# What is a Mouse-Trap Car and How does it Work?

A mouse-trap car is a vehicle that is powered by the energy that can be stored in a wound up mouse-trap spring. The most basic design is as follows: a string is attached to a mouse-trap's lever arm and then the string is wound around a drive axle causing the mouse-trap's spring to be under tension. Once the mouse-trap's arm is released, the tension of the mouse-trap's arm pulls the string off the drive axle causing the drive axle and the wheels to rotate, propelling the vehicle. This most basic design can propel a vehicle several meters for any first-time builder. But in order to build vehicles that can travel over **100 meters** or extreme speed cars that can travel **5 meters in less than a second,** you must learn about some of the different variables that affect the performance of a mouse-trap car. For example, how does friction affect the overall distance that a vehicle can travel? How does the length of the mouse-trap's lever arm affect the performance? By reading each section of this book you will learn about many of the different variables that will affect a vehicle's performance. Also you will learn how to modify different variable in order to build a top performing vehicle.
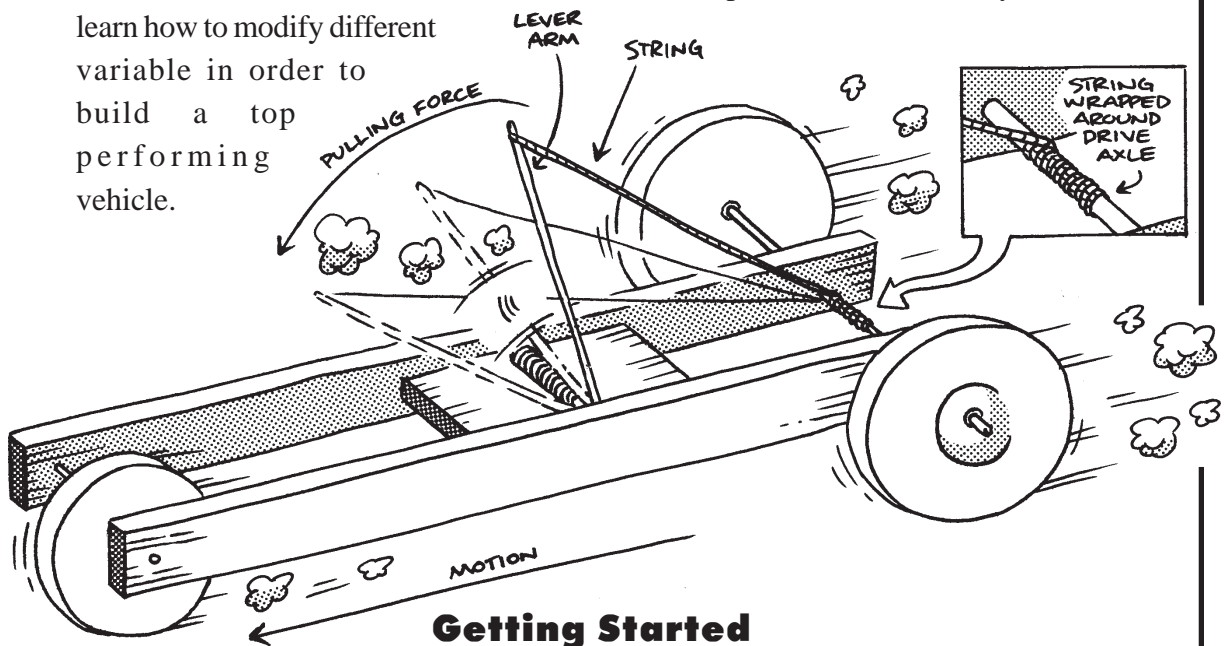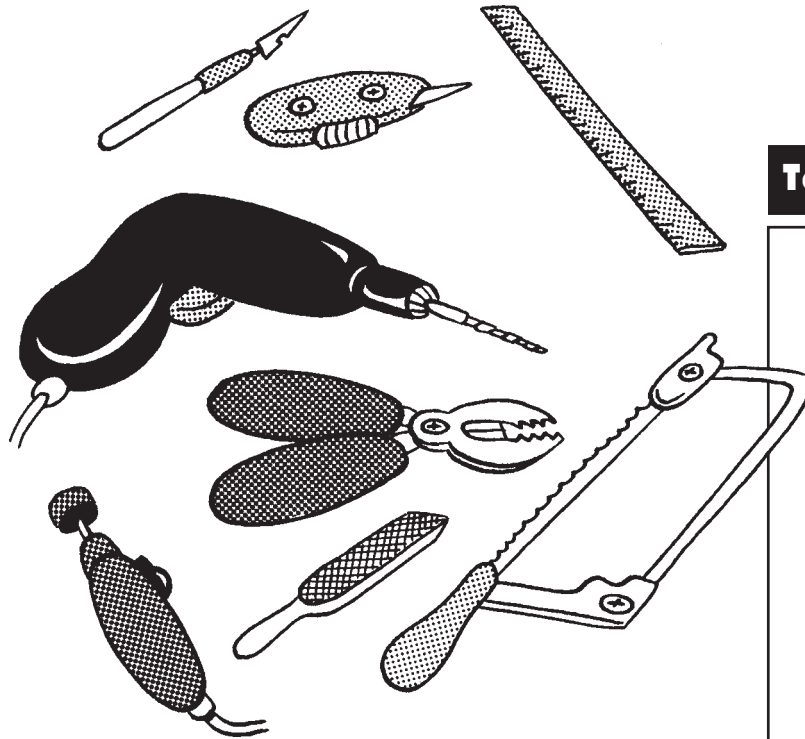
Getting Started

Why build a mouse-trap car? Building mouse-trap cars allows you to experience the process of design and engineering first-hand. When you build a vehicle, you have to start with an ideas and then turn that idea into a real-life model that works. Building a mouse-trap car is an advanced form of problem solving with two main ingredients:

1. **You don't know what the problems are.** *Many of the problems in building a mouse-trap car will be discovered and solved as you go along; each person's challenges will be different.*

2. **There is never one right answer!**

One last thought before we get started. Throughout the construction of your car, you will have to deal with tradeoffs. For example, building a car that accelerates quickly usually means sacrificing fuel efficiency. When applying any of the ideas and hints in this book to the construction of a mouse-trap car, understand that any extreme exaggeration of just one varible may have a large negative effect on the performance of your vehicle. **It is best to find a harmonious balance between each varible through repeated experimentation.** Experimentation is essential in order to achieve maximum performance. Experiment often and early, don't worry about making mistakes! Making a mistake is alearning experience. Keep in mind you will not know many of the problems until you encounter them as you build your car. Engineering is a process by which ideas are tested and re-tested in an effort to produce the best working product. A good engineer knows one way to get something to work and 99 ways it won't work. **Do not be afraid to try your different ideas; your tested ideas will lead you to success!** Also, by understanding the basic conceptual physics concepts presented in this book, you will be able to make good decisions about building the perfect car. **Don't delay, get started!**

Getting Started

Almost any materials can be used in the construction of a good mouse-trap car. It is up to the designer to determine the appropriate application of such materials. Sizes, lengths, diameters, widths, and kinds of materials are more-or-less left up to the designer. The human imagination is a wonderful gift, and our own ingenuity allows us to take ordinary objects with functions different from what were intended and turn them into components of a working machine. For example, a compact disc is a good device for storing information and playing it back, but it also makes a great wheel. Good luck!

Tools of the Trade

- *Dremel Tool*
- *Hobby Knife*
- *Files*
  - *Round*
  - *Square*
  - *Knife*
- *Power Drill*
- *Drill Bits*
- *Glue*
  - *Super Glue*
  - *Wood Glue*
  - *Hot Glue*
  - *Rubber Cement*
- *Coping Saw or Hack Saw*
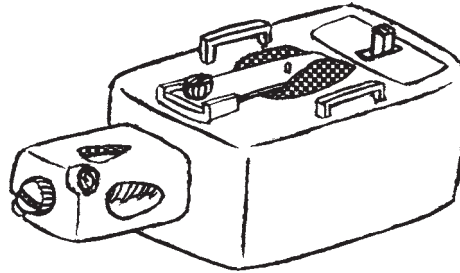- *Pliers*

Getting Started

Lab #1 - Chasing the Mouse

Purpose

To analyze the motion of a mousetrap powered vehicle over 5 meters.

Equipment Needed

Ticker Timer
Ticker Tape
Meter Stick
Stopwatch

Discussion

In this experiment you will collect data from your mousetrap car using a ticker timer. A ticker timer is a device that makes marks on a ticker tape at equal intervals of time. A long piece of ticker tape will be attached to the back of your mousetrap vehicle. As your vehicle is in motion the ticker timer will leave a series of marks on the tape that is attached to your vehicle. Because the time between each mark is the same, a variety of variables can be measured and calculated from the position of each mark. I recommend analyzing the motion of your car over a five meter distance. After your vehicle has made its run, you will be measuring the distance from the first mark to each of the following marks. Velocity is the rate at which your vehicle is covering distance. The greater the rate, the more distance that is being covered per time. The average velocity is the travel distance divided by the travel time. The actual velocity at each mark is calculated from the average velocity by using Formula #2 from the list of formulas. Acceleration is the rate at which your vehicle is changing velocity. In order to find the acceleration you will have to first find the change in velocity between each point using Formula #3. By dividing the change in velocity for each interval, you will calculate the acceleration between each mark (Formula #4).

Motion

d = distance
v = velocity
t = time
a =acceleration

Formulas

Formula #1: $\bar{v} = \dfrac{\Delta d}{\Delta t}$ $\bar{v} = \dfrac{d_{t_f} - d_{t_0}}{\Delta t}$

Formula #2: $\bar{a} = \dfrac{\Delta v}{\Delta t}$ $\bar{a} = \dfrac{v_{t_f} - v_{t_o}}{\Delta t}$

Using a Stopwatch: Alternative Approach

I suggest timing the vehicle over 5 meters if you plan on using a ticker timer, but if you have a long-distance car that travels great distances, you should not use the ticker timer because the vehicle will become too heavy by pulling of the long ticker tape. You can collect data with an alternative approach: Mark out the floor with masking tape every meter or two meters, depending on the distance that your car will go. Using a stopwatch that can handle split times, walk along side your mousetrap car and call out the time at each mark on the floor. A partner should be recording the times as you relay them using the split-time function. Calculations are the same, but realize that in this example the distance was held constant and not the time.
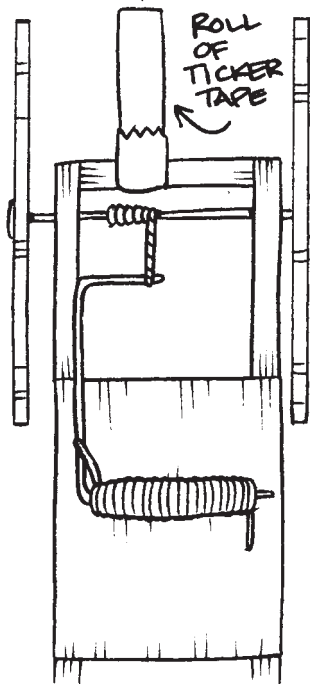
Please take note: It is assumed that the experimenter uses standard S.I. units for all activities.

Motion

The Set-up

CARBON PAPER

TAPE TIMER

40 ↑ 10
OFF
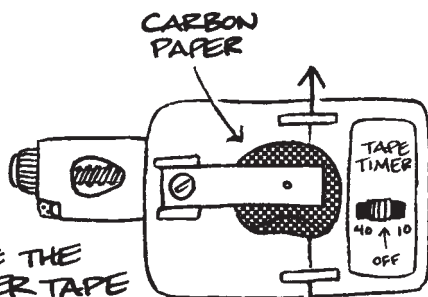
TAPE THE TICKER TAPE TO THE BACK OF THE CAR AND INSERT IT INTO THE TAPE TIMER AS SHOWN →

ROLL OF TICKER TAPE

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Label one end of the tape as the front. Thread the ticker tape through the timer and attach the front of the tape to the rear of the car using a small piece of tape. Position the tape such that the tape does not get tangled with your vehicle's operations during the timing.
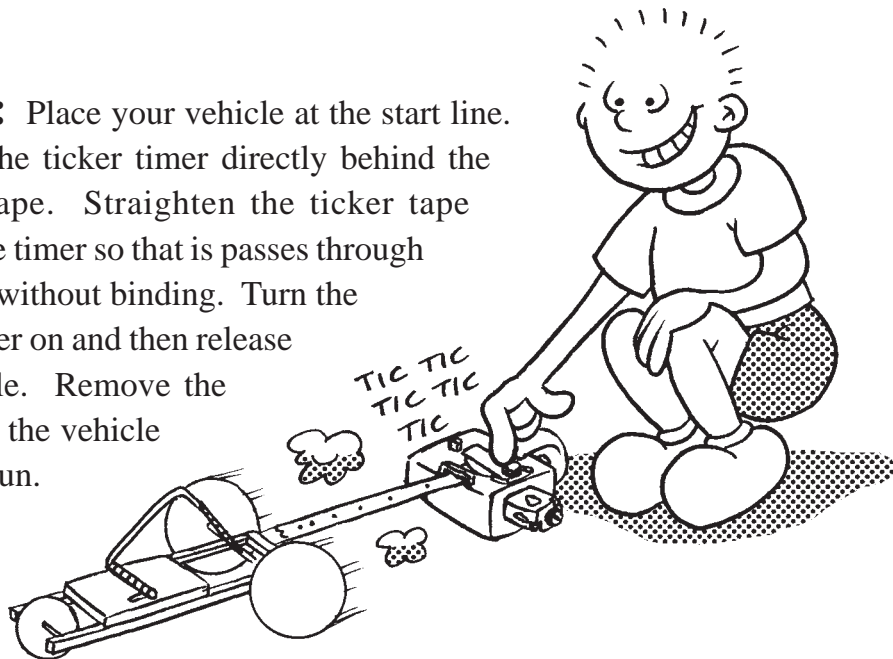
Motion

Ticking Away the Time

Step 1: Determine the distance for which the data will be collected. Tear off enough ticker tape to cover the distance of the timing.
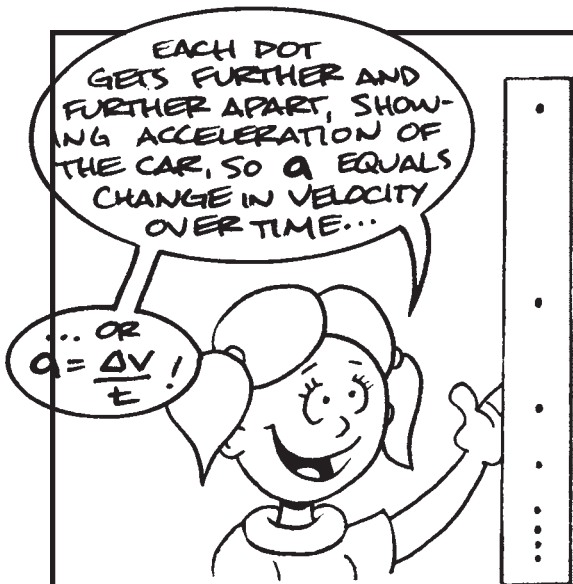
Step 2: Select or determine the frequency of the ticker timer. The frequency of the ticker tape determines the time between each mark. If the frequency is 10Hz, the time between marks is 0.1s. If the frequency is 60Hz, the time between marks is 1/60 s. Record this frequency in your data table under "time."

