LAKE FOREST COLLEGE
Department of Physics

Physics 114 **Experiment #5: Forces on an object resting on an inclined plane v3** Fall 2024

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Date: 09/26/2024
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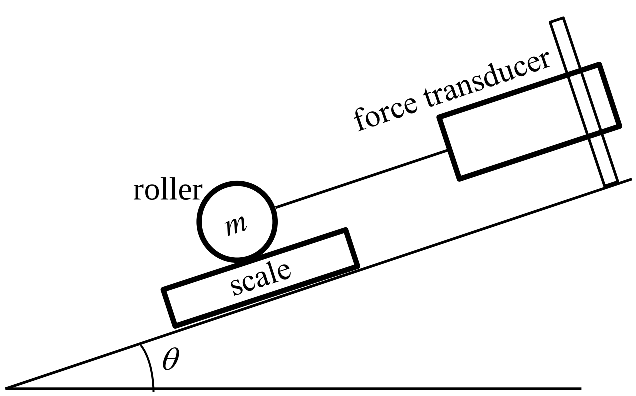
Preliminary Instructions
Create a folder for you and your lab partner. Save a copy of these instructions for each student to that folder. Include your name in the filename. Save one copy of the Excel template with both your and your partner's name included in the filename.

Experimental purpose of today's experiment
Measure the forces acting on an object which is at rest on an inclined plane and compare to the predictions of Newtonian mechanics.

Pedagogical purpose of today's experiment
Learn to apply Newton's laws to an object in static equilibrium.

Background
When an object is in static equilibrium, the net force acting on it must be zero. In this experiment, an object is held at rest on an inclined plane by a string. There are three forces acting on the object: the force of gravity, the normal force of the incline on the object, and the tension in the string. Keep the roller in the box when it is not attached to the apparatus, so that it doesn't fall to the floor!



Procedure

1. Use the following steps to derive a symbolic formula for the magnitudes of the normal force and the tension force in terms of the mass of the roller *m* and the angle of the incline θ.
   - Draw a free body diagram indicating the directions of each of the three forces.
   - Orient *x* and *y* axes such that the *x* axis is parallel to the incline and directed up the incline and the *y* axis is perpendicular to the incline and directed away from the incline.
   - Set up a force-component table and calculate the *x* and *y* components of each of the three forces in terms of the magnitudes of these forces and the incline angle.
   - Use Newton's second law for each component. Solve for the magnitude of the normal force and the magnitude of the tension force in terms of the mass of the object, the angle of the incline and the magnitude of the gravitational acceleration.
   - **Paste a picture of your diagram and derivation here.**

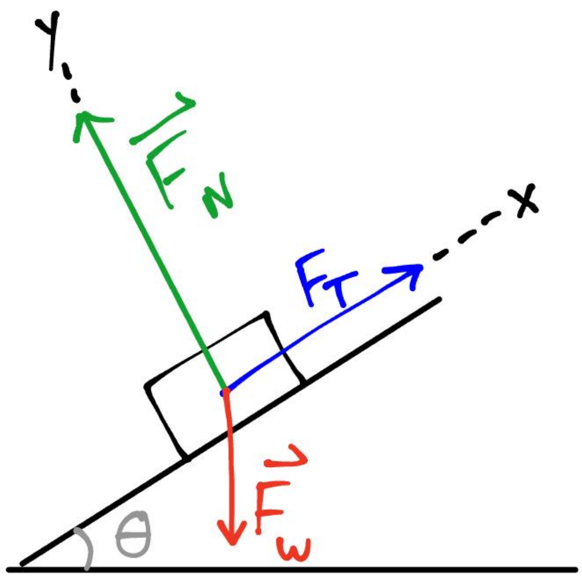


Figure 1. Free Body Diagram. F_T , in blue, represents the tension force. The x-axis runs along this vector. F_N, in green, represents the normal force. The y-axis runs along this vector. F_w , in red, represents the weight force. Θ, in grey, represents the angle between the lab bench and the inclined plane.

2. Measure the mass of the roller plus frame on the Mettler bench-top scale located at the back of the laboratory. Record the mass in kilograms. The mass of the short string is negligible in this experiment.

Roller Mass (kg)	*g* (m/s²)	conversion troy oz to N (N/oz t)
2.248	9.8029	0.30502

Table 1. Excel Constants and roller weight.

