Experimentally Deriving Newton's Universal Law of Gravitation by Measuring Mass, Distance, and G in a Simulation

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Objectives

Use the Gravitational force simulation to determine the dependence of the gravitational force on the mass of the objects involved.

Use the same simulation to determine the dependence of the gravitational force on the distance between the two masses.

Determine the experimental value of the universal gravitational constant (G). (This is what relates the gravitational force to the masses and distance rather than being these proportional. G must be included in your final equation.)

Determine an Equation for the Universal Law of Gravitation based on your data, using only symbols.

Introduction

Background

The concept of gravitational force has been misunderstood for most of history, commonly attributed to divine or supernatural causes until Sir Isaac Newton published his groundbreaking *Principia*. In the Principia, Newton asserted that every mass exerts an attractive force on every other mass, a phenomenon described by Newton's Universal Law of Gravitation (NLUG). This law states that the magnitude of the gravitational force between two masses is

$$F = G\frac{m_1 m_2}{r^2},$$

where F is the gravitational force, m_1 and m_2 are the interacting masses, r is the distance between their centers. G is the universal gravitational constant, a constant of proprtionality that has been calculated to be

$$G = 6.674 \times 10^{-11}\ \mathrm{N\,m^2\,kg^{-2}}.$$

In the scientific community, NLUG is treated as an absolute truth, and many important discoveries and applications rely on its accuracy. From engineering to astrophysics, NLUG has profound importance, and its validity is vital to the functioning of scientific advancement.

Purpose

This lab aims to use a computer simulation to verify NLUG by deriving the relationship between gravitational force, masses of objects, and the distance between them. First, a gravitation simulation will be used to derive the relationship between objects' masses and the gravitational force. Then, the same process will be repeated with comparing gravitational force to the distance between objects. Data collected from these two setups will be used to (hopefully) re-establish the relationship of proportionality proposed by Newton, and the collected data will also solve for the universal Gravitational constant, G.

Materials

The following methods and apparatus were used to determine the coefficients of static and kinetic friction:

- 119g Wooden block
- Adjustable angle metal inclined plane with protractor

Procedure

1. Set the plane angle to 0° and place the block at the far end, roughly 10 cm from the edge.
2. Slowly raise the plane and stop when the block starts to slide down.
3. Record the angle value in a data table under **static friction**.
4. Repeat steps 1–3 five times, then take the average of the angles. This average angle will be used to calculate static friction.
5. Repeat step 1.
6. Slowly raise the plane while tapping the edge to overcome the static friction. Stop when the block starts to slide down the ramp without slowing down.
7. Record the angle value in a data table under **kinetic friction**.
8. Repeat steps 5–7 five times, then take the average of the angles for kinetic friction.

Experimental Setup

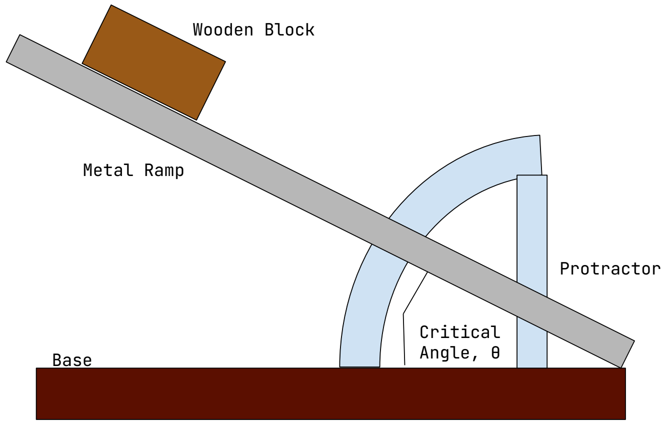

Figure 1: Experimental setup for measuring static and kinetic friction using an inclined plane.

Results

Table 1: Measured critical angles for static and kinetic friction.

Trial	**Static Friction Angle (°)**	**Kinetic Friction Angle (°)**
1	19.0	15.0
2	17.5	14.5
3	18.5	15.0
4	18.0	16.0
5	19.0	14.0
Average	18.4	14.9

The coefficients of static and kinetic friction were calculated using the relationship:

$$\mu = \tan(\theta)$$

where θ is the average critical angle measured for each case.
Average angle for static friction:

$$\theta_s = 18.4°$$

Coefficient of static friction:

$$\mu_s = \tan(18.4°) = 0.33$$

Average angle for kinetic friction:

$$\theta_k = 14.9°$$

Coefficient of kinetic friction:

$$\mu_k = \tan(14.9°) = 0.27$$

Note that the minute acceleration due to the tapping of the block is neglected, as it's acceleration is assumed to be negligible. Also neglected is the force of air resistance, as it is assumed to be very small compared to the other forces acting on the block.

Error Analysis

The first major source of error lies in the method of raising the angle to the right amount. The acceleration of the raising of the block must be zero; otherwise, the block may start to slide earlier than it should have. Hence, the raising of the block is assumed to be the major source of error in this experiment. Alongside this, the human reaction time to accurately read the protractor within decent tolerance is also a source of error. Since the coefficients of static and kinetic friction were calculated using $\tan\theta$ and involved precise decimal values, inconsistency in the measured angles could result in either an overestimate or underestimate of the actual coefficients.

Discussion

The physics concepts used in the lab are the coefficients of static and kinetic friction, which have major applications in the real world, specifically in materials science and engineering. For example, understanding friction is crucial in designing systems like car wheels, where controlling the friction is vital to driving in different conditions (especially slippery roads). Another such application of friction is in the design of screws, as the friction within threads is what allows them to hold materials together securely. Hence, a lower coefficient of static friction would result in a looser screw, while a higher coefficient would result in a tighter screw, which can be crucial in construction, manufacturing, and architecture. Understanding static and kinetic friction is not only important in product design but can be crucial to ensure safety in various applications, impacting everyday life.

Another way that this lab can be carried out is by using a spring scale to directly meassure the force needed to start moving the block and keep it moving at a constant velocity. This method would also accurate measure the coefficients of static and kinetic friction, although it may be prone to different sources of error. A second method this lab can be carried out is by using a motion sensor to track the block's movement down the incline, and similar to the cart and ramp lab, the motion sensor can be used to derive the acceleration (by differentiating the velocity data). From the acceleration, the net force acting on the block can be calculated using Newton's Second Law, which can be used to calculate the frictional coefficients.

Conclusion

Through this lab, it was determined that the coefficient of static friction (μ_s) of wood on metal is roughly **0.33**, and the coefficient of kinetic friction (μ_k) is roughly **0.27**. The coefficient of static friction can be compared to the established range $0.2 - 0.6$ for such surfaces. The experimentally determined value falls within this range, indicating that the results are accurate and that the lab was completed successfully.