Step 3: Label one end of the tape as the front. Thread the ticker tape through the timer and attach the front of the tape to the rear of the car using a small piece of tape. Position the tape such that the tape does not get tangled with your vehicle's operations during the timing.

Step 4: Place your vehicle at the start line. Line up the ticker timer directly behind the vehicle tape. Straighten the ticker tape behind the timer so that is passes through the timer without binding. Turn the ticker timer on and then release the vehicle. Remove the tape from the vehicle after the run.

EACH DOT GETS FURTHER AND FURTHER APART, SHOWING ACCELERATION OF THE CAR, SO **a** EQUALS CHANGE IN VELOCITY OVER TIME...

... OR $a = \frac{\Delta v}{t}$!

Step 5: From the front of the ticker tape, darken each mark and label as follows: t_0, t_1, t_2, t_3, t_4, t_5, …t_n.

Step 6: Design a data table where you can record the following: total time (t), distance between marks (Δd), total distance (d), velocity at mark (v_f), change in speed from previous mark (Δv), acceleration between marks (a).

Data Table #1

Total Time	Change in Time	Change in Distance	Total Distance	Change in Velocity	Acceleration
$t_1=$	$t_{0,1}=$	$\Delta d_{0,1}=$	$d_1=$	$v_{f,1}=$	$a_{0,1}=$
$t_2=$	$t_{1,2}=$	$\Delta d_{1,2}=$	$d_2=$	$v_{f,2}=$	$a_{1,2}=$
$t_3=$	$t_{2,3}=$	$\Delta d_{2,3}=$	$d_3=$	$v_{f,3}=$	$a_{2,3}=$

Step 7: Measure the distance from the first mark (t_0) to the second mark (t_1) and record this as ($t_{0,1}$) distance between marks ($\Delta d_{0,1}$). Measure the distance from the second point to the third mark and record this as t_2 distance between marks ($\Delta d_{1,2}$). Measure the distance between each of the following marks and record as the distance between marks ($\Delta d_{2,3}$, $\Delta d_{3,4}$, $\Delta d_{4,5}$ …Δd_n).

Step 8: Add the change in distance between $d_{0,1}$ and record as d_1 total distance. Add the change in distance between $d_{0,1}$ and $d_{1,2}$ and

Recommendations
Try to set-up a **spread sheet** *on a computer in order to handle your data more* **efficiently**.

Motion

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$d_{1,2}$ and record as d_2 total distance. Add the total distance between $d_{1,2}$ and $d_{2,3}$ and record as d_3 total distance. Continue this approach until you have the total distance from each mark to the first point.

Step 9: From equation #1 find the average change in velocity between each point or mark on your ticker tape using the following equation:

$$\overline{v} = \frac{\Delta d}{\Delta t}$$

$$\overline{v}_{0,1} = \frac{\Delta d_{0,1}}{\Delta t_{0,1}} \quad , \quad \overline{v}_{1,2} = \frac{\Delta d_{1,2}}{\Delta t_{1,2}} \quad , \quad \overline{v}_{2,3} = \frac{\Delta d_{2,3}}{\Delta t_{2,3}}$$

Record as change in velocity at mark $v_{0,1}, v_{1,2}, v_{2,3}, \ldots v_n$.

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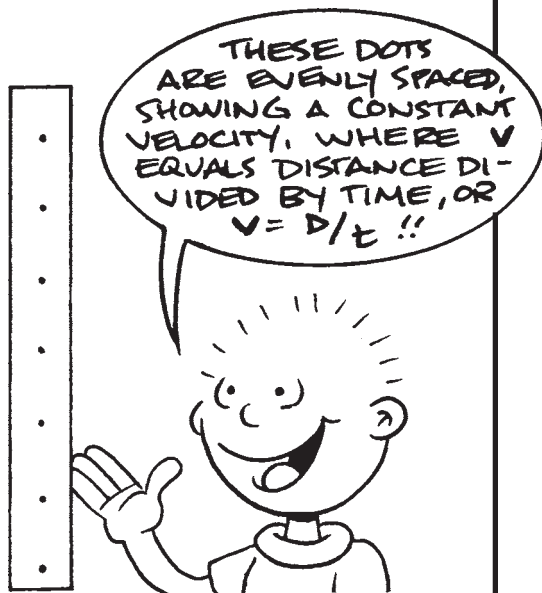**Step 10:** Calculate the acceleration using formula #2 and record as follows:

$$\overline{a} = \frac{\Delta v}{\Delta t} \quad , \quad a_{01,} = \frac{\overline{v}_1 - \overline{v}_0}{\Delta t_{0,1}}$$

$$a_{1,2} = \frac{\overline{v}_2 - \overline{v}_1}{\Delta t_{1,2}} \quad , \quad a_{2,3} = \frac{\overline{v}_3 - \overline{v}_2}{\Delta t_{2,3}}$$

Record as acceleration between marks as
$a_{0,1}, a_{1,2}, a_{2,3}, \ldots a_n$.

Motion

THESE DOTS ARE EVENLY SPACED, SHOWING A CONSTANT VELOCITY, WHERE V EQUALS DISTANCE DIVIDED BY TIME, OR V = D/t !!

Graphing the results

You will now graph your data in order to learn from your results. In each of the following graphs attempt to draw a "best fit" line. If data is widely scattered do not attempt to connect each dot but instead draw the best line you can that represents the shape of the dots. If you have access to a computer you can use a spread sheet like Microsoft Exel to plot your data.

1. Graph **Total Distance** on the vertical axis and **Total Time** on the horizontal.

2. Graph **Velocity Final** at each point on the vertical axis and **Total Time** on the horizontal.

3. Graph **Acceleration** on the vertical axis and **Total Time** on the horizontal.

Analysis

1. Identify the time intervals where your vehicle had the maximum positive and negative acceleration. Where did your vehicle have the most constant acceleration?

2. What was the vehicle's maximum speed over the timing distance and at what point did this occur?

3. How far was your vehicle pulled by the string? From the graph is it possible to determine when the string was no longer pulling the vehicle? Explain.

4. Compare your performance to the performance of other vehicles in the class and discuss how yours relates.

Purpose

To determine the amount of rolling friction acting against your mousetrap car and the coefficient of friction.

Materials

Ruler (A caliper works better for smaller measurements.)
Smooth Ramp
Tape Measure

Variables needed from other labs

Total Potential Energy from Lab #5

Discussion

Friction is a force that acts against the motion of all moving objects. Energy is required to overcome friction and keep an object moving. Mousetrap cars start with a limited supply of energy. This energy is used to overcome friction and propel the vehicle. The less friction acting against a moving mousetrap car, the less energy that is consumed to friction and the further that the vehicle will travel. A moving mousetrap car is affected by two type of friction: airfriction and bearing friction. Airfriction is a large factor only with cars that are moving fast and is nearly negligible for slow-moving distance cars; therefore, in this lab you will only take bearing friction into consideration. Bearing friction is actually caused by two surfaces rubbing against one another. The amount of friction depends on the materials that are doing the rubbing and the force pressing them together (Formula #3). In this lab you will find the combined force of friction from all bearings on your vehicle. This combined frictional force will be called the rolling friction. The smaller the coefficient of friction, the more efficient your mousetrap car and the greater the travel distance will be.

Rolling Friction

The Set-up

Finding the theoretical rolling friction requires placing your mousetrap car on a smooth and flat board or ramp. The ramp will be elevated from one end slowly until your mousetrap car "JUST" begins to roll at constant velocity. This point or angle is where the force pulling the car down the ramp is equal to the force of rolling friction acting against the car (Formula #2). The force pulling the car down the ramp is a combination of two forces: the force of gravity pulling straight down and the normal force of the ramp pushing back (Formula #4). As the angle of the ramp is increased, the normal force decreases (Formula #5). The force of gravity remains unchanged for all angles. The difference between the two forces causes the force down the ramp to increase. The greater the angle required to move the car, the more friction there will be acting against the car's motion. The angle is directly proportional to the force of friction or the coefficient of rolling friction. **LOWER ANGLES** are more desirable (Formula #7).

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Fd = Ff
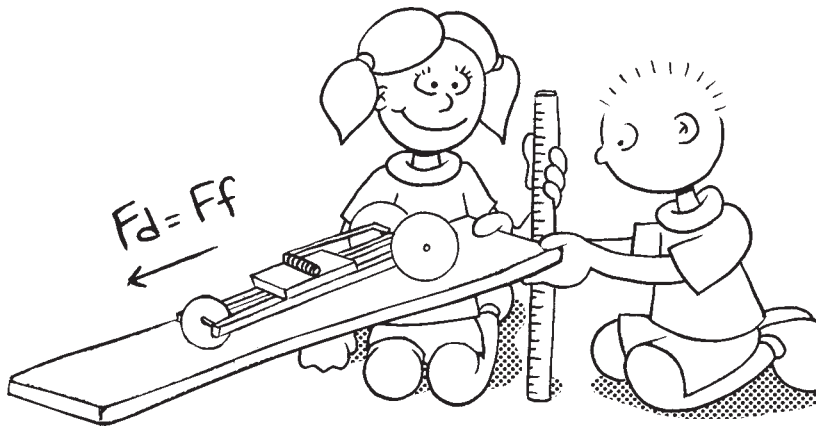
How it Works:
The force pulling the vehicle down the ramp is equal to the force of friction acting against the car AS LONG as the mousetrap car moves down the ramp at a constant velocity. In some cases, once the vehicle starts to move the ramp has to be lowered in order to maintain constant velocity.

Rolling Friction

Formulas

Formula #1: $\sum F = 0$

The sum of all forces must equal "zero" if there is no acceleration.

Formula #2:   Force Pulling = Force of Friction

Formula #3: $f_{rf} = \mu N$

Force of friction is equal to the coefficient of friction times the normal force

$$\sin\theta = \frac{h}{L}$$

Because your measurements are from a slope, you will have to use some trigonometry

Formula #4: $f_{rf} = \sin\theta \cdot w$

The force down an angled ramp is equal to the force of friction as long as the vehicle rolls down the ramp with a constant velocity.

Formula #5: $N = \cos\theta \cdot w$

The normal force is the force that is perpendicular to the angled ramp.

