Trust | Deliver | Learn

SIMPLE MACHINES
INCLINED PLANE

CAT NO. WDSM10

Experiment Guide

GENERAL BACKGROUND :

There are six simple machines that all other machines are made out of. Even complex machines like an automobile really consist of simple machines that all convert energy in order to do work. Machines are used to make work easier. Here work is defined as a force applied over a given distance. The force applied and the distance traveled must be in the same direction.

Simple machines can either change the direction the force is applied, or increase the mechanical advantage by doing the same amount of work over a longer distance and therefore decreasing the amount of force needed.

Mechanical advantage is a way of measuring how much easier it is to do work or how much less force is required. Written as a formula:

$$\text{Mechanical Advantage} = \frac{\text{Output force (load)}}{\text{Input force (effort)}}$$

The load is the amount of force or weight that is being lifted.
The effort is the amount of force or weight being applied to the rope in order to move the load.

The six simple machines are pulleys, levers, wedges, inclined planes, screws and wheels & axles. Compound machines have two or more simple machines that when used together make work easier.

A pulley is a variation of a wheel and axle in which a rope or cord is stretched over a wheel to make it rotate as the rope is pulled. Pulleys are used to raise and lower flags, on oil derricks, to raise, lower, and adjust sails on a sailboat, and to pull open or close curtains. A single pulley can change the direction that a force is needed to be applied in order to make doing work more convenient. A combination of several pulleys can make it easier to do work, by applying a smaller force over a larger distance mechanical advantage is gained.

Levers are in use when a long stiff object, like a post or board rests on a fulcrum. The fulcrum is simply the pivot point on which the board or post rests. The pivot point does not undergo any translational motion (it doesn't move). The lever lifts a load by applying an effort force. The arrangement of the effort, load and fulcrum determines the “class” of levers. There are three classes of levers.

In first class levers as shown in diagram 1:

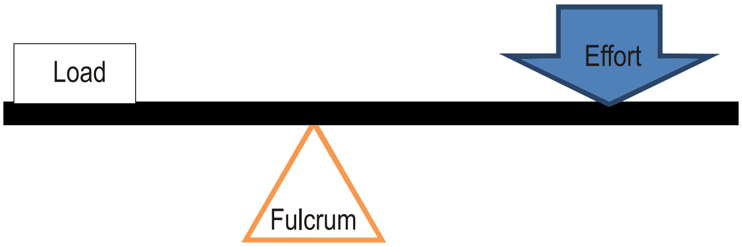

Diagram 1

Examples of class one levers are a teeter totter or see-saw, a catapult, scissors, or a crowbar.

In class two levers as shown in diagram 2:

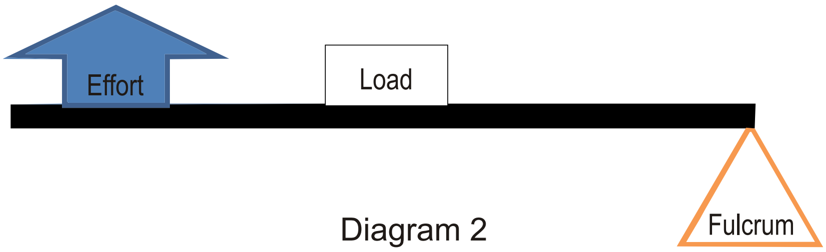

Diagram 2

Examples of class two levers are wheel barrows, shovels and nutcrackers.

In class 3 levers as shown in diagram 3:

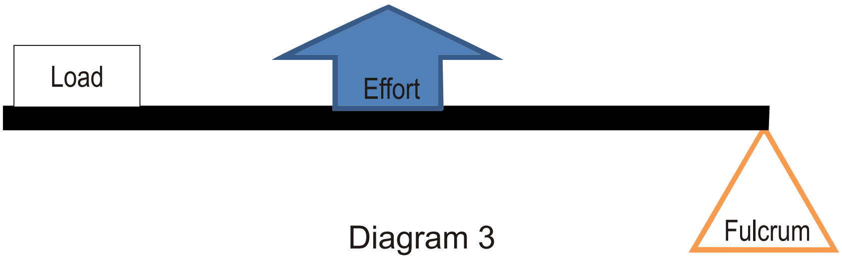

Diagram 3

A fishing pole, your arm, or tweezers are good examples of class three levers.

