# Gyroscope Lift Force Experiment

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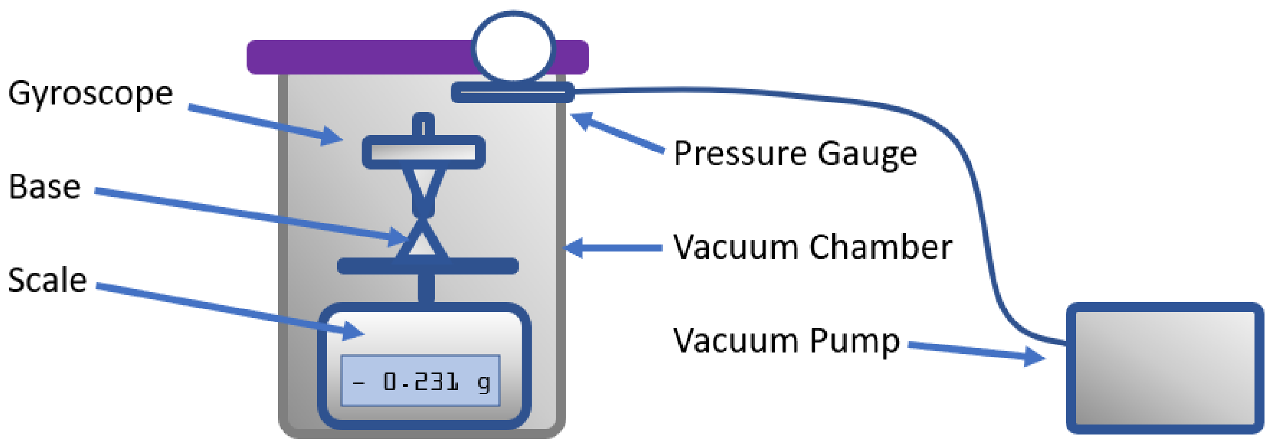
Any object in motion around the Earth experiences a centripetal force upwards, and this should also apply to objects that are stationary but rotating rapidly. The objective of this experiment is to measure this small effect that a rapidly spinning object ought to have in a gravitational field. The experiment requires measuring the effective mass of a rapidly spinning object with a sensitive scale in a vacuum. As of January 2022, the necessary equipment can be obtained in the United States for less than $2000.

**Experimental Setup:**

The approximate size of the levitation effect for the 430g gyroscope rotating at 16,000 RPMs is only 0.014 g. This is a very small effect compared to the mass of the gyroscope. Therefore we need to be very careful to account for all effects that could contribute to changing the measurement of the weight if we are to actually measure it. This requires a precise high quality gyroscope, a scale sensitive to 0.001g that is also able to support the full weight of the gyroscope, a vacuum chamber large enough to fully contain the scale and the gyroscope, and a vacuum pump powerful enough to generate a vacuum much faster than the gyroscope would lose its rotational energy. In addition to this, the experiment requires a reliable and safe way to spin up the gyroscope to extremely high rotational velocities (at least 20,000 RPMs). I chose to use an angle grinder fitted with a circular plastic disk to do this. Once it is spinning rapidly, the gyroscope must be placed upon the scale within the vacuum chamber. The vacuum chamber must be sealed, and data collection must begin immediately. If that all goes well, then this data may be compared to the theoretical expectation calculated using the physics of centrifugal force.




**Equipment Necessary for the Experiment:**

1) Advanced Gyro from Grand Illusions
    a. $140
    b. 430 g gyroscope. 50g for the base that it spins on. The gyroscope doubles as a fun science toy!
    c. 

2) Bonvoisin Lab Analytical Balance from [Amazon](Amazon)

   a. $140

   b. Max weight 500g, Precision 0.001g.

   c. Scale must use a 9V battery for power since it is within the vacuum chamber.

   d. 


3) 2 stage vacuum pump from Amazon

   a. $150

   b. ½ hp engine, ultimate vacuum 0.3 Pa.

   c. 


4) Vacuum Chamber, 10 Gallon size from BVV

   a. $330

   b. In order for the scale and gyroscope to fit inside requires at least this size.

   c. Includes the purple hose that connects to the vacuum pump.


d.

5) Faraday Fabric and duct tape for building EM field shielding layers, from [Amazon]

   a. $140 for faraday fabric, and $10 duct tape

   b. My experiment used approximately 5 m^2 of shielding, in about 4 nested shield layers.

   c. Shield layers were built primarily with scrap cardboard wrapped in this Faraday fabric and secured with duct tape.

   d. 

