Quantum Wave Flexible Track

Experiments in classical mechanics using Quantum Levitation

Classical Mechanics by Quantum Levitation

The Quantum Wave experiment setup allows students to experience frictionless motion and conduct experiments in classical mechanics and modern physics (superconductivity).

Each experiment contains three stages:

1. Planning and setting up the experiment (objective, method).
2. Performing the experiment and camera-recording the motion. Repeating, if necessary, using different parameters.
3. Analyzing the results, calculating requested properties (energy, momentum, etc.) and plotting various graphs.

For each experiment we present the relevant equations and the experiment objective. In most cases the data is measured and analyzed using video. The student is required to video the motion (using a typical smartphone camera) and then analyze the recording using a dedicated video analysis software. We recommend using the open source, easy-to-use and powerful software – 'Tracker'.

A link to download 'Tracker' can be found here: www.quantumlevitation.com/tracker

Before we begin, some warnings:

The flexible magnetic track uses powerful magnets. If not handled with caution these magnets can dislodge and cause serious damage. Keep the track away from any sensitive electronic equipment and DO NOT bend the track into a full circle.

Liquid Nitrogen (N2)

Liquid nitrogen contains nitrogen gas that was cooled to temperatures below 77K (-196C) until liquefied. While not toxic, the liquid is extremely cold and can cause serious cold burns when in contact with exposed skin. Do not touch the liquid directly or any surface that was cooled in the liquid nitrogen. Pay special care to metallic surfaces as they conduct heat very well and will 'suck' the heat from your body more quickly leaving you with a nasty cold burn.

Introduction

1. Superconductivity taught as part of high school Physics?

Since its discovery in 1911, superconductivity was only discussed at the high school physics level as an interesting topic or an anecdote. The phenomenon couldn't be observed in class because it occurred only at extremely low temperatures – a few degrees above absolute zero (0 K / -273C).

During the late 1980s, the rapid succession of newly discovered high-temperature superconductors which can operate at liquid nitrogen temperatures (77 K) turned the tables. Superconductivity was now well within the reach of high school students. It was now possible to perform classroom demonstrations of magnetic levitation and to easily observe quantum phenomena using relatively accessible and inexpensive liquid nitrogen!

Quantum Levitation demonstrations always capture students' attention. They become entranced by an upside down levitated magnet, they wonder how it works and predict what it can be used for – scientific inquiry has begun! Students' curiosities are limited only by their imagination.

Superconductivity is widely regarded as one of the great scientific discoveries of the 20th century and, in four occasions, the Nobel Prize in Physics was awarded for work on superconductivity. Nevertheless, the history of superconductors is only just now beginning. The possible discovery of room temperature superconductors has the potential to bring superconducting devices into our everyday lives. Superconductivity is already being applied to many diverse areas such as transportation, power production, medicine and more. At the dawn of the 21st century, superconductivity forms the basis for new horizons that are transforming our daily life as we speak.

Fascinating properties of superconductors

1. Zero Resistance at low temperatures

It had been known for many years that the resistance of metals fell gradually when cooled below room temperature, but it was not known what limiting value the resistance would approach if the temperature were reduced to very close to absolute zero.

The era of low-temperature physics began in 1908 when Dutch physicist Heike Kamerlingh Onnes first liquefied helium, which boils at 4.2K. Three years later, Onnes passed a current through a very pure mercury wire and measured its resistance as he steadily lowered the temperature. Much to his surprise, there was no leveling off of resistance until the temperature reached 4.2K, at which point the resistance suddenly vanished. Current was flowing through the mercury wire and nothing was stopping it; the resistance was zero. Onnes called this new state of **zero** resistance **'superconductivity.'**

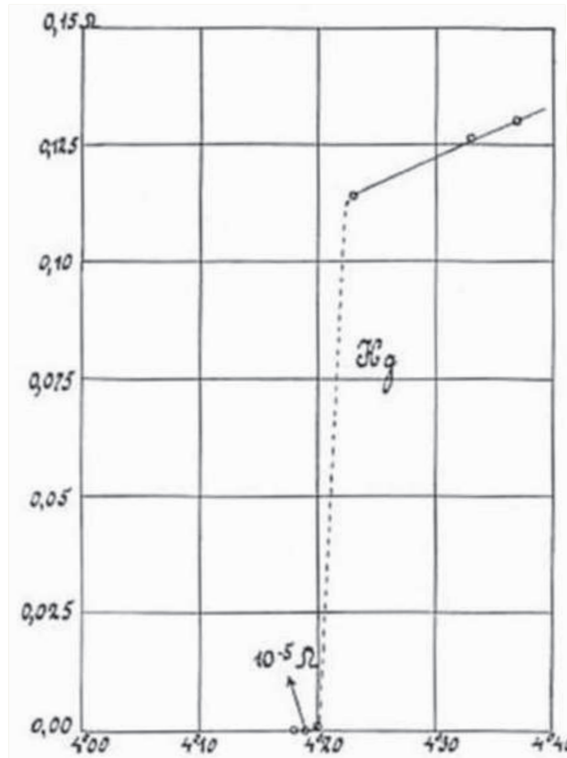


Figure 1: The original graph from Onnes's publication from 1911 showing the resistance of mercury as a function of its temperature. (H. K. Onnes, Comm. Leiden, 124c, 1911).

In 1913, Onnes was awarded the Nobel Prize in physics for the study of matter at low temperatures and the liquefaction of helium. Soon afterwards, many other metals were found to exhibit zero resistance when their temperatures were lowered below a certain characteristic temperature, called the critical temperature, or Tc.

The importance of this discovery to the scientific community as well as its commercial potential was clear. An electrical conductor with no resistance could carry current to any distance without loss.

Did you know?

In one experiment conducted by S. S. Collins in Great Britain, a current was maintained in a superconducting ring for 2.5 years, stopping only because a trucking strike delayed delivery of the liquid helium that was necessary to maintain the ring below its critical temperature.