Formula #6: $\mu = \dfrac{\sin\theta \cdot w}{\cos\theta \cdot w} = \tan\theta$

Resolving for the coefficient of friction from Formulas #3, #4 and #5

Formula #7: $\mu = \tan\theta$

The coefficient of friction

Rolling Friction

Trigonometry

Trigonometry is a fancy type of mathematics that is based on simple relationships of all right triangles. Ancient mathematicians found that all right triangles are proportional by ratios of their sides and angles. These ratios times the angle are known as sine, cosine, and tangent. Knowing one of the angles other than the right angle-and any one of the sides to the triangle-will allow you can calculate everything else you would ever need to know about that triangle's sides or angles.
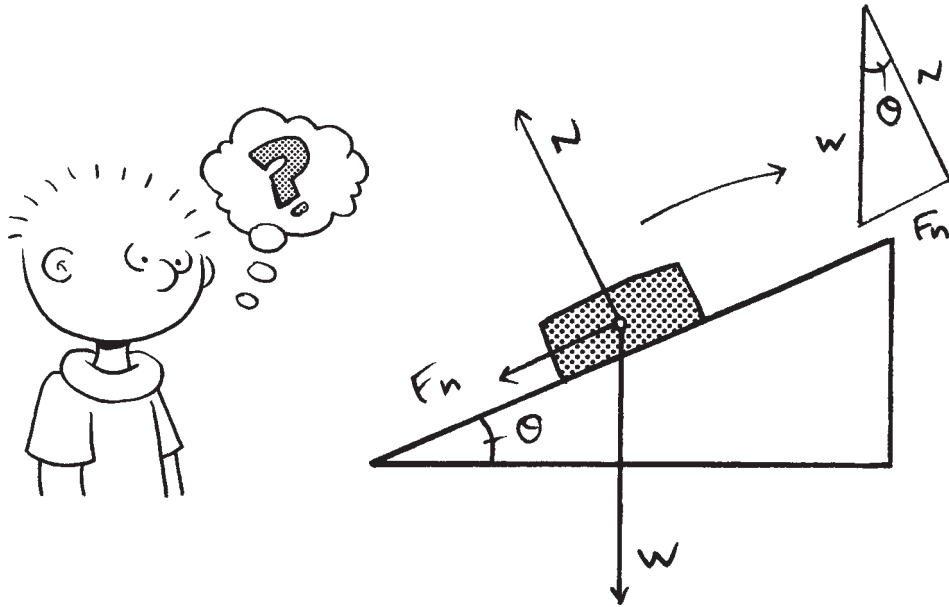
How it Works

The angle of the ramp in this experiment forms a right triangle. The force due to gravity and the normal force of the ramp's surface cause a force directed down the ramp called "Force Down." These three forces form a right triangle which has the same angle as the base of the ramp. Knowing the angle of the base of the ramp and the weight of the car on the ramp, we can solve for any other force including the force acting down the ramp and which is equal to the force of friction.
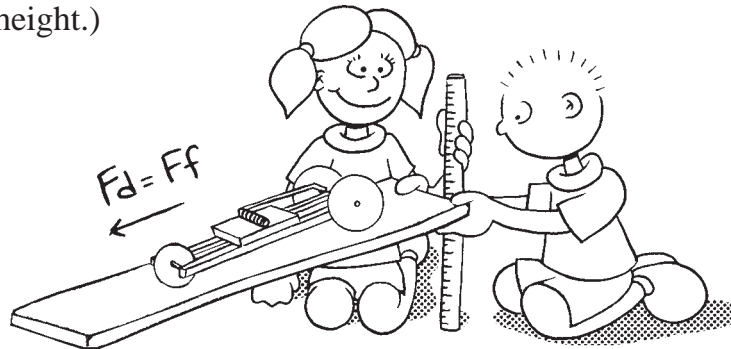
Rolling Friction

Let The Good Times Roll

Step 1: Start by selecting a long and smooth board or ramp that will not bend or flex when lifted at one end. Your vehicle must fit on the ramp.

Step 2: Measure the length of the board and record this measurement as the board length (L).

Step 3: Place your vehicle on the ramp and begin lifting by one end. Slowly lift until the vehicle "JUST" begins to roll. Measure carefully and accurately the elevation of the board when the vehicle begins to roll and record this in the data table as the height (h). Repeat this process 5 to 10 times for more accurate results. (Note: You must subtract the thickness of the board from the height. Measure both ends of the ramp to correctly calculate the height.)
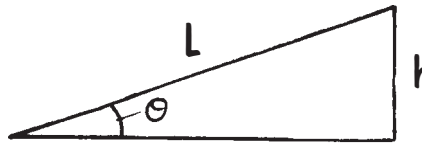
$Fd = Ff$

Data Table #1

Trial #	Board Length (m)	Raised Height (m)	Angle	Coefficient of Rolling Friction	Friction (N)	Starting Energy (J)	Predicted Travel Distance
1	$L=$	$h_1=$	$\theta_1=$	$\mu_1=$	$f_1=$	$PE=$	$d_1=$
2	$L=$	$h_2=$	$\theta_2=$	$\mu_2=$	$f_2=$	$PE=$	$d_2=$
3	$L=$	$h_3=$	$\theta_3=$	$\mu_3=$	$f_3=$	$PE=$	$d_3=$
4	$L=$	$h_4=$	$\theta_4=$	$\mu_4=$	$f_4=$	$PE=$	$d_4=$
AVE		$h=$	$\theta=$	$\mu=$	$f=$		$d=$

Rolling Friction

Step 4: Calculate the angle for each trial using the following equation:

$$\theta = \frac{h}{L}\sin^{-1}$$

Step 5: From the derived formula, calculate the coefficient of friction for each trial. The coefficient of friction is directly proportional to the angle of the ramp. Smaller angles translate into greater travel distance.

$$\mu = \tan\theta$$

Step 6: If this lab is performed correctly, the force of rolling friction acting against your car is equal to the force pulling the vehicle down the ramp in the elevated state. Calculate the force of friction by assuming that the force down the ramp is equal to the force of friction acting against the motion of your vehicle. Solve for the force down the ramp. MAKE SURE to use the weight of your vehicle in Newtons. If you have the mass in killograms, you can calculate the weight by multiplying the mass of your vehicle by 9.8 m/s^2 or find the weight by weighing your vehicle on a spring scale.

$$f_{rf} = \sin\theta \cdot w$$

Step 7: Using the starting energy that you calculated in Lab #4 you can calculate the predicted travel distance by using the following:

$$\text{Predicted Travel Distance} = \frac{\text{Total Potential Energy}}{\text{Rolling Friction}}$$

Rolling Friction

Purpose

To determine the amount of grip or traction your drive wheels have on the floor.

Materials

spring scale or foce probe
string
tape to lock wheels

Discussion

If your vehicle does not have enough grip on the floor AND you have too much pulling force your wheels will spin-out! The more "grip" or traction your wheels have on the floor surface, the greater the acceleration that is possible for your vehicle. If you are making a speed-trap or a power pulling vehicle you want to test different materials on your wheels to make sure you have the maximum traction possible; for example, rubber balloons on wheels, rubber bands on wheels, differnet compounds, etc. Once you have found the maximum traction, you can adjust the length of your mousetrap's lever arm in order to achive the greatest possible pulling force. Shorter lever arms have greater force for more power or acceleration for your vehicle. keep in mind that the amount of traction will vary from surface to surface because not all surfaces have the same grip. Example, your car will have more grip on concrete than on ice; because of this, you must test your vehicle's traction on the actual course where you will be running your contest or activity. In this activity you will find that actual for of traction and the coefficient of friction between youur vehicles drive wheels and the floor. The coefficient of friction tells you how slippery two surfaces are together. The larger the coefficient of friction, the more grip or traction your vehicle will have with that surface.

Rolling Friction

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Formulas

Formula #1: $\sum F = 0$

The sum of all forces must equal "zero" if there is no acceleration.

Formula #2: Force Pulling $=$ Force of Traction

Formula #3: $f_{rf} = \mu N$

The force of traction or friction is equal to the coefficient of friction times the normal force or the force the drive wheels press on the floor.

Step 1: With a piece of tape lock the drive wheel(s) to prevent them from turning. The non-drive wheels should be aloud to turn freely.

Step 2: Attach a sensitive spring scale or force probe to the front of the car. It is best to tie a string to the front of that car and then attach the spring scale to the string.

Step 3: Pull the vehicle on the race surface at an even force and CONSTANT speed keeping the scale or force probe parallel to the road. Pull the vehicle several time and record the readings each time calculating an average. The force required to drag your car is eqaul to the force of traction, calculate the average and record.

Step 4: To find the coeficient of friction between the drive wheels and the floor you need to attach the spring scale to the drive axle and lift directly up untill the drive wheels just lift off the table. Record this number as the force on the drive wheels. Usng the formuls, divide the force of traction by the force on the drive wheels

$$\mu = \frac{f}{N}$$

Rolling Friction

Purpose

In this activity you will find the rotational inertia of your wheels.

Materials
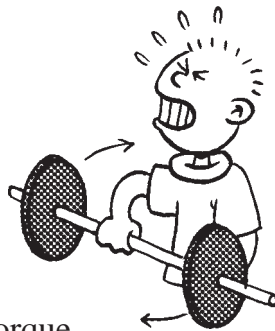
A Small Mass (no larger than 50g)
Stopwatch
String
Meter Stick
Pulley Set-up

Discussion

Rotational inertia is the resistance an object has to changing its state of rotation. The more rotational inertia a wheel has, the more torque that will be required to change its state of rotation. The torque is generated from the mousetrap's lever arm. More torque means shorter lever arms which translates into less pulling distance. With distance cars you want the longest possible pulling distance; therefore, you want a long lever arms. In most cases, whether you are building a speed or distance car it is best to have wheels with as little rotational inertia as possible. The less rotational inertia that a wheel has, the easier it will be to

Just as an object at rest tends to stay at rest and an object in motion tends to stay in motion, an object in a state of rotation about an axis tends to remain in that state of rotation about the same axis unless an external force or torque acts on it. Try an experiment to learn about rotational inertia. Try twisting a barbell with the weight spaced close together and then far apart. You will definitely get a good feel for rotational inertia after this experiment.

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Rotational Inertia

The Set-up

accelerate the wheel and get the car moving. Rotational inertia is equal to the amount of torque acting on a system divided be the angular acceleration (Formula #1). The angular acceleration is equal to the linear acceleration divided by the radius of the wheel (Formula #2). The torque is equal to the applied force times the radius from the point of rotation (Formula #3). Putting Formula #1, #2 and #3 together you get Formula #4.

In this lab a weight is tied to a string and then wrapped around the axle of each wheel. The weight is allowed to fall causing the wheel(s) to spin. As the weight falls it is also timed. Based on the time it takes the weight to reach the tabletop or floor, you can calculate the rotational resistance of your wheel(s). The weight, as it falls, is being pulled downwards by gravity and upwards by the resistance of the wheel(s). The greater the rotational resistance or inertia, the longer it will take the weight to fall. The acceleration of the falling weight is found by Formula #5. Combine Formula #4 and #5 to get one formula that will be used for this lab to calculate the rotational inertia, based on the time of fall for the hanging mass. The total rotational inertia is the combination of all wheels added together.

Rotational Inertia
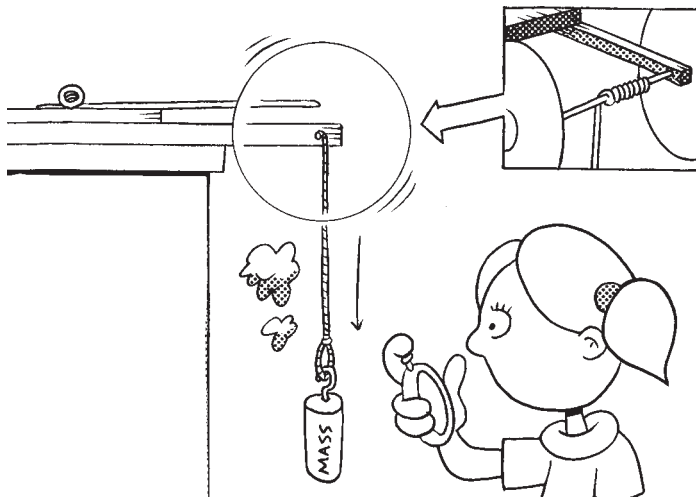
In this lab a weight is tied to a string and then wound around an axle. Based on the time it takes the weight to reach the tabletop or floor, you can calculate the rotational resistance of your wheel(s). The greater the rotational resistance or inertia, the longer it will take the weight to fall.

I = **Rotational Inertia**
τ = **Torque**
α = **Angular Acceleration**
a = **Linear Acceleration**
F = **Applied Force**
r = **Lever Length**
h = **Fall Height of Mass**
v_0 = **Starting Falling Velocity (zero in this lab)**
t = **Time of Fall for Mass**
a = **Linear Acceleration**

Formulas

Formula #1: $\quad \tau = Fr$

Formula #2: $\quad I = \dfrac{\tau}{\alpha}$

Formula #3: $\quad \alpha = \dfrac{a}{r}$

Angular acceleration based on linear acceleration

Formula #4: $\quad I = \dfrac{Fr}{\dfrac{a}{r}}$

Formulas 1 - 3 combined

Formula #5: $\quad I = \dfrac{Fr^2}{a}$

Rotational inertia from Formula #3 based on linear acceleration

Formula #6: $\quad h = v_o t + \dfrac{1}{2}at^2$

The height of fall based on an accelerating object through time

Formula #7: $\quad a = \dfrac{2h}{t^2}$

Rotational Inertia

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Solving for acceleration

Formula #8: $$I = \frac{Fr^2t^2}{2h}$$

Rotational inertia of a wheel based on a falling mass

Another Way to Get The Job Done

If your wheel(s) is (are) not glued to the axle, then you may have to design a test device to hold and measure the rotational inertia. Design a pulley apparatus that can hold each of your wheels and that will allow them to spin freely. The smaller the pulley or axle that the string is wrapped around, the smaller the acceleration of the falling mass, which makes timing more accurate.

