The Mechanical Paul Trap
Introducing the Concept of Ion Trapping

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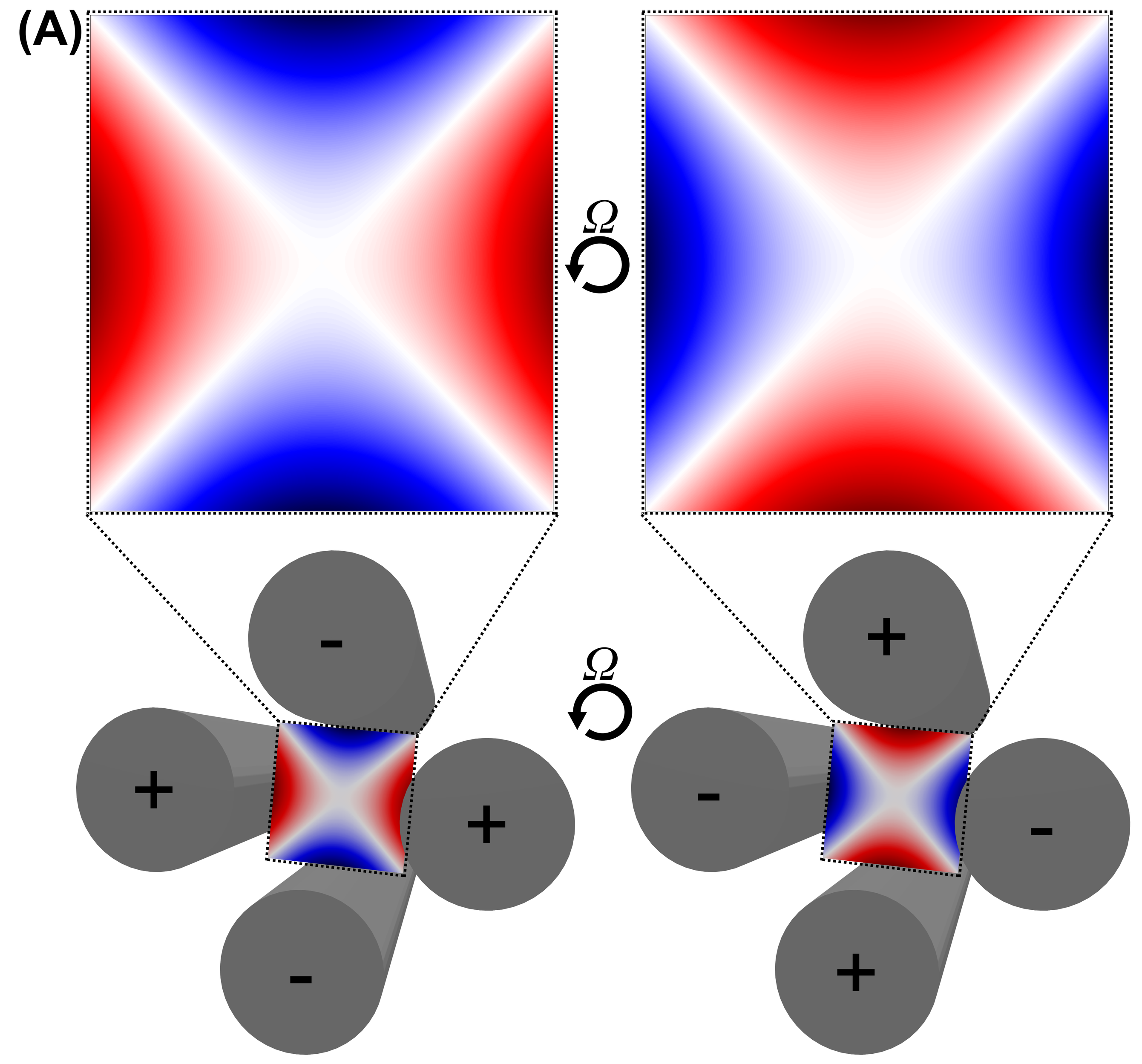
Background

Nobel laureate Wolfgang Paul first showed, back in the 1950s, that charged particles can be trapped using alternating electric fields[1]. Nowadays, this technique is commonly referred to as Paul traps or radiofrequency traps (RF-traps) and is used in various areas of modern physics. Two popular and exciting examples are particle accelerators and quantum computes, which coincidentally are fields that often manage to spark an interest among the general public. Moreover, even though there are a lot of exciting fields within modern physics, they are seldom incorporated into the high school classroom. The mechanical Paul trap can be used as a demonstration tool or an experimental setup to simulate how a real Paul trap works or investigate interesting physical phenomena[2-5].