2. Expulsion of magnetic fields – the Meissner effect

The magnetic properties of superconductors are as dramatic as their complete lack of resistance. In 1933, Hans Meissner and Robert Ochsenfeld studied the magnetic behavior of superconductors and found that below their critical temperatures, superconductors exclude magnetic fields. They discovered that a superconductor will not allow a magnetic field to penetrate its interior. It achieves this by producing a "magnetic mirror," surface currents which produce a magnetic field that exactly counters the external field. The phenomenon of the expulsion of magnetic fields from the interior of a superconductor is known as the **Meissner effect.**

The Meissner effect will occur only if the external magnetic field is smaller than the superconductor's critical magnetic field, or Bc. If the magnetic field becomes too great, it penetrates the interior of the metal and the material loses its superconductivity.

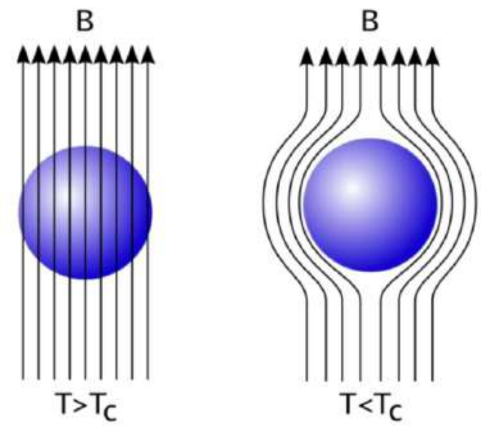
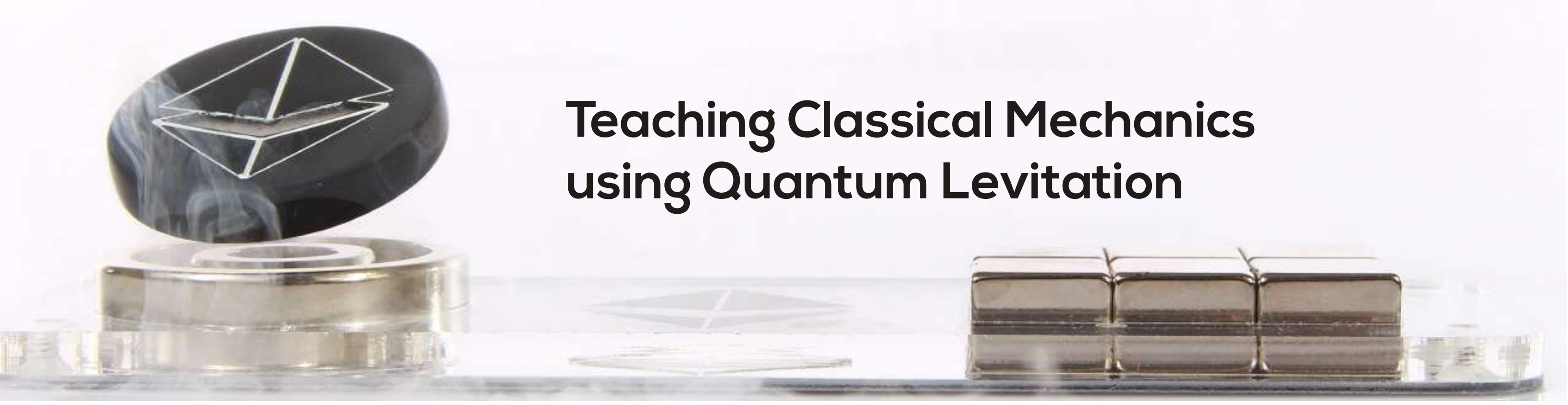


Figure 2: superconductor in the presence of an external magnetic field. (a) At temperatures above Tc, the field lines penetrate the sample because it is in its normal state. (b) When the rod is cooled to T<Tc and becomes superconducting, magnetic flux is excluded from its interior by the induction of surface currents.

3. Type-II Superconductors

In 1935 a new type of superconductors was discovered by Shubnikov & Rjabinin. They noticed that in some cases magnetic fields gradually (with increasing external field) penetrate into the superconductor. This was later explained by Ginzburg & Landau and later expanded by Abrikosov who showed that in certain materials magnetic fields do penetrate the superconductor in the form of quantized flux tubes or fluxons. Depending on the superconductors properties, these flux tubes can be pinned inside the material in a certain energetically favorable configuration.

This locking of magnetic flux, or Quantum Locking, allows a superconductor to stably levitate above or below a magnet. It also means that a superconductor will move freely, without friction, along a path of identical magnetic field. If we construct a magnetic track in which the field along the track is uniform a superconductor that is locked above or below the track will be able to glide completely frictionless along.



Teaching Classical Mechanics using Quantum Levitation

Quantum Levitation allows a superconductor to levitate above or below a magnet and move without friction along a track of uniform magnetic fields. Our Quantum Wave uses a flexible track of magnets which can be adjusted and fixed in various positions with the included base and clamps.

<u>Frictionless vs. locking force</u>

The quantum locking due to flux pinning is proportional to the magnetic field strength. The closer we lock the levitator to the magnets the stronger the pinning forces. In order to have truly frictionless motion we need a uniform magnetic field along the track. The magnets on the track, while sitting close to each other still have small gaps between them (otherwise the track would not be flexible). This means that the magnetic field close to the track is not completely uniform. When we lock the superconductor very close to the track we can feel this irregularity in the magnetic field.

<u>Experiment: Frictionless motion vs. locking force</u>

Objective: Determining the optimal levitation height and mastering Quantum Levitation.

Method:

1. Take the magnetic track and place it flat on the stand in the designated groove.
2. Dip the levitator in liquid nitrogen for a few seconds until the bubbling subsides.
3. Using the supplied tongs take the levitator out of the liquid and bring it close to the track, placing it above the track.
4. Push the levitator towards the track down to a minimal distance. Note the locking distance (between the track and levitator).
5. Give the levitator a little push along the track. Note how it moves.
6. Using the tongs, try to pull the levitator away from the track. Feel the ‘friction’ and resistance to be pulled away.
7. Repeat steps 3-6 for different locking distances.

Observe:

When the levitator is closest to the track:

1. Locking forces are the strongest.
2. Motion is NOT frictionless. The levitator ‘feels’ the gaps in the magnetic field.

The optimal distance for frictionless experiments would be such that the motion is as smooth as possible and the locking forces are the strongest. The best way to achieve that is to lock the levitator as close as possible to the track and then taking it a few millimeters away.

