Lab 04: Paul trap for Charged Particles

Objectives:

1. Calibration - measure Camera and lens Calibration in both horizontal + vertical (needs to be done whenever zoom is touched)
2. Combined motion
   - Load one particle into frame and record for a long time to observe both micromotion and secular motion. (FR ≥ 150 Hz)
   - Record the transient response of the particle after "trapping" or giving "kick" in another way
3. Stability
   measure the range of voltages you can keep the particle trapped. Does this range depend on the number of particles you trap?
4. Capture at 60 Hz, and in nearby freq to help isolate secular motion. Compare w/ 150 Hz Captures
5. Load in multiple particles + explain the resulting "Coulomb Crystals"

Post-Lab Questions

1. How does the physics of a particle in a Paul trap compare to that of an optically trapped particle in lab 03? Is the motion over or under damped? Are they more similar with the micromotion removed?
2. Calculate the apparent particle mass by making a histogram of the velocity (or is velocity squared better?) and fitting a room-temperature thermal distribution to it with mass as a fit parameter. Should this include the micromotion? Justify your approach and complete the calculation. Is your result reasonable?

* 3. Compare the calculated stability range of the trap with what you observed. Estimate any unknowns. Do your experiments agree with the calculation?

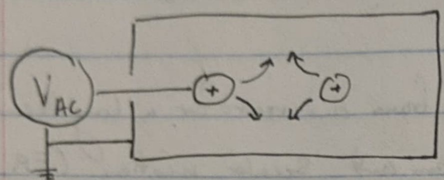


Figure 5 from Improved microparticle Electrodynamic Ion traps for physics teaching

positive ring driven by AC in grounded box

From that same reference

$$z(t) = z_0 + v_0 t - \frac{qE_0}{m\omega^2}\sin(\omega t) \qquad (1)$$

$$\langle F \rangle \approx - \frac{q^2 E' E_0}{2m\omega^2} \qquad (3)$$

$E' = \frac{dE}{dt}$ for small E'

Neg means gets pushed into weaker field!

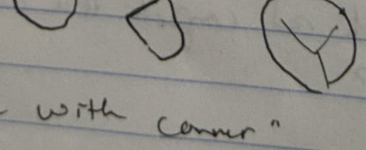
Our damped, as Γ (damping coefficient) ~ 960 Hz, opposed to $\omega = 2\pi(60\text{ Hz}) \sim 377\text{ Hz}^{-1}$

$\omega^2 + \Gamma^2 \to \Gamma^2$ For accuracy within 15%!

- A laser light may be used (and will be used) to add light to particles to allow for better viewing

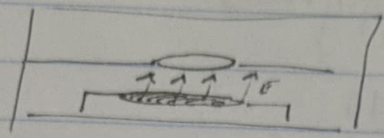
- 1kV may be too weak
  10kV may cause sparking/arcing
  6kV is that happy spot

- Particles to be used Lycopodium (Dragon's Breath)
  See Figure 9 in aforementioned source



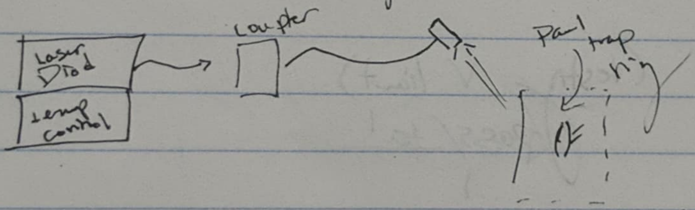
"Sphere with corner"

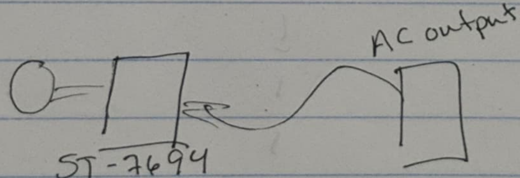
- micromotion can also be removed with a static E-Field



HINT Camera settings: Gain all the way up
Exposure low

Computar Macro zoom lense: 0.3X ~ 1X 1:4.5
Same laser set up as lab 03





Variable Voltage regulator
model No: SC-3M
AC 60 Hz, 0 - 135 V range

Dragons Breathe
#FC31 (see pictures taken)
30cc

/opt/pylon/bin/pylonviewer
python3 -m pythics

Exposure: 339μs
Gain: 36 dB
requested fr: 89.2061 Hz

135V

Paul test ~~Delay~~ 00: 1000 pics @ 89 Hz
paul test 01: 1000 " at 60Hz
paul test 02: 1000 " at 60.5Hz
paul_test 03: 1000 " at 59.5Hz

Calibration_01

Lost data. Y/use yet. Figuring out how to get gain

Dropping Particle (testing V limit)

~~Input~~ Voltage	pass/fail
127 V	1
125 V	1
120 V	1
115 V	1
110 V	1
105 V	1
↓	
60 V	1
55 V	0

trial 2 65 V Dropped
trial 3 50 V Dropped
trial 4 50 V Dropped

paul trap04 - paul trap08 → Calibration 02

Heading into Day 2 (Notes + points):

- Reanalyze weakest strength (lower sight)
- "Record the transient response of the particle after "trapping" the particle or "kicking" the table by another means"
- "Load multiple particles into the trap and record images of particle arrangements that form
- play with freezing motion in real time

Data Collected:

Trapped one particle alone

Day one saw a lot of dramatic shifting in particle location, obviously not the 60Hz micromotion.

Today, taped sides down better, pulled curtain behind trap closed and put microscope slide over particle drop hole. virtually removed turbulance (the probable culprit for last week's bad data).

Retook 30, 60, 120 Hz w/ one particle

60 ± 0.5 Hz

150 Hz

Paul trap 11 - Paul trap 16

Calibration 11 (Horizontal + vertical)

→ Forgot to bring in focus

Where's 2?
Great question

Same thing as above, but some turbulence got reintroduced as the box fell & had to resecure it.

Retook 30, 60, 120 Hz

60 ± 0.5 Hz

200 Hz

Paul trap 31 - Paul trap 36

transient 12

Calibration 31

Dropping Voltage

Lost at 35V [Dropped by moving to adjust Cam and knocking out w/ turbulance]

Lost at 20V [one returned, but seemed like outlier]

Lost at ~22V

Lost at 20V

Post Lab questions:

1. Compare to last Lab.

On the surface, the only that seems to be the same between the two labs is that they have a particle in a pseudo-stable setup. However, once the micro-motion is removed from this Lab the analysis was nearly identical.

The description of the particle in a simple harmonic oscillator ~~[illegible]~~ is a little weaker in this second Lab since the micromotion is so dominant, however, the same analysis could be done to possibly check the strength of the correcting force from the trap. However, the way the particle is trapped is not from a potential well, but a dynamic E-field, so the analysis wouldn't be as enlightening

2. All the analysis can be seen in the paper, python code & ~~[illegible]~~ jupyter notebook.

From the paper:

60Hz data : 0.39 ± 0.04 pg

200Hz data : 0.045 ± 0.006 pg

this is incredibly unlikely; I think that air currents and a possible bug in code threw those numbers off so far.

Doing the analysis with another groups data:

60Hz : 523 ± 46 pg

198Hz : 24.8 ± 0.3 pg

these are much more reasonable numbers!