Inclined Plane

Anfngerpraktikum fr B.Sc. Physik

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1 Abstract

I like to ski. Skiing is like this experiment. For skiing an inclined plane is required. The ski have friction with the snow. If the snow is good skiing makes a lot of fun. If the snow is bad not. The theory of this sliding will be researched in this report.

2 Theory

2.1 Decomposition of forces

The weight force F_G always acts perpendicular to the earth's surface. However, we often also consider inclined planes with a degree of inclination of angle . Here the weight force is divided into a normal force F_N perpendicular to the plane and a tangential force F_T parallel to the plane. Both forces can be calculated with the weight force as follows:

$$F_N = F_G \cdot cos(\alpha) \tag{1}$$

$$F_T = F_G \cdot sin(\alpha) \tag{2}$$

2.2 Static Friction

Static friction occurs when both bodies are not moving and are in contact at at least one point. The static friction counteracts any force that tries to set a body in motion. Only when the applied force is greater than the static friction force F_{HR}

$$F_{HR} = \mu_H \cdot F_N \tag{3}$$

the body can start to move. μ_H is the coefficient of static friction. In general, the sliding friction force is smaller than the static friction force.

2.3 Sliding Friction

There are different types of friction. In particular, sliding friction occurs precisely when one body moves parallel to another body. In this case, the force between the two bodies is exerted parallel to the interface and against the direction of motion. The frictional force can be calculated without lubrication, i.e. as Coulomb friction, as follows:

$$F_{GR} = \mu_G \cdot F_N \tag{4}$$

The sliding friction force F_{GR} is proportional to the normal force F_N. The coefficient of sliding friction μ_G varies according to the nature of the surfaces. The acceleration a body on an inclined plane is subjected to is equal to the difference between the tangential component of the gravitational force and the friction force.

$$F = m \cdot a = F_T - \mu \cdot F_N = F_g \cdot (sin(\alpha) - \mu \cdot cos(\beta)) \tag{5}$$

3 Experimental procedure

The experiment itself will now be considered, which consists of a slide, a plane with a variable angle, three weights plane, three weights, various sensitive force gauges, and an ultrasonic sensor. At the slider is a slider with a mass of 249 grams, to whose sliding surface a kind of felt is attached. is attached. The weight bodies are free and can thus be applied to the slider in each case, so that its mass and thus also the forces can be varied in each case. Of interest here are the masses of the Weight body 1 has a mass of 609 grams, while bodies 2 and 3 each have a mass of 613 grams. can be determined. The plane can be set between a minimum angle of 0 degrees and a maximum angle of 40 degrees to the horizontal. value of 40 degrees against the horizontal. In the first test, the test of the physical force decomposition, the forces acting on the slider must be measured by varying the angle of the plane five times with the aid of the force gauges. In this case, the tangential force, which is taken parallel to the plane, and the normal force, which is orthogonal to the plane. By precise observation the values are thus recorded shortly before lift-off. An addition here is the calculation of the angle, which is done by the sine theorem and by measuring the length of the plane (hypotenuse) and the length of the height. The second experiment is used to determine the coefficient of static friction. Here, the plane assumes an angle of 0 degrees. The force required to set the slide in motion is measured 15 times just before the movement. The procedure is first performed with one weight (weight 1) and then repeated with an additional weight (weight 2). (weight 2). The third section of the test is used to determine the coefficient of sliding friction. Here, at three constant angles, the movement of the slide is recorded with the aid of the ultrasonic sensor, which is connected to a computer, and the data is logged. The procedure is carried out twice more for each angle.

4 Results and Discussion

4.1 Force decomposition

In the following graphs the ration of tangential to weight, normal to weight and tangential to normal forces are plotted. These can respectively be seen as the cosine, the sine and the tangent of the inclination angle as seen in equations 2 and 1.

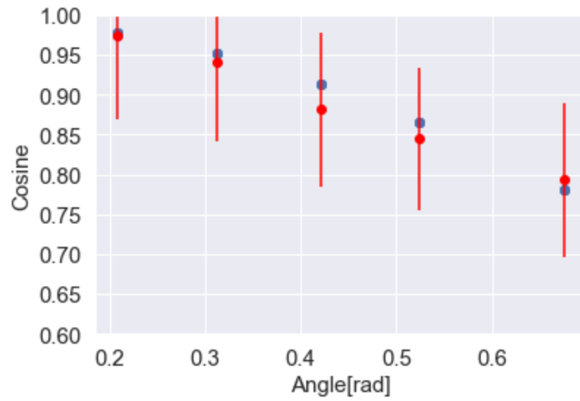

Figure 1: Ratio of normal and weight force vs angle in rad. Experimental values with error in red vs theoretical values in blue.

