Forty-two?

Ground-breaking experiments in the last 10 years

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15 October 2013

Forty-two?

You can **never** go faster than light...

"Space and time are distorted by motion"

- At the speed of light, distances would contract to nothing
- So you can **never** go faster than light

Your physics supervisor

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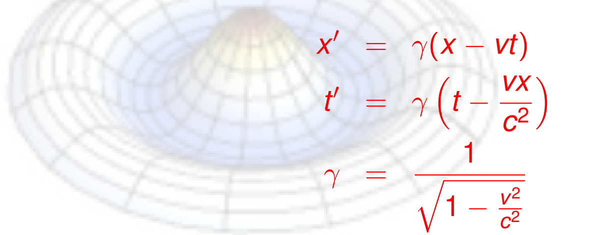

$$
\begin{aligned}
x' &= \gamma(x - vt) \\
t' &= \gamma\left(t - \frac{vx}{c^2}\right) \\
\gamma &= \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}
\end{aligned}
$$

(theory of special relativity)

...except in quantum mechanics

"Quantum mechanics plays by different rules"

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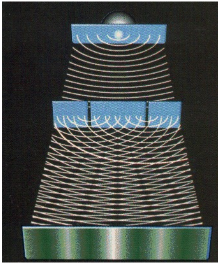

Double-slit interference experiment

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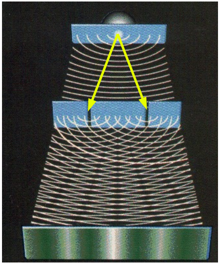

Double-slit interference experiment

- Electron splits in two

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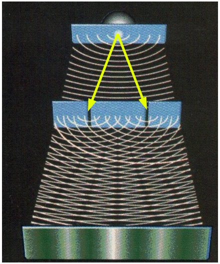

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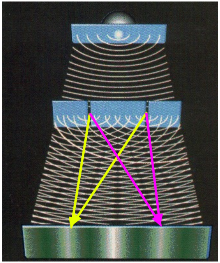

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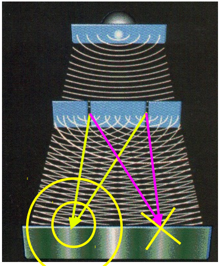

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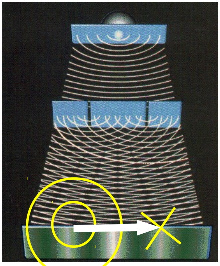

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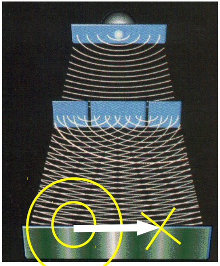

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Mechanism not understood

- Can't observe it (no actual faster-than-light signals)
- Hundreds of millions of dollars spent on quantum computers but they don't seem to work (Aaronson $100,000 bet outstanding)

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Your supervisor might fidget uncomfortably, or might say...

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Information goes backwards in time

Transactional (Cramer)

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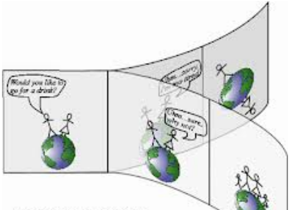

A representation of the split that occurs based on the possible outcomes for each action, according to Everett's Many-Worlds interpretation (courtesy of Max Tegmark).

Information goes backwards in time

Transactional (Cramer)

A new universe is spawned with each measurement

Many worlds (Everett)

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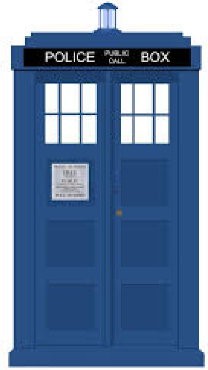

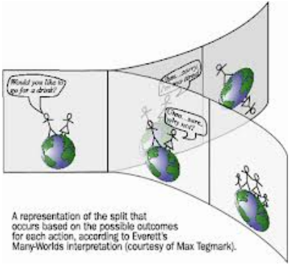

Information goes backwards in time	A new universe is spawned with each measurement	Shut up and calculate
Transactional (Cramer)	Many worlds (Everett)	Mainstream

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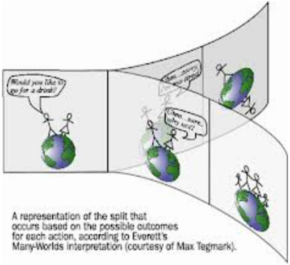