Different representations of a Paul trap

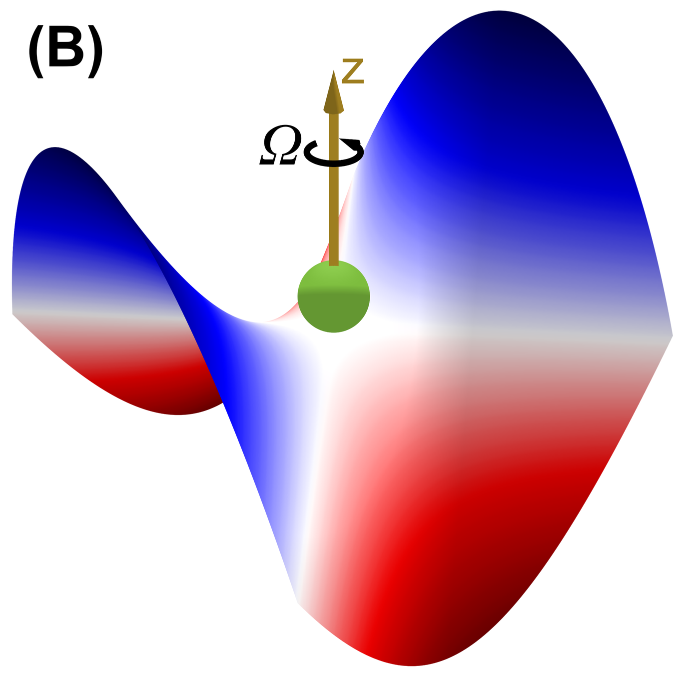
A linear Paul trap **(A)** confines particles by connecting four metal rods to an AC source. With opposite rods having the same polarity and changing their polarity with some frequency, we create a net force towards the middle of the changing field.

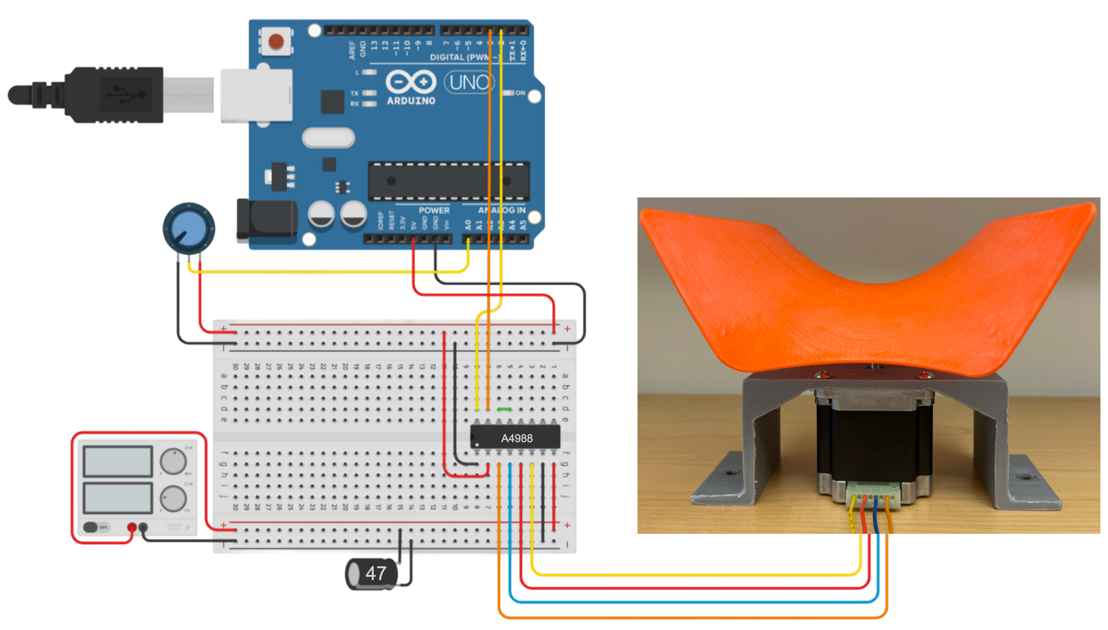
Moving to a three-dimensional representation **(B)**, the field strength is represented as the height of the z-axis. Here, the repulsive force is shown as an uphill slope and the attractive force as a downhill slope.

We can further reduce the abstract representation of the field by constructing a macroscopic version of the Paul trap. The mechanical Paul trap **(C)** is visually similar to the field strength in the linear Paul trap. Rotating the mechanical Paul trap is similar to flipping the polarity of the charged rods.

The varying electric and gravitational potential are similar (see below), apart from a cross-dependent sinusoidal term for the gravitational potential. This term shows that the potential in the mechanical trap is bounded, which must be true for a solid surface.

$$\Phi(t) = \frac{V_0}{2R^2}\left(x^2 - y^2\right)\cos(\Omega t) \qquad U_g(t) = \frac{mgh}{R^2}\left[\left(x^2 - y^2\right)\cos(2\Omega t) + 2xy\,\sin(2\Omega t)\right]$$





Bring it home

Utilizing the power of 3D printers, cheap electronic components, and easy to program Arduino, you can create your own mechanical Paul trap. Scan the QR codes to learn more.

