Spring Scale, ***use*** your correction factor (**N/n**), and ***compute*** the value of F_2 (N). ***Record*** M_1, D_1, D_2, the Spring Scale reading, your correction factor, and F_2. ***Include*** the masses of the mass hanger, **0.005 kg**, and clip, **0.002 kg** in M_1.

M_1 = 0.2 + 0.005 + 0.002 = 0.207 kg; D_1 = 0.08 m; D_2 = 0.165 m;

Spring Scale reading = 1.3 N (Units); **Corr. Factor** = .951 ___ (Units); F_2 = 1.236 N (Units)

2. Use a small piece of masking tape to ***mark*** the position of the bottom of the round base of the Spring Scale base on the Experiment Board. ***Use*** a ruler to ***measure*** the distance in centimeters from the table to an easily identifiable point on the hanging mass or hanger. ***Record*** the initial distance of the hanging mass from the table. NOTE: The rulers do not start at zero. This does not matter. Why not? If you don't know, ask.

Slowly push the Spring Scale upward or downward ~ ***0.5 cm***. Moving slowly keeps force effectively constant. Moving ~0.5cm keeps the angle between bar and force vector approximately 90 degrees. Why are both necessary to make the process work? If you don't know, ask.

(**CAUTION**: move the Spring Scale by pushing the magnetic base of the Spring Scale along the experimental board–do not push on the plastic tube or the stem.) If you push the Spring Scale slowly enough, the reading on the Spring Scale will not vary appreciably. The simple linear model we are using to calculate the work done by the applied force assumes a constant force. Thus, it is important that the force as indicated by the Spring Scale reading remain (approximately) constant. Also, by moving the Spring Scale only a small distance, we can neglect the fact that the forces no longer are acting exactly perpendicular to the beam. ***Mark*** the new position of the bottom of the round base of the Spring Scale with another small piece of masking tape. Use a ruler to ***measure*** the distance from the table to the same point on the hanging mass you used earlier. ***Record*** the distance, d_1, the hanging mass moved and the distance, d_2, the Spring Scale was moved. See Figure 12.4.

d_1 = 0.005 m d_2 = 0.005 m

ANALYSIS:

3. ***Calculate*** and ***record*** the weight, W_1 which is the gravitational force acting on beam as a result of M_1. ***Include*** hanger and clip masses.

$W_1 = M_1 g$ = (0.2 + 0.005 + 0.002) x g = 2.03 (N)

4. ***Calculate*** and ***record*** all the work performed on the system as you slowly moved the Spring Scale. Subtract the work done by the clip in moving the bar downward.

Work = $F_2 \times d_2 - M_{clip} \times g \times d_2$ = 1.236 x 0.005 - 0.002 x 9 x 0.005 = 0.0061 (N/m

5. ***Calculate*** and ***record*** the change in potential energy, ΔU, of the hanging mass as it was moved in the earth's constant gravitational field.

$\Delta U = W_1 \times d_1$ = 0.01015 (N·m)

(N/n), and calculate the value of F_x (N). ***Record*** the values of F_x, the measured force along the inclined plane, in Table 12.1.

Use the correction factor determined above.

NOTE: You may find it convenient to use a second pulley in the setup shown in Figure 12.1 for the larger angles to avoid having to change the length of the string. One pulley is better–less friction. You may also have the spring scale at a large angle from vertical as long as the rod below the spring does not touch the washer at the bottom of the Spring Scale tube.

Table 12.1 Data and calculated values for force parallel to the Inclined Plane.

Angle of incline (deg)	*Spring scale reading (n)*	*F_x (corrected) (N)*	*W_x = $W\sin\theta$ (N) (calculated)*	$\% Diff = \frac{F_x - W_x}{(1/2)(F_x + W_x)} \bullet 100\%$
15	0.4	0.380	0.394 ~~0.098~~	-3.6%
30	0.8	0.761	0.761	0%
45	1	0.951	1.076	-12.3%
60	1.4	1.331	1.317	1.07%

3. ***Be sure*** the string connecting the Rolling Mass to the Spring Scale is parallel to the Inclined Plane. Why? If you don't know, ask. You may (if you must) ***use*** two pulleys for angle of 45° and 60°.

ANALYSIS:

4. For each angle, ***calculate*** W_x, using equation (12.11). For each angle, ***calculate*** percent difference between F_x and W_x using equation in Table 12.1. ***Record*** results in column 5, Table 12.1.

