NEW YORK INSTITUTE OF TECHNOLOGY

COURSE NAME: GENERAL PHYSICS I LAB

COURSE CODE: PHYS 170 - M05L

SEMESTER: FALL 2024

Laboratory Report

Estimation of the Kinetic Frictional Coefficient Between the Air Truck and Cart

MAIN REPORT WRITER: ZHASMIN TUIACHIEVA

COLLABORATORS: NENCY VIKASBHAI PATEL, JENCY PRAKASHBHAI MAYANI

LAB INSTRUCTOR: DR. RAY D.SAMESHIMA

LAB PERFORMANCE DATE: 2024-11-18

ABSTRACT

In this experiment, we aimed to estimate the kinetic frictional coefficient (μ_k) between an **air track and a glider system(cart)** (Fig.1). The experiment was conducted using two different masses (0.1947 kg and 0.3948 kg) and involved measuring the velocity and height changes as the cart moved along an inclined track. The time it took for the cart to pass through two photogates was recorded to calculate its velocities at different points. From these measurements, the change in kinetic and potential energy was determined. The angle of the incline was estimated from the known height and length of the slope, and the frictional force was calculated using the **work-energy theorem**. The kinetic frictional coefficient was then estimated and compared to a reference table for similar materials.

Fig. 1. *Experimental apparatus featuring an inclined air track with photogates to measure the motion of the glider.*

THEORETICAL BACKGROUND

The **Work-Energy Theorem** is central to understanding the relationship between work, energy, and motion. It states that the work done on an object is equal to the change in its kinetic energy:

$$W = \Delta KE = KE_f - KE_i$$

where:

- W is the net work done on the object,
- KE_f and KE_i are the final and initial kinetic energies, respectively.

Kinetic energy (KE) is given by:

$$KE = \frac{1}{2}mv^2$$

where:

- m is the mass of the object,
- v is its velocity.

In this experiment, the cart is moving along an inclined air track, and we need to account for both gravitational and frictional forces. The force of friction (F_f) opposes the motion of the cart, reducing its kinetic energy. The frictional force is given by:

$$F_f = \mu_k N$$

where:

- μ_k is the kinetic friction coefficient (the quantity we aim to determine),
- N is the normal force.

EFFECT OF THE INCLINE ON THE NORMAL FORCE

On an inclined plane, the normal force N is reduced because only a component of the gravitational force acts perpendicular to the surface. The normal force is given by:

$$N = mgcos(\theta)$$

where:

- m is the mass of the cart,
- g is the acceleration due to gravity (9.81 m/s^2),
- θ is the angle of inclination of the air track.

FINDING THE ANGLE OF ELEVATION

To calculate the angle of elevation θ of the inclined track, we use the change in height ($\Delta h = h_f - h_i$) and the distance the cart travels along the incline d. The angle θ can be found using the following equation:

$$\theta = \arcsin\left(\frac{\Delta h}{d}\right)$$

where:

- Δh is the change in height between the initial and final positions of the cart along the incline,
- d is the distance the cart travels along the incline.

WORK DONE BY FRICTION

The work done by the frictional force as the cart moves along the track is:

$$W_f = F_f \cdot d = \mu_k mgcos(\theta) \cdot d$$

This work results in a loss of kinetic energy, as the frictional force opposes the motion of the cart.

ENERGY CONSERVATION AND FRICTIONAL LOSSES

In the absence of significant external forces other than friction, the mechanical energy of the system is conserved, but friction causes a loss in the system's total mechanical energy. The total mechanical energy at the start (initial kinetic energy plus potential energy) is transformed primarily into kinetic energy, with some of it lost as heat due to the frictional force. This change in energy can be used to estimate the kinetic friction coefficient.

The gravitational potential energy at the start is given by:

$$PE_i = mgh_i$$

Where h_i is the initial height of the cart, and the kinetic energy at any point is:

$$KE = \frac{1}{2}mv^2$$

Using the principle of conservation of mechanical energy, the work done by friction is equal to the loss in mechanical energy:

$$W_f = \Delta KE - \Delta PE$$

Where:

- ΔKE is the change in kinetic energy,
- ΔPE is the change in potential energy as the cart moves down the track.

CALCULATING THE FRICTIONAL COEFFICIENT

By measuring the initial and final velocities of the cart, we can calculate the change in kinetic energy. The distance travelled along the incline and the height difference give us the angle of the incline. Using these measurements, the kinetic friction coefficient μ_k can be estimated through the following relationship:

$$\mu_k = \frac{W_f}{mgcos(\theta) \cdot d}$$

PROCEDURE

MATERIALS:

- An air track with an adjustable incline
- A cart with a flag
- Two photogates to measure the cart's speed
- A meter stick for precise distance measurement

- A scale for measuring the cart's mass
- A computer with data acquisition software to record and calculate the cart's initial and final time as it passes through the photogates

SETUP:

1. Set up the air track on a stable surface, ensuring it is inclined at a small angle.
2. Position the photogates along the track at fixed distances, making sure they are aligned properly for accurate timing measurements. Attach a flag to the cart to trigger the photogates.

Fig.2. *The air track was set up horizontally with two photogates placed at measured distances along the track. A flag was attached to the cart to trigger the photogates. The cart was released from a fixed starting point, and its velocity was measured at the photogates. The height of the track was adjusted slightly to introduce a vertical component.*

EXPERIMENT:

1. Measure the mass of the cart using a digital balance. Record the mass for later use in the energy and friction calculations.
2. Release the cart from a starting position at the top of the inclined air track.
3. Use the photogates to record the initial and final times as the cart passes through them. Run the cart multiple times to ensure accuracy and consistency in the time measurements.