6) Master Force Angle Grinder and plastic pad, from [Menards]

   a. $90 for the angle grinder, $20 for the backing pad

   b. 9000 RPM, used to spin up the gyroscope, the guard must be removed to attach the 7” pad

   c. Note that these things are ***not supposed*** to be attached together, and you do this at your own risk. ***The angular velocity of the angle grinder (9000 RPMs) exceeds the maximum angular velocity value noted on the pad (8000 RPMs).*** The consequences of structural failure of the backing pad would result in high velocity plastic shrapnel that could hurt you or someone else or cause property damage. Take appropriate precautions if you use these or similar items. **Again: You do this experiment at your own risk!**


d.

e. Plastic backer pad at [Menards](#)

f. 


7) Tachometer, to measure the angular velocity of gyroscope, from [Amazon](#)

   a. $25

   b. Since the vacuum chamber has a glass lid, this device is able to measure the angular velocity of the gyroscope from outside the vacuum chamber.


c.

8) Digital Multimeter and wires to ground and verify grounding of gyroscope, from [Amazon](#)

   a. $20


   b.

9) EM field multimeter to measure ambient EM fields and verify that shielding is effective, from [Amazon](#)

   a. $170

b. 


10) Camera to record the mass measurement. I used a GoPro

a. $350 for the camera and memory stick

b. 


**Setting up the Experiment:**

1) Remove the windshield glass from the scale, and replace with a layer of cardboard, magnetic shielding, and duct tape to isolate the gyroscope from the electronics in the scale. The top part must remain open so that you can lower the gyroscope onto its base.

2) Secure the base of the gyroscope to the circular scale plate with a layer of vibration absorbing material between them. 6 layers of paper towel and 2mm of rubber material worked for my experiment. Use duct tape to secure the base and the scale plate. This is required because without it, the gyroscope will hit resonance frequencies that knock it off the base during the experiment.

3) Ensure that there is an electrical connection from the gyroscope base to the scale plate, to the magnetic shielding, to the vacuum chamber, to ground. This will ensure that there is no static buildup placed on the gyroscope that could make a small magnetic field since it will be spinning rapidly. Be as gentle as possible

connecting between the scale plate and the magnetic shielding so that the connection does not affect the mass measured by the scale.

4) Place some sort of secure base inside the vacuum chamber so that the scale is as high as possible while still allowing room for the gyroscope to spin atop the base. Otherwise, the angular velocity measurements will be much more inaccurate.
5) Build another layer of EM shielding around the scale that fits inside the vacuum chamber.
6) Build a layer of magnetic shielding on both sides of the vacuum chamber lid. Include 2 holes such that there is a hole for the camera to record the measurements from the scale, and there is a hole for you to use the tachometer to measure the angular velocity of the gyroscope. Make sure that your magnetic shielding layer will not compromise the vacuum seal.
7) Build a layer of magnetic shielding that encapsulates the vacuum chamber from the outside entirely. Ensure that you can still measure the Air Pressure and Angular Velocity. Also build a small magnetic shield around the camera so that the electronics in it will not add much noise to your data.
8) Remove the 6” guard from the angle grinder and the abrasive grinding disk. Attach the 7” plastic backing pad to the Angle Grinder. This will be used to spin the gyroscope up to approximately 24000 RPMs at the start of the experiment. The plastic pad is used because it will not damage the gyroscope, and because it has a larger radius.
9) The gyroscope must be modified so that the tachometer will be able to read the angular velocity. I used 2 reflective stickers that came with the tachometer and black permanent marker to modify the gyroscope such that it looks like this:
    a. 

b. Carefully balance the reflective stickers so that they do not cause the gyroscope to be out of balance. When using 2 stickers, be sure to divide the tachometer reading by 2 to get the real angular velocity. Painting the rest of the gyroscope as black as possible will improve the accuracy of the tachometer.
c. The exposed portion at the edge of the gyroscope is the area that is in contact with the angle grinder when spinning up. You can try painting it black, but the angle grinder will most likely rub it off.

10) Add a bit of lubricant (such as WD-40) to the three ball bearings in the base that the gyroscope will be resting upon. The shell eventually spins extremely fast on these three ball bearings as it receives some of the rotational energy from the gyroscope. Without this lubricant, the gyroscope can fall off the base sometimes, and lose energy more quickly.
11) Attach the vacuum pump to the vacuum chamber. Verify that you are able to get a vacuum seal. It should take about 7 minutes to achieve a complete vacuum using the same equipment.
12) Get your camera ready to record the data. You may need to adjust camera settings to see the readings from the scale. I had to reduce the exposure time because the illuminated background of the scale's digital reading was too bright and was washing out the reading.
13) Make sure that the scale has a fresh 9V battery and turn it on. The scale's instructions suggest allowing it to warm up for about 20 minutes before measurement. I used rechargeable 9V batteries since the scale seems to use them up quickly, and if the battery fails during data collection, then your data will be useless.
14) Carefully balance the gyroscope along with its base on the scale and tare the scale so that it reads 0.000 g. Positioning the base slightly off center can help if you are unable to balance the gyroscope on it with the base secured to the scale plate.
15) Ensure that the vacuum chamber is secured firmly on a sturdy surface, and that the mechanical vibrations from the vacuum pump are dampened and isolated. Failure to do this can add noise to your data.
16) Using the digital multimeter verify that there is an electrical connection between the gyroscope base and the vacuum chamber wall. Also verify that the vacuum chamber is electrically grounded. The gyroscope can pick up a static charge from friction with the angle grinder, so this electrical connection allows the static charge to dissipate.
17) **Safety first! You do this experiment at your own risk! Only appropriate for adults with experience with doing experiments.**
    a. ***The most dangerous part of this experiment is using the angle grinder to spin up the gyroscope.*** This part can fail in several ways that could result in injury to yourself or others or damage to your property.