5. ***Answer*** questions 1. and 2

Force perpendicular to the Inclined Plane:
PROCEDURE:

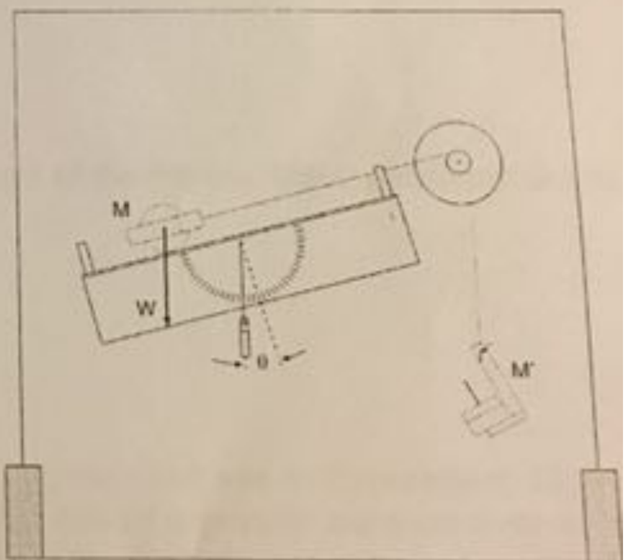

Figure 12.2. Equipment Setup to Measure Normal Force

6. ***Measure*** the force exerted by the Rolling Mass perpendicular to the Inclined Plane, F_y. ***Set up*** the equipment as in Figure 12.2. Set θ to 45°. Place **0.070 kg** on the mass hanger. Hanger mass is 0.005 kg. Vary the angle of the Inclined Plane until the system is in static equilibrium. ***Test*** for static equilibrium. Static equilibrium exists when a light push on the Rolling Mass in one direction causes about the same amount of motion as an approximately equal push in the opposite direction. ***Be sure*** the string from the Rolling Mass is parallel to the Inclined Plane.

7. ***Record*** the mass, ***M'***, and weight, ***W'***, of the hanging mass plus the hanger, and the angle of inclination, ***θ***, of the Inclined Plane. The mass of the mass hanger is ***0.005 kg***. **Include** units.

M' = 0.75 kg; ***W'*** = 0.375 N;
θ = 45° deg

8. ***Set up*** the Spring Scale and a pulley as shown in Figure 12.3. ***Do not move*** the Inclined Plane. ***Adjust*** the pulley and Spring Scale so the string from the Rolling Mass to the pulley is perpendicular to the Inclined Plane. I.e., so the Spring Scale pulls the Rolling Mass bracket at a 90° angle to the surface of the Inclined Plane. The pulley enables you to make the string lifting the Rolling Mass exactly perpendicular to the Inclined Plane. ***Use a protractor*** to ***check*** the angle. ***Move*** the Spring Scale vertically until the Rolling Mass **just barely** lifts off the Inclined Plane. ***Record*** the Spring Scale reading in Newtons (**n**), ***record*** your correction factor from page 12-3, and ***calculate*** the value of the force, F_y (**N**). (TIP: Move the spring balance very, very slowly until the Rolling Mass **just begins** to lift off the Inclined Plane.)

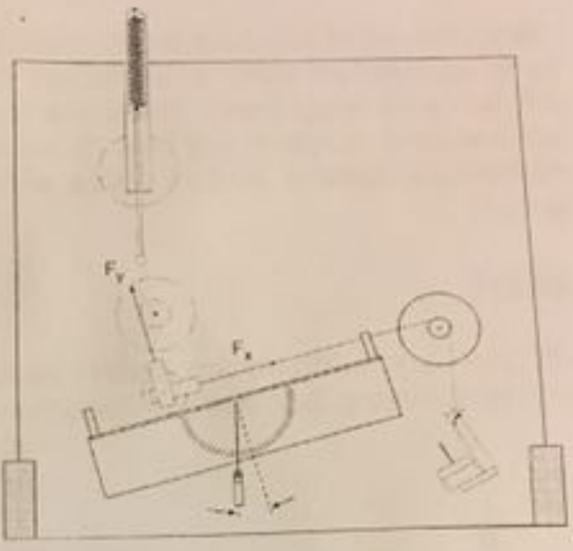

Figure 12.3. Measuring Normal Force

Spring Scale reading = 0.2 N ***Correction factor*** = 0.951 (From page 12-3.)