Rotational Inertia
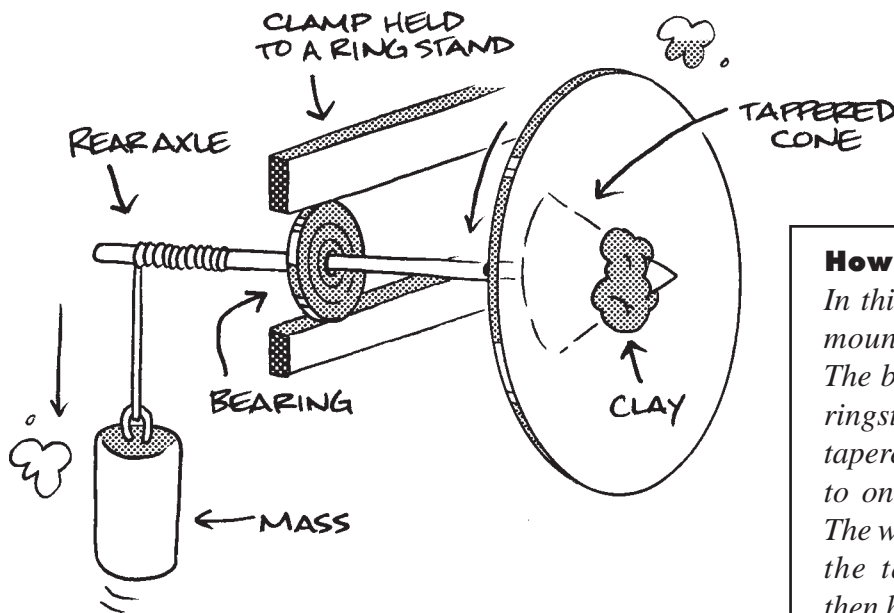
How it Works:
In this set-up an axle is mounted in a bearing. The bearing is held to a ringstand by a clamp. A tapered cone is attached to one end of the axle. The wheel is placed onto the tapered cone and then held in place with a small amount of clay. The string is wrapped around the opposite side of the axle.

Let's Get Spinning

IMPORTANT: Steps 1-5 are only for those who test their wheels on a pulley sytem. If you art measuring your wheels' rotational inertia on your vehicle's axles, then skip to Step 6.

Finding the rotational inertia of the pulley set-up

Step 1: Because the pulley set-up has rotational inertia of its own you will have to calculate its rotational inertia in order to subtract it from that of your wheel. Make the following data table:

Data Table #1

Fall Distance of Mass	Time of Fall	Radius of Pulley	Weight of Falling Mass	Rotational Inertia of Pulley
$d_1=$	$t_1=$	$r_p=$	$W=$	$I_{pulley\ 1}=$
$d_2=$	$t_2=$	$r_p=$	$W=$	$I_{pulley\ 2}=$
$d_3=$	$t_3=$	$r_p=$	$W=$	$I_{pulley\ 3}=$
$d_4=$	$t_4=$	$r_p=$	$W=$	$I_{pulley\ 4}=$
AVE	$t=$		$W=$	$I_{pulley}\ =$

Step 2: Calculate the weight of your hanging mass by dividing grams by 1000 and then multiping by 9.8. This will give you weight in Newtons. Record in the data table as W. It is best to use a smaller mass no larger than 50g. I suggest 20g. Attach the weight to the end of a string that is long enough to reach from the pulley to the floor or table top, depending on the fall distance that you will use for your measurement. Attach the other end of the string to the axle or pulley set-up and wind the string up around your setup.

Step 3: Measure the fall distance from the bottom of the hanging weight to the surface below and record this measurement as fall distance of mass (d). Measure the radius of the axle or pulley where the string is wound and record as the pulley radius (r).

Rotational Inertia

Step 4: Allow the weight to fall while timing with a stopwatch and record the time in the data table (t). Repeat several times and record in the Data Table #1. Find an average. Make sure that you drop the weight from the same point each time that you repeat the experiment.

Step 5: Using the following formula, calculate the rotational inertia of your pulley.

$$I = \frac{Fr^2t^2}{2h}$$

$$I_{\text{Rotational Inertia of pulley}} = \frac{(\text{Weight of Hanging Mass}) * (\text{Radius of Pully})^2 * (\text{Time of Fall})^2}{2 * (\text{Distance that mass falls})}$$

Finding the rotational inertia of your wheels

Step 6: Depending on whether you will measure each wheel by itself or if you will measure the rotational inertia of an axle system, make a copy of Data Table #2 for each wheel or axle sysetm for your vehicle. If you had to perform steps 1-5 then record the average rotational inertia from your pulley set-up in Data Table #2.

Data Table #2   (Front Axle System or Wheel #1)

Fall Distance of Mass	Time of Fall	Radius of Pulley	Weight of Falling Mass	Rotational Inertia of Pulley	Rotational Inertia of Wheel
$d_1 =$	$t_1 =$	$r_p =$	$W =$	$I_{pulley} =$	$I_{wheel\ 1} =$
$d_2 =$	$t_2 =$	$r_p =$	$W =$	$I_{pulley} =$	$I_{wheel\ 2} =$
$d_3 =$	$t_3 =$	$r_p =$	$W =$	$I_{pulley} =$	$I_{wheel\ 3} =$
$d_4 =$	$t_4 =$	$r_p =$	$W =$	$I_{pulley} =$	$I_{wheel\ 4} =$
AVE	$t =$				$I_{wheel} =$

Rotational Inertia

Step 7: Attach one wheel at a time to the pulley apparatus if you are measuring each wheel by itself. If you are measuring a complete axle system, then perform the following:

Attach one end of a string to the axle and the other end of a weight. The string should be long enough to reach the surface below. Calculate the weight of your hanging mass by dividing grams by 1000 and then multiping by 9.8. This will give you weight in Newtons. Record in the data table as W. It is best to use a smaller mass no larger than 50g. I suggest 20g. Wind the string around the axle and measure the starting possition of the mass so that in all trials the mass falls from the same height.
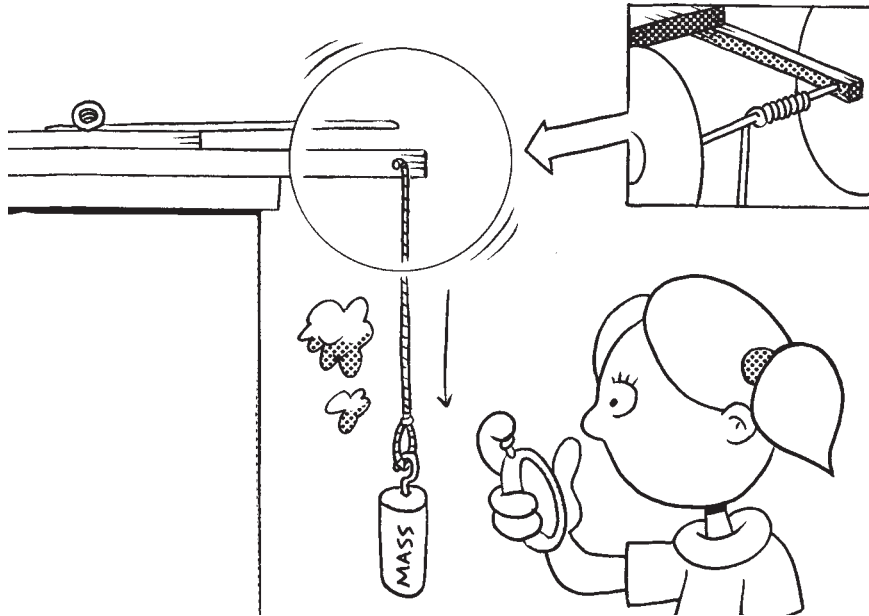
Step 8: Allow the weight to fall while timing with a stopwatch and record the time in the data table (t). Repeat several times and record in the Data Table #2. Find an average. Make sure that you drop the weight from the same point each time that you repeat the experiment.

Rotational Inertia

Step 9: Using the following formula, calculate the rotational inertia of your wheel. Look carefully at the formula. It is the same as in Step 5 except this time you have to remove the rotational inertial of the pulley. Do not forget to subtract the resistance inertia of the pulley.! If you did not use a pulley set-up ignore the rotatioanl inertia of the pulley and plug in all varibles except for the rotational inertia of the pulley.

Rotational Inertia of a Wheel or an Axle System

$$I_{\text{Rotational Inertia of Wheel}} = \frac{(\text{Weight of Hanging Mass}) * (\text{Radius of Pully})^2 * (\text{Time of Fall})^2}{2 * (\text{Distance that mass falls})} - I_{\text{Pulley}}$$

Step 10: Repeat for each wheel or axle system of your car and record your results in Data Table #3 as follows: "Front Wheel #1," "Rear Wheel #2," or "Front Axle system," "Rear Axle system" .

Data Table #3

	Front Wheel #1 Or Front Axle System	Front Wheel #2	Rear Wheel #1 Or Rear Axle System	Rear Wheel #2
Rotational Inertia	$I_{f1} =$	$I_{f2} =$	$I_{r1} =$	$I_{r2} =$
Radius of Wheel	$r_{f1} =$	$r_{f2} =$	$r_{r1} =$	$r_{r2} =$

Step 11: Add the rotational inertia for all components together in order to get the total rotational inertia.

Total Rotational Inertia = _____ kg • m^2

Rotational Inertia

Purpose

To calculate the starting potential energy and to find the spring coefficient.

Equipment Needed

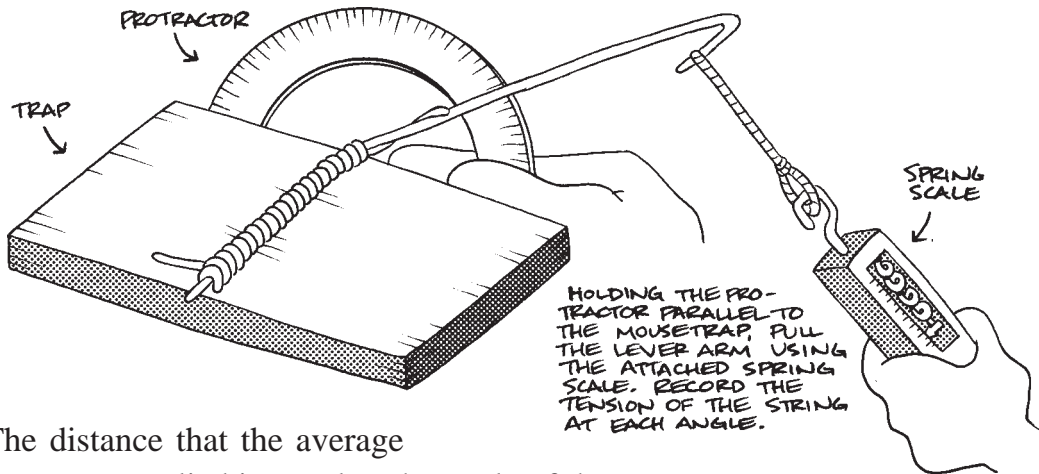Spring Scale or a Computer Force Probe
Tension Wheel (recommended but not needed)
String

Discussion

Energy has the ability to do work. Your mousetrap car's performance will depend directly on the strength of your mousetrap's spring. The stored energy of your spring in the fully wound-up position is called potential energy. The amount of stored potential energy is the same as the work that was required to wind the spring. The force required to wind the spring times the distance the force was applied is equal to the work that was done on the spring (Formula #1). Because the force required to wind the spring changes and depends on how much the spring is wound, you will have to find the average force between a series of points and then calculate the work done between those marks. The total work (or the stored potential energy) is equal to all the changes of energy between all the points added together (Formula #2). In order to measure the winding force you have to use a spring scale attached to a lever. The lever is lifted and the force is measured every 5 or 10 degrees. The scale has to be held such that the string attached to the lever arm is perpendicular. A problem with this method is that as the spring scale is held in different positions it becomes inaccurate. The spring scale cannot change from the position at which it was zeroed. For this reason I recommend using a tension wheel. A tension wheel allows the spring scale to remain in one position, producing more accurate results and it is easier to use.

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Potential Energy, Spring Constant

The Set-up

PROTRACTOR

TRAP

SPRING SCALE

HOLDING THE PRO-
TRACTOR PARALLEL TO
THE MOUSETRAP, PULL
THE LEVER ARM USING
THE ATTACHED SPRING
SCALE. RECORD THE
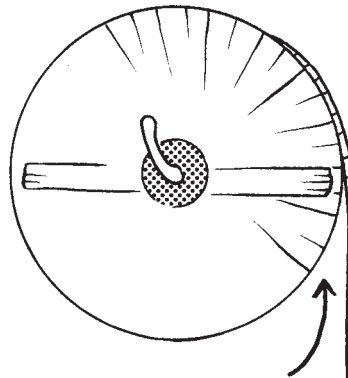TENSION OF THE STRING
AT EACH ANGLE.

The distance that the average force was applied is equal to the angle of the measurement in radians times the length of the measuring lever arm. If you are using a tension wheel, then the radius of the wheel is the measuring lever arm (Formula #3). Formula #4 allows you to convert from degrees to radians.