b. Ensure that you and anyone nearby has appropriate protection that would protect them in case the plastic backing pad would explode while spinning up the gyroscope.

c. There is an inherent tension between safety and getting good data in the experiment because it is desirable to make the gyroscope spin as fast as possible, but that is also dangerous.

d. The maximum RPM that the gyroscope can handle before failure is unknown to me, I only know that it survived 25,000 RPMs.

18) Doublecheck that everything is prepared. You must do these following steps very quickly at the start of the experiment because the gyroscope rapidly loses energy due to friction with the atmosphere:

a. Turn on the vacuum pump.

**b.** ***This part is dangerous! Be careful!*** Grasp the gyroscope's shell in one hand such that the main part of the gyroscope is free to spin and facing upwards. Using your other hand, use the angle grinder with the plastic pad attached to accelerate the gyroscope by having the edge of the gyroscope be in continuous contact with the edge of the plastic pad. Do this for about 20 seconds, until you are confident that the gyroscope is at full speed. I found that having the angle grinder facing upwards with its back resting on a surface allowed for the best control.

c. ***The gyroscope should feel powerful!*** Be careful not to touch the spinning part, or let it touch anything else. Quickly and carefully lower the gyroscope into the vacuum chamber and place it upon its base upon the scale plate. Don't worry if you placed it such that it has a bit of precession, it will straighten itself out quickly.

d. Quickly and carefully place the vacuum chamber lid on and press down to help get the vacuum seal started as soon as possible.

e. Use the tachometer to get the first reading of the gyroscope's angular velocity. It should be at least 20,000 RPMs

f. Place the camera on the vacuum chamber lid to read the scale's readings.

g. Place any additional magnetic shielding that you have prepared. The largest source of EM fields is from the vacuum pump, so you may want to have it shielded from the experiment too.

h. Take regular readings of the air pressure using the valve on the vacuum chamber by verbally recording it using the camera. Stop once the vacuum is at the maximum value given by the scale (about 7 minutes).

i. Take regular readings of the angular velocity using the tachometer by verbally recording it using the camera. Stop when the angular velocity of the gyroscope drops to about 2000 RPMs, as it will soon fall off the base (about 25-40 minutes).

19) Be sure to run at least one control run for the experiment, where you just place the gyroscope on the scale without spinning it. This control run is important for verifying that the scale's reading remains constant throughout the process of generating the vacuum and collecting about 40 minutes of data.

**Data Analysis:**

1) Once the experiment is finished, all the data should be recorded in the video file from the camera, which should contain about 25-45 minutes of footage. The audio part of the video is what records the angular velocity and air pressure, while the picture records the scale reading. Save the video file as your raw data.
2) It is a tedious process, but you must translate that data from video into whatever spreadsheet or data analysis program you like. This can be a good place for young aspiring scientist to participate in the experiment. I had the data transcribed into Excel spreadsheets. I chose to create one data point every 5 seconds.
3) Next, you must have a theoretical prediction to compare your data too. You have to calculate the expected levitation effect as a function of the air pressure, the angular velocity of the main part, and the angular velocity of the shell. See the theory section of this paper for my calculations and the justifying physics.
4) Next, you must write a computer program to simulate what the data ought to look like. You can get a copy of the C# console program that I created for this experiment from GitHub here. This program uses a very basic brute force algorithm to numerically solve the differential equations that govern the air pressure and angular velocity of the gyroscope's two parts. The output of this computer program produces data similar to the data that you collected. The next step is to compare the experimental values to the simulation.
5) You should adjust the simulation such that it successfully reproduces the angular velocity and the air pressure that you measured. There are numerous constants in the differential equations that can be adjusted such as factors for the friction forces and the initial values.
6) You will need to add or subtract some small constant value from all the data points to account for slight changes in the scale's calibration between experiments.
7) Plot the data for the difference in measured mass as a function of time on a logarithmic scale. The logarithmic scale is important because the levitation effect is far smaller than the Bernoulli effect which is dominant before the vacuum removes enough of the atmosphere.