Corrected force, F_y = 0.19 N

ANALYSIS:

9. ***Calculate*** W_y (=$W\cos\theta$), the component of the weight of the Rolling Mass perpendicular to the Inclined Plane.

W_y = 0.5197 N

10. ***Answer*** question 3.

Part 2:

BACKGROUND:

Class I and Class II levers, like the Inclined Plane, and (as we shall see in Experiment 13) lik pulley systems, enable a reduction in physical force at the cost of a greater distance over whic the force must act. For levers, the two concepts we need for analysis are the conservation energy as shown in equation (12.3) and the concept of torque where torque is to angul acceleration of a body what force is to linear acceleration of the body

$$\vec{\tau} = I\vec{\alpha} = \vec{d} \times \vec{F} \quad \textbf{(12.1}$$

here $\vec{\tau}$ is torque, $\vec{F}$ is force, $\vec{d}$ is distance from the point of action of the force to the center otation, and × indicates a vector cross-product. Thus, torque is the product of a force and ngth of a line, perpendicular to the line of action of the force, from the line of action of the fo the point around which the force causes the body to rotate.

Table 12.2. Friction force and the coefficient of friction.

M	$F_N = W + Mg$	F_f (N) 1st			$\mu = \dfrac{F_f}{W + Mg}$		
(kg)	(N)	A	B	C	A	B	C
0	0.5706	0.1617	0.1568		0.2834	0.2748	
0.050	1.0606	0.343	0.245		0.3234	0.2310	
0.150	2.0406	0.637	0.441	0.245	0.3122	0.2161	0.1201
0.250	3.0206	0.833	0.637		0.2758	0.2109	

5. Repeat Steps 3 and 4 for each of the other three values of ***M*** given in column 1, Table 12.2. Record the normal force, F_N, and friction force, F_f, for each value of added mass.

6. ***Place*** the Friction Block so side B, the narrow wood-surfaced side, is against the Inclined Plane. ***Repeat*** Steps 2, 3, 4, and 5.

7. ***Place*** the Friction Block so side C, the large side with two strips of teflon tape, is against the Inclined Plane. ***Repeat*** Steps 2, 3, and 4. ***Use*** only one value, ***0.150 kg***, for M_1

ANALYSIS:

8. ***Calculate*** the values for μ and ***record*** them in the appropriate cells in the table.

9. Answer questions 13 through 16.

Turn in all pages with data or calculations along with answered questions on the LR pages.

Note: Figures and text taken from PASCO "Introductory Mechanics System." Material used by permission.

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already in motion. We will examine sliding friction. We will test three hypotheses:

Hypothesis: Friction force depends on the normal force.
Hypothesis: Friction force depends on the materials in contact.
Hypothesis: Friction force depends on contact area.

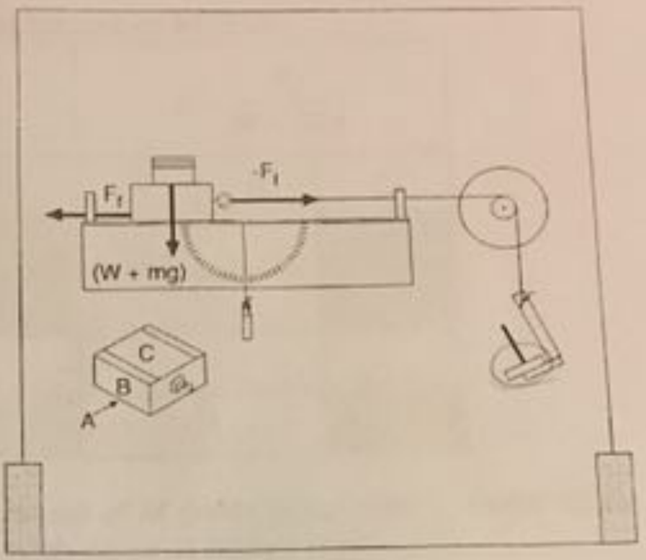

Figure 12.7. Equipment Setup.

PROCEDURE:

1. ***Place*** the Spring Scale vertically on the Experiment Board. ***Zero*** the Scale. ***Hang*** the wooden Friction Block on the Spring Scale. ***Record*** the Spring Scale reading in Newtons (**n**), ***record*** the correction factor determined in Part 1; ***calculate*** and ***record*** the weight, ***W*(N)**, of the Friction Block.