4. For each trial, measure the time it takes for the cart to pass through the photogates and record the data.
5. Repeat the process for different distances along the incline. Record the corresponding times and calculate the velocities at each photogate.
6. Use the recorded times and the known length of the flag attached to the cart to calculate the initial and final velocities (v_i and v_f) of the cart as it passes through the photogates.
7. Using the measured velocities, calculate the initial and final kinetic energies of the cart using the formula:

$$KE = \frac{1}{2}mv^2$$

8. Calculate the potential energies at the initial and final positions using the formula:

$$PE = mgh$$

9. Calculate the angle of elevation θ of the air track using the formula:

$$\theta = \arcsin\left(\frac{\Delta h}{d}\right)$$

10. Calculate the work done by friction using the change in kinetic and potential energy and estimate the kinetic friction coefficient μ_k for each trial using the appropriate formulas.

DATA & ANALYSIS

In this experiment, several measurements were taken to estimate the kinetic friction coefficient μ_k between the air truck and the cart on an inclined air track. The key data points include the measured times at the photogates, the velocities, the changes in height, the calculated potential and kinetic energies, and the estimated frictional force.

Table of Results (******full table can be accessed via link in the reference list***)**: Below is the table of the results obtained from the twelve trials, including distances, times, velocities, height measurements, and energy values for both initial and final positions.

Run	Distance (m)	Mass (kg)	Velocity (v_1) (m/s)	Velocity (v_2) (m/s)	Change in PE	Change in KE	Angle in Rad	M_k
1	1.50	0.1947	0.34992	1.20047	-0.126060	0.128373	0.044	0.00081
2	1.40	0.1947	0.34996	1.16437	-0.118420	0.120061	0.044	0.00061
3	1.30	0.1947	0.34878	1.12660	-0.110780	0.111716	0.045	0.00038
4	1.20	0.1947	0.34821	1.08765	-0.101230	0.103360	0.044	0.00093
5	1.10	0.1947	0.34755	1.04775	-0.091680	0.095109	0.044	0.00163
6	1.00	0.1947	0.35064	1.01812	-0.084040	0.088942	0.044	0.00257
7	1.50	0.3948	0.35063	1.20285	-0.255617	0.261338	0.044	0.00099
8	1.40	0.3948	0.34877	1.16527	-0.240125	0.244028	0.044	0.00072
9	1.30	0.3948	0.34942	1.12654	-0.224633	0.226419	0.045	0.00036
10	1.20	0.3948	0.34806	1.08822	-0.205268	0.209852	0.044	0.00099
11	1.10	0.3948	0.34704	1.04941	-0.18590	0.193613	0.044	0.00181
12	1.00	0.3948	0.34957	1.00147	-0.170411	0.173860	0.044	0.00089

The results showed a consistent but small kinetic friction coefficient μ_k across all trials, suggesting minimal friction between the cart and the air track. This is expected, as the air track minimizes friction by using air cushions to support the cart.

The average values obtained were within the expected range for systems with low friction, like "bone lubricated by synovial fluid" or “steel on ice” where the coefficient is around 0.015 and 0.02 respectively.

The minor variations in the kinetic friction coefficient can be attributed to experimental uncertainties such as timing accuracy, slight changes in the cart's path, or fluctuations in the angle measurement.

CONCLUSION

The purpose of this experiment was to estimate the kinetic frictional coefficient (μ_k) between the air truck and the cart on an inclined air track. The results show that the frictional force acting between the surfaces was minimal, with the calculated coefficient of kinetic friction consistently being very low across all trials.

By analysing the energy changes during the motion of the cart, we were able to estimate the work done by the frictional force and compute the kinetic friction coefficient using the work-energy theorem. The calculated values of μ_k were within the expected range for low-friction systems, comparable to materials such as “steel on ice” or "bone lubricated by synovial fluid” (where the coefficient is around 0.02 and 0.015).

While the average value of μ_k was small, there were slight variations between trials. These variations can be attributed to potential sources of error such as small inaccuracies in timing, measurements of height, or the distance traveled along the incline. However, these deviations were minimal and did not significantly affect the overall result.

In conclusion, the estimated kinetic friction coefficient for the air truck and cart system is extremely low, which is typical for a system with minimal contact due to air cushion effects. This result suggests that air trucks are an efficient means for reducing friction, which is beneficial in applications requiring smooth motion.

ACKNOWLEDGMENTS

I would like to acknowledge my lab partners, Nency Vikasbhai Patel and Jency Prakashbhai Mayani for their assistance in data collection. I also appreciate Dr. Ray D. Sameshima's guidance during the lab.

REFERENCE LIST

Moebs, W., Ling, S. J., & Sanny, J. (2016, September 19). *University Physics: Volume 1*. Loyola Marymount University & Truman State University.

Halliday, D., Walker, J., & Resnick, R. (2014). *Fundamentals of Physics Extended* (10th ed.). Wiley.

Reed College. (n.d.). *How to write a lab report*. Reed College Writing Center. Retrieved from https://www.reed.edu/writing/paper_help/labreport.html

Fig. 1. Air track setup image. Retrieved from https://cdn2.webdamdb.com/md_wmxnFi0nkxo1.png?1565279260

Fig. 2. Tuiachieva, Z. (2024, November 11). Inclined air track with the experimental setup. [Zhasmin Tuiachieva]. Personal collection.

Table of Data: Tuiachieva, Z. (2024). Table of results from the kinetic friction experiment [Data set]. Retrieved from https://nyinstituteoftechnology-my.sharepoint.com/:x:/g/personal/ztuiachi_nyit_edu/EYUcr6FQxPBJsLWQaOUdYNsBN1zZDi7ZmWXOsb04SgRGGg?e=EwyjNe