Experiments in Classical Mechanics

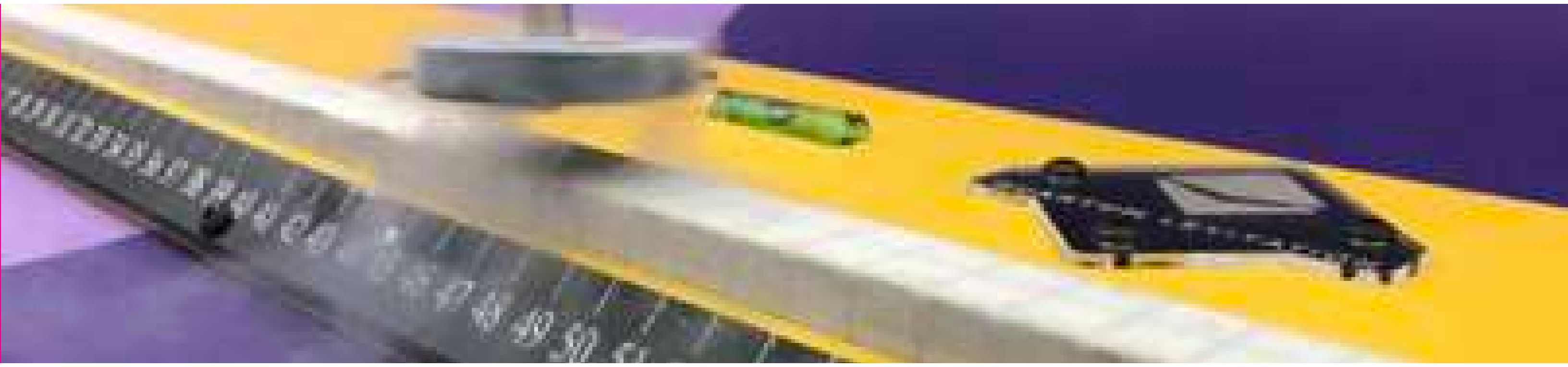
Kinematics

Equation of motion

1. Constant velocity $x(t) = x_0 + v_0 t$

Objective: Measure the displacement vs. time at constant velocity.

Equipment: Quantum Wave, Medium Levitator, Tweezers, Mobile Phone Camera



Method:

1. Place the flexible track **on the base** in the designated groove. Using the attached level - make sure it sits as flat and horizontal as possible.
2. Dip the levitator in liquid nitrogen for a few seconds until the bubbling subsides.
3. Place the levitator on the track, push it downwards towards the track (~1mm) and then lift it slightly so it is not locked too close (5-10mm) and moves without friction.
4. Place the camera phone on the table pointing to the side of the track. Make sure you cover as much of the track as possible and that the track appears horizontal.
5. Push the levitator slightly from one side of the track to the other. Video the motion.
6. Export the video to a dedicated computer.
7. Repeat steps 2-6 with different initial velocities, different masses.
8. Analyze the motion using the 'Tracker' software package and export the data to Excel or similar software.

Data Analysis:

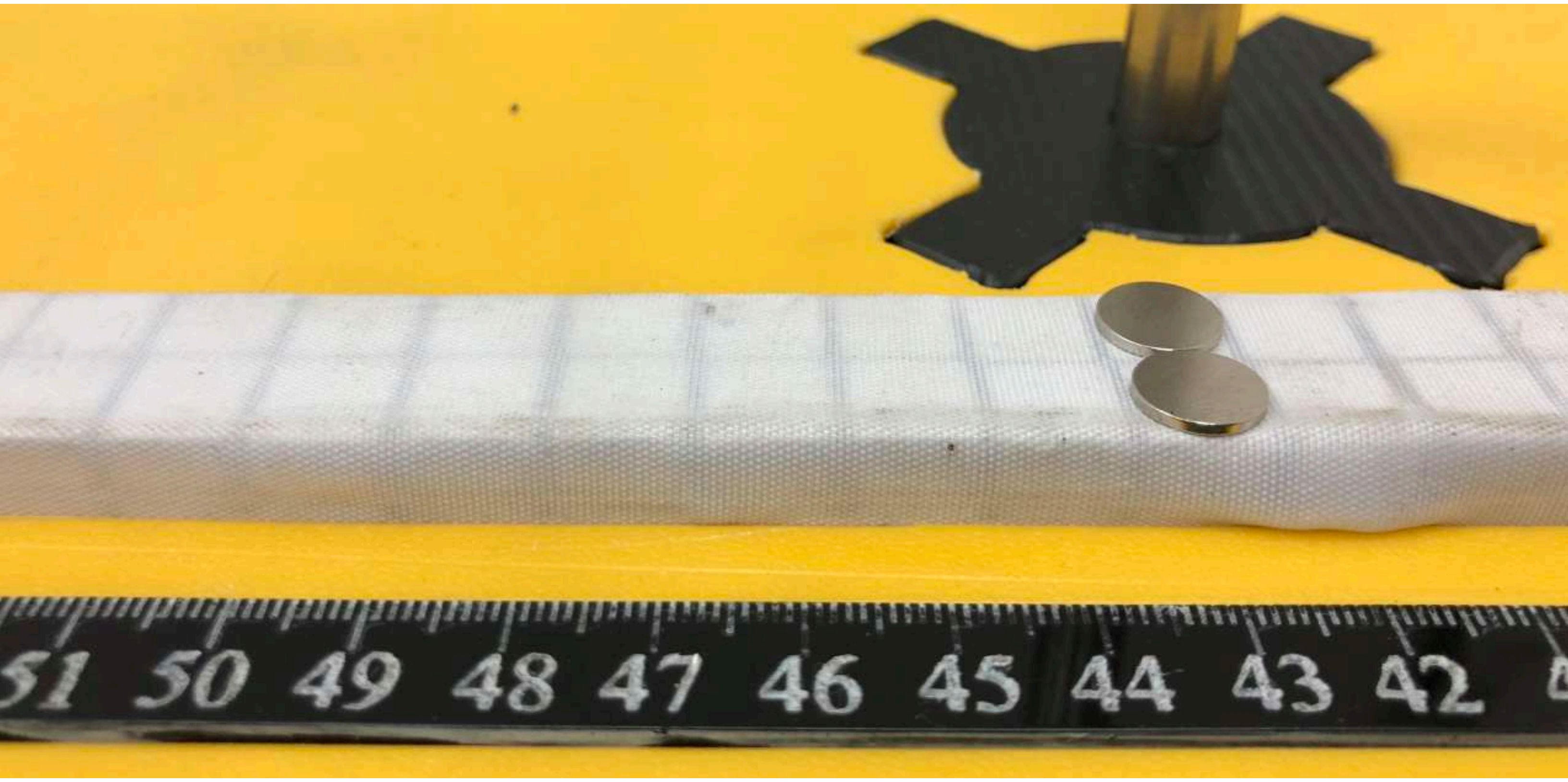
Plot the displacement (x) vs. time. Show that it is linear with a coefficient (v_0) that is constant in time: $x(t) = x_0 + v_0 t$

