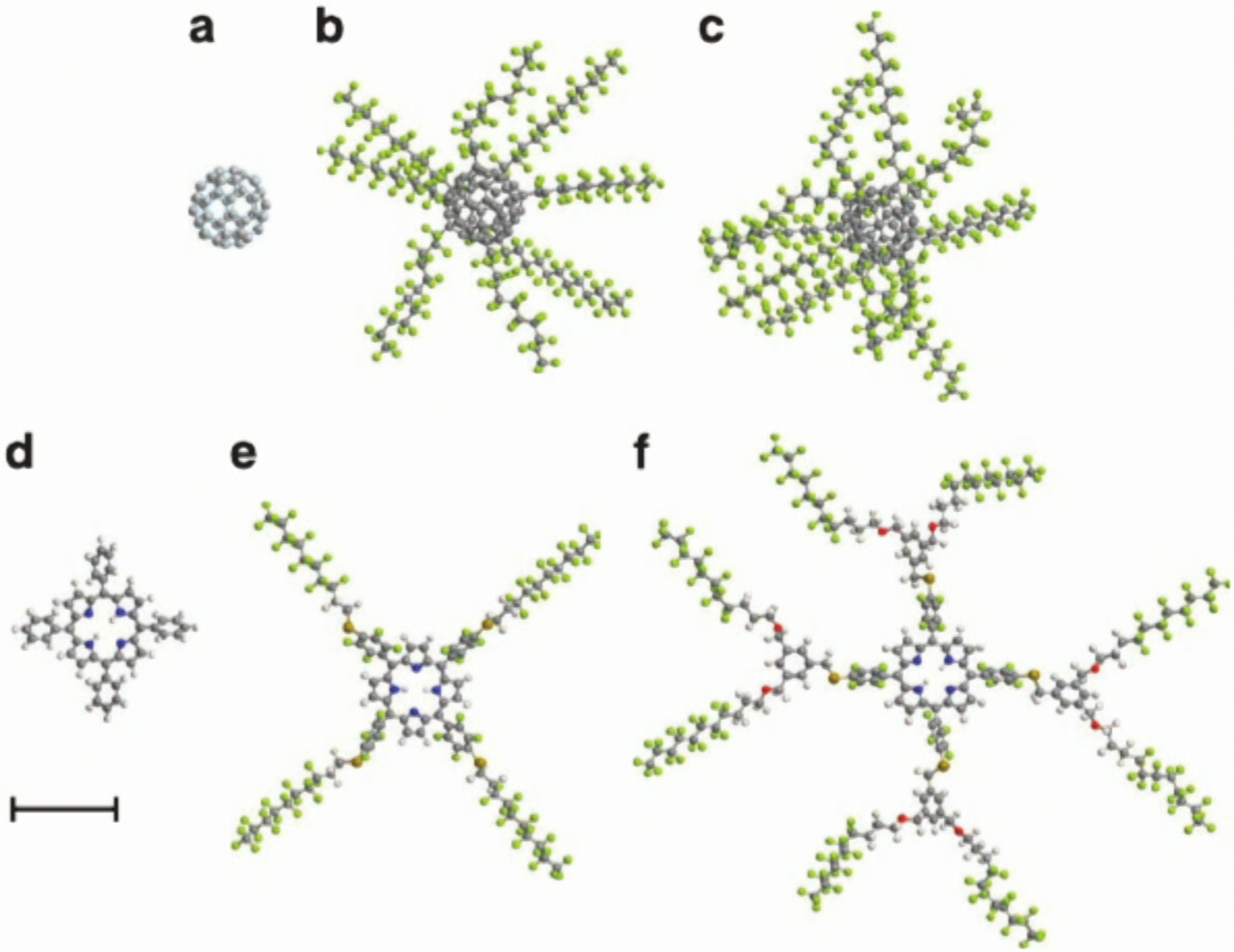



A standard configuration for a Penning trap consists of a ring electrode and two end caps. A static voltage differential between the ring and end caps confines ions along the axial direction (between end caps). However, as expected from Earnshaw's theorem, the static electric potential is not sufficient to trap an ion in all 3 dimensions To provide the radial confinement, a strong axial magnetic field is applied

$$\omega_c = \frac{eB}{M}$$

$$x = \frac{E}{\omega_c B}(1 - \cos(\omega_c t)),$$
$$y = -\frac{E}{\omega_c B}(\omega_c t - \sin(\omega_c t))$$
$$z = 0.$$