Information goes backwards in time	A new universe is spawned with each measurement	Shut up and calculate
Transactional (Cramer)	Many worlds (Everett)	Mainstream ('Oxford')

Our purpose today

Purpose of this presentation

- To open your eyes to calculations in 1952
- Given new life by experiments in the last 10 years
- which suggest physics might not be so weird after all

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To be accessible to the audience

- Using as few equations as possible

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To recruit volunteers

- To beta test our new student's guide
- Aimed at bright freshers (and professors)
- Currently about 100 pages

Experiments on waves in an ideal fluid

And associated conferences and books

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Emergent quantum mechanics

Quantum mechanical behaviour emerging from fluid motion

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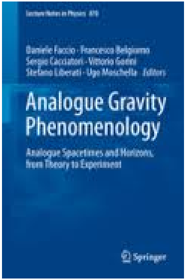


Analogue gravity (secondary to this talk)

Special and general relativity emerging from fluid motion

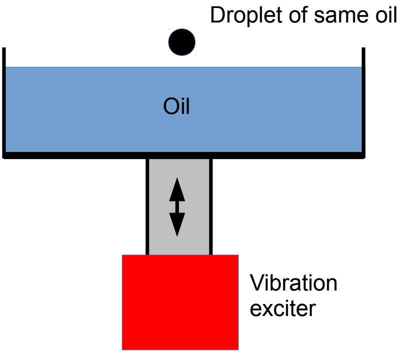
- ‘Dumb hole’ – acoustic analogue of black hole
- Hawking radiation observed in ultracold atoms

C. Barceló, S. Liberati, M. Visser *Analogue gravity* Living Reviews in Relativity, 14(3) (2011)
W G Unruh *Dumb holes: Analogues for black holes*, Philos. Trans. R. Soc. London A, 366, 2905–2913 (2008)

The Paris experiments (repeated at MIT)

Simple apparatus

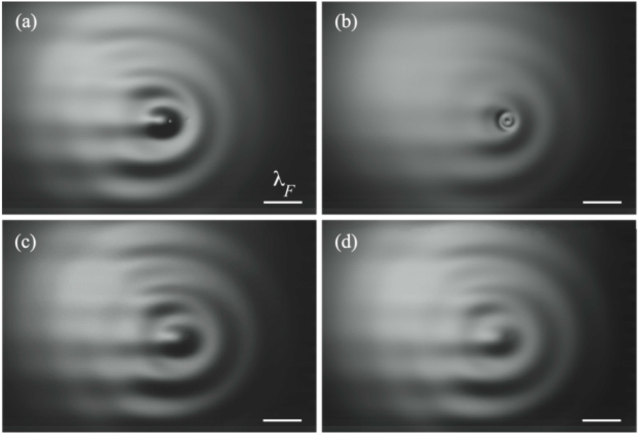
- Dish of oil glued to a loudspeaker (student project)
- Vibration exciter, wind shielding (research version)



http://www.youtube.com/watch?v=B9AKCJjtKa4

‘Ghost droplets’ or quasiparticles

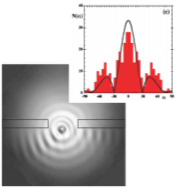
The actual droplet is (almost) superfluous



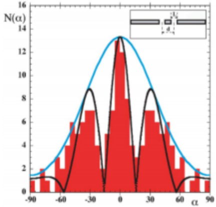
Droplet collapses in (b). Motion continues (c) 5 cycles later and (d) 15 cycles later [animation]

Forty-two?

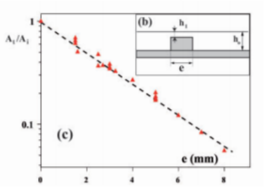
Single slit



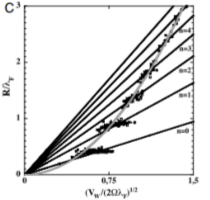
Two-slit



Tunnelling



Quantised orbits



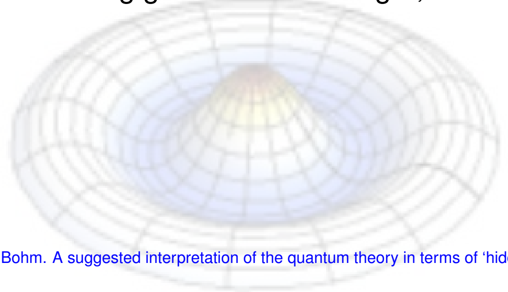
Y Couder, E Fort 'Single-Particle Diffraction and Interference at a Macroscopic Scale' PRL 97 154101 (2006)
A Eddi, E Fort, F Moisi, Y Couder 'Unpredictable tunneling of a classical wave-particle association' PRL 102, 240401 (2009)
E Fort et al 'Path-memory induced quantization of classical orbits' PNAS 107 41 17515-17520 (2010)