If the distance between the effort and the fulcrum is smaller than the distance between the load and the fulcrum, we will be able to apply less force to lift a heavier object. This is true in class 1 and class 2 levers.

A wedge is a simple machine that changes the direction of a force. The force applied is usually perpendicular to the force acting on the object. Examples of wedges are door stops, nails, axes, teeth (incisors, not molars), pins, a chisel.

Wheels and axles increase mechanical advantage, by covering a longer distance using less force. The larger the wheel the greater the mechanical advantage. When bikes were first invented, many inventors tried to increase the mechanical advantage of the bike by increasing the size of the wheel that was being rotated.

As a wheel turns the distance traveled by the one rotations of the wheel is directly proportional to the diameter of the wheel. For the penny farthing bike one rotation of the petal equals one rotation of the bike's wheel. However the distance covered by the person's foot is much smaller than the distance covered by the bike’s wheel. Examples of wheels and axles include bike tires, car tires, wind mills, and steering wheels.

Inclined planes also increase mechanical advantage by increasing the distance traveled and decreasing the amount of force applied. Examples of inclined planes include ramps, hills, ladders, stairs and the backs of dump trucks.

Screws are really just inclined planes wrapped around a post as shown in diagram 4. Examples of common screws are screw top jar lids, drill bits, meat grinders, corkscrews, swivel stools, and of course, screws.

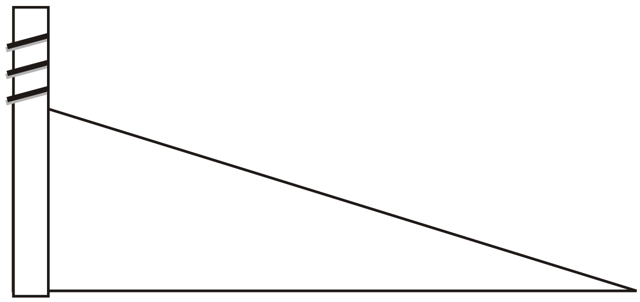

Diagram 4

REQUIRED COMPONENTS (INCLUDED)

Name of Part	***Quantity***
Triangle shaped wedge	1
Incline plane base	1
Blue trolley with string attached to the blue mass	1

REQUIRED COMPONENTS (NOT INCLUDED)

Name of Part	***Quantity***
Small masses (pennies, small weights)	15
Ruler	1
Protractor	1

ACTIVITY 1: MOVING WITH LESS EFFORT (TEACHER ANSWERS)

Let's say that you own a moving business and want to lift a 100 N box on the back of a truck, 1.0 meter off the grown as shown in diagram 5, but you can only pull or push with a force of 50N. How could you get the box into the truck?

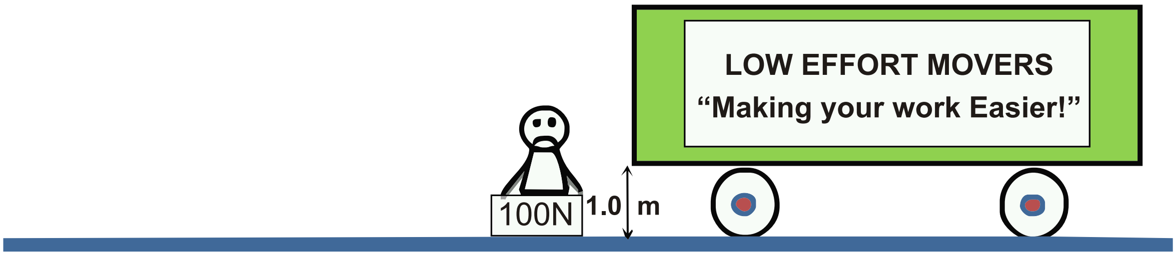

Diagram 5

If you use a frictionless ramp (aka inclined plane) to help you move your box, you will need to push your box up two meters of ramp, but you will be able to push with only 50 N and therefore be able to push your box to the top of the truck.

