Phys 11A - Eiteneer

Lab: Friction on an Inclined Plane

Online version

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Purpose

To practice with drawing FBDs and working with net force; to learn to work with inclined planes and frictional forces.

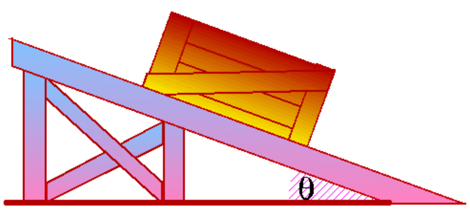
Introduction

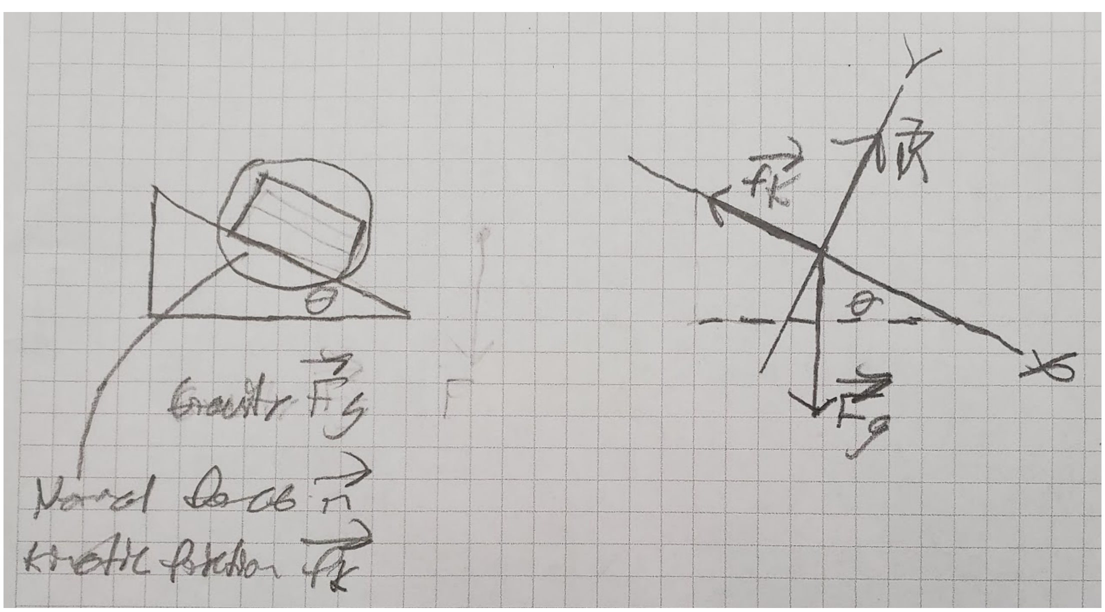
Newton's Laws assert that if a particle is in equilibrium then the total force on it must vanish, i.e. the vector sum of the applied forces must be equal to zero, $\sum_i \vec{F}_i = 0$. If the total force is not zero, the particle is not in equilibrium, and then $\sum_i \vec{F}_i = m\vec{a}$.

The purpose of this experiment is to work with a system which can be in equilibrium, or not in equilibrium (what is the main difference and how can you tell?). We will also practice drawing FBD and working with friction.

Prelab

1. Below is a schematic of an inclined plane problem. In the space provided, draw a free-body diagram and label all the forces acting on the box. How can you tell if this box is in equilibrium or not?





We can determine if this box is in equilibrium or not by looking at the net force on the box. If the net force on the box is zero, then we can say that it is in equilibrium. Two possible ways for the box to be in equilibrium is if it were to be at rest or if it were to move in a straight line at a constant velocity.

2. Is there a difference between drawing an FBD for a static case vs. kinetic case? Why or why not?

Yes, there is a difference because an object can only have static friction if the friction keeps the object still or prevents it from moving. As such, static friction acts in the direction that prevents slipping (usually opposite the direction the object would move if there was no friction). An object can only have kinetic friction if it is sliding across a surface. Kinetic friction tends to oppose the motion of an object and as such tends to point in the direction opposite the velocity.