Note that repeated experiments give different initial velocities (v_0). Conclude that as long as no external forces are applied along the motion direction, the velocity doesn't change.

2. Average velocity $\vec{v} = \frac{\vec{\Delta x}}{\Delta t}$

Objective: Demonstrate the concept of average velocity and understand how it differs from instantaneous velocity.

Equipment: Quantum Wave, Medium Levitator, Tweezers, mobile phone camera



Method:

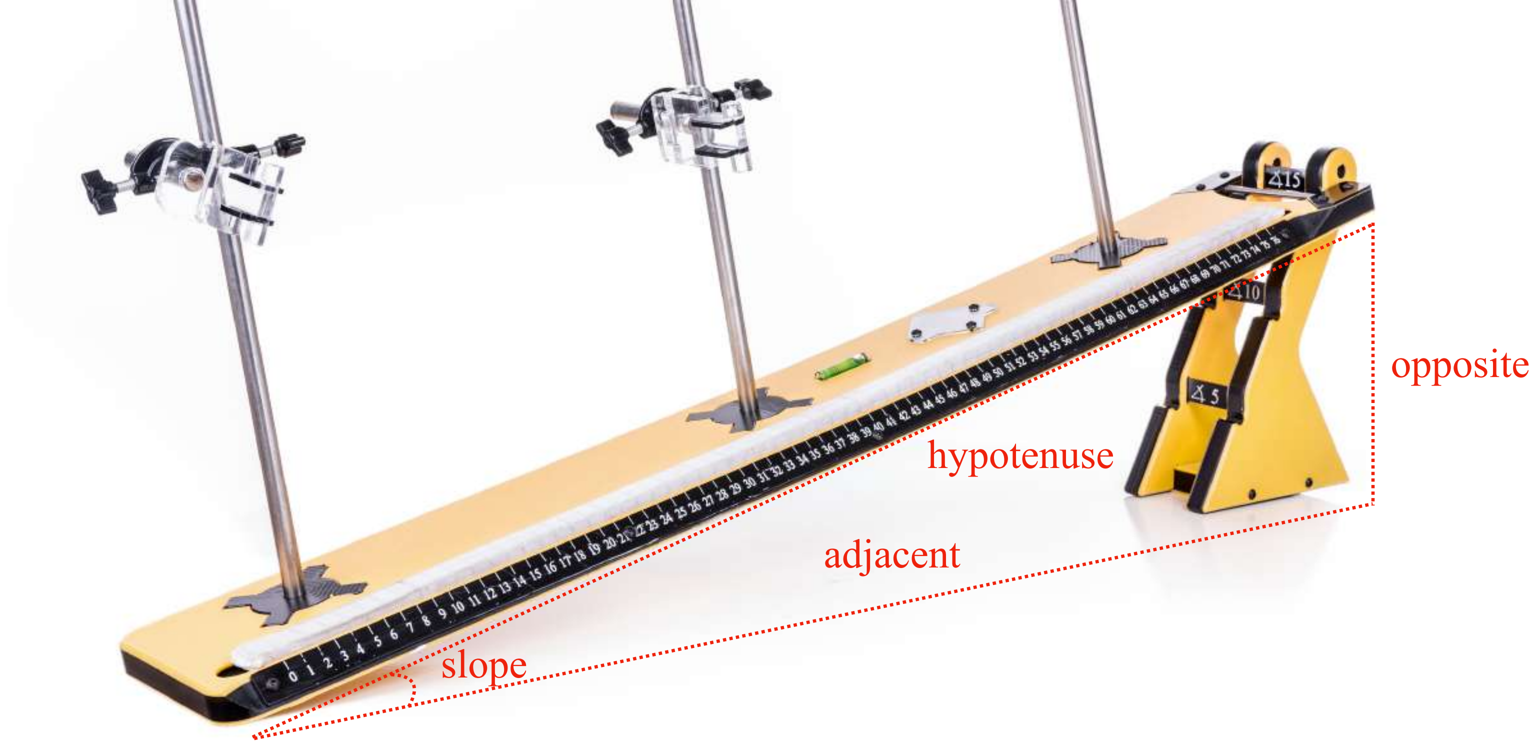
1. Place the flexible track **on the base** in the designated groove. Using the attached level - make sure it sits as flat and horizontal as possible.
2. Carefully put two small flat magnets side-by-side in the middle of the track.
3. Dip the levitator in liquid nitrogen for a few second until the bubbling subsides.
4. Place the levitator on the track, push it downwards towards the track (~1mm) and then lift it slightly so it is not locked too close (5-10mm) and moves without friction.
5. Place the camera phone on the table pointing to the side of the track. Make sure you cover as much of the track as possible and that the track appears horizontal.
6. Push the levitator from one side of the track. Make sure that the levitator manages to overcome the magnetic barrier in the middle (to flat magnets) and continues to the end of the track. Video the motion.
7. Analyze the motion using the “Tracker” software and export the coordinate and velocity data to Excel (or compatible software) for easy data analysis.
8. Plot the displacement vs. time.
9. Repeat steps 2-6 with different initial velocities, different masses.

Data analysis:

Plot the displacement, $x(t)$, and the velocity, $v(t)$, of the motion. Note that the velocity is constant at the beginning and at the end of the motion (as far away from the magnet barrier as possible).