***Spring Scale reading =** .6 N; correction factor = .095; W = .5706 N*

2. ***Set up*** the equipment as shown in Figure 12.7. ***Make*** the Inclined Plane perfectly horizontal using the built-in plumb bob and protractor. Why is this important when measuring friction? ***Adjust*** the position of the pulley so the string is parallel to the Inclined Plane. Why is this important? If you don't know, you do not understand the key elements of this experiment. Ask.

3. ***Measure*** and ***record*** the effective contact areas for sides A, B, and C of the Friction Block. Note: Side A is the large wooden side that is on the bottom in Figure 12.7. Note also: The effective contact area of side C is the area of the two strips of teflon tape.

***Area A =** .0033 m **; Area B =** .0048 m **; Effective Area C =** .00115 m*

4. ***Place*** side ***A*** of the Friction Block against the Inclined Plane. ***Be sure*** the string is parallel to the plane. With no masses added to the Friction Block, ***adjust*** the mass on the hanger until, when you give the Friction Block a small push to start it moving it continues to move at a very slow, constant speed. Note: The friction of the surface of the plane is not perfectly uniform so you are not likely to get the Friction Block to move at a slow, constant speed along the entire length of the plane. A slow constant speed over about 5 cm (~2") is acceptable. When a small push causes the Friction Block to move without accelerating, the force on the hanging mass ($m_{hanging}g$) is equal to the friction force, F_f. ***Record*** the normal force, $W + Mg$ in column 2, Table 12.2. W is the weight of the Friction Block and M is the total mass added to the block. In this case, $M = 0$. ***Record*** the friction force, F_f, in column 3, Table 12.2.

Class III Lever:

PROCEDURE:

11. Place the pivot clip at extreme left end of the beam (farther left than in Figure 12.6). Place the clip for the Spring Scale at the center of mass of the beam. Place the clip for F_1 at extreme right end of the beam (farther right than in Figure 12.6). ***Repeat*** the movements of the Spring Scale and measurements as directed in Step 1. ***Repeat*** steps 2 through 5, and 7 for the Class III lever shown in Figure 12.6. M_1 includes 0.100 kg + hanger mass (0.005kg) + clip mass (0.002kg). You must subtract the weight of the clip and the weight of the beam (m_{beam} = .031kg) from F_2, the Spring Scale reading.

M_1 = 0.1 + 0.02 + .005 = 0.107 kg;
D_1 = 0.14 m; D_2 = 0.28 m.

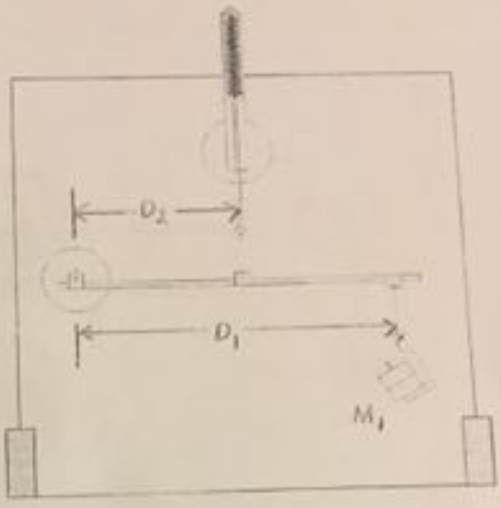

Figure 12.6. Class III Lever.
Use .100kg M_1, D_2/D_1 = .5

Spring Scale reading = 2.15 N; *Corr. Factor* = 0.05 N/n; F_2 = 2.52 N;

d_1 = 0.01 m; d_2 = 0.005 m; $W_1 = M_1 g$ = (0.1 + 0.002 + 0.005)g = 1.05 N.

Subtract the force of gravity on the clip and beam mass (0.031kg) in moving the bar.

Work = $(F_2 - W_{clip} - W_{beam})d_2$ = (2.52 - 0.156 - 0.3038) x 0.005 = 0.009 N;
$\Delta U = W_1 d_1$ = 0.105 N; $W_1/(F_2 - W_{clip} - W_{beam})$ = 0.478; D_2/D_1 = 0.5

ANALYSIS:

2.52 − 0.1466

12. Answer questions 10, 11, and 12.

Part 3:

BACKGROUND:

In most physical systems, the effects of friction are not easily predicted, or even measured. Recall our work in Experiment 7 when we measured, α_f, the deceleration of our rotating disk as a result of friction. α_f was the slope of our angular velocity versus time plot. Recall also our work in Experiment 10, Part 2, in which we determined $m_{friction}$, the "friction mass." $m_{friction}$ was the mass on the hanger that permitted the disk to turn at a constant velocity, with no acceleration, when given a small push. The friction force was given by $m_{friction}g$.