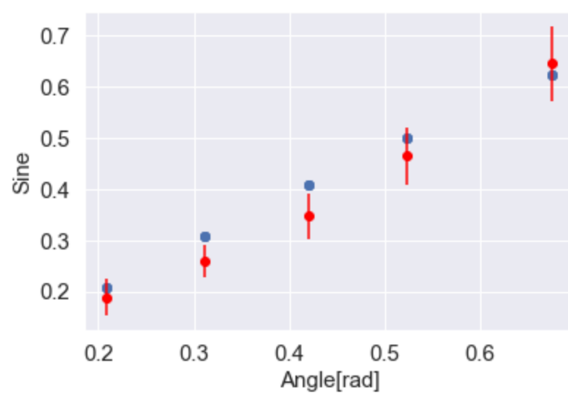

Figure 2: Ratio of tangential and weight force vs angle in rad. Experimental values with error in red vs theoretical values in blue

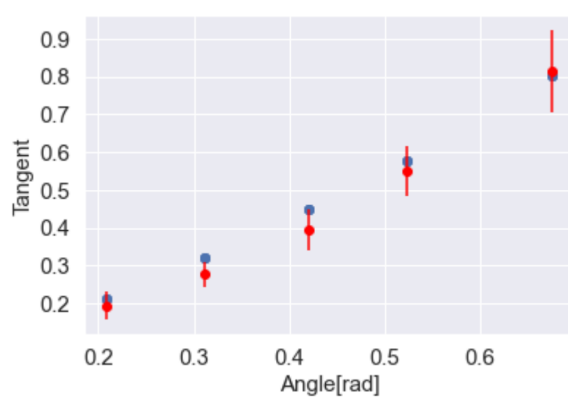

Figure 3: Ratio of normal and tangential force vs angle in rad. Experimental values with error in red vs theoretical values in blue

The experimental values strongly resemble the theoretical ones even if for some figures, like for example 2 , the theoretical values are not completely within error bounds of the experimental values this most likely has to do with the gross underestimation of the errors in these experiment since it was performed and measured in suboptimal conditions. The human error assumed at the start was of 10%, all other non statistical errors were ignored since they would be orders of magnitude lower than the human error involved in this experiment.

4.2 Static friction coefficient

Table 1: Friction force for the different masses

	Slider	Slider+1mass	Slider+2masses
Mass [g]	335	944	1557
Force [N]	0.598±0.138	1.401 ±0.196	2.116 ±0.289

In table 1 the measurements of static friction force are written down above the respective masses being pulled on. These have then been plotted on graph 4 and fitted with equation 3. The normal force in this case just being the weight since the measurement was performed on a flat surface. The static friction coefficient came out as a fit parameter as $\mu = 1.41 \pm 0.3$. the errors taken into consideration were the statistical error given by the standard deviation plus a variety of human and readout errors. This error being fairly big since pulling and reading out the instrument at the same time while making sure that it was at the verge of starting to move was not easy. An error of 10% was thus considered for that.

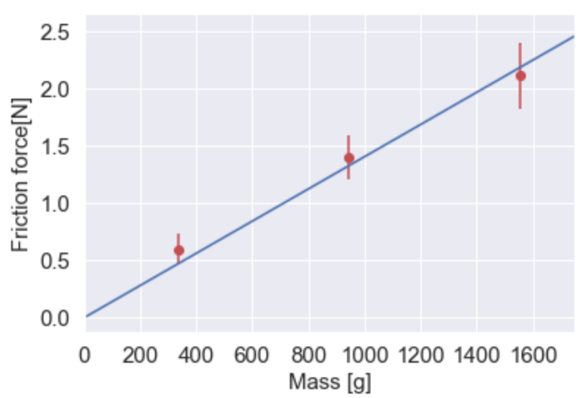

Figure 4: Fit of static friction coefficient by plotting friction force against mass

