Physics 4A

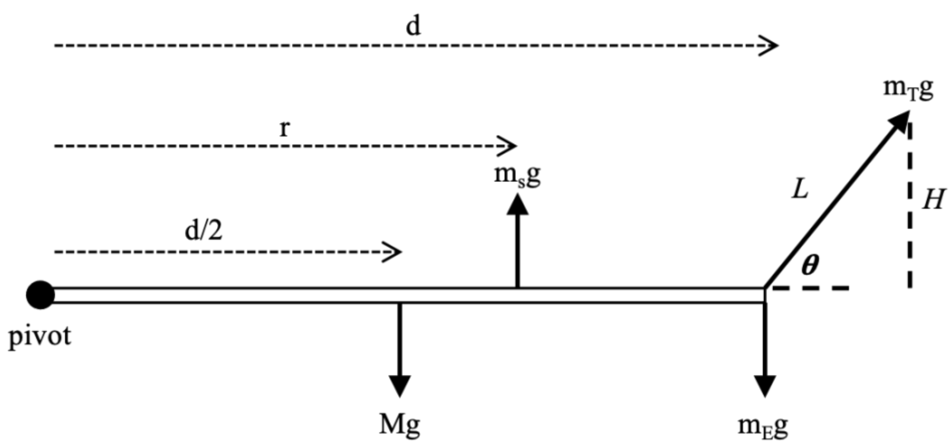
Lab 11: Torques in Equilibrium

Objective: To verify that the sum of the torques equals zero for objects in equilibrium.

Theory:

An object at rest or moving with a constant angular velocity is in equilibrium. If the object is in equilibrium, then the sum of the torques (using any reference point) is equal to zero: $\sum \tau = 0$. A torque causes rotation. A clockwise torque is designated as a negative value, and a counterclockwise torque is designated as a positive value. In terms of clockwise and counterclockwise torques, equilibrium can be restated as $\sum \tau_{CW} = \sum \tau_{CCW}$.

In this lab, there is a meterstick, with a pivot at one end, and a string connected to masses on the other end providing an upward force at an angle. In the middle of the meterstick are masses providing a downward force, and an upward support force. The length of the meter stick is given by *d*, and *r* is the distance from the support force to the pivot. The mass of the meterstick and masses located at the meter stick's center of mass is given by *M*. The mass read by the support force, m_S, acts upward on the meterstick. There is a mass at the end of the meter stick, m_E, and the force provided by the tension in the string is given by $m_T g$. The string is at an angle θ with respect to the length of the meterstick, where the hypotenuse of the triangle is given by the length *L*, and the height of the triangle is given by *H*. A free body diagram of the system, which is in equilibrium, is given below.



There are two parts to this lab:

Part 1: The support force will move along the meter stick, changing the value for *r*.
Part 2: The angle that tension is acting on the system will change.

Prelab:

This portion of the lab will be due before the rest of the lab can be completed.

On a separate sheet of paper, write out the equation of equilibrium for this system.

For part 1, solve the equation of equilibrium for m_S, where your equation will look like:

$$m_s = \alpha r^{-1}$$

where α is slope of the line. Clearly identify what the slope of the line is, as you will use this equation in section 1.4 of the lab.

For part 2, solve the equation of equilibrium for m_s, but this time your equation will look like:

$$m_s = \beta H + \gamma$$

where β is the slope of the line, H is the height of the triangle, and γ is the y-intercept of the line. Clearly identify what the slope of the line is, as well as the y-intercept, as you will use this equation in section 2.3 of the lab.

Procedure:

Part 1: Varying Location of Support

1.1. Introduction

Watch the following video to learn about the apparatus and experiment:
https://youtu.be/FFkwC2KdAgE

The video gives the length of the meterstick, d. Record this value in the Excel spreadsheet.

For Part 1, the tension in the string, m_T = 300 g. Record this value in the Excel spreadsheet.

1.2. Data

To get the masses, watch the following video: https://youtu.be/VyHy7_j-P-g

Record the mass of the end bracket, m_e, and the mass meter stick with hanging masses, M, for Trials 1, 2, and 3.

For each of the 3 trials, the mass of the meter stick with hanging masses is different. For each trial, 8 data points are obtained by varying the location of the support. Watch the following videos to obtain data for the location of the support, r, and the mass of the support, m_s, and record them in Excel. Note, at the start of the Trail 1 video, you will also obtain the height of the meter stick above the table, H_1, the height of the triangle above the table, H_2. By subtracting these values, you can obtain the height of the triangle itself, H.

Trial 1: https://youtu.be/UrptiEGFDco
Trial 2: https://youtu.be/k3WVuxiVAZ0
Trial 3: https://youtu.be/Cus3KJAY46I

Calculate r^{-1} (hint: r^{-1} = 1/r) for each of the support locations.

1.3. Graphs

Highlight r^{-1} and m_s for Trial 1, and create a scatterplot of the data. Include axis labels, a legend, and give the graph a title. Find the slope of the line as well.

On the same graph, add data from Trial 2 and Trial 3. Include the linear curve fit, and move the equations around so it is clear which curve fit belongs to which line. Change the axis of the graph so the data fills most of the graph.

1.4. Calculations

Calculate the expected slope for Trials 1, 2, and 3.

Input the measured slopes for each trial.

Calculate the percent error between the expected slope and measured slope. Percent errors should be less than 20%. If you obtain errors larger than this, ask me (your instructor) for help.

Part 2: Varying String Angle

2.1. Data

For each data point, the distance from the pivot to the support, r, is constant, and the angle of the string is changed. For each trial, the mass of the meter stick with hanging masses changes. Watch the following video, where each trial runs through 5 different angles. Record the distance from the pivot to the support in the Excel spreadsheet.

Trials 1, 2, & 3: https://youtu.be/3yTSO-3dqBA

For each of the trials, record the height to the top of the triangle, H_2, and record the associated support mass, m_s.

For Part 2, the tension in the string, m_T = 400 g. Record this value in the Excel spreadsheet.

For each of the 5 different angles, calculate the height of the triangle, H, where $H = H_2 - H_1$.

2.2. Graphs

Highlight H and m_s of Trial 1, and create a scatter plot. Include axis labels, a legend, and a linear fit with an equation on the plot. Add data from Trail 2 and Trial 3 onto the same plot, each with their own linear fits and equations. Move the equations around so it is clear which equation goes with which linear fit. Change the axis so that the data covers most of the plot area.

2.3. Calculations

Calculate the expected slope, β, for all 3 trials (which should be the same value).

Calculate the average slope from the 3 trials, and enter that value in the Excel spreadsheet.

Calculate the percent error between the expected slope and the measured average slope.

Calculate the y-intercept, γ, for each of the 3 trials (which should be different for each trial).

Calculate the percent error between the expected y-intercept and the measured y-intercept for all three trials.

Percent errors should be less than 3%. If you obtain errors larger than this, ask me (your instructor) for help.

2.4. Questions

Answer the questions provided in the Excel spreadsheet, under the tab labelled “Questions”, and submit to Canvas.