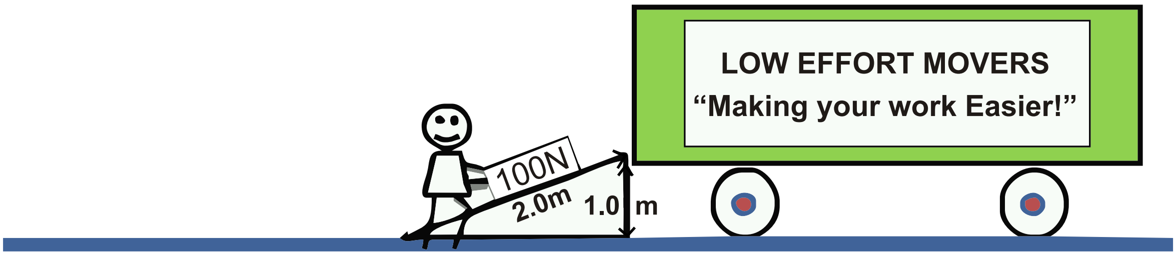

Diagram 6

The work done in diagram 5 is the force applied by the distance traveled:
Work = Force x distance = 100 N x 1.0 m = 100 J

The same amount of work is done in diagram 6, however the distance traveled is twice as far, so the force is half as much.

Work = Force x distance = 50 N x 2.0 m = 100 J

Therefore the mechanical advantage of the ramp is:

$$\text{Mechanical Advantage} = \frac{\text{Output force (load)}}{\text{Input force (effort)}} = \frac{100\ \text{N}}{50\ \text{N}} = 2$$

Now in real life, a ramp is rarely frictionless, so reduce the effect of friction; movers usually use a dolly with wheels on it. In this apparatus, the friction is also reduced with a trolley with wheels on it.

PROCEDURE:

Diagram 7

1. Set up your inclined plane as shown in diagram 7. The blue block represents the maximum amount of force you can apply to move your boxes onto your truck. The blue cart represents the boxes on a dolly. The triangle shaped wedge will help you adjust your ramp height.

2. Move the triangle wedge left or right to find the steepest slope the ramp can be set at and the "boxes on the dolly" (the blue trolley) will move up the ramp. You may need to give your trolley a little nudge to see if it will go up the ramp. It does get stuck a little bit do to friction.

3. Let's pretend that the height of your truck bed off of the ground is 8 cm. Hold your ruler perpendicular to the base of the inclined plane as shown in diagram 8. Find the spot on the ramp where you will have lifted the boxes (blue trolley) 8.0 cm.

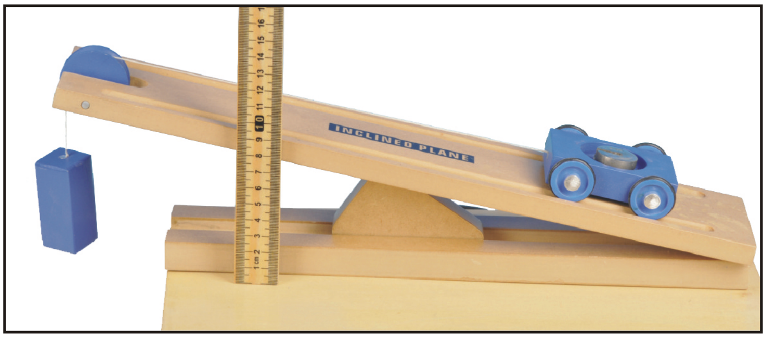

Diagram 8

4. Now measure and record the length of the ramp needed to lift the trolley 8.0 cm.
   (15 cm)

5. Now try to move a heavier package. Increase the weight of your boxes by adding some extra weight to your blue trolley (I used 15 pennies, but anything heavy that will stay in the cup of the trolley will work.)