For a spring that is stretched or compressed longitudinally, Hooke's Law applies and says that the force is equal to the spring constant times the stretching or compressing displacement. But a mousetrap spring does not stretch longitudinally. A mousetrap spring is a torsion spring and winds up. For this type of spring a different formula is needed (Formula #5). It is a torque that must be applied to the spring to wind it and the displacement is measured in radians (Formula #6). The units associated with the spring constant become Newtons * Meters/ Radians. For a spring that compresses or stretches in a linear direction, the total potential energy is one half the spring constant times the displacement squared (Formula #7). For a torsion spring the displacement is substituted by the angle in radians (Formula #8).
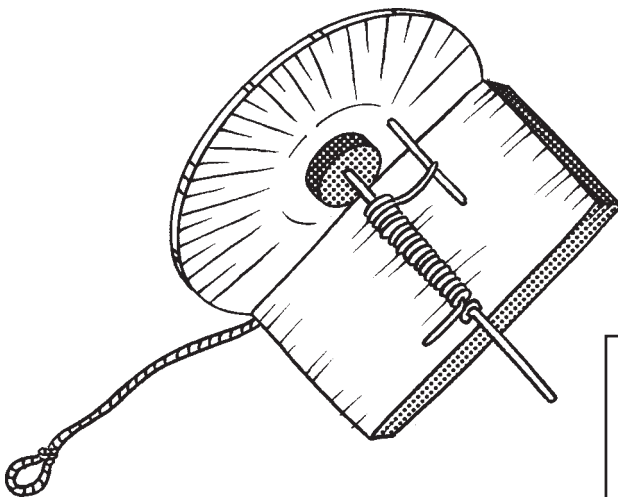
Potential Energy, Spring Constant

Tools of the Trade: **Tension Wheel**

*A **tension wheel** is designed to direct the pulling force in the same direction as the spring is wound. This prevents the scale from having to be re-zeroed as its direction of pull changes. Degree markings make it easy to measure force and angle.*
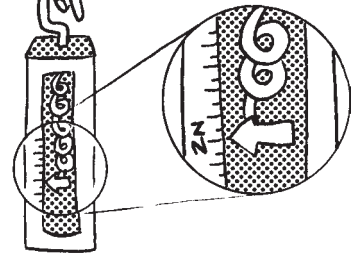
EACH DASH REPRESENTS A DEGREE, OR ANGLE. USING THIS TECHNIQUE, YOU CAN FIND THE TENSION OF YOUR STRING AT EACH ANGLE

SPRING SCALE

IN

How it Works:
As the wheel is turned clockwise the spring on the mousetrap is compressed. The value of the spring constant depends on the material the spring is made from, the diameter of the wire, the diameter of the coil, and the number of coils.

Need A Tool?
This tool can be ordered from Doc Fizzix at (512) 218-0454
www.docfizzix.com

Formulas

W = Work
F = Force
d = Displacement
k = Linear Spring Constant
κ = Torsion Spring Constant
x = Spring Displacement
τ = Torque
θ = Angle
PE = Potential Energy

Formula #1: $W = F \cdot d$

Work formula used with a constant (non-changing) force

Formula #2: $W = \int_0^{\pi r} F(x)\, d(x)$

Work formula used with a changing force as with a mousetrap spring

Formula #3: $d = \theta r$

A formula to calculate the linear distance of travel for a wheel

Formula #4: $\text{degrees} \times \dfrac{\pi}{180^o} = \theta$

A formula used to change degrees into radians

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Formula #5: $F = -kx$

Hooke's Law. Force of a stretched or compressed spring

Formula #6: $\tau = \kappa \theta$

From Hooke's Law. Used to calculate the torque from a torsional spring

Formula #7: $PE = \dfrac{1}{2} kx^2$

Potential energy of a stretched or compressed spring

Formula #8: $PE = \dfrac{1}{2} \kappa \theta^2$

Potential energy of a stretched or compressed torsion spring

Potential Energy, Spring Constant

Pulling Your Weight

PROTRACTOR

TRAP

SPRING SCALE

HOLDING THE PRO-
TRACTOR PARALLEL TO
THE MOUSETRAP, PULL
THE LEVER ARM USING
THE ATTACHED SPRING
SCALE. RECORD THE
TENSION OF THE STRING
AT EACH ANGLE.

Step 1: In this lab you can use either a spring scale or a force probe in order to measure the spring's tension at different points along its travel. Start by attaching a string to the end of your mousetrap's extended lever arm. The point where you attach the string on the mousetrap's lever arm must extend pass the edge of the mousetrap's base so that all measurements can be taken from 0 to 180 degrees without the mousetrap's base blocking the measuring process. The string should be about 20 centimeters in length or less. Attach the spring scale to the other end of the string. Hold or attach a protractor to the mousetrap so that the center point of the protractor is in the middle of the spring and the zero degree point on the protractor is lined up with the starting point of the relaxed lever arm.

Step 2: Start at "0" degrees and pull up on the lever arm with the spring scale until the lever arm "just" lifts up from the base of the mousetrap and record this measurement as the starting force. Continue to pull up on the spring scale, stopping at every 5 or 10 degrees. Record the tension at each point in the data table. You must keep the scale perpendicular to the lever arm at each point you measure. Record the tension and angle in the data table.

Potential Energy, Spring Constant

Data Tables

<div style="border:1px solid black">

Recommendations:
Try to set-up a **spread sheet** *on a computer in order to handle your data more* **efficiently**.

</div>

Data Table #1

Angle	Tension	Change in Radians	Total Radians	Change in Displacement	Total Displacement
5	$F_0=$	$\Delta\theta_0=0$	$\theta_0=0$	$\Delta d_0=0$	$d_0=0$
10	$F_1=$	$\Delta\theta_1=$	$\theta_1=$	$\Delta d_1=$	$d_1=$
15	$F_2=$	$\Delta\theta_2=$	$\theta_2=$	$\Delta d_2=$	$d_2=$
20	$F_3=$	$\Delta\theta_3=$	$\theta_3=$	$\Delta d_3=$	$d_3=$
25	$F_4=$	$\Delta\theta_4=$	$\theta_4=$	$\Delta d_4=$	$d_4=$
180	$F_{36}=$	$\Delta\theta_{36}=$	$\theta_{36}=$	$\Delta d_{36}=$	$d_{36}=$

Data Table #2

Spring Constant	Torque	Change in Potential Energy	Total Potential Energy
$k_0=0$	$T_0=$	$\Delta PE_0=0$	$PE_0=0$
$k_1=$	$T_1=$	$\Delta PE_1=$	$PE_{0-1}=$
$k_2=$	$T_2=$	$\Delta PE_2=$	$PE_{0-2}=$
$k_3=$	$T_3=$	$\Delta PE_3=$	$PE_{0-3}=$
$k_4=$	$T_4=$	$\Delta PE_4=$	$PE_{0-4}=$
$k_{36}=$	$T_{36}=$	$\Delta PE_{36}=$	$PE_{0-36}=$
Ave		Total	

Potential Energy, Spring Constant

Step 3: Calculate the change in radians for each angle and record them in the data table. If each measurement was made at the same increment (e.g., 5, 10, 15, 20 …) you can use the same change in radians for all angles. Use the following method to calculate the change in radians:

$$\Delta\theta_1 = (\text{degrees}_1 - \text{degrees}_0) \times \frac{\pi}{180^o}$$

$$\Delta\theta_2 = (\text{degrees}_2 - \text{degrees}_1) \times \frac{\pi}{180^o}$$

Step 4: Measure the length of the lever arm from the spring to the point where the scale was attached to the arm and record this as the radius. Calculate the change in displacement, also known as the arc length, for each angle using the following formula. If each measurement was made at the same increment, (e.g. 5, 10, 15, 20 …) you can use the same arc length (displacement) for all angles.

$$\Delta d_1 = \Delta\theta_1 r \qquad \Delta d_2 = \Delta\theta_2 r \qquad \Delta d_3 = \Delta\theta_3 r$$

Step 5: Calculate the total displacement for each angle by adding each of the previous changes in displacement to the next.

Step 6: Calculate the change in potential energy for each point using the following method. Multiply the average force between the starting and ending points with the change in distance. Add each of the change in PE values together in order to find the total potential energy from the column. This added value should be the energy your vehicle starts with before it is released.

Potential Energy, Spring Constant

$$\Delta PE_{0,1} = \frac{F_0 + F_1}{2} \cdot \Delta d_1$$

$$\Delta PE_{1,2} = \frac{F_1 + F_2}{2} \cdot \Delta d_2$$

$$\Delta PE_{2,3} = \frac{F_2 + F_3}{2} \cdot \Delta d_3$$

Step 7: Calculate the spring constant for each change in angle. The spring on a mousetrap is an example of a torsion spring, a spring that coils as opposed to one that stretches; use the following equation to calculate the spring constant: $\tau = \kappa\theta$. Torque is equal to the spring constant times the angle measured in radians. Torque is calculated from the force that is applied to a lever arm times the length of the lever arm. $\tau = Fr_{\text{lever arm}}$ You will need to subtract the starting torque in order to find the actual change in torque for each change in angle. Total each spring constant and find an average.

$$\kappa = \frac{\tau}{\theta}$$

$$\kappa_1 = \frac{(F_1 - F_0)r_{\text{arm length}}}{\theta_{0,1}}$$

$$\kappa_2 = \frac{(F_2 - F_1)r_{\text{arm length}}}{\theta_{1,2}}$$

$$\kappa_3 = \frac{(F_3 - F_2)r_{\text{arm length}}}{\theta_{2,3}}$$

Potential Energy, Spring Constant

Graphing the results

In each of the following graphs attempt to draw the best fit lines. If data is widely scattered do not attempt to connect each dot but instead draw the best shape of the dots. If you have access to a computer, you can use a spread sheet like Microsoft Exel to plot your data.

1. Graph **Pulling Force** on the vertical axis and the **Displacement** on the horizontal axis.

2. Graph **Torque** on the vertical axis and **Angle in Radians** on the horizontal.
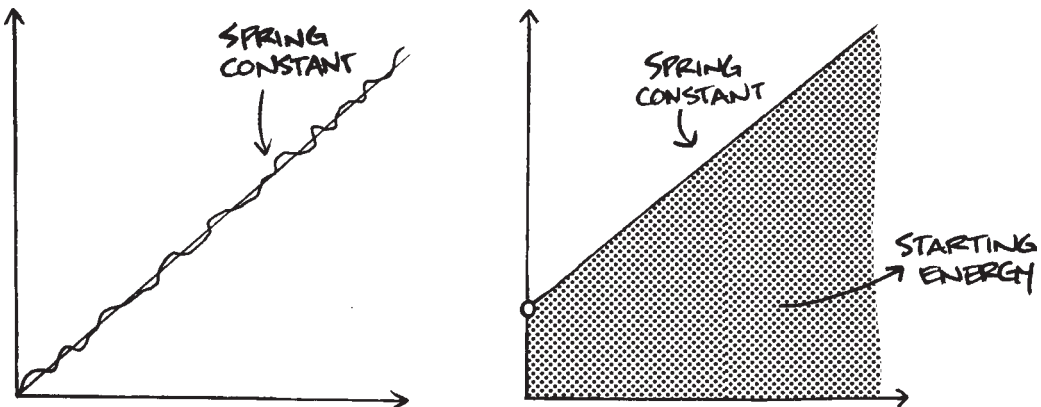
GRAPHING THE TENSION AT EACH ANGLE, YOU CAN GET THE **SPRING CONSTANT** AND THE **STARTING ENERGY.** YOUR RESULTS SHOULD ROUGHLY FORM A STRAIGHT LINE.

Potential Energy, Spring Constant

Analysis

1. The slope from your graph of "torque vs. angle" represents the spring constant. Does the slope change or remain constant? Do you have an ideal spring that follows Hooke's Law?

2. What does the slope of the line from each of your graphs tell you about the strength of your spring compared to other students' graphs?

3. Calculate the area under all parts of the best-fit line from the graph of "torque vs. angle." This number represents the potential energy you are starting with. The larger the number, the more energy you have to do work. This number should be close to the total potential energy calculated from your data table. How does the slope compare to the number in the data table?

4. How does your potential energy compare to other students' potential energy in your class? Discuss.

Purpose

To determine the force of friction against your vehicle.

Equipment Needed

Meter Tape

Variables Needed From Other Labs

Total Potential Energy from Lab #5

Discussion

Mousetrap cars convert their starting energy into work. Work is done to overcome the frictional forces acting against the vehicle. In most cases the largest amount of friction is the rolling friction caused by the bearings on the axles. The total work that your car will do is equal to the starting energy of your vehicle that you calculated in Lab #4. The predicted travel distance is equal to the starting energy divided by the force of rolling friction. You should observe (by comparing your results to other students' results) that the less rolling friction that there is, the greater the distance a vehicle should travel.

Formula #8: $PE = f_{rf}d$

Work is equal to the starting energy.

Formula #9: $d = \dfrac{PE}{f_{rf}}$

The maximum distance depends on the starting energy and the force of rolling friction

Rolling Friction, Work

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Calculate the Friction from the Actual Travel Distance

Step 1: Wind-up and release your vehicle. Measure the total travel distance. Test your result several times, then calculate the average travel distance for your vehicle.

Data Table #2

Trial #	Actual Travel Distance	Starting Energy	Friction	Coefficient of Rolling Friction
1	$d_1=$	PE=	$f_1=$	$\mu_1=$
2	$d_2=$	PE=	$f_2=$	$\mu_2=$
3	$d_3=$	PE=	$f_3=$	$\mu_3=$
4	$d_4=$	PE=	$f_4=$	$\mu_4=$
AVE	$d=$		$f=$	$\mu=$

Step 2: Calculate the rolling friction from the actual travel distance using the following formula:

$$\text{Work} = \text{Force} \cdot \text{Distance}$$

$$f_1 = \frac{PE_1}{d_1}$$

Step 3: You are going to calculate the coefficient of friction from the following formula. Note: For mass, remove the wheels and use ONLY the mass of the frame. It is the frame that rests on the bearings and presses the bearings' surfaces together. Therefore, you must remove the wheels and "mass" only the frame.

$$\mu = \frac{f}{mg}$$

Rolling Friction, Work

Lab #7 - How Far Can I Go?

Purpose
To determine the pulling distance, the power output, and the mechanical advantage.