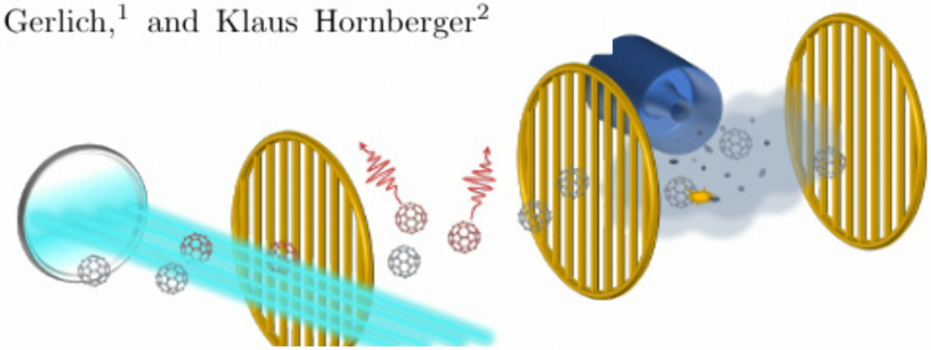



a
b
c
d
e
f

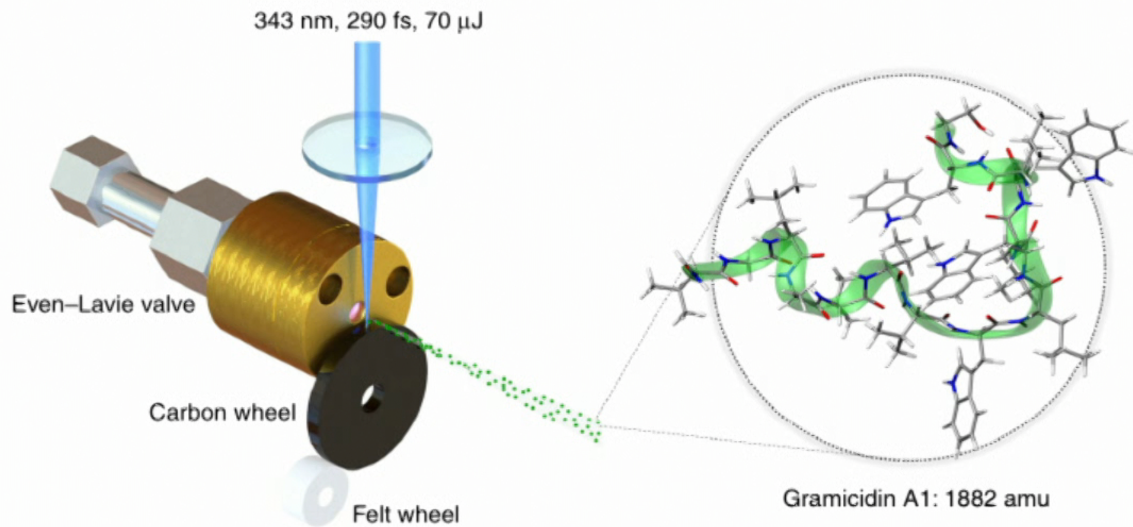
# Self Quantum Interference of Big Molecules

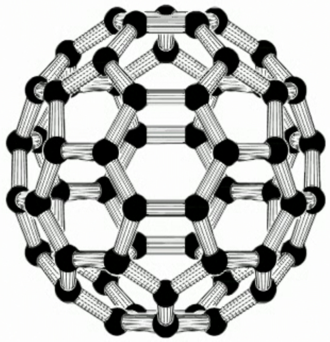
## Experimental decoherence in molecule interferometry