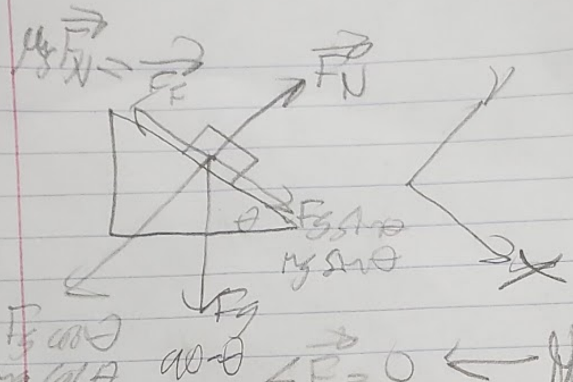
Experimental Procedure & Data Analysis

Part I – Static case

1. For this part of the experiment, an inclined plane (consisting of a "frictionless" track) as shown in the figure in the prelab was set up. The angle was adjusted such that it was **just** enough to keep the object from sliding. *Hint:* think static friction!
2. Measure the mass of the object and the angle (see "StaticAngle"). Don't forget experimental uncertainties and units!

m = 111 g ± 1 g θ = _20° _ ± _1°___

3. Using the FBD you drew in the prelab, set up both $\Sigma\vec{F}$ equations, and use them to derive the expression for the coefficient of static friction. Show all work! You may use additional sheet of paper if necessary.



$\cos(90-\theta) = \sin\theta$

$\sin(90-\theta) = \cos\theta$

$\sum \vec{F} = 0$ ← Newton's 1st law

$\sum \vec{F_x} = 0$
Left = Right

$\sum \vec{F_y} = 0$
up = Down

(1) $mg \sin\theta = \mu_s F_N$ (2) $F_N = mg \cos\theta$

$\frac{(1)}{(2)} \quad \frac{\mu_s \cancel{F_N} = \cancel{mg} \sin\theta}{\cancel{F_N} = \cancel{mg} \cos\theta}$

$\mu_s = \frac{\sin\theta}{\cos\theta}$ $\boxed{\mu_s = \tan\theta}$

$\sum F_x = \cancel{ma_x}$

$G \cos(90-\theta) - F = ma_x$ $\cos(90-\theta) = \sin\theta$

$mg \sin(\theta) - \mu_s N = 0$ ← Need N
in
Y-direction

$\sum \cancel{F_y = ma_y}\ 0$

$N_{force} - G \sin(90-\theta) = 0$

$N_{force} = G \sin(90-\theta)$

$\sin(90-\theta) = \cos\theta$

$\cancel{mg} \sin\theta = \mu_s \cancel{mg} \cos\theta$

$\mu_s = \frac{\sin\theta}{\cos\theta}$ → $\boxed{\mu_s = \tan\theta}$

4. You should've derived $\mu_s = \tan\theta$. Using propagation of error analysis, derive the expression for uncertainty in μ_s.

To get uncertainty in μ_s use to the following below;

$\mu_s = \tan(\theta)$

$\delta\mu_s \Rightarrow \delta \tan(\theta) = \frac{d}{d\theta}(\tan\theta)\,\delta\theta$

$\delta\mu_s = \left(\frac{1}{\cos\theta}\right)^2 \delta\theta$

If v is a function of x, then;

$\Delta v = \frac{dv}{dx}\Delta x$

$$\boxed{\delta\mu_s = \left(\frac{1}{\cos\theta}\right)^2 \delta\theta}$$

5. In cases like this, θ can be expressed in degrees, but $\delta\theta$ **must** be in radians. Take your $\delta\theta$ from #2 above, convert it to radians, and use it to calculate $\delta\mu_s$. Show all work!