3. Place the Vernier Dual-Range Force Sensor facing downward on the small, horizontal crossbar. Start Logger Pro. Set the sensor range to $\pm 50\ \mathrm{N}$. Go to Experiment->Calibrate and choose the Dual Range Force sensor. The click “Calibrate Now.” With no weight on the sensor enter 0 N under “Reading 1” then click “Keep.” Now put the 1 kg mass on the sensor and enter 9.80 N (1 kg * 9.80 m/s^2) under “Reading 1” then click “Keep.”

4. Move the sensor to the post on the inclined plane. Go to Experiment→Data Collection and set the duration to 2 seconds. Press collect and verify that the force sensor is operating. You will use the statistics feature to record the mean value of the force.

5. Set the incline angle to zero and level the center of the plate of the Ohaus bench-top scale by adjusting the feet of the apparatus using the digital Wixey angle gauge. The repeatability of the angle indicator is $\pm 0.1^{\circ}$. Use the smaller (upper) numbers on the angle gauge.

6. Level the horizontal cross bar using the Wixey angle gauge.

7. Set the incline angle to 30.0±0.1° by adjusting the horizontal bar and sliding the apparatus. Hold the apparatus in place with the lead brick. Record the measured incline angle in Table 2 of the spreadsheet.
   A. Without the roller, re-zero the scale at this angle by briefly pressing the ON/ZERO OFF button. Set the scale unit to “oz t” to measure the normal force in troy ounces. 1 troy ounce = 0.30502 newton
   B. Without the roller, re-zero the force sensor at this angle by selecting Experiment→Zero in Logger Pro.
   C. Attach the roller to the force transducer with the short string. The roller should be centered on the scale. Make sure that the force sensor is parallel to the string. Use a ruler to assure that the string is parallel to the incline. **Paste a picture of the apparatus here. Label the important pieces. Include a list of equipment with their model numbers.**

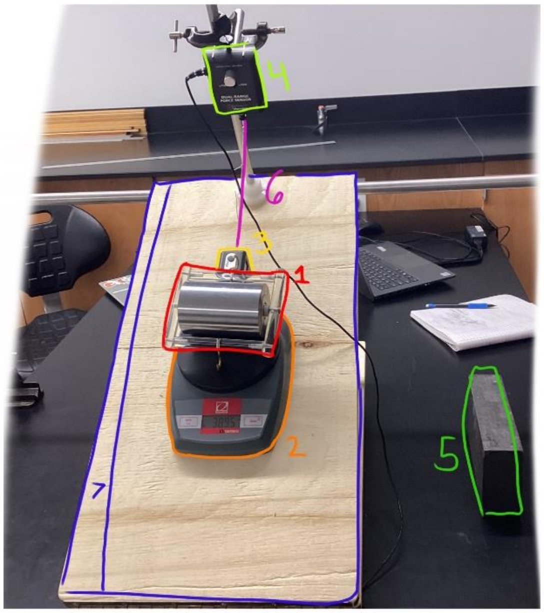


Figure 2. Force Sensing Apparatus. Number 1 in red represents the roller and frame. Number 2 in orange represents the CLseries balance (scale). Number 2 in yellow represents Wixey Digital Gauge. Number 4 in light green represents the force sensor. Number 5 in dark green represents the lead box. Number 6 in pink represents the string. Number 7 in blue represents the incline plane.

D. Use the scale to measure the normal force exerted by the incline on the roller. Record the value in troy ounces (oz t) in Table 2. Use an Excel formula to convert it to newtons (N).

E. Use Logger Pro to collect data from the force transducer to measure the magnitude of the tension force of the string on the roller. Record the mean value in newtons (N) in your spreadsheet.

F. Remove the roller, change the incline angle by removing the brick and slightly sliding the board. Then return it to within 0.1° of 30.0°.

G. Repeat the A-F process to get five measurements at 30°.

H. Determine the average and standard deviation of your 30.0° normal force measurements and your 30.0° tension force measurements.

8. Fill in the first row of Table 3 with your 30.0° measurements. Use the mean values from table 2 as the measured normal and tension forces. Use the standard deviations from table 2 as their uncertainties.

