Exercise 5: Force of friction

Purpose: To investigate the kinetic and static friction forces acting on an object.

Introduction

Friction is a force that opposes the relative motion between two surfaces. The frictional force depends on the nature of the surfaces and the reaction force acting between the surfaces. The frictional force depends on whether the surfaces are initially at rest relative to the other or not. In the case where the objects are at rest, then the minimum force required to just start them moving relative to the other is a measure of the maximum frictional force prior to the motion, and this is called the maximum static frictional force, or the critical force. It is observed that the magnitude of the static frictional force of an object on a flat surface is given by

$$F_s \leq \mu_s N,$$

where N is the normal force on the object and μ_s is the coefficient of static friction.

If the surfaces are in relative motion then the force opposing the motion is less than that of static friction and is called the dynamic frictional force. The magnitude of the kinetic frictional force is given by

$$F_k = \mu_k N,$$

where μ_k is the coefficient of kinetic friction.

Laboratory assignment

The laboratory assignment will have two parts: (A) determine the coefficient of static friction of two types of materials on an aluminum track, and (B) determine the coefficient of kinetic friction of the same two types of materials on the same aluminum track. The procedures for each part will be different.

Part 1: static friction

1. Attach each meter stick to the two vertical posts. Make sure that the two meter sticks start at the same height relative to the table.
2. Place on of the vertical meter sticks at the 70 cm mark ruled out on the track. Place the other vertical meter stick at the 10 cm mark ruled out on the track keeping the track flat on the table.
3. Place the cork bottomed boat on the aluminum track and leave it stationary for 10 seconds before moving on to step 3.
4. Gradually increase the angle of the track by picking up the track on the end with the highest ruled values. Keep watching the height changes of both meter sticks and the change in hypotenuse between the two vertical meter sticks.
5. When the cork bottom boat begins to move, keep the track stable. Then record the two height values from the meter sticks and the two locations of the meter sticks on the ruled section of the track.
6. Repeat these steps two more times and tabulate your data and place it in Table 1. The notation in the table is such that h_1 and h_2 are the heights of the track measured by the meter stick, d_1 and d_2 are the positions of the vertical meter sticks recorded from the ruled track, θ_{avg} is the average angle that you calculate, and σ_θ is the standard deviation of the calculated angle.

Table 1: cork boat static friction measurements.

	h_1 (cm)	h_2 (cm)	d_1 (cm)	d_2 (cm)	θ (°)	θ_{avg} (°)	σ_θ (°)
Trial 1							
Trial 2							
Trial 3							

7. Calculate the angles of each trial using the relationship $\sin\theta = \frac{h_2 - h_1}{d_2 - d_1}$.
8. Calculate the average angle θ_{avg} and standard deviation σ_θ.
9. Repeat steps 1-7 after replacing the cork boat with the felt boat but place the data in Table 2.

Table 2: felt boat static friction measurements.

	h_1 (cm)	h_2 (cm)	d_1 (cm)	d_2 (cm)	θ (°)	θ_{avg} (°)	σ_θ (°)
Trial 1							
Trial 2							
Trial 3							

10. Draw a free body diagram for the friction boat in the space below.

11. Derive an expression for the static coefficient of friction μ_s in terms of the critical angle θ using your free body diagram. Place the derivation of μ_s in the space below.

12. Calculate the coefficient of static friction μ_s for both the felt and cork materials on the aluminum track and the propagated error and give the numerical results in the form $\mu_s = \mu_{s,\text{avg}} \pm \Delta\mu_s$. (Be sure to change the units for uncertainty in the angle to radians!!!)

$\mu_s^{\text{cork}} =$ ____________________. $\mu_s^{\text{felt}} =$ ____________________.

Part 2: kinetic friction

13. Place the track flat on the table and fasten the pulley to the end of the track so that a hanger can freely move beyond the table.
14. Place the motion sensor on the track and orient it to read the carts velocity.
15. Start the "capstone" software and select the velocity measurement.
16. Use a scale to find the mass of the cork boat.
17. Place the cork boat roughly 10 cm away from the motion sensor and attach the string to the boat and the other end to the hanger with the string in the pulley's groove.
18. Add a 250 g mass to the cork boat and place some small masses on the hanger.
19. Run the motion sensor software and give the boat a small flick down the track. (look at the graph of the velocity for the motion sensor; does it speed up, stay at constant velocity, or slow down).
20. Either add or remove masses on the hanger and repeat step 19 until the cart moves roughly at constant velocity.
21. Record the a) total mass of the boat plus mass riding inside and b) the mass of the hanger plus the masses on the hanger.
22. Add an additional 250 g to the boat for a total of 500 g in the boat and repeat steps 19-21. Then repeat again with a total of 750 g riding in the cart.
23. Present your data by placing it in Table 3, where M_b is the mass of the boat + the masses riding in it and M_h is the mass of the hanger + the masses added to it.

Table 3: cork boat kinetic friction measurements.

M_b (g)			
M_h (g)			

24. Repeat steps 13-23 by replacing the cork boat with the felt boat but place the data in Table 4.

Table 4: felt boat kinetic friction measurements.

M_b (g)			
M_h (g)			

25. In the space below, draw a free body of the boat mass and another free body diagram of the hanger.

26. Derive an expression for the kinetic coefficient of friction μ_k in terms of M_b and M_h. Place the derivation of μ_k in the space below.

27. Graph M_h as a function of M_b for both the cork boat and the felt boat and place both graphs side-by-side in the space below.

28. Use your program from Lab 1 to find the slope and the uncertainty of the slope (which is coefficient of kinetic friction and uncertainty; be sure to set N = 3 data points if using C++ code). Present your numerical results below for both materials in the form $\mu_k = \mu_{k,\text{avg}} \pm \Delta\mu_k$.

$\mu_k^{\text{cork}} =$ ____________________. $\mu_k^{\text{felt}} =$ ____________________.

29. Compare your results for the case of static friction and kinetic friction for both materials. Did you find that $\mu_s \geq \mu_k$? Which has greater frictional coefficients on aluminum, cork or felt?

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Equipment list: aluminum track, friction boats, mass hanger set, strings, 250g rectangular cart masses (3), vertical stand (2), meter stick (2), motion sensor, laptop.