1 degree in radians;

$1 \times \frac{\pi}{180} = \frac{\pi}{180}$ radians

$$\delta\mu_s = \left(\frac{1}{\cos(\theta)}\right)^2 \delta\theta$$

$$\downarrow$$

$$= \left(\frac{1}{\cos(20^\circ)}\right)^2 \frac{\pi}{180}$$

$$= \left(\frac{1}{0.939}\right)^2 \frac{\pi}{180}$$

$$= (1.132)\left(\frac{\pi}{180}\right) \approx 0.0197$$

$$\boxed{\delta\mu_s \approx 0.0197}$$

6. Report your final value for $\mu_s \pm \delta\mu_s$: _0.3639_ ± _0.0197__________________

Part II – Kinetic case

7. The angle is now increased, such that the object slides down the incline. *Hint:* think kinetic friction!
8. Measure the new value of the angle (see "KineticAngle"). Don't forget experimental uncertainties and units!

θ = 25° ± 1°

9. Measure the time (with uncertainty and units) it takes the object to slide down the incline (use the video "KineticMovie" – you may need to pause it to determine the exact length that the object slides and the time). Use "KineticInitialPosition" for initial position. It actually does not matter where the final position is, as long as you record the distance traveled and the corresponding time. Record both the time and position with uncertainty and units.

t = 3 seconds ± 0.5 seconds d = 210cm ± 1cm

10. Calculate the acceleration of the object down the incline, using $d = \frac{1}{2}at^2$.

10. $\frac{1}{2}at^2$

$210\text{ cm} = \frac{1}{2}a(3s)^2$

$= 46.667 \text{cm/s}^2$

$= 0.46667 \text{ m/s}^2$

11. Using propagation of error method, derive an expression for uncertainty in acceleration, δa.
Hint: $a = a(d,t)$.

$$d = \frac{1}{2} a t^2$$

$$\frac{2d}{t^2} = \frac{a \cancel{t^2}}{\cancel{t^2}}$$

$$a = \frac{2d}{t^2}$$

$$\boxed{\delta a = \frac{2}{t^2} \delta d}$$

12. Using the equation you derived in the previous problem, calculate uncertainty in acceleration. Show your work! Make sure to keep track of units.

$$\delta a = \frac{2}{t^2}\delta d$$

$$= \frac{2}{(3.0)^2}(0.01)$$

$$= \frac{2}{9}(0.01)$$

$$\boxed{\delta a \approx 0.00222\ m/s^2}$$

13. Using the FBD you drew in the prelab, set up both $\Sigma\vec{F}$ equations, and use them to derive the expression for the coefficient of kinetic friction. Show all work! You may use additional sheet of paper if necessary (remember $\Sigma\vec{F} \neq 0$!).

13) $mg\sin(\theta) - f = ma$

$mg\cos\theta - N = 0$

$N = mg\cos\theta$

$mg\sin(\theta) - \mu_k N = ma$

$mg\sin(\theta) - \mu_k mg\cos\theta = ma$

$$\mu_k = \frac{mg\sin\theta - ma}{mg\cos\theta}$$

$$\mu_k = \tan\theta - \frac{a}{g\cos\theta}$$

14. You should've derived $\mu_k = \tan\theta - \dfrac{a}{g\cos\theta}$. Using propagation of error analysis, derive the expression for the uncertainty in μ_k. Take g to be exact. Show all work!

14. $\delta u_K = \delta\left(\tan\theta - \dfrac{a}{g\cos\theta}\right)$

$= \sec^2\theta\,\delta\theta + \dfrac{a\tan\theta}{g\cos\theta}$

$\delta u_K = \left(\sec^2\theta + \dfrac{a\tan\theta}{g\cos\theta}\right)\delta\theta$

15. Using your derivations in the previous two questions, calculate the coefficient of kinetic friction and the uncertainty $\delta\mu_k$.

15) $\mu_k = \tan\theta - \dfrac{a}{g\cos\theta}$

$= \tan(25^\circ) - \dfrac{0.4667\ m/s^2}{9.8\ m/s^2 \cos 25}$

$= 0.466 - 0.00525$

$= 0.461$

$\delta\mu_k = \delta\left(\tan\theta - \dfrac{a}{g\cos\theta}\right)$

$= \sec^2\theta\ \delta\theta - \dfrac{a\tan\theta}{g\cos\theta}$

$\delta\mu_k = \left(\sec^2(25^\circ) - \dfrac{0.4667\ m/s^2 \tan 25}{9.8\ m/s^2 \cos 25}\right)\dfrac{\pi}{180}$

$= \left(1.217 - \dfrac{0.217}{8.881}\right)\dfrac{\pi}{180}$

$= 0.0208$

16. Report your final value for $\mu_k \pm \delta\mu_k$: _0.461_ ± _0.0208____________________

17. Did the μ_k end up being smaller than the μ_s? If not, what could be the reason? *Hint:* there is something about the **setup** of this experiment that usually gives the wrong result here. What is it? It is not obvious.