6. Adjust the height of your ramp again so that the boxes just start moving up the incline, you may need to give your cart a gentle nudge.

7. Compare the steepness of the slope for the lighter set of boxes to the steepness of the slope for the heavier set of boxes.

   (The lighter boxes could use a steeper slope than the heavier boxes.)

8. Again hold your ruler perpendicular to the base of the inclined plane as shown in diagram. Find the spot on the ramp where will have lifted the boxes (blue trolley) 8.0 cm.

9. Now measure and record the length of the ramp needed to lift the trolley 8.0 cm.

   (32 cm)

QUESTIONS:

1. Finish this sentence: As the mass of the boxes being lifted by the same force increases, the length of the ramp *(increases).*

2. If I wanted to use the least amount of force possible to move boxes into my truck, would I prefer the longest ramp I have, the shortest ramp I have, or a ramp somewhere in the middle?

   (The longest ramp would allow me the greatest mechanical advantage.)

3. There are several simple machines in this apparatus, give an example of at least three.

   (There is a pulley that helps to pull the trolley up the inclined plane. There are wheels and axles on the trolley, and there is a wedge to adjust the height of the inclined plane and obviously the ramp is an inclined plane, also the wedge provides an effort force that lifts the incline plane, and the base of the incline plane is a fulcrum, so the ramp itself is also a lever as its height is being lowered and raised.)

4. Which ramp had a greater mechanical advantage, the longer ramp, or the shorter ramp? Justify your response.

   (The longer ramp has a greater mechanical advantage. The steeper the slope, the greater the force needed to raise the boxes up the incline. The longer ramp had a gentler slope and therefore needed less force to raise the boxes up the incline, so the mechanical advantage was greater.)

NAME:________________________________ DATE:____________

ACTIVITY 1: MOVING WITH LESS EFFORT

Pre-Lab:

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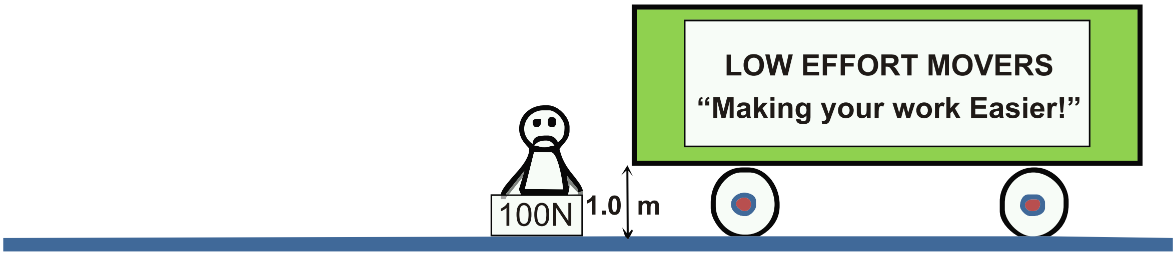

Diagram 5

If you use a frictionless ramp (aka inclined plane) a to help you move your box, you will need to push your box up two meters of ramp, but you will be able to push with only 50 N and therefore be able to push your box to the top of the truck.

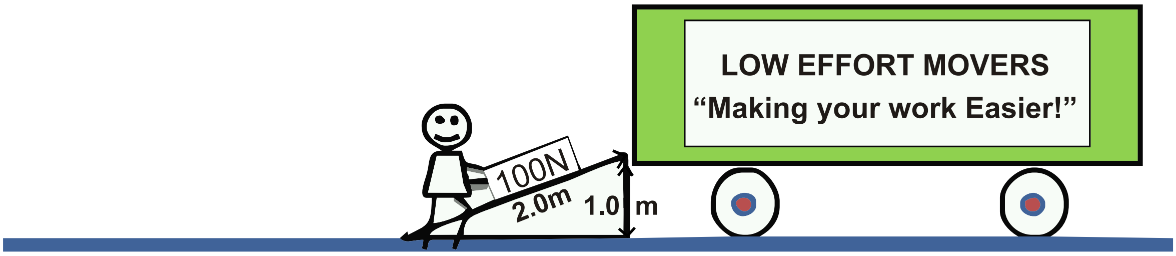

Diagram 6

The work done in diagram 5 is the force applied by the distance traveled:

Calculate the work done using the formula below:

Work = Force x distance =

The same amount of work is done in diagram 6, however the distance traveled is twice as far, so the force is half as much. Calculate the work done in diagram 6. Show all work including formula and substitution with units.