Answer the following questions:

1. What is the velocity 5cm left to the magnets?
2. What is the velocity 5cm right to the magnets?
3. What is the total distance of the motion? How long did it take the levitator to reach from one side of the track to the other?
4. Calculate the average velocity of the entire motion.
5. Show that the average velocity is roughly the average of the two instantaneous velocities. Can you explain the discrepancies?
6. Push the levitator from one side of the track. Make sure that the levitator manages to overcome the magnetic barrier in the middle (to flat magnets) and continues to the end of the track. Video the motion.



3. Constant acceleration – changing slope $x(t) = x_0 + v_0 t$

Objective: Measure the displacement of an object at constant acceleration. Investigate the motion of an object under different accelerations and with different masses.

Equipment: Quantum Wave, Medium Levitator, Tweezers, mobile phone camera

Method:

1. Place the flexible track on the base in the designated groove. Make sure it sits as flat as possible. Raise the base from its right side and place it on the tilted stand or on a standard lab stand.
3. Dip the levitator in liquid nitrogen for a few seconds until the bubbling subsides.
4. Place the levitator on higher side of the track, push it downwards towards the track (~1mm) and then lift it slightly so is locked in a distance of 5-10mm above the track and can move without friction.
5. Place the camera phone on the table pointing to the side of the track. Make sure you can see and record as much of the track as possible.
6. Let the levitator slide downwards on the track (you can give it a little push). Record the motion with your phone camera.
7. Analyze the motion using the “Tracker” software and export the coordinates and velocity data to Excel (or a compatible software package).
8. Calculate the trend line of the displacement vs. time.
9. Repeat steps 2-8 with different initial velocities (slightly different initial pushes) and different track angels (5/10/15 degrees).

Data analysis:

1. Plot the displacement, $x(t)$, and the velocity, $v(t)$, of the motion. Note that the velocity increases linearly.
2. Calculate the acceleration and repeat this calculation for three different slopes.
3. Measure the slope angle by using the length of the track (hypotenuse) and the height of the track edge (opposite): $slope = arcsin(\frac{opposite}{hypotenuse})$
4. Using the acceleration value you calculated in (2) and the gravitational acceleration (g) calculate the track slope in each experiment. Compare the results with the ones from (3). Compare the two values.
5. Alternatively, calculate the earth's gravity (g) using the measured track angle (α) and measured acceleration (g').

   $g'(\alpha) = gsin(\alpha)$

4. Constant acceleration – changing mass $F = m'g$

Objective: Verify experimentally Newton's second law of motion - $F = m'g$

Equipment: Quantum Wave, Medium Levitator, Enhanced Medium Levitator Tweezers, mobile phone camera

Method:

This experiment is similar to the previous one (**Constant acceleration**) but with different masses (levitators).

1. Place the flexible track **on the base** in the designated groove. Using the attached level - make sure it sits as flat and horizontal as possible.
2. Dip two levitators in liquid nitrogen for a few seconds until the bubbling subsides.
3. Raise the right side of the track and place it on the tilted stand.
4. Place one levitator on the higher side of the track, push it downwards towards the track (~1mm) and then lift it slightly so is locked in a distance of 5-10mm above the track as there will be substantial friction.
5. Place the camera phone on the table pointing to the side of the track. Make sure you cover as much of the track as possible and that the track appears horizontal.
6. Let the levitator slide from one side of the track (you can give it a little push). Record the motion with your phone camera.
7. Analyze the motion using the "Tracker" software and export the coordinate and velocity data to Excel (or a compatible software package) for easy data analysis.
8. Plot the displacement vs. time, $x(t)$, and add a trend line.
9. Repeat steps 2-8 **with a different levitator** (one with a different mass) and at different angels (5/10/15 degrees).

Data analysis:

Calculate the acceleration of each of the levitators. Measure the angle of the track using the right angle triangle formula (see previous experiment). Compare the accelerations of two different levitators gliding at the same slope.

Answer these questions:

1. Plot the forces acting on the levitator while it is moving.
2. Are different levitators, running on the same slope, moving with the same acceleration?
   Explain that within the framework of Newton's second law and Newton's law of gravity: $F_{gravity} \propto \frac{mM}{r}, F = ma \propto \frac{mM}{r} \rightarrow a \propto \frac{M}{r}$
3. What would be the displacement formula for each of the levitators on the moon? (assume that the moon's gravitational force is 1/6th of earth's gravitational force)

5. Relative velocity $\vec{v}_{B|A} = \vec{v_B} - \vec{v_A}$

Objective: Investigate the concept of relative velocity and relative motion.

Equipment: Quantum Wave, Medium Levitator, Enhanced Medium Levitator Tweezers, mobile phone camera.

Method:

1. Place the flexible track **on the base** inside the groove. Using the attached level - make sure it sits as flat and horizontal as possible.
2. Dip two levitators in liquid nitrogen for a few seconds until the bubbling subsides.
3. Place one levitator at one end of the track and the other levitator on the second end. Push each levitator slightly downwards towards the magnets. Make sure they're not locked too close ~10mm and can move freely.
4. Place the camera phone on the table pointing to the side of the track. Make sure you cover as much of the track as possible and that the track appears horizontal.
5. Simultaneously push the two levitators one towards the other. Record the motion with your camera phone.
6. Analyze the motion of each levitator separately and export the data to an XLS format for easy data analysis (or any data analysis software of your choice).
7. Mark the meeting point of the levitators.
8. Use Excel or any other data analysis software to calculate the trend line of the displacement vs. time for both levitators.
9. Repeat steps 2-8 with different initial speeds.

Data analysis:

1. Calculate the displacement vs. time of each levitator. Make sure you choose the **same** reference frame for both levitators.
2. What is the initial velocity of each levitator?
3. Write down the equation of the coordinates of each levitator vs. time. How is this different from the displacement vs. time?
4. From the coordinate equations, calculate the meeting point of the levitators.

   $$x_0^1 + v_0^1 t^\dagger = x_0^2 + v_0^2 t^\dagger$$

   compare the calculated meeting coordinate to the measured value.
5. If you were sitting on one of the levitator, what would be the velocity of the second one?

   Write the equation of motion of the second levitators as it is seen from the reference point of the first levitator.

6. Choosing the frame of reference (linear motion)

Objective: Investigate and understand the importance of choosing the frame of reference.