The μ_k did not end up being smaller than μ_s. The issue might be our coefficient of kinetic friction expression that we derived. In physics, the coefficient of kinetic friction is always lower than the coefficient of static friction. This is because when an object is moving, there is less intermolecular attraction between the objects than if an object were to be still. We believe our expression did not take into consideration the fact that the object's acceleration is going in the negative direction. This is so because our object is technically speeding up in a negative direction .

18. List all the errors that you can think of, in relation to this experiment, and classify them as systematic or random.

Some errors that we may have experienced with regard to this experiment are:
Incomplete Definition(Systematic in our case): When it came to determining what the position of the box is, we may choose to start measuring from the back of the box or its center. This leads to significant changes in our results.
Failure to account for a factor(Systematic): We ended up with a coefficient of kinetic friction that was higher than static friction due to not taking the direction of acceleration into account.

19. The coefficients of friction for felt on aluminum are 0.184 (kinetic) and 0.28 (static). Calculate the % error between the actual values and the values you obtained from the experiment.

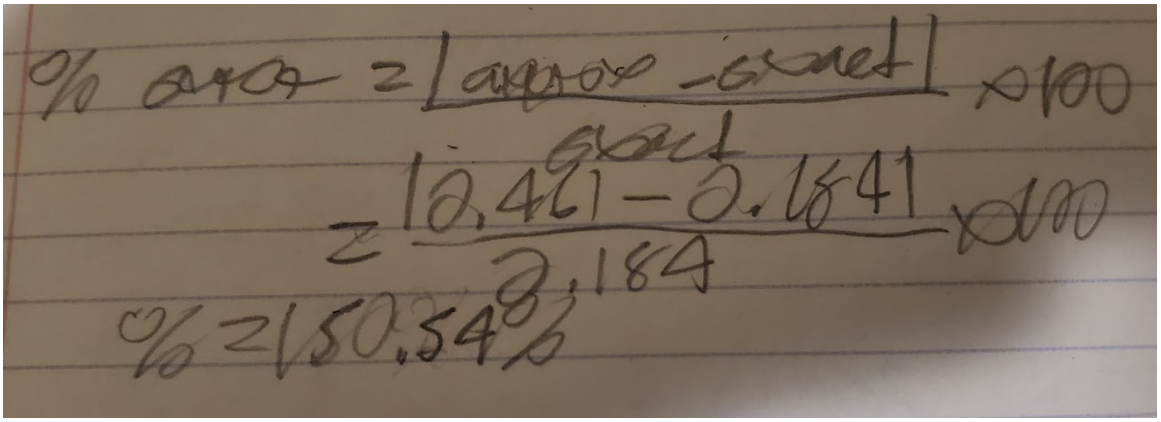
% error for static coefficient of friction:

$$\% \text{ error} = \frac{|\text{approx} - \text{exact}|}{\text{exact}} \times 100$$

$$= \frac{|0.36 - 0.28|}{0.28} \times 100$$

$$\% = 28.57\%$$

% error for kinetic coefficient of friction:



$$\% \text{ error} = \frac{|\text{approx} - \text{exact}|}{\text{exact}} \times 100$$

$$= \frac{|0.461 - 0.1841|}{0.184} \times 100$$

$$\% = 150.54\%$$

20. What could be done differently to reduce percent error and to assure that $\mu_k < \mu_s$?

One thing that can be done differently to reduce percent error is to push the box several times with the same force applied to make sure that we get the same amount of seconds for this lab.

21. What do you notice about the mass in all of your derivations/calculations? Why do you suppose this happens, physically/conceptually?

We noticed that mass seemed to be negligible in our derivations/calculations. This may be because all objects experience the same gravitational acceleration, regardless of mass.