Markus Arndt,[1] Stefan Gerlich,[1] and Klaus Hornberger[2]



arXiv (2021)





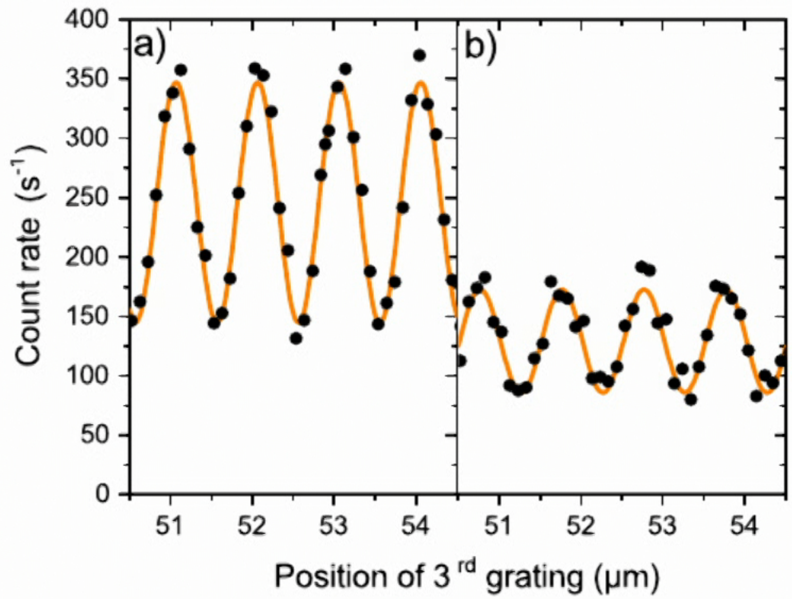
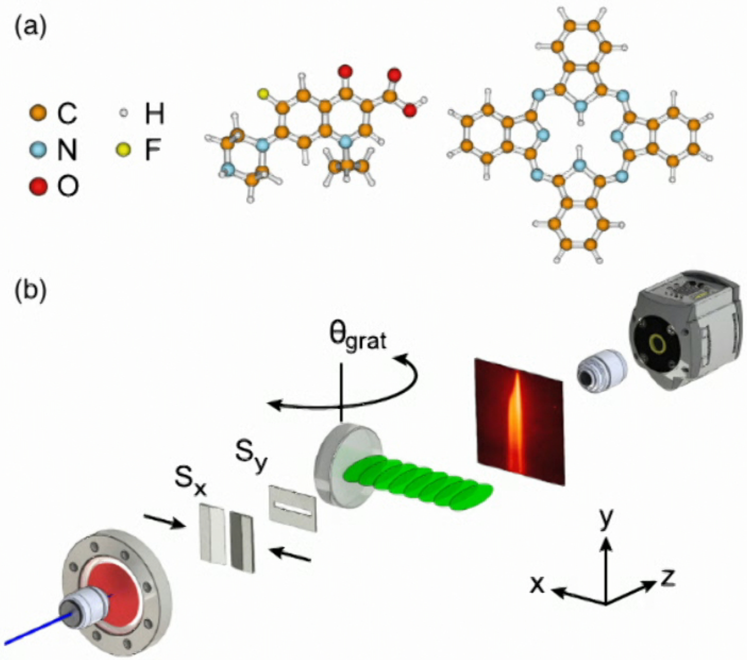
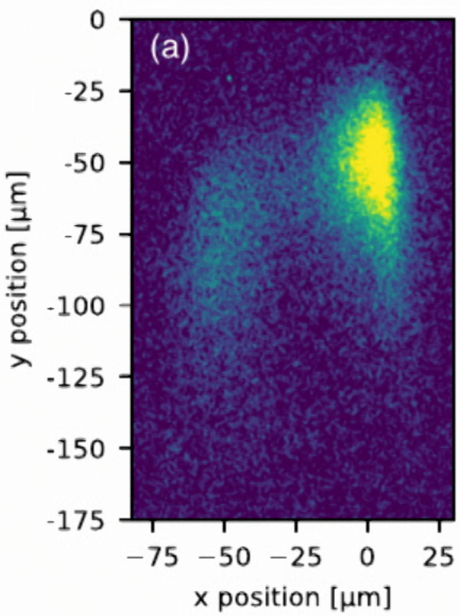