9. Change the angle of the incline, re-zero the scale and force transducer at the new angle without the roller. Add the roller and measure the normal and tension forces. You only need to do this once for each new angle. Repeat for 5 different angles ranging from approximately 10 degrees to approximately 60 degrees. Save all of your Logger-Pro files in your folder on Teams. **Paste one of your Logger-Pro graphs here.**

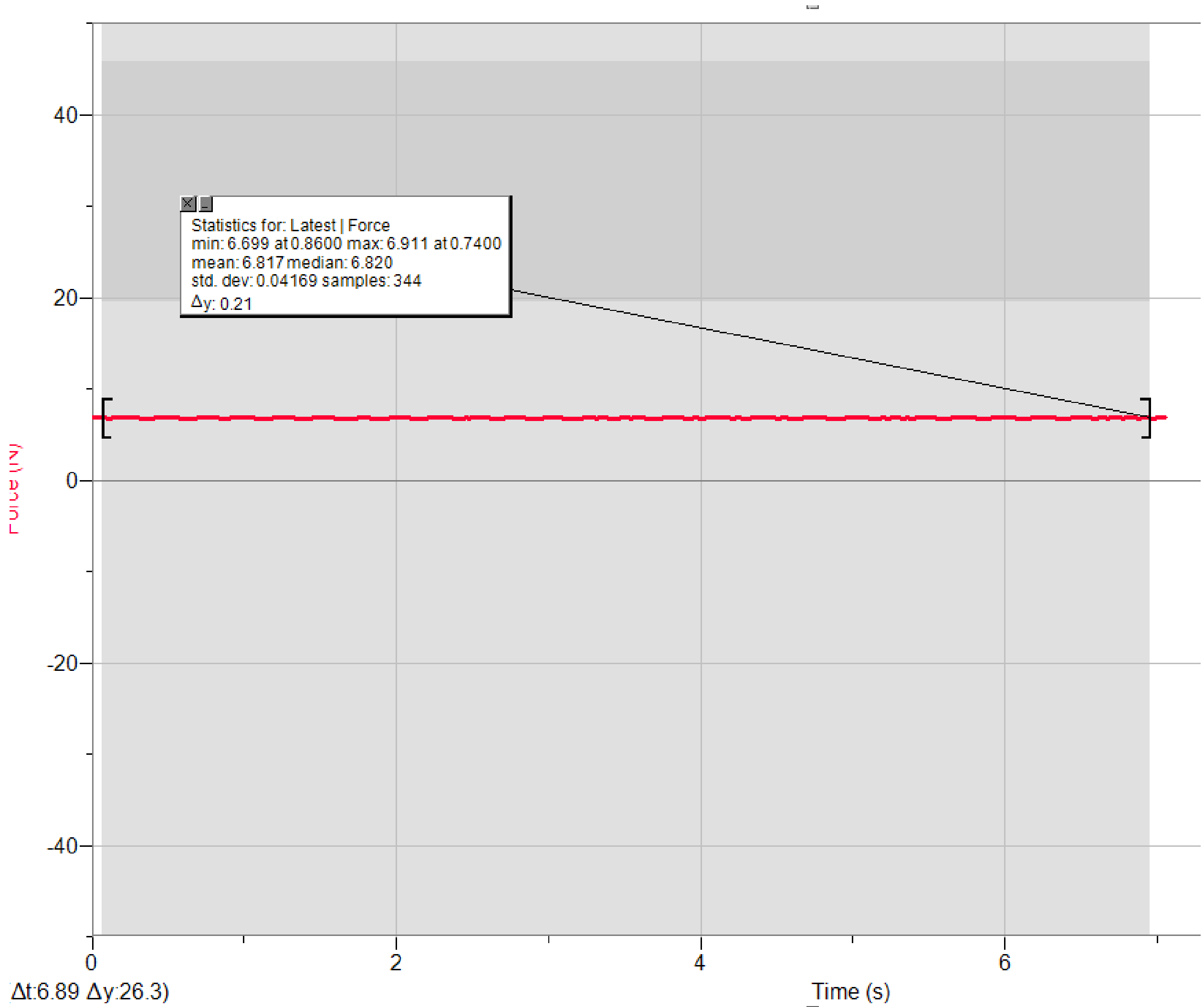


Figure 3. Logger Pro Graph. This graph represents the tension force at a 20 degree angle. The mean is the average force across the approximately 7 seconds that data was recorded. The standard deviation represents the deviation for only that trial.