Equipment Needed
Ruler (A caliper makes smaller measurements easier)
Stopwatch
Meter Tape

Variables Needed From Other Labs
Total Potential Energy from Lab #5

Discussion
The pulling distance is the measurement from where the vehicle starts to where the pulling force on the drive axle ends. In this lab you will calculate how far your mousetrap car should be pulled by the mousetrap's lever arm. Once you have predicted the pulling distance you will then measure and time the actual pulling distance in order to find the power rating. The pulling distance does not tell you how far your mousetrap car will travel, only how far it will be pulled by the mousetrap's lever arm. The distance that your mousetrap car is pulled is directly proportional to the size of the drive wheels and the length of string that is wrapped around the drive axle. The travel distance is inversely proportional to the size of the drive axle. What all this means is the following: the larger the drive wheel(s), the greater the pulling distance. The more string that can be pulled off the drive axle, the greater the pulling distance. The larger the drive axle, the shorter the pulling distance. In order to get more string wound around the drive axle, you can do one of the following: use a smaller diameter drive axle or extend the length of the mousetrap's lever arm and then place the trap further from the drive axle.

Power Output, Gear Ratio, Mechanical Advantage

The pulling distance is calculated from the number of turns that your wheel makes times the circumference of your wheel. The number of turns that your wheel will make depends on the length of string wound around the pulling axle divided by the circumference of the drive axle. By putting the first two formulas together you can predict the pulling distance.

Power Output

Power is the rate at which work is being done. Your mousetrap car will convert stored potential energy from the wound-up spring into work to overcome friction. The rate at which your mousetrap car converts this stored energy into work is your vehicles power rating. You will calculate the power rating by dividing the starting energy by the time through the pulling distance (Formula #4). As a general rule of thumb, higher power ratings mean less efficiency and less overall travel distance. A good mousetrap car that is designed for distance should have a low power rating.

Power Output, Gear Ratio, Mechanical Advantage

Formulas

$$\text{Pulling Distance} = \text{Number of Turns} \times 2\pi r_{wheel}$$

$$\text{Number of Turns} = \frac{\text{Length of String}}{2\pi r_{axle}}$$

$$\text{Pulling Distance} = \frac{\text{Length of String} \times r_{wheel}}{r_{axle}}$$

$$P_1 = \frac{PE_{total}}{\Delta t_1}$$

Power is the rate at which energy is being used

CALIPER

REAR AXLE
WITH STRING
WOUND TIGHTLY

How it Works:
A caliper is used to measure the thickness of the drive axle in order to calculate the diameter. For a more accurate calculation of the diameter of the drive axle two measurements will be taken, without string and with string.

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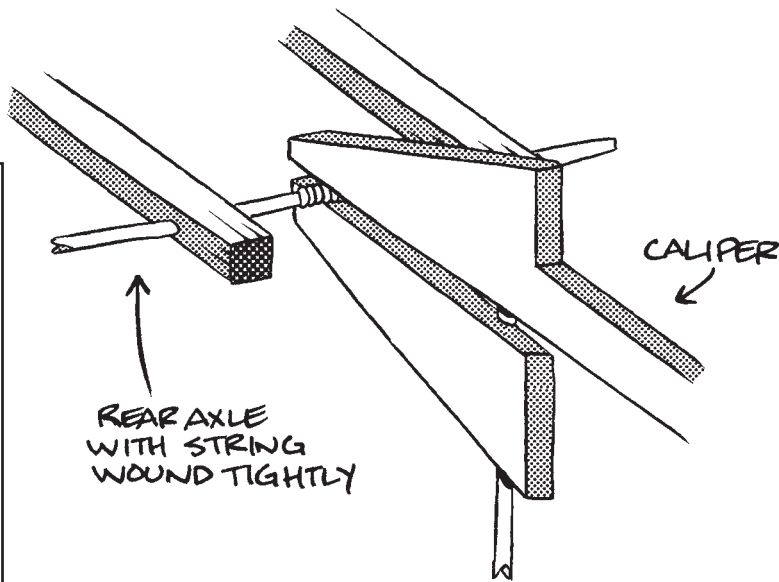
Power Output, Gear Ratio, Mechanical Advantage

Getting The Measurements

Step 1: Use a caliper or micrometer to measure and calculate the average diameter of the drive axle. Calculate the average diameter of the drive axle by first measuring the drive axle without string on it and then measuring it with string wound-up as it will normally be before a race. It is important that the string be wound evenly and not "balled" or "clumped." Add the two measurements together and then divide by 2. This will give you an average diameter for your calculations. Calculate the average radius from the average diameter.

Ave Drive Axle Diameter = _____ meters

Ave Drive Axle Radius = _____ meters

Step 2: Use a caliper or a ruler to measure the diameter of the drive wheel(s) and record the diameters as well as the radii.

Drive Wheel(s) Diameter = _____ meters

Drive Wheel(s) Radius = _____ meters

Step 3: Measure only the length of string that is normally pulled from the drive axle. Important: If there is more string attached to the lever arm than is needed, you may have to wind the string around the drive axle and then mark the string where it starts and ends with respect to the lever arm's travel range.

String Length = _____ meters

Power Output, Gear Ratio, Mechanical Advantage

Step 4: Calculate the pulling distance using the following formula:

$$\text{Pulling Distance} = \frac{\text{Length of String} \times r_{wheel}}{r_{axle}}$$

Step 5: Calculate the mechanical advantage from the following formula

$$\frac{F_{\text{Force string applies to drive axle}}}{F_{\text{Force of wheel to road}}} = \frac{r_{\text{radius of wheel}}}{r_{\text{radius of drive axle}}} = \frac{d_{\text{Distance vehicle is pulled by lever arm}}}{d_{\text{String on axle}}} = \text{IMA}$$

Part II   Determine Power Output

Step 6: Time your vehicle over the pulling distance. Perform 3 to 5 trials. Record your data in the data table.

Data Table #1

Pulling Distance	Total Travel Distance	Time Over Pulling Distance	Starting Energy from Lab #2	Power Output
$d_1 =$	Total $d_1 =$	$t_1 =$	$PE =$	$P_1 =$
$d_2 =$	Total $d_2 =$	$t_2 =$	$PE =$	$P_2 =$
$d_3 =$	Total $d_3 =$	$t_3 =$	$PE =$	$P_3 =$
Ave $d =$		Ave $t =$		Ave $P =$

Power Output, Gear Ratio, Mechanical Advantage

Step 7: Calculate the power by dividing the total starting energy from Lab #2 by the time over the pulling distance. Compare your value to other vehicles' power.

$$P_1 = \frac{PE_{total}}{\Delta t_1} \qquad P_2 = \frac{PE_{total}}{\Delta t_2}$$

Graphing the Results

1. Make a graph of the Power Rating vs. total travel distance. Put "power" on the horizontal axis and "distance" on the vertical axis.
2. Make a graph of Pulling Distance vs. Mechanical Advantage. Put "mechanical advantage" on the horizontal axis and "pulling distance" on the vertical axis.

Analysis

1. Describe any relationship that might exist between power rating and travel distance.
2. Describe any relationship that might exist between wheel to axle ratio and pulling distance.
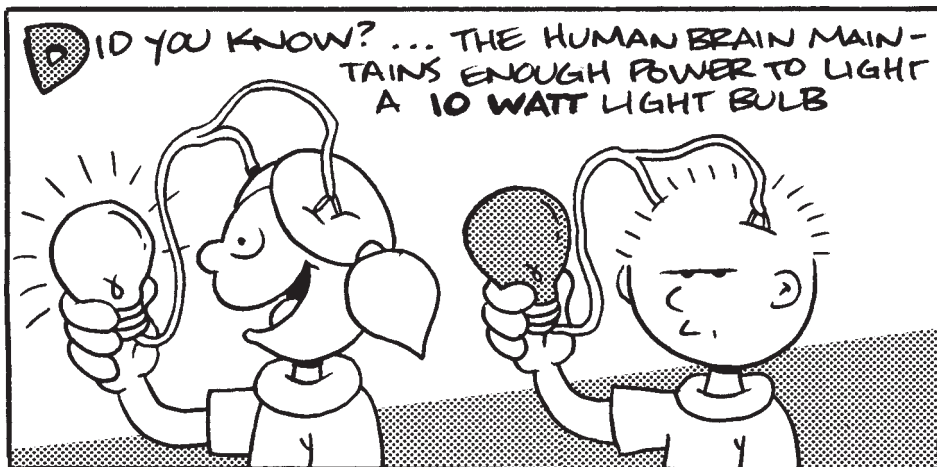
DID YOU KNOW? ... THE HUMAN BRAIN MAINTAINS ENOUGH POWER TO LIGHT A 10 WATT LIGHT BULB

Power Output, Gear Ratio, Mechanical Advantage

Purpose

In this activity you will calculate the efficiency of your mousetrap car

Materials

Ruler
Caliper
Stopwatch

Variables needed from other labs

Total Potential Energy from Lab #5
Rolling Friction from Lab #6
Coefficient of Rolling Friction from Lab #6
Rotational Inertia for each Wheel or Axle System from Lab #4

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Discussion

In this lab you will calculate the overall efficiency of your vehicle. Efficiency is how effectively a machine can transform energy into work without losing energy to friction. It is a rule of nature that in all transformations of energy some energy will be lost to the surroundings because of friction. More efficient machines lose less energy to friction. Efficiency allows you to see just how much of your energy is being used as designed. A mousetrap car uses energy to change speed and displace its position. With a slow-moving distance car, you would expect a more efficient vehicle to travel further than a less efficient car. With a distance car the objective is to reduce friction to a minimum, thereby increasing distance to a maximum.

With a speed car, the objective is to quickly transform the stored potential energy into energy of motion. For a speed car you can measure the efficiency by comparing the starting potential energy to the ending kinetic energy as

Lets Get Rolling
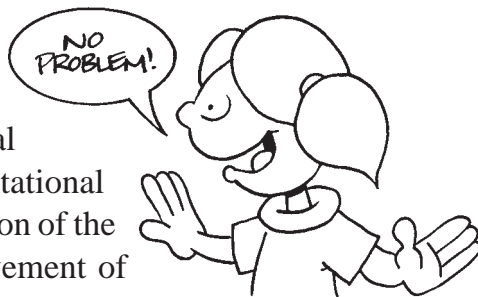
the vehicle crosses the finish line. The kinetic energy will be stored in two forms: rotational kinetic energy and linear kinetic energy. Rotational kinetic energy is the energy that is in the rotation of the wheels. Linear kinetic energy is in the movement of the car. These two forms of kinetic energy have to be calculated independently and then added together in order to find the total energy at the finish.

Finding the Rolling Friction

Step 1: Use the information from Lab # 2 and record your mousetrap cars starting potential energy .

Total Starting Energy = _____ Joules

Data Table #1

Pulling Distance	Time	Final Velocity	Linear Kinetic Energy	Total Rotational Energy	Total Kinetic Energy	Work Done	Efficiency
$d_1=$	$t_1=$	$v_1=$	$KE_{tran\ 1}=$	$KE_{rot\ 1}=$	$KE_1=$	$w_1=$	$E_1=$
$d_2=$	$t_2=$	$v_2=$	$KE_{tran\ 2}=$	$KE_{rot\ 2}=$	$KE_2=$	$w_2=$	$E_2=$
$d_3=$	$t_3=$	$v_3=$	$KE_{tran\ 3}=$	$KE_{rot\ 3}=$	$KE_3=$	$w_3=$	$E_3=$
$d_4=$	$t_4=$	$v_4=$	$KE_{tran\ 4}=$	$KE_{rot\ 4}=$	$KE_4=$	$w_4=$	$E_4=$
AVE	$d=$	$h=$	$KE_{tran}=$	$KE_{rot}=$	$KE=$	$w=$	$E=$

Step 2: Place your mousetrap car on the start line Walk along side of your mousetrap car and measure the pulling distance. You can also use the data you calculated from Lab #3: *Predicting Pulling Distance.* Record the pulling distance in Data Table #1 under "Pulling Distance. "

Conservation of Energy

Step 3: Place your mousetrap car on the start line. Release the mousetrap car and time it over the pulling distance only. **Do not time beyond the pulling distance**. Test three to five times and record in Data Table #1 under "Time."

Step 4: Use the following formula to calculate the final velocities for each trial. Record your results in Data Table #1 under "Final velocity."

$$\text{Final Velocity} = \frac{2 * \text{Pulling Distance}}{\text{Time}}$$

Step 5: Find the mass for your vehicle so that you can calculate the linear kinetic energy. Calculate the linear kinetic energy for each trial using the mass times the final velocity squared. Record your answer under "Linear Kinetic Energy" in Data Table #1.

$$KE_{tran_1} = \frac{(m) * (V_{f_1})^2}{2}$$

Finding the Rotational Kinetic Energy
Step 6: From Lab#5 record the rotational inertia for each wheel or axle system in data table #2. Aslo record the radius for each wheel on your vehicle.