Therefore the mechanical advantage of the ramp is:

$$\text{Mechanical Advantage} = \frac{\text{Output force (load)}}{\text{Input force (effort)}} =$$

Now in real life, a ramp is rarely frictionless, so reduce the effect of friction; movers usually use a dolly with wheels on it. In this apparatus, the friction is also reduced with a trolley with wheels on it.

PROCEDURE:

1. Set up your inclined plane as shown in diagram 7. The blue block represents the maximum amount of force you can apply to move your boxes onto your truck. The blue cart represents the boxes on a dolly. The triangle shaped wedge will help you adjust your ramp height.

Diagram 7

2. Move the triangle wedge left or right to find the steepest slope the ramp can be set at and the “boxes on the dolly” (the blue trolley) will move up the ramp. You may need to give your trolley a little nudge to see if it will go up the ramp. It does get stuck a little bit do to friction.

3. Let's pretend that the height of your truck bed off of the ground is 8 cm. Hold your ruler perpendicular to the base of the inclined plane as shown in diagram 8. Find the spot on the ramp where you will have lifted the boxes (blue trolley) 8.0 cm.

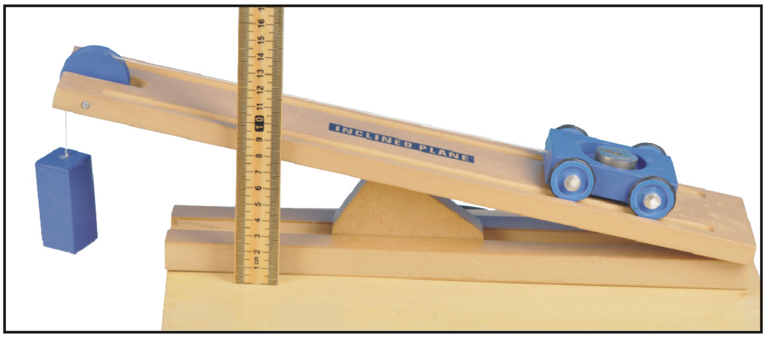

Diagram 8

4. Now measure and record the length of the ramp needed to lift the trolley 8.0 cm.

5. Now try to move a heavier package. Increase the weight of your boxes by adding some extra weight to your blue trolley.

6. Adjust the height of your ramp again so that the boxes just start moving up the incline, you may need to give your cart a gentle nudge.

7. Compare the steepness of the slope for the lighter set of boxes to the steepness of the slope for the heavier set of boxes in the space provided.

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8. Again hold your ruler perpendicular to the base of the inclined plane as shown in diagram 8 and find the spot on the ramp where will have lifted the boxes (blue trolley) 8.0 cm.

9. Now measure and record the length of the ramp needed to lift the trolley 8.0 cm.

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QUESTIONS:

1. Finish this sentence: As the mass of the boxes being lifted by the same force

   increases, the length of the ramp ______________________.

2. If I wanted to use the least amount of force possible to move boxes into my truck, would I prefer the longest ramp I have, the shortest ramp I have, or a ramp somewhere in the middle?

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3. There are several simple machines in this apparatus, give an example of at least three.

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4. Which ramp had a greater mechanical advantage, the longer ramp, or the shorter ramp? Justify your response.