10. Assume that the uncertainties that we found for the 30.0° measurements stay the same at other angles. That is, all of the entries in table 3 column E are equal to the standard deviation for the normal force for 30.0° that we found in table 2. Treat the tension force uncertainties in a similar manner.

11. Use the equations derived in step #1, the measured mass (m) and the magnitude of the gravitational acceleration (g) to predict the normal force and tension force at each of your incline angles. Record your predictions in Table 4. Your Excel formulas should use both relative and absolute references (dollar signs). Remember to convert the angles to radians for the trigonometric functions: COS(RADIANS(A24)) for example.

$$\vec{F} = m\vec{a}$$

$$x = F_T - mg\sin\Theta \qquad F_T = mg\sin\Theta = \$A\$3 * \$B\$3 * \mathrm{SIN(RADIAN(\Theta))}$$

$$y = F_N - mg\cos\Theta \qquad F_N = mg\cos\Theta = \$A\$3 * \$B\$3 * \mathrm{COS(RADIAN(\Theta))}$$

$$1\,oz = 0.30502\ N$$

Figure 4. Equation Sheets F_T in blue represents the tension force, F_N in green represents the normal force, and Θ represents the angle between the lab bench and the inclined plane (Figure 1). The $ make excel use an absolute reference (Table 1). The conversion factor between oz and N is also included.

12. Use the ratio test to compare your measured values to the predicted values for both the normal force and tension force at each incline angle. The predicted forces have uncertainties due to the uncertainty in the angle. Use a rough approximation of 0.2 N for the uncertainty in both the normal and tension predicted forces.

13. Format your Excel file to make it easy to read and **paste it here**.

Trial at 30.0±0.1 degrees	Measured Angle (degrees)	Measured Normal Force (oz t)	Measured Normal Force (N)	Measured Tension Force (N)
1	29.3	62.1	18.94	10.37
2	30.2	62.45	19.05	10.71
3	30.2	61.75	18.83	10.44
4	29.7	61.80	18.85	10.42
5	30.4	61.5	18.76	10.66
Mean	30.0		18.89	10.52
St. Dev			0.1	0.15

Incline Angle (degrees)	Measured Normal Force (oz t)	Measured Normal Force (N)	Measured Tension Force (N)	Approximate Measured Normal Force Uncertainty (N)	Approximate Measured Tension Force Uncertainty (N)
10.3	71.65	21.85	3.507	0.1	0.15
19.9	67.65	20.63	6.817	0.1	0.15
29.3	62.1	18.94	10.37	0.1	0.15
39.9	55.35	16.88	14.17	0.1	0.15
50.2	45.55	13.89	16.48	0.1	0.15
60.4	34.00	10.37	18.77	0.1	0.15

Incline Angle (degrees)	Calculated Normal Force (N)	Calculated Tension Force (N)	Approximate Calculated Force Uncertainties (N)	Ratio Test for Normal Force	Ratio Test for Tension Force
10.3	21.68	3.94	0.2	0.43	1.4
19.9	20.72	7.50	0.2	0.22	2.2
29.3	19.22	10.8	0.2	0.69	1.3
39.9	16.91	14.1	0.2	0.06	0.1
50.2	14.11	16.9	0.2	0.53	1.5
60.4	10.88	19.2	0.2	1.29	1.3

Table 2 Excel Table.

14. **Write a brief analysis here.** Do your measured normal force and tension force magnitudes agree with your calculations from Newton's laws? What possible systematic effects could influence your results?

As the angle increased the weight force of the object decreased, and the tension force of the object increased. Most of the results agree, in accordance with the ratio test, however the results for the tension force at $\Theta = 19.9$ is inconclusive.

15. **Write a brief conclusion here.**

This experiment works thanks to Newton's second law. The force changes between the tension and weight but the force does not disappear.

16. Adjust the formatting (pagination, margins, size of figures, etc…) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page.

17. Clean up your lab station. Turn off the scale. Put the equipment back where you found it. Remove any temporary files from the computer desktop. Make sure that you logout of Moodle and your email, then shut down the computers. Ensure that the laptop is plugged in.

18. Check with the lab instructor to make sure that they received your submission before you leave.