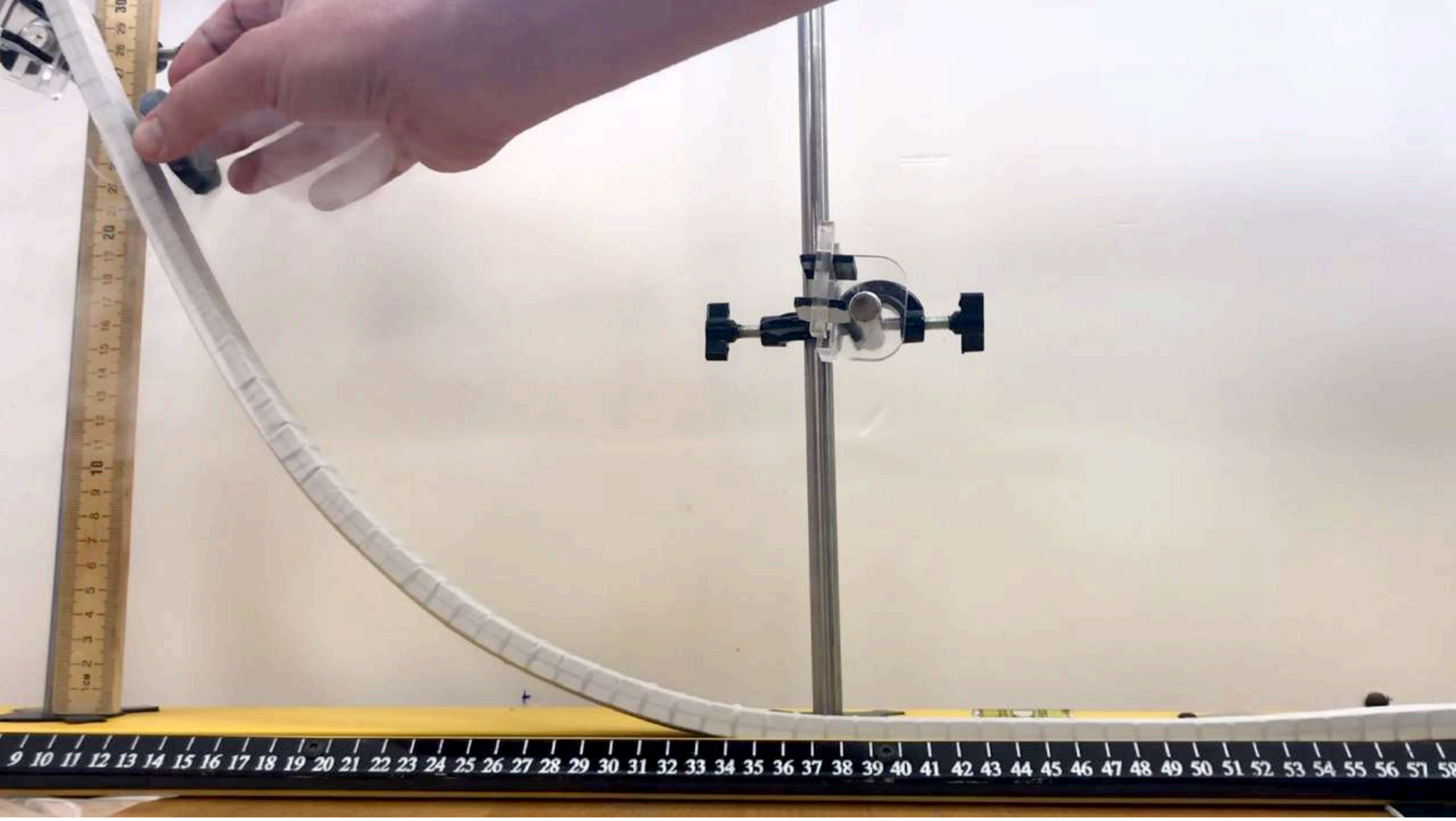
Equipment: Quantum Wave, Medium Levitator, Tweezers, mobile phone camera.

Method:

1. Place the flexible track **on the base** inside the groove. Make sure it is as flat as possible.
2. Raise the right side of the track and place it on the tilted stand.
3. Dip the levitator in liquid nitrogen for a few seconds until the bubbling subsides.
4. Place the camera phone on the table pointing to the side of the track. Make sure you cover as much of the track as possible and that the track appears horizontal.
5. Place the cooled levitator at the higher end of the track and push it slightly downwards towards the magnets. Make sure it's not locked too close and move freely.
6. Let the levitator slide downwards. Record the motion with your camera phone.
7. Export the data to the 'Tracker' software. Analyze the data and calculate the coordinate equation of the levitator according to the question below.

Data analysis:

1. Choose a reference frame that is parallel to the track. Write down the equation of motion.
2. Repeat the analysis with a reference frame parallel to the table. Write the x(t) and y(t) coordinates of the mass.
3. Calculate the total scalar velocity of the levitator 10cm from the initial starting point: $|\vec{v}| = \sqrt{v_x^2 + v_y^2}$
4. Calculate the velocity of the levitator 10cm from the start using the first reference frame (parallel to the track). Compare the result with the one from (3).



7. Conservation of mechanical energy - $E_{mechanical} = \frac{1}{2} m\vec{v}^2 + mgh$

Objective: Calculate the total energy (potential and kinetic) of an object. Investigate the preservation of mechanical energy.