Data Table #2

	Front Wheel #1 0r Front Axle System	Front Wheel #2	Rear Wheel #1 0r Rear Axle System	Rear Wheel #2
Rotational Inertia	$I_{f1}=$	$I_{f2}=$	$I_{r1}=$	$I_{r2}=$
Radius of Wheel	$r_{f1}=$	$r_{f2}=$	$r_{r1}=$	$r_{r2}=$

Conservation of Energy

Step 7: Using the final velocities from Table #1, calculate the rotational kinetic energy for each trial. You must calculate each wheel or axle system separately.

$$\text{KE } 1_{\text{rot 1}} = \frac{(I_1) * (v_{f1})^2}{2*(r_1)^2}$$

Data Table #3

Trial #	KE_{rot} Wheel #1	KE_{rot} Wheel #2	KE_{rot} Wheel #3	KE_{rot} Wheel #4	Total Rotational Kinetic Energy
1=	KE $1_{rot\ 1}$=	KE $2_{rot\ 1}$=	KE $3_{rot\ 1}$=	KE $4_{rot\ 1}$=	KE $_{rot\ 1}$=
2=	KE $1_{rot\ 2}$=	KE $2_{rot\ 2}$=	KE $3_{rot\ 2}$=	KE $4_{rot\ 2}$=	KE $_{rot\ 2}$=
3=	KE $1_{rot\ 3}$=	KE $2_{rot\ 3}$=	KE $3_{rot\ 3}$=	KE $4_{rot\ 3}$=	KE $_{rot\ 3}$=
4=	KE $1_{rot\ 4}$=	KE $2_{rot\ 4}$=	KE $3_{rot\ 4}$=	KE $4_{rot\ 4}$=	KE $_{rot\ 4}$=

49

Step 8: Once you have found the rotational kinetic energy for each wheel, add each value together for each trial in order to get the total rotational kinetic energy, record in Data Table #3 and then transfer the Total Rotational Kinetic Energy to Table #1.

$$KE_{rot_1} = KE\ 1_{rot_1} + KE\ 2_{rot_1} + KE\ 3_{rot_1} + KE\ 4_{rot_1}$$

Step 9: From Table #1 add the linear kinetic energy with the total rotational kinetic energy. This value represents the total energy of your vehicle when all the potential energy is converted into kinetic energy.

$$KE_1 = KE_{rot_1} + KE_{tran_1}$$

Conservation of Energy

Step 10: Subtract the total kinetic energy from the starting potential energy to get the work lost to friction.

$$W_1 = PE_1 - KE_1$$

Step 11: With a distance vehicle the objective is to convert the starting potential energy into distance by doing work to overcome friction. With a speed car the objective is to convert the starting potential energy into kinetic energy. Calculate the efficiency for your vehicle by dividing the total kinetic energy by the starting potential energy and then multiplying by 100 in order to get a percentage.

$$\text{Efficiency}_1 = \frac{KE_1}{PE_{start}} * 100$$

50

Step 12: Calculate the amount of rolling friction acting against your vehicle using the energy lost to friction or the work divided by the pulling distance.
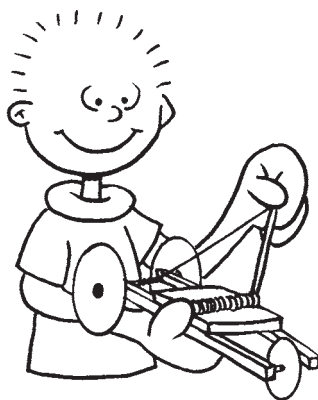
$$f_1 = \frac{W_1}{d_1}$$

Conservation of Energy

Graphing the Results

You will now graph your data in order to learn from your results. In each of the following graphs, attempt to draw a "best fit" line. If data is widely scattered, do not attempt to connect each dot but instead draw the best line you can that represents the shape of the dots. If you have access to a computer, you can use a spread sheet like Microsoft Exel to plot your data.

1. Graph **Pulling Distance** vs. **Work** for each vehicle in the class.

2. Graph **Pulling Distance** vs **Efficiency** for each vehicle in the class.

Analysis

1. Explain how pulling distance is related to energy lost to friction or the work done.

2. Explain the relationship that exists between pulling distance and efficiency.

Building the Perfect Distance Cars
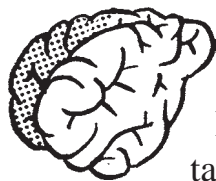
Brain Tip

Key Ideas you should consider when building a good distance vehicle

- **Longer lever arms** The more string that can be pulled off the drive axle translates into more turns that the wheels can make, this causes your vehicle to cover more distance under the pulling force.

TRAP

- **Large Drive Wheel(s)** Large drive wheels cover more linear distance for each rotation than a smaller diameter wheel. The best wheels tend to be between 1-2 feet in diam-eter.

- **Small Drive Axle** You can get more turns with a smaller axle for the same length of string than with a larger one. More turns of the axle means more turns of the wheel, which means greater travel distance.

- **Small Power Output** Vehicles that move slower tend to be more energy efficient in comparison to an equally built car of same rolling friction. You can slow a car down by increasing the lever arm length and repositioning the mousetrap further from the drive axle. At low speeds, air resistance is not a large factor in the motion of a moving object, but as the speed of an object increases, the force of air resistance also increases; therefore, at higher speeds moving objects will have to expend more energy to maintain constant velocity. For this reason, it is best to build a slow moving distance car!

Distance Car

LONG LEVER ARM

LARGE AXLE TO WHEEL RATIO

MOTION
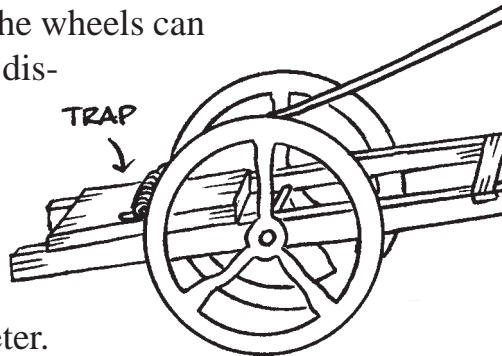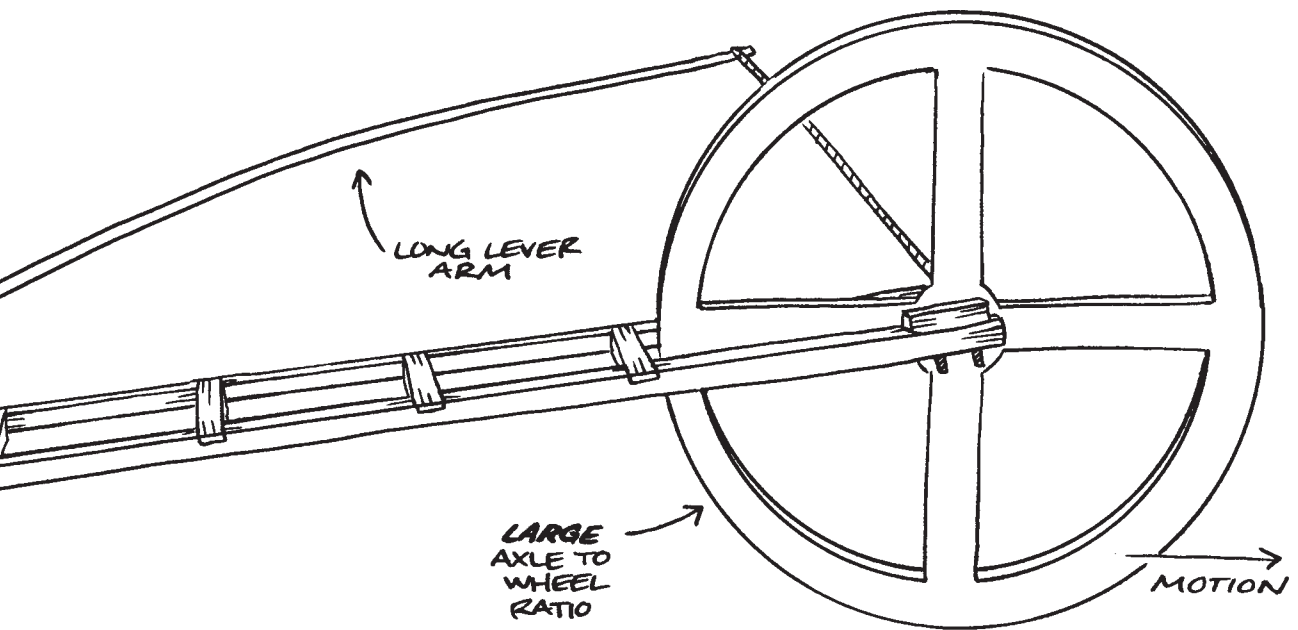
Decrease Mass and Rotational Inertia Build a lightweight frame and use lightweight wheels. Remove mass from wheels to decrease rotational inertia.

- **Sample Different Mousetraps** Not all mousetrap springs have the same spring tension. The greater the tension in a mousetrap, the more energy you will be able to store when the spring is wound-up.

- **Remove ALL Friction** This one is impossible but the more you can reduce friction, the less energy that will be lost to heat and sound which translates into greater travel distance. Your vehicle should have the lowest possible energy consumption; this means that your vehicle should be a slow mover and use ball bearings.

Using these principles, mouse-trap cars have traveled 100$^+$ meters!

Distance Car

1   *Decrease rolling friction by re-working the friction points. Polish bushings or use ball bearings. If you are using bearings, soak them in WD-40; this will remove any oil or grease. Although grease and oil are lubricants and often used to reduce friction, adding them to mouse-trap car bearings slows the car down because of the large viscosity of the lubricants.*

FRICTION POINTS BETWEEN AXLE AND FRAME
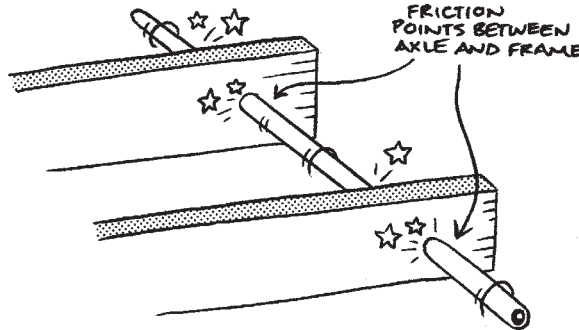
2   *Decrease the force required to pull the vehicle by decreasing the rotational inertia. Decrease the rotational inertia by removing mass from the inside of the wheels. Decrease the overall mass of the car by removing mass from the frame and use a light-weight lever arm. Move the trap away from the pulling axle and extend the lever arm. Re-adjust the string and the string attachment point. Don notadd mass around the outside of wheels such as rubber bands or balloons.*
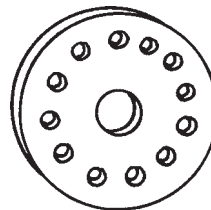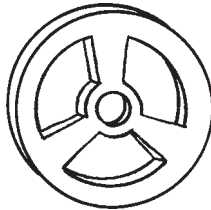
3   *Use a larger drive wheel. Try making a wheel out of mat board. Mat board is stiff and light weight.*

Distance Car

4 *Use a smaller drive axle. The larger the ratio of drive wheel(s)-to-axle(s) diameter, the farther you car will go for each turn of the wheel and the greater the pulling distance will be.*

LARGE
AXLE:WHEEL
RATIO

THIN
AXLE
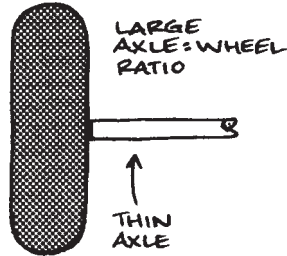
5 *Find a stronger mouse trap. Test different mouse traps in order to find the strongest one.*

6 *If your car is stopping and the spring is not at its resting point, find a stronger mouse trap or try to make a tapered axle so you can change the torque required to turn the wheels as the pulling force to the drive axle changes, or build up the drive axle with tape.*
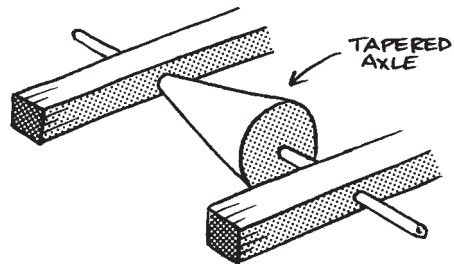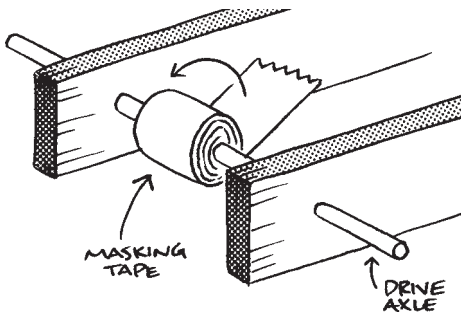
TAPERED
AXLE

MASKING
TAPE

DRIVE
AXLE

7 *Check string alignment and make sure that the string is attached directly over the drive axle with the lever arm held in the fully wound position.*

Distance Car

Building the Perfect Speed Cars

Brain Tip

Key Ideas you should consider when building a good speed vehicle. Using these principles, I have seen mouse-trap cars travel 5 meters in under 1 second!

- **Shorter lever arms** shorter lever arms have more pulling force, more pulling force means greater acceleration, greater acceleration mean less time before the vehicle reaches top speed. If the lever arm is too short your vehicle will slip off the start and will waste energy. Therefore, adjust the lever length in order to find the best performance

- **Smaller Drive Wheel(s)** Wheels should be around 2-5 inches in diameter but no larger than a compact disc. If the wheel-to-axle ratio too small your vehicle will slip off the start and will waste energy. Therefore, adjust the ratio in order to find the best performance

- **Increase the Traction** Use rubber bands on the drive wheels and/or Traction Action$^®$ on the wheels in order to increase the traction. More traction means greater acceleration.

- **Larger Diameter Drive Axle** You can get more torque with a thick axle. More torque means greater acceleration! You can build the axle up with tape to increase the axle diameter.

- **Large Power Output** The vehicle should be designed to have a large energy consumption in a short period of time (i.e., a large power output). A vehicle that can get-up to its top speed as fast as possible will have a shorter time over a timed distance. With a car designed for speed , the objective is how quickly can the vehicle convert its potential energy into kinetic energy.