The interactions between objects that cause them to resist sliding against each other seem to be due in part to microscopic irregularities or the surfaces, but they are also in part due to interactions on a molecular level. Although the phenomena are not fully understood, there are some properties of friction that hold for most materials under many different conditions. In this experiment, we will examine the effect of three variables on friction: The normal force pressing the materials together; the contact material; and the contact area. Typically static friction, the force that resists the initial slipping of two objects against one another, is larger than sliding friction, the force that resists the slipping of two objects against each other when they are

Note that we have not considered the mass of the beam acting at the center of mass because the clip for the pivot is at the beam center of mass.

6. ***Answer*** question 4.

7. <u>***Calculate***</u> and <u>***record***</u> $W_1/(F_2\text{-}W_{clip})$ and D_2/D_1. (Remember, D_1 and D_2 are the distances of the action points of the forces, W_1 and F_2, respectively, from the pivot point.) Since you were careful to move the Spring Scale slowly, the system was effectively in static equilibrium at any given instant.

$W_1/(F_2\text{-}W_{clip})$ = 2.031/(1.236 - 0.1062) = 1.6688
D_2/D_1 = 2 .

8. Answer questions 5 and 6.

Class II Lever: D_2/D_1 = 2
<u>PROCEDURE:</u>

9. Figure 12.5 shows a Class II lever. Place the pivot clip as close as possible to the left end of the beam. Place the clip for F_1 (M_1) at the beam center of mass. Place the clip for F_2 (Spring Scale) as close as possible to the right end of the beam. <u>***Record***</u> D_1 and D_2. <u>***Repeat***</u> Steps 1 through 5, and 7 for the Class II lever shown in Figure 12.5. <u>***Include***</u> masses of hanger, clip, and beam (.031kg) in M_1.

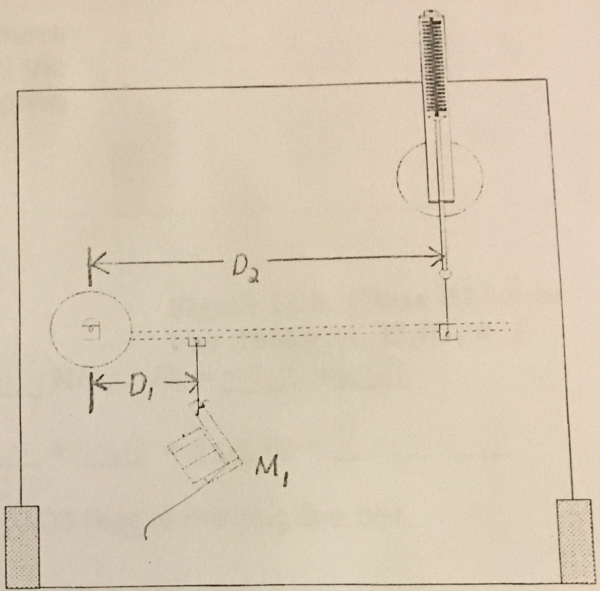

Figure 12.5. Class II Lever.
Use .150kg. Note: D_2/D_1 = 2

M_1 = 0.15 + 0.005 + 0.002 + 0.031 = 0.188 (kg);
D_1 = 0.145 m;
D_2 = 0.29 m; ***Spring Scale reading*** = 1 n; ***Corr. Factor*** = 0.951 N/n; F_2 = 0.951 N
d_1 and d_2 are the distances M_1 and the Spring Scale move respectively.
d_1 = 0.005 m; d_2 = 0.005 (m); $W_1 = M_1g$ = (0.15 + 0.005 + 0.002 + 0.031)g = 1.8424 (N)

In computing the work done by F_2, subtract the work done by the clip as you did above.

Work = $F_2 \times d_2 - M_{clip} \times g \times d_2$ = 0.951 x 0.005 - 0.002 x 9.8 x 0.005 = 0.047 (N·m)
$\Delta U = W_1d_1$ = 0.0092 (N); $W_1/(F_2\text{-}W_{clip})$ = 1.98 N;

<u>ANALYSIS:</u>
10. Answer questions 7, 8, and 9.