Print the parts

Program the Arduino

Study the simulation

Watch the trap in action

Student investigations

Physical properties of a saddle point

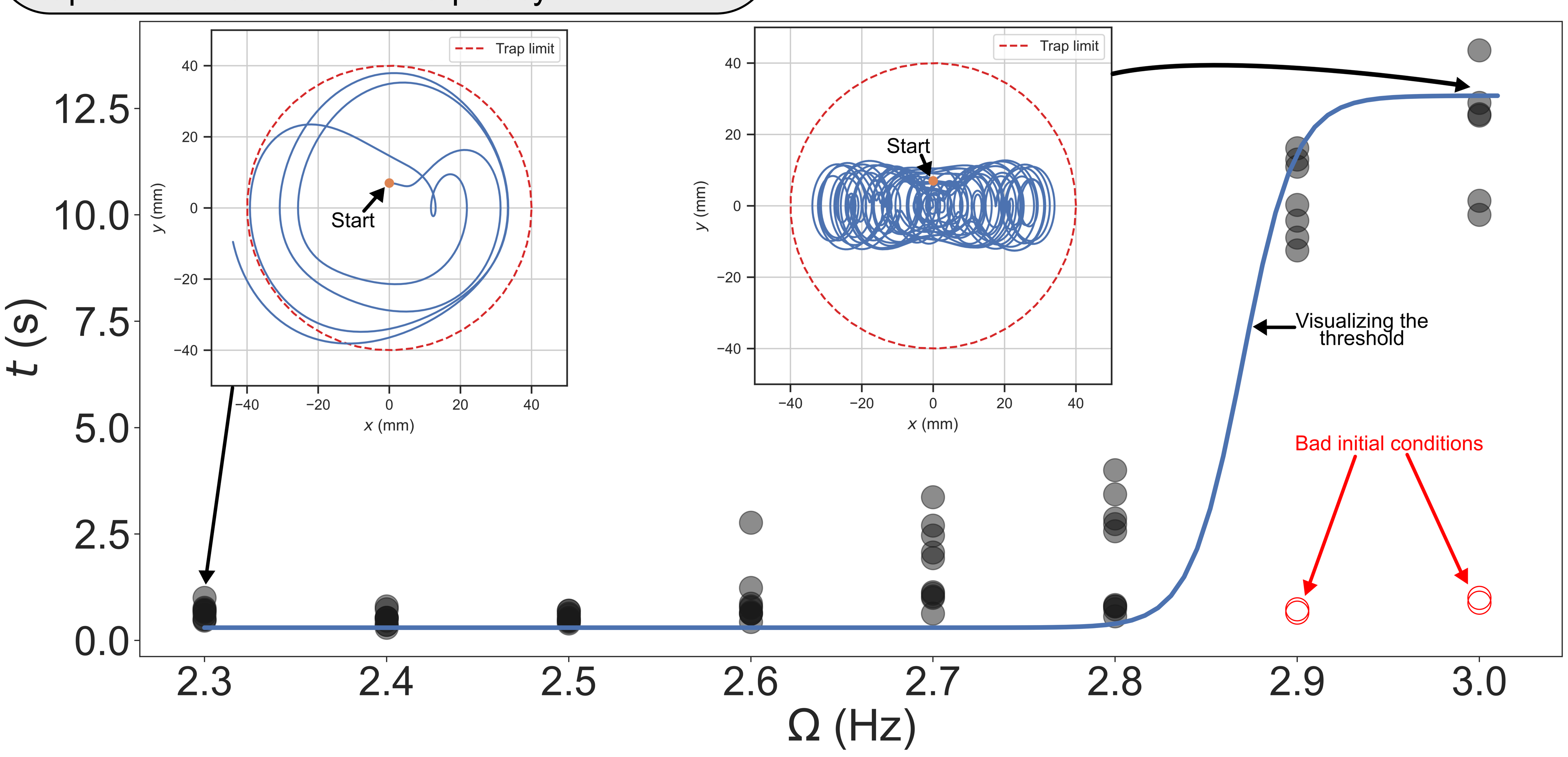
Using the mechanical Paul trap, one can intuitively understand the concept of saddle points by trying to place a ball on the trap when the trap is stationary.
What does it take for the ball not to roll off?
Why does the ball tend to roll off the surface?

Threshold frequencies

There is a range of possible frequencies for which it is possible to trap a ball. The lower bound is called the threshold frequency. Use a computer simulation and the mechanical Paul trap to find the threshold frequency.

Varying frequency

1. Place a ball on the saddle surface using the following rotational frequencies: 2.3 Hz and 3 Hz. Is it possible to catch the ball at any of the frequencies?
2. Using a computer simulation, investigate if a "ball" can be trapped using the following rotational frequencies: 2.3 Hz, 3 Hz, and 9 Hz. Have the particle start at x = 0 mm, y = 7 mm.



References

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