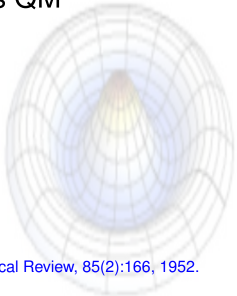
Very full analogue of quantum mechanics

Explained by Bohm in 1952

de Broglie-Bohm or ‘pilot wave’ model (1952)

- Bohm hypothesised an electron is a tiny particle, guided by waves
- He proved the observables are indistinguishable from conventional quantum mechanics (maths turns out to be identical)
- e.g. double-slit experiment: the particle takes an ordinary path; nothing goes faster-than-light; same statistics as QM





D. Bohm. A suggested interpretation of the quantum theory in terms of ‘hidden’ variables. Physical Review, 85(2):166, 1952.

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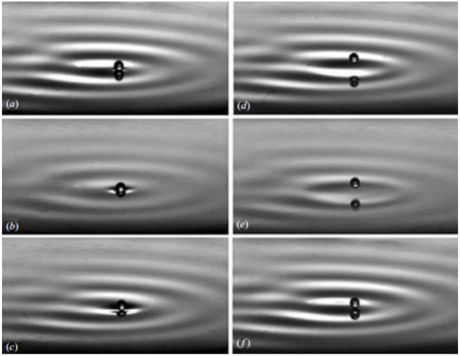
The droplets obey **very nearly** the same mathematics

- Solutions to Euler’s equation for the fluid, averaged over a cycle
- (there are differences between the models since de Broglie Bohm assumes a tiny particle but the solution is for a ‘ghost droplet’ or quasiparticle)

D. Bohm. A suggested interpretation of the quantum theory in terms of ‘hidden’ variables. Physical Review, 85(2):166, 1952.
J Molacek, J Bush *Drops walking on a vibrating bath: towards a hydrodynamic pilot-wave theory* hdl.handle.net/1721.1/80417
R Brady. *The irrotational motion of a compressible inviscid fluid*. ArXiv 1301.7540, 2013.
Beta test the book!

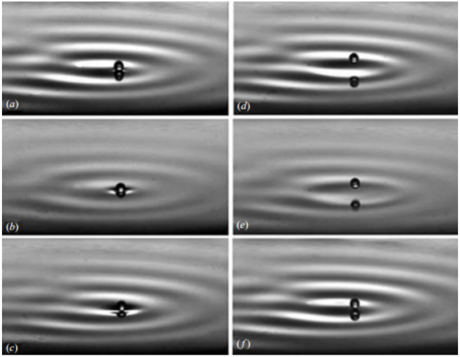
Forty-two?

The bouncing motion

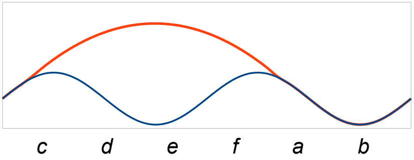


→ "Walker" at velocity V

The bouncing motion



The droplet touches down every other vertical vibration



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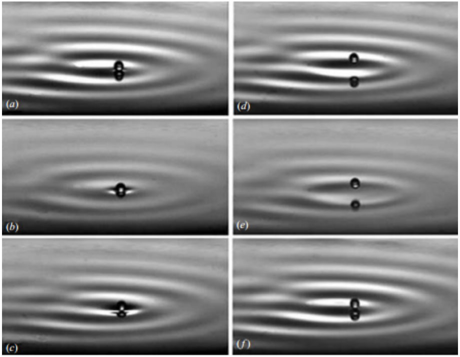