4.3 Sliding friction coefficient

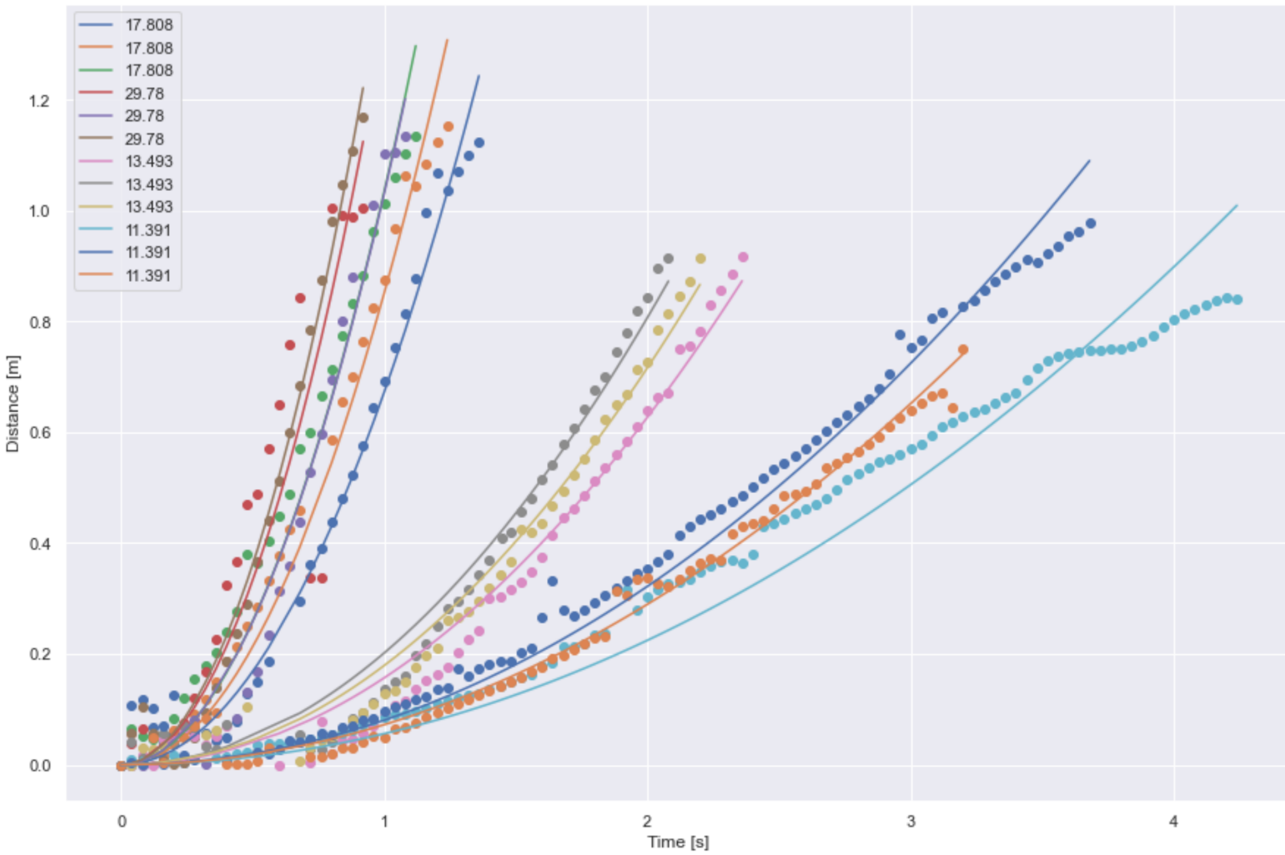

Figure 5: Trajectories of slider data plots and fits at multiple angles (given in the legend in degrees)