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ACTIVITY 2: FRICTION OF EVERYDAY OBJECTS (TEACHER ANSWERS)

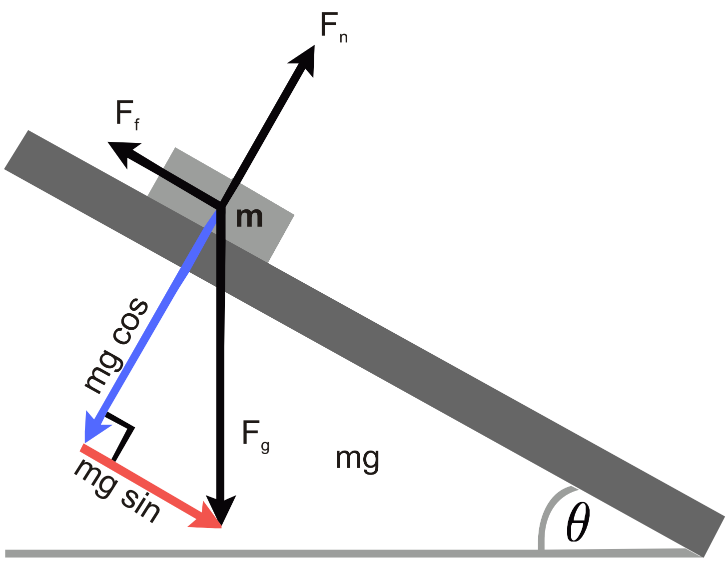
In this experiment, you will use the inclined plane to compare the coefficient of static friction for a variety of objects. Friction is a force that occurs when two objects are in contact with each other. Friction always opposes motion and so friction always acts in the direction opposite to that which the objects are trying to move with respect to one another. How strong this friction force is depends on the materials the two objects in contact are made out of. Each material combination has a different "co-efficient of friction", which is a fancy way of saying that how "sticky" or "slippery" two objects are when slid across each other.

Remember that when you are doing work, the distance traveled and the force applied need to be in the same direction. The force of friction is always pushing opposite the direction you are trying to go. If you are pushing with 10 Newtons to move an object and friction is pushing back on you with 3N, then the object will move as if you were only pushing with 7 Newtons of force. Friction robs you of energy. In some cases, this is good, like if you want to slow down in your car while applying breaks; however, we often try to reduce friction so we don't have to apply as much force to do work. If we move our object 1.0 meters then we have done 10 Joules of work. The amount of work done against friction was 3.0 N x 1.0 meters = 3 Joules and therefore only 7 Joules of work was done on our box.

The steeper the slope on an inclined plane, the easier it is for something to slide off of that slope. The stickiest objects should be able to stay on the slope even when the slope is steep, and the slickest or slipperiest objects should start to slide down the slope when the slope is at a small angle.

Although this may be a bit advanced for some students, here is mathematically how static friction is related to the angle of incline on a plane.

Here is a free body diagram of the forces exerted on one of the objects in the experiment. The components of the force of gravity is resolved into components parallel and perpendicular to the plane of the surface.



The sum of the forces in any direction is equal to the mass times the acceleration in that direction. The object never leaves the plane of the board so the acceleration in the perpendicular direction is always zero:

$$F_n = mg \cos \quad = 0$$

Where “F_n” is the normal force, “m” is the mass of the sliding object, “g” is acceleration due to gravity and “ ”is the incline of the ramp.

<u>For the direction parallel to the plane of the board, we find:</u>

$$mg \sin \quad - F_f = 0$$

Where “F_f” is the maximum force of friction.

The maximum value of static friction is $F_f = \; _sF_n$

Where “ $_s$” is the co-efficient of static friction.

Therefore:

$$F_n = mg \cos$$

$$_sF_n = mg \sin$$

If we divide the top equation into the bottom equation, we eliminate mass, the normal force, and the gravitational constant and find:

$$_s = \tan$$

Therefore, the co-efficient of static friction is dependent only on the tangent of the angle of incline. Since the angle of incline can only be from 0 to 90 degrees, as the angle of incline increases, the co-efficient of static friction increases as well. Mass of the object and surface area of the object sliding down the incline have no effect on the angle each object reaches before sliding down the ramp.