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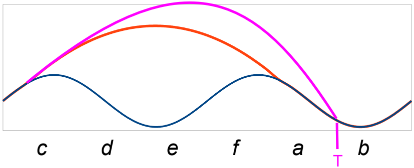
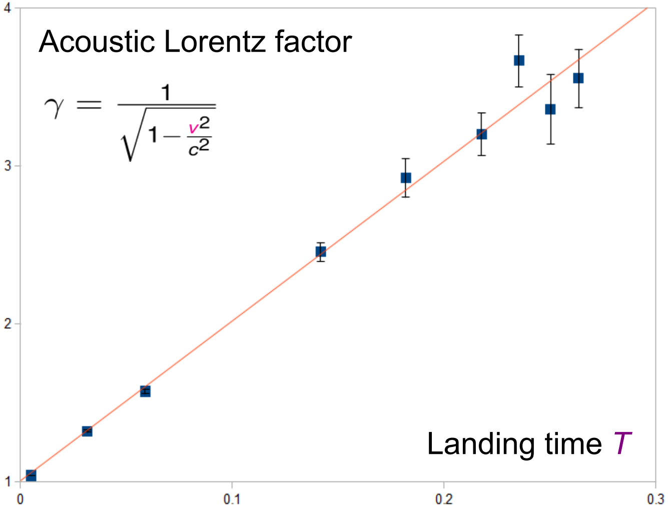


Greater vertical amplitude

- Lands at later time T
- The later the droplet lands in the cycle, the greater the walking velocity v
- Due to surface waves guiding the droplet

(Re)-plot the original (2005) experimental results



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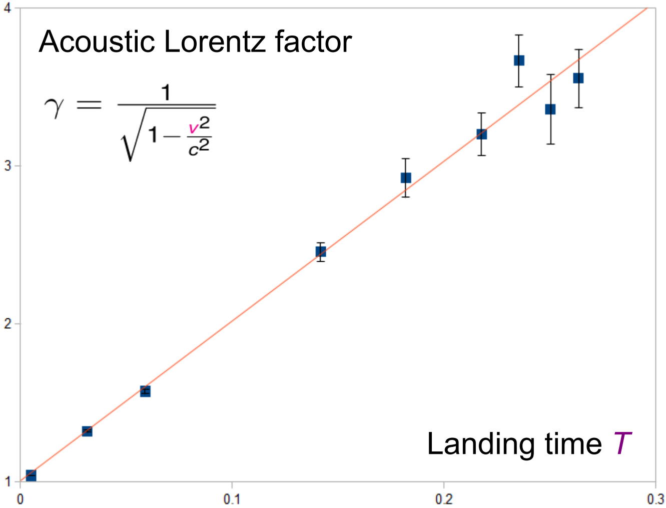

Good experimental match to the relativistic time dilation formula

Speed of sound instead of light

Known in analogue gravity as the ‘Acoustic metric’

Explanation

If $f(x, t)$ is a solution to the wave equation

$$\frac{1}{c^2}\frac{\partial^2 h}{\partial t^2} - \frac{\partial^2 h}{\partial x^2} - \frac{\partial^2 h}{\partial y^2} = 0$$

then so is $f(x', t')$ where

$$\begin{aligned} x' &= \gamma(x - vt) \\ t' &= \gamma\left(t - \frac{vx}{c^2}\right) \\ \gamma &= \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \end{aligned}$$

(extends to Euler's equation averaged over a cycle)

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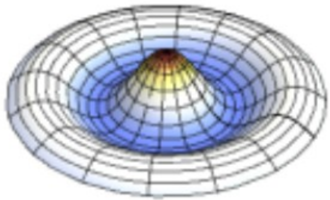
If $f(x,t)$ is a solution to any equation of physics then so is $f(x',t')$ (theory of special relativity)

Stationary quasiparticle solution

$h = \cos(\omega_o t) J_o(k_r r)$



J_o Bessel function

Example

Stationary quasiparticle solution

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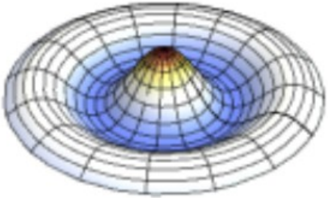
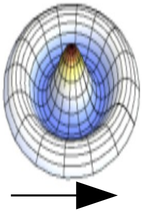


J_o Bessel function

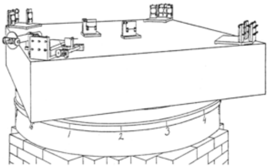
Quasiparticle moving at v

$h = \cos(\omega_o t') J_o(k_r r')$



Lorentz contracted, time-dilated

Michelson-Morley experiment



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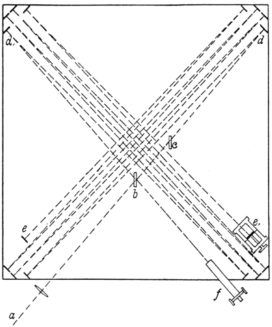
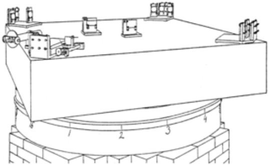


