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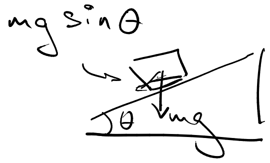
B. Results and data analysis (58 pts)

Part I. Measurement of Work and Energy

Table 1 Measurement of Work and Energy (13 pts)



Mass of the car, m_{car} = 0.246 kg

Length of the inclined plane, L = 0.60m

Incline angle	Total mass, up (kg)	F_u (N)	Total mass, down (kg)	F_d (N)	Height, h (m)	f_k (N)
15°	0.0686	0.673	0.0619	0.608	0.155	0.033
30°	0.130	1.28	0.126	1.18	0.300	0.049
45°	0.182	1.78	0.172	1.69	0.424	0.049

Table 2 Calculation of Work and Energy (13 pts)

Incline angle	F_u L (J)	f_k L (J)	ΔGPE (J)	f_k L + ΔGPE (J)	Percent difference* between F_u L and (f_k L + ΔGPE)
15°	0.404	0.0197	0.375	0.394	2.33 %
30°	0.765	0.0294	0.724	0.753	1.55%
45°	1.07	0.0291	1.02	1.05	1.66 %

* Since both F_u L and (f_k L + ΔGPE) are measured results, neither of them is more reliable than the other one. In this case, when calculating the Percent difference, we take the average of the two as the denominator in the formula:

$$\text{Percent difference} = \frac{|F_u L - (f_k L + \Delta\text{GPE})|}{(F_u L + f_k L + \Delta\text{GPE})/2} \times 100\%$$

Part II. Measurement of the coefficients of kinetic and static friction

Table 3 The coefficient of friction measured on a flat surface (13 pts)

Mass of the car, m_{car} = 0.246 kg

Experimental Arrangement	Mass required to pull the car (kg)	Force of Friction (N)	Coefficient of friction
Sliding friction	0.0520	f_k = 0.510	μ_k = 0.211
Static friction	0.0530	f_s = 0.520	μ_s = 0.215

$f_k = \underset{Mg\cdot\mu}{\underline{N\cdot\mu}} = mg$

$\mu = \frac{f_k}{Mg}$

Table 4 The coefficient of friction measured on an inclined plane (13 pts)

Mass of the car, m_{car} = ____________________

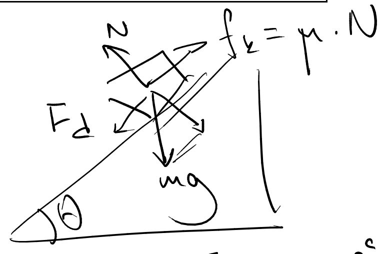
Experimental Arrangement	Limiting angle	Coefficient of friction
Rolling friction	2.5°	$\mu_{k,\ rolling}$ = 0.0437
Sliding friction	12	$\mu_{k,\ sliding}$ = 0.213
Maximum static friction	13°	μ_s = 0.231

Calculation of percent difference (6 pts):

i. Coefficient of sliding kinetic friction μ_k:

$$\frac{|\mu_k' - \mu_k|}{\mu_k} \cdot 100 = \frac{|0.213 - 0.211|}{0.211} \cdot 100\%$$

$$= 0.95\%$$



$$\underbrace{\mu N}_{\mu mg \cos\theta} = f_k = F_d = mg \cdot \sin\theta \qquad \mu = \tan\theta$$

ii. Coefficient of static friction μ_s:

$$\frac{|\mu_s' - \mu_s|}{\mu_s} = \frac{|0.231 - 0.215|}{0.231} = 0.0693 = 6.93\%$$

TA signature: Zi Ang Wang

C. Answer the following questions after the experiment (6 pts each)

4. In part I of the experiment, the incline angle affects the frictional force involved in pulling the car up the plane. Show how the frictional force depends on the incline angle.

$$f_k = \mu N = \mu \cdot mg \cos\theta \Rightarrow f_k \sim \cos\theta$$

If θ increases, f_k should decrease

5. Does the Work-Energy Theorem (Eq. (1)) hold when moving the car along the inclined plane? Specify one set of data from your measurements to support your answer. Discuss the possible sources of error in this part of the experiment.

It does. In Table 2, the % difference between $F_u L$ and $f_k L + \Delta GPE$ is within 3% for all three values of θ. The error may be due to the uneven friction of the plane, even after cleaning, which makes it harder to measure the moment when the car "just starts moving when given a push". The largest source of error here is human error.

6. In part II of the experiment, did you see any difference between the coefficient of rolling friction and the coefficient of sliding friction? What do your results indicate about the relative advantage of rolling, over sliding, an object up an incline?

The sliding friction coefficient far exceeds the rolling friction coefficient, which means that rolling an object with wheels is much more efficient than just sliding it across. This is due to the reduced area of friction (only the friction in the wheels), as well as a lower friction coefficient in the wheels.

7. Assume you add a large weight to the car, and thereby increase the normal force F_n, in the measurement of the coefficient of rolling friction μ_k. Do you expect any difference in the measured value of μ_k? Explain.

As seen on p. 7, $\mu_k = \tan\theta$, so it doesn't depend on the weight of the car. Hence, I would not expect a difference.