We will rank four or five objects by their co-efficient of friction by assuming that the greater the angle the incline plane can reach before the object begins to slide, the greater the co-efficient of friction.

HYPOTHESIS:

What objects will you use in your experiment? List them below according to what you predict their coefficient of static friction with the inclined plane to be (highest to lowest). One object should be a wooden block and one object should be your trolley.

Highest co-efficient of static friction

Penny

Trolley

Wooden block

Playing Card

Low coefficient of static friction

PROCEDURE:

1. Pick four or five objects made of different materials to measure (erasers, calculators, pads of paper, shoes, etc...). At least one object should be the trolley and another object should be the wooden block.
2. Lay the plane flat on the table, setting the angle to zero degrees.
3. Place an object on the inclined plane.
4. Slowly increase the inclined plane's angle by pushing the triangle wedge towards the end of the incline plane, trying to raise the plane as smoothly as possible.
5. Determine and record the angle at which the object begins to slide by measuring the angle that the inclined plane makes with the base of the incline plane. Try to avoid jostling the inclined plane. As soon as the object begins to slide, lower the plane slightly until it stops and then raise it again and check that it slides again at the same angle.
6. Repeat steps 3-4 for each of your chosen objects.

DATA:

Record the minimum angle at which each object slides on the inclined plane in the table below.

Object	***Angle (degrees)***
Trolley	4
Penny	19
Wooden Block	22
Playing Card	28

QUESTIONS:

1. Restate your hypothesis and then compare your hypothesis to your results. What were you right about? Did any results surprise you?

   (I thought the trolley with the rubber wheels would have the more friction, but the trolley started to roll down the inclined plane much sooner than the other objects. I guess the wheels really do decrease the amount of friction. The lowest co-efficient of friction was the trolley, followed by the penny, the wooden block and the playing card.)

2. If you wanted to pull a box up your incline plane on each of your four or five materials, which material would require the most force as you pulled it up your incline plane? Justify your answer using your data table.

(The playing card had the greatest angle before it started sliding, which was 28 degrees, and therefore the playing card had the greatest co-efficient of friction. It would take the most force to push my box up the ramp on a playing card.)

3. What does the phrase “doing work against friction” mean when talking about pushing a box up a ramp?

(It takes energy to overcome friction. When pushing a box up a ramp, friction pushes in the opposite direction. If friction is pushing on the box with 10 N and you need 50N of force to push the box up the ramp, then you really have to push with 60N to get the box up the ramp. That extra 10N times the distance traveled is the extra work you had to do to overcome friction.)

4. A rubber tub has a higher co-efficient of friction than a plastic tub. If you pushed a rubber bath tub weighing 20 Newton and a Plastic crate weighing 20 Newtons up an incline plane, which object is easier to push up the incline plane? Why?

(The plastic crate is easier to push up the incline plane because it has less friction pushing against me as I'm trying to move the objects up the ramp.)

5. Mechanical Advantage is the ratio of effort force used, to the amount of load force (Load force is how much the object weighs.) How would pushing something up a ramp with a high co-efficient of friction effect the mechanical advantage you gain by using a ramp?

(Something with a large friction force would increase the amount of force I would have to use to push something up my ramp. If my effort force is greater, than my mechanical advantage would be lower, so a large friction force would reduce my mechanical advantage.)

6. For your moving company, what kinds of materials would you use to slide up your ramp? Materials with a high or low co-efficient of friction? Justify your answer.

(I would use materials with a low co-efficient of friction because then I could use less effort to move things up the ramp.

7. Explain to your movers why using a dolly with wheels would make it easier to load packages into your truck. Use examples from your experiment to justify your answer.

(The dolly with wheels would make it easier to do work. The trolley on wheels had the lowest co-efficient of friction out of all the objects tested in my experiment. Rolling has much less friction than sliding. The lower the friction force, the greater the mechanical advantage of using a ramp because the friction force causes us to use more force and more effort to lift our boxes. We want to use the least amount of force possible to lift our boxes onto our truck and a dolly will help us do just that.)

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