Michelson-Morley 1887

- Tried to measure the motion of the earth through the light medium
- Obtained a null result

Two possible ways to account for this

Michelson-Morley experiment



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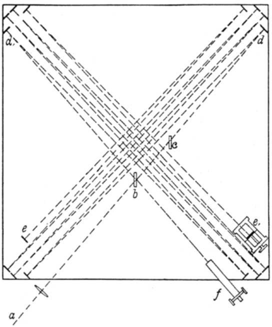

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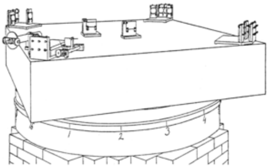

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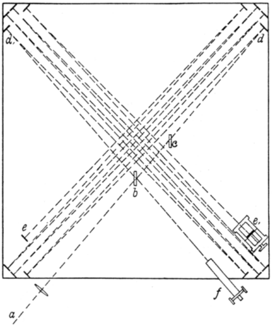

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Two possible ways to account for this

(a) (Analogue gravity) The apparatus is made of waves. Waves are Lorentz covariant, so the apparatus is incapable of detecting absolute rest.

(b) (Your physics supervisor) Space and time are distorted by motion. The magnitude of the distortion is calculated by assuming the (null) experimental result.

Forty-two?

The Dyson force

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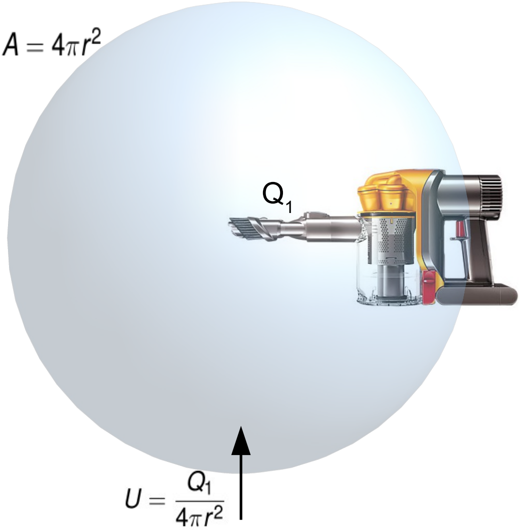

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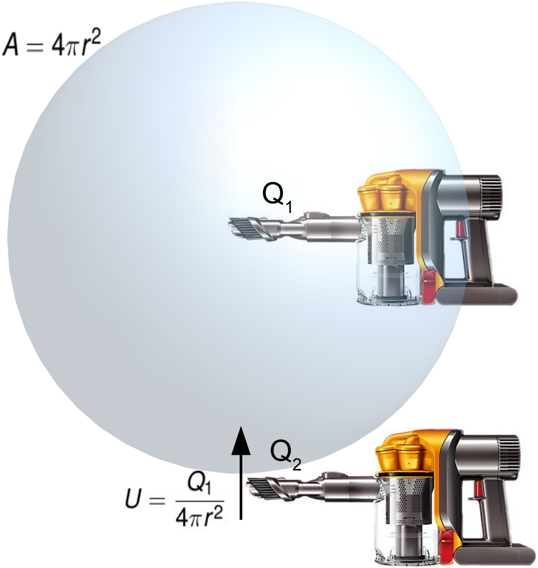

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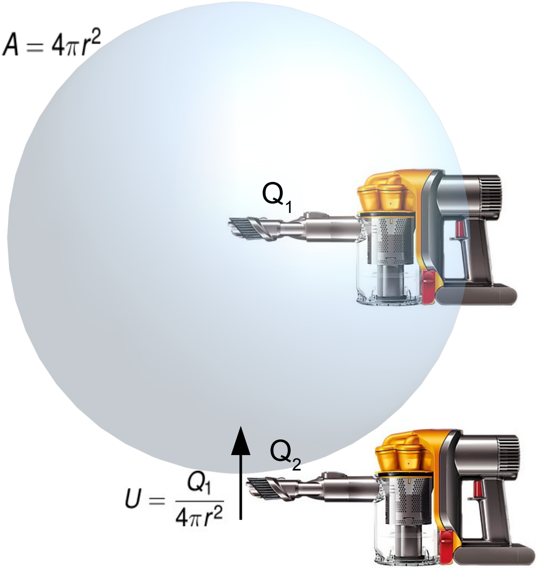
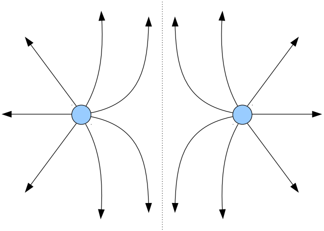