The tangential accelerations obtained in the previous fit are then divided by the earth acceleration g and plotted against the angle their were measured at. By rearranging equation [5] and using μ as a fit parameter the following value was obtained

$$\mu = 0.382 \pm 0.04 \tag{6}$$

The fit can be seen in 6

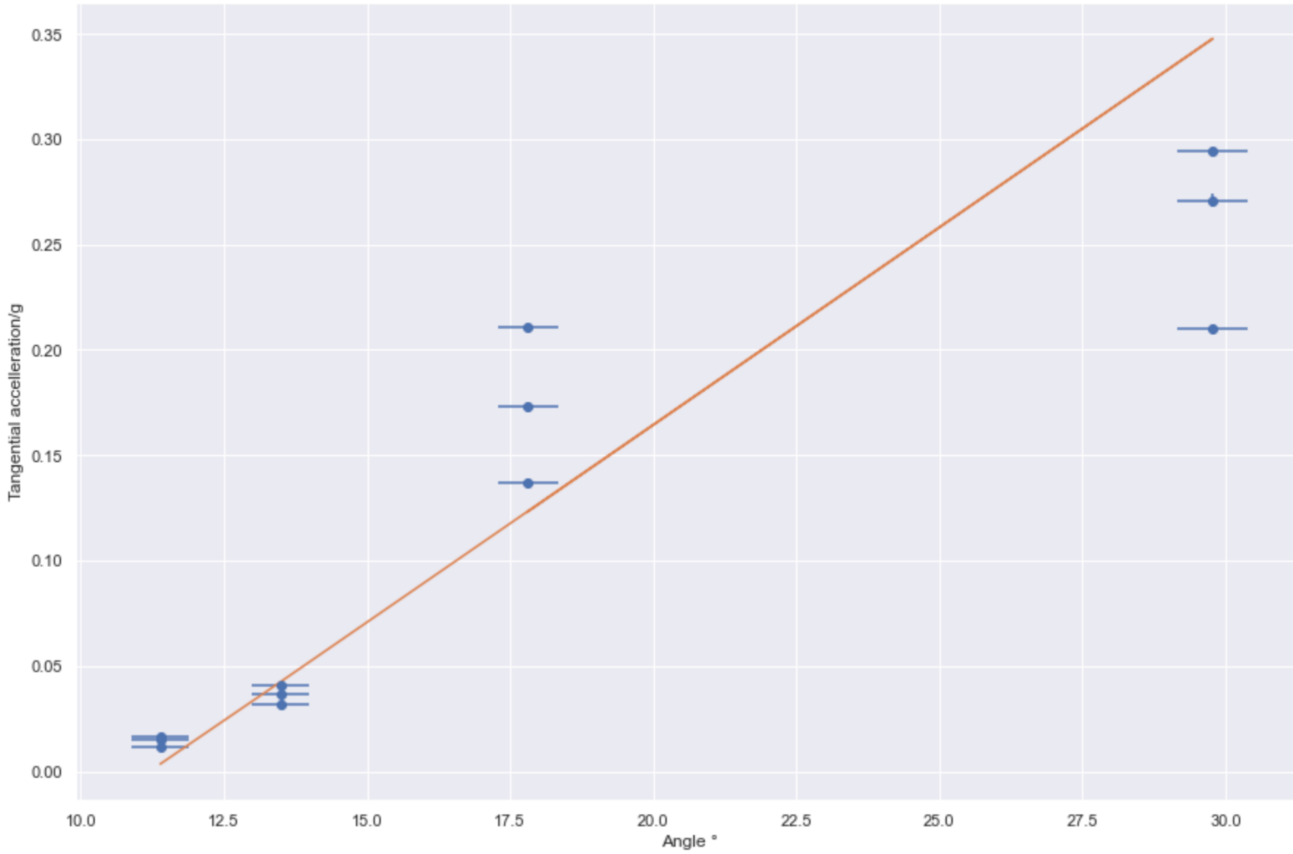

Figure 6: Fit of sliding friction coefficient by plotting tangential acceleration normalized by g against angle

5 Appendix

5.1 Error propagation

For the error propagation the python library uncertainties [3] was used. Errors were treated according to the methods described in [2]. Since most measurements were performed under less than optimal condition and the error in performing the experiment and reading out the result would be much larger than any error given by the precision of the measuring device and such a standard error of 10% was assigned across the board to all measurements. The error for the fitted measurements were calculated with [4]

References

[1] Pdf Document from Moodle:
`https://www.ph.tum.de/academics/org/labs/ap/ap1/SEB.pdf`

[2] ABW for Uncertainties from Moodle:
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[3] Python ”Uncertainties” library:
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[4] Python ”scipy.odr” function:
https://docs.scipy.org/doc/scipy/reference/odr.html