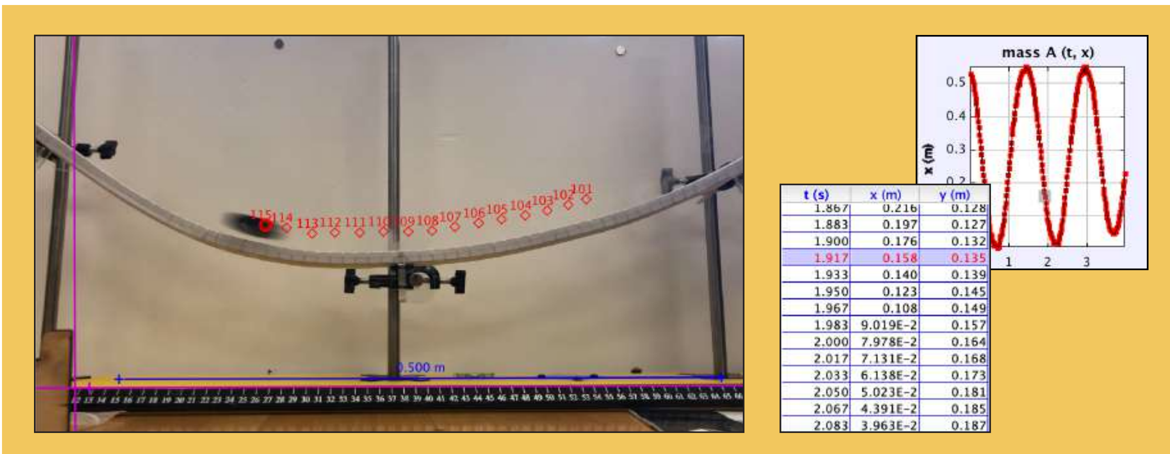
Equipment: Quantum Wave, Medium Levitator, Tweezers, mobile phone camera

Method:

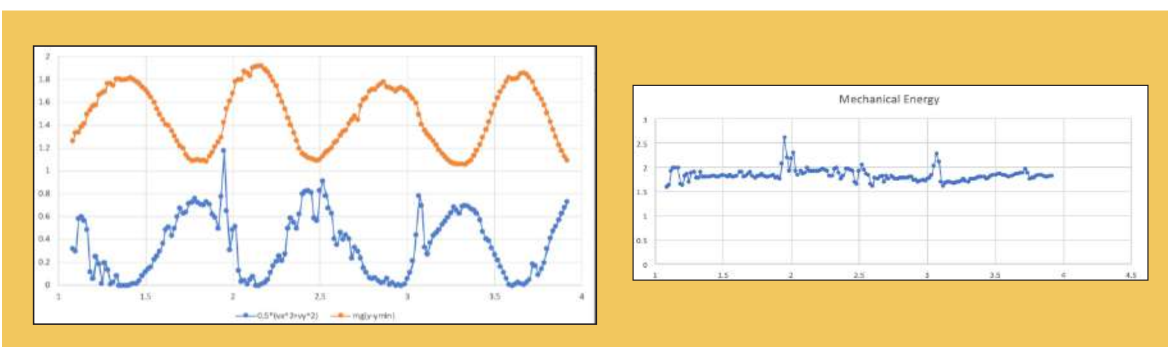
1. Place the flexible track on the adjustable stand using the magnetic adaptors. Adjust the shape of the track into a **parabolic shape**.
2. Dip the levitator in liquid nitrogen for a few seconds until the bubbling subsides.
3. Place the camera phone on the table pointing to the side of the track. Make sure you cover as much of the track as possible.
4. Place the levitator on one end of the track. Lock it a few millimeters above the track so it moves without friction.
5. Let the levitator slide from one side of the track downwards (you can give it a little push). Video the motion.
6. Export the video and analyze the motion using the 'Tracker' software package or a similar software package.

Data analysis:

1. Using the 'Tracker' software package, analyze the coordinates (x(t), y(t)) and velocities (vx(t), vy(t)) of the mass.
2. Make a table of the total scalar velocity of the levitator - $|\vec{v}| = \sqrt{v_x^2 + v_y^2}$
3. Plot the total velocity vs. time of the levitator.
4. Make a table of the height of the levitator vs. time. Choose the lowest point in the motion as the zero point. Why is the choice of zero y-coordinate arbitrary?
5. Plot a graph of the height vs. time.
6. Make a table with the followings values: $mgh = \frac{1}{2}m\vec{v}^2$



Because we are comparing the kinetic and potential energies, we can choose an arbitrary mass value. Why? Assume a mass of exactly 1.



7. Plot the kinetic and potential energies vs. time.
8. Plot the sum of the two energies vs. time. Show that the total mechanical energy $(E_p + E_k)$ is preserved.

   Explain any discrepancies.

   Specifically discuss: measurement error, friction

8. Collision – elastic two masses $m_1\vec{u_1} + m_2\vec{u_2} = m_1\vec{v_1} + m_2\vec{v_1}$

Objective: Explore and analyze the collision process of two masses. Show that linear momentum is preserved.

Equipment: Quantum Wave, Medium Levitator, Medium Levitator Enhanced, Tweezers, mobile phone camera

Method:

1. Place the flexible track **on the base** inside the groove. Make sure it is as flat as possible.
2. Cool two levitators with liquid nitrogen for a few seconds until the bubbling subsides.
3. Weigh the cooled levitators (place them in another vessel to avoid cooling the scale). Put the levitators back in the liquid nitrogen.
4. Place the camera phone on the table pointing to the side of the track. Make sure you cover as much of the track as possible and that the track appears horizontal.
5. Put one of the levitators in the middle of the track. Lock it a few millimeters above the track (push it down as much as possible and then pull back a few millimeters to avoid magnetic friction).
6. Place another levitator at the edge of the track. Push the levitator towards the center. Let the levitators collide.
7. Record the motion of both levitators using your camera phone.
8. Analyze the motion and answer the questions below.
9. Repeat the experiment for:

   - Enhanced levitator in the middle
   - Standard levitator in the middle
   - Different initial speeds

Data analysis:

1. Using the 'Tracker' software package measure the velocity of the levitators at the beginning of the motion and after the collision. In each case show the velocity along a 5cm length and show that it is constant.
2. Calculate the energies of the levitators before and after the collision.
3. Calculate the linear momentum of the levitators before and after the collision.
4. Show that the energy is not preserved in the collision. Explain why.
5. Show that linear momentum IS preserved in the collision. Explain why.
6. Repeat this analysis for different initial conditions.