$$F = -\rho \frac{Q_1 Q_2}{4\pi r^2}$$

Inverse square force of attraction

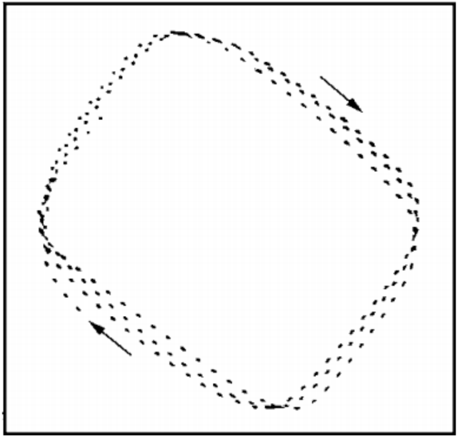
Dyson force used for degassing oil



Apply ultrasonic vibration

- Bubbles expand and contract in phase
- Induces flows in the oil
- Same equations as the Dyson force
- inverse square force of attraction
- Bubbles attract and merge
- Degas oil in 5 seconds

Dyson force in the droplet experiment

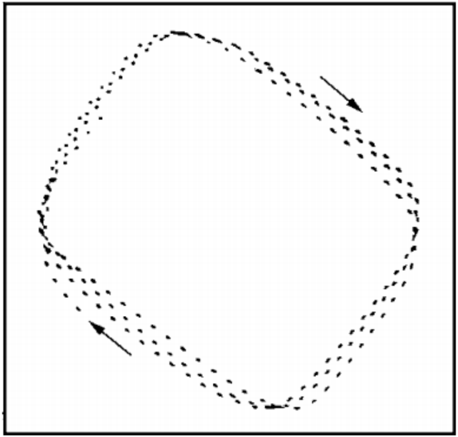


Stroboscopic photograph

'Image droplet' in boundary

bounces antiphase → repulsion

Dyson force in the droplet experiment



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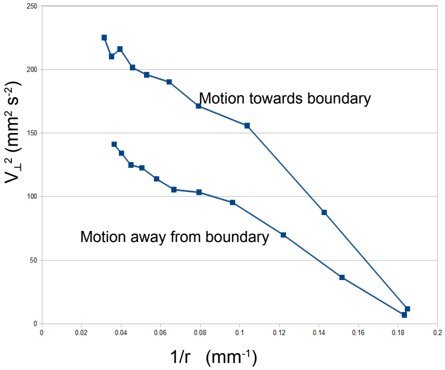

Inverse square force

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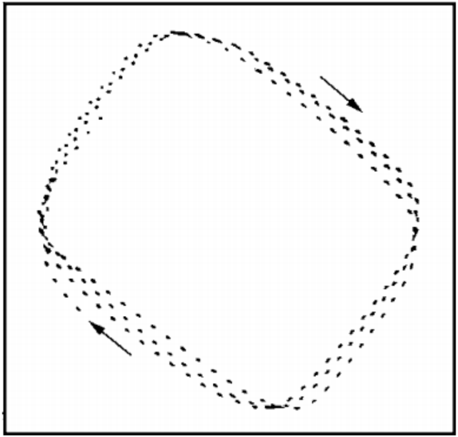

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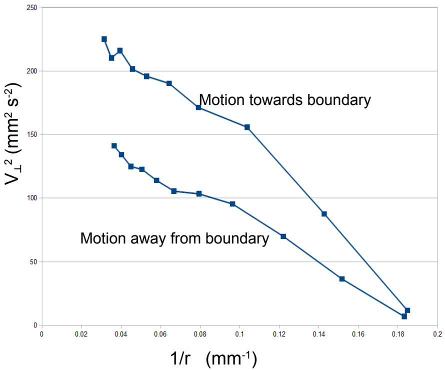

Inverse square force

Lower line evidences a magnetic interaction (detail in book)

Forty-two?

New experimental results in the last 10 years

- Emergent quantum mechanics (bouncing droplets)
- Emergent relativity (analogue gravity, Hawking radiation)
- Excitations in superfluid helium (‘rotons’ - not time today)

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Seeking volunteers to beta test the book