FIG. 3. **a)** Typical interferogram of $C_{70}$ molecules in a TLI at

A roadmap for universal high-mass matter-wave Interferometry
F. Kialka et al., AVS Quantum Sci. 4, 020502 (2022)

Bragg Diffraction of Large Organic Molecules
C. Brand et al.,
PHYSICAL REVIEW LETTERS 125, 033604 (2020)



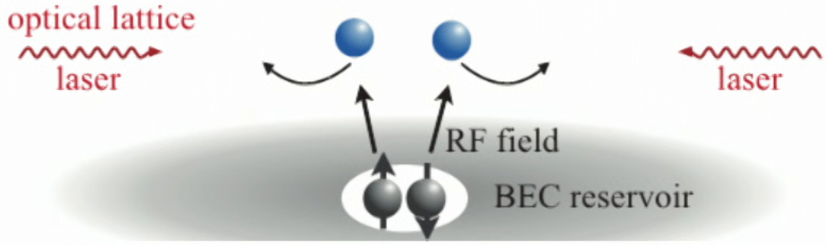



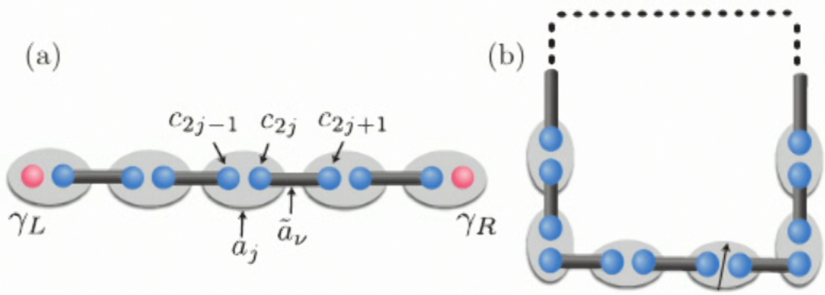

... more than 100 vibrational degrees of freedom thermalized at 700–1000 K ... quantum coherent manipulation of functional, hot, and polar molecules.

PHYSICAL REVIEW A **89**, 022319 (2014)

# Hybrid topological quantum computation with Majorana fermions: A cold-atom setup

C. Laflamme,[1,2,*] M. A. Baranov,[1,2,3] P. Zoller,[1,2] and C. V. Kraus[1,2]

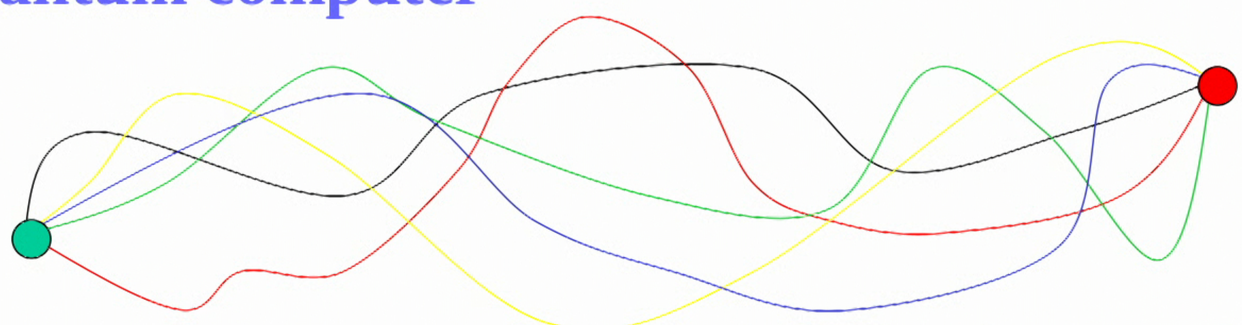


## classical computer


**unique computational path**

## quantum computer



**many paths sampled simultaneously with possibility of interference - complex amplitudes**