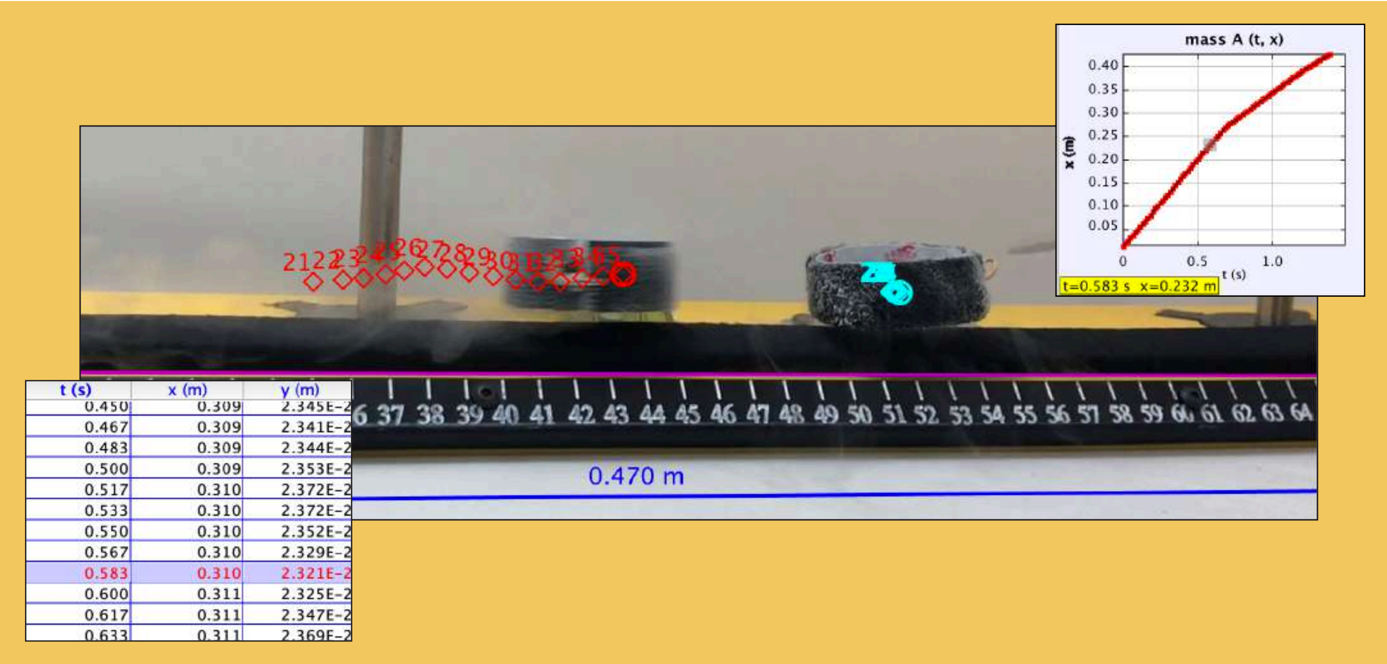
9. Collision – plastic two masses $m_1\vec{u_1} + m_2\vec{u_2} = (m_1 + m_2)\vec{v}$

Objective: Explore and analyze plastic collisions between two masses. Show that linear momentum is preserved.

Equipment: Quantum Wave, Medium Levitator, Medium Levitator Enhanced, Tweezers, Velcro strips, mobile phone camera

Method:

1. Place the flexible track **on the base** inside the groove. Make sure it sits as flat as possible.
2. Cover two levitator with Velcro strips - one with hooks and the other with loops.
3. Dip both levitators in liquid nitrogen for a few seconds until the bubbling subsides.
4. Weigh the cooled levitators (place them in another vessel to avoid cold damage to the scale). Put the levitators back in the liquid nitrogen (we assume that the weight of a levitator filled with liquid nitrogen remains the same between refills).
5. Place the camera phone on the table pointing to the side of the track. Make sure you cover as much of the track as possible and that the track appears horizontal.
6. Put one of the levitators in the middle of the track. Lock it a few millimeters above the track (push it down as much as possible and then pull back a few millimeters to avoid magnetic friction).
7. Place another levitator at the edge of the track. Push the levitator towards the center. Let the levitators collide. Make sure that the levitators stick to each other using the Velcro. If they do not, repeat the experiment until the do. (since the Velcro is cold it may take a few trials to make it stick)
8. Record the motion of both levitators using your camera phone.
9. Repeat the experiment several times with different initial speeds.



t (s)	x (m)	y (m)
0.450	0.309	2.345E-2
0.467	0.309	2.341E-2
0.483	0.309	2.344E-2
0.500	0.309	2.353E-2
0.517	0.310	2.372E-2
0.533	0.310	2.372E-2
0.550	0.310	2.352E-2
0.567	0.310	2.329E-2
0.583	0.310	2.321E-2
0.600	0.311	2.325E-2
0.617	0.311	2.347E-2
0.633	0.311	2.369E-2

Data analysis:

1. Using the ‘Tracker’ software package measure the velocity of the levitators at the beginning of the motion and after the collision. In each case show the velocity along a 5cm length and show that it is constant.
2. Calculate the energies of the levitators before and after the collision.
3. Calculate the linear momentum of the levitators before and after the collision.
4. Show that the energy is not preserved in the collision. Explain why.
5. Show that linear momentum IS preserved in the collision. Explain why.
6. Repeat this analysis for different initial conditions.

10. Shortest path experiment (brachistochrone curve)

Objective: Understand the shortest path problem. Using trial and error find the shortest path shape.

Equipment: Quantum Wave, Medium Levitator, Tweezers, mobile phone camera

Method:

1. Place the flexible track on the adjustable stand using the magnetic adaptors.
2. Place the right holder 5cm from the base and the left holder 20cm high. Make sure these heights are kept throughout the experiment. You can change the slope of the holders and the height of the middle holder.
3. Cool the levitator with liquid nitrogen for a few seconds until the bubbling subsides.
4. Place the camera phone on the table pointing to the side of the track. Make sure you cover as much of the track as possible.
5. Put the levitators on the left (higher) side of the track. Lock it a few millimeters above the track (push it down as much as possible and then pull back a few millimeters to avoid magnetic friction).
6. Let the levitator go and record the motion using your camera phone.
7. Analyze the motion using the 'Tracker' software package.
8. Repeat the procedure for different track shapes.

Data Analysis:

1. Using the 'Tracker' software package analyze the levitator motion.
2. Measure how long it take the levitator to reach from point A (left side higher holder) to point B (right side lower holder).
3. Repeat the experiment and try to find the shortest path shape.
4. Explain why the linear shape will not work.
5. Will the steepest track work? Explain in simple terms.

QUANTUM EXPERIENCE