Speed Car

- **Decrease Mass and Rotational Inertia** MORE IMPORTANT WITH A SPEED CAR THAN A DISTANCE VEHICLE. Build a lightweight frame and use lightweight wheels. A wheel with a large rotational inertia can really limit a cars performance, remove as much mass as possible from wheels to decrease rotational inertia.

- **Sample Different Mousetraps** Not all mousetrap springs have the same spring tension. The greater the tension in a mousetrap, the more energy you will be able to store when the spring is wound-up.

- **Remove ALL Friction** This one is impossible but the more you can reduce friction, the less energy that will be lost to heat and sound, which translates into greater speed. Your vehicle should have the lowest possible energy consumption do to friction; this means that your vehicle should use ball bearings.
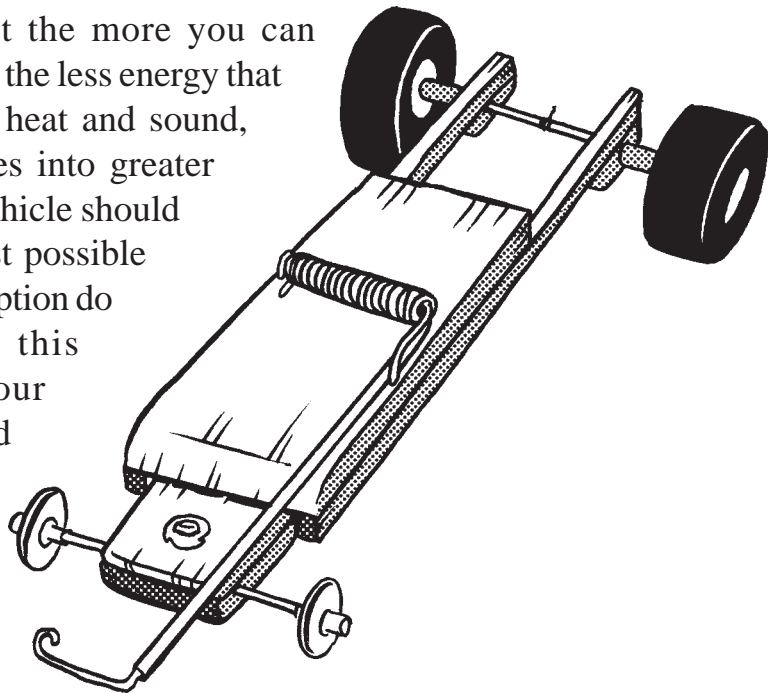
Speed Car

Ideas for Increasing Speed

1   *Move the mouse trap closer to the drive axle as long as the wheels are not spinning and decrease lever arm accordingly.*

MORE SPEED

Drive Axle

FRONT AXLE
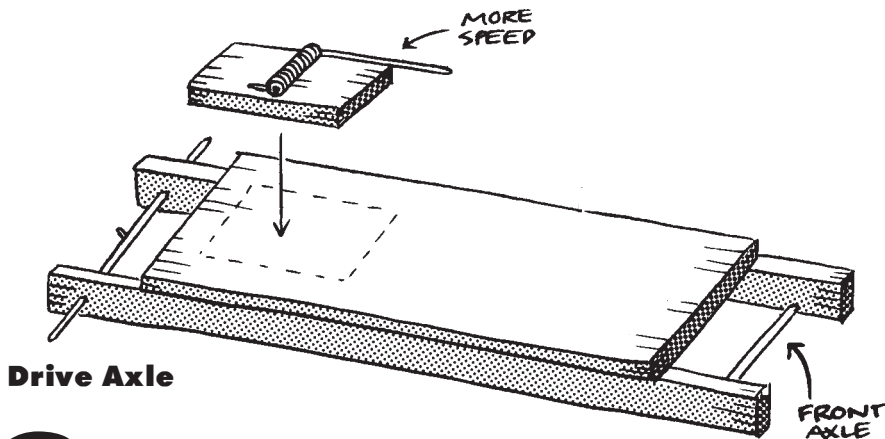
2   *Increase traction on drive wheels by using rubber bands or the middle section of a rubber balloon around the drive wheels. Try adding mass directly above the drive axle.*

GLUE

COMPACT DISK

RUBBER BAND

RUBBER BAND
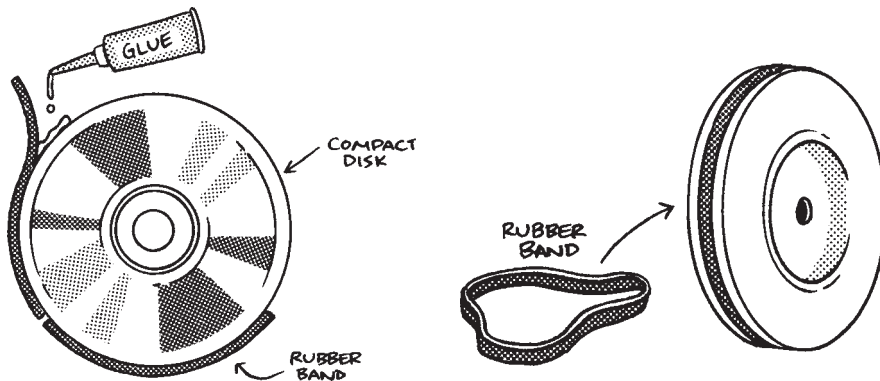
3   *Move the trap away from drive wheel(s)* **only if the wheels are slipping**. *This will decrease the pulling force which is the reason for the slipping wheels.*

Speed Car

4 *Decrease rolling friction by re-working the friction points. Polish bushings or use ball bearings. If you are using bearings, soak them in WD-40l; this will remove any oil or grease. Although grease and oil are lubricants and often used to reduce friction, adding them to mouse-trap car bearings slows the car down because of the large viscosity of the lubricants.*

FRICTION
POINTS BETWEEN
AXLE AND FRAME

SPIN A BEARING ON
A PENCIL TO REMOVE
GREASE AFTER SOAK-
ING IN ALCOHOL
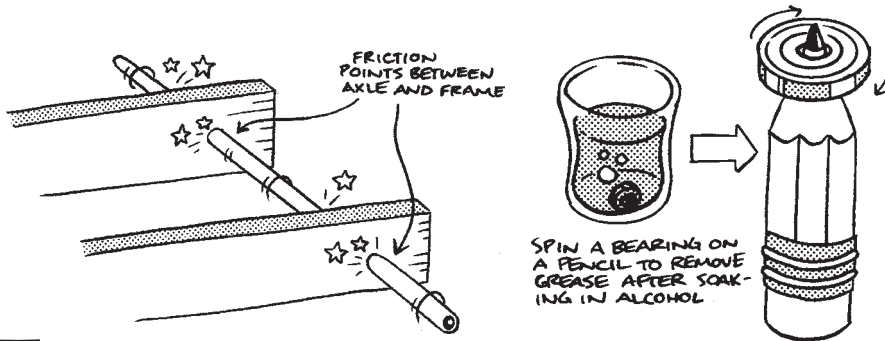
5 *Decrease rotational inertia of wheels by removing mass from the inside of the wheels. Also, try smaller diameter wheels.*

6 *Adjust the wheel-to-axle ratio by adding or removing tape on the drive axle.*
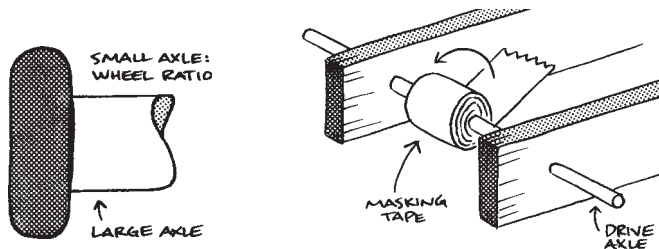
SMALL AXLE:
WHEEL RATIO

LARGE AXLE

MASKING
TAPE

DRIVE
AXLE

7 *Check string alignment and make sure that the string is attached directly over the drive axle with the lever arm held in the fully wound position.*

Speed Car

PROBLEM:

Axle slides back and forth causing wheels to rub against the frame of the car, slowing or stopping the car.

1. Add thrust washer between wheels and the frame for a smoother rubbing surface with less friction.

THRUST WASHER
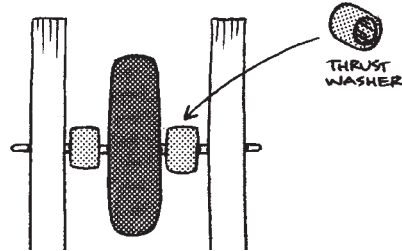
2. Make spacers out of brass tubing to hold the wheels in place and limit the side-to-side play of the wheels or axles.
3. If you are using bearings, the axle may be moving side to side. Carefully glue the axles to the bearings without getting glue in the bearings.

BEARING

AXLE

GLUE

60
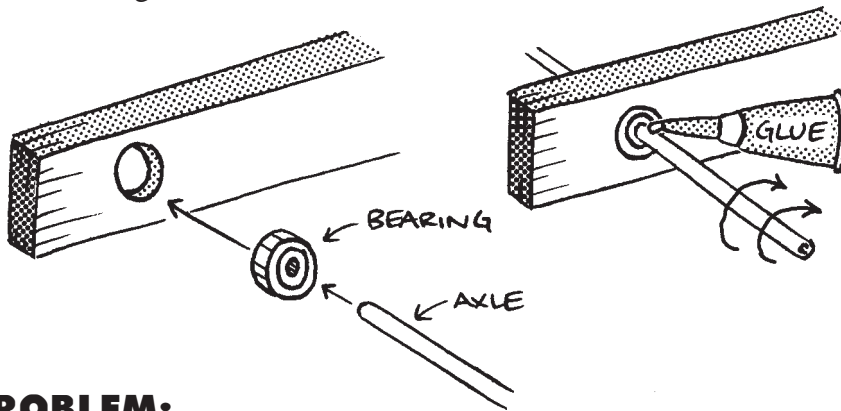
PROBLEM:

Can't find an axle to fit the wheels or bearings.

1. Re-size the axle or change the wheel's hole size with a spacer.

1/4 L SINK WASHER USED AS A WHEEL SPACER

PROBLEM:

Mouse trap falls quickly but car moves slowly.

1. Drive wheels are not glued to the axle and the axle is spinning inside the wheels. Glue wheels to axle.
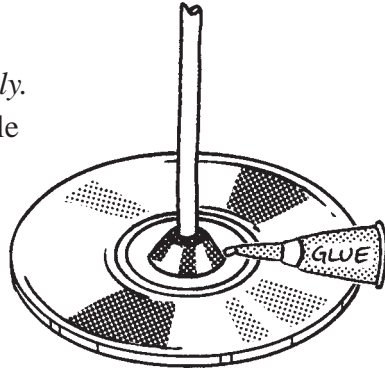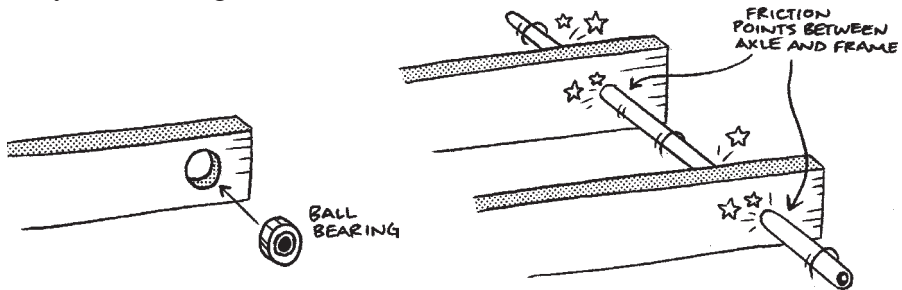
2. There is no hook on the axle for attaching the string and/or the string is slipping off the axle without pulling. The hook may not be glued to the axle and is slipping under the tension of the string.
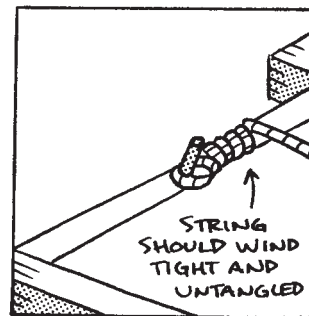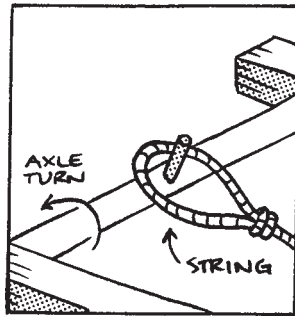
PROBLEM:

Mouse trap car does not start or moves slowly.

1. Too much friction in the rolling points. Re-do the rolling points or try ball bearings.

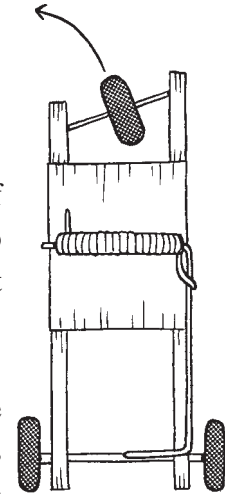## Technical Help

PROBLEM:

Mouse trap car does not start or moves slowly. (Continued)

    2. Not enough tension in the pulling string. Move the trap closer to the drive axle and adjust the string attachment point on the lever arm accordingly *or* try to build up the drive axle with tape. Lastly, test different mouse traps and use the strongest one.

LESS FORCE

MORE FORCE

MASKING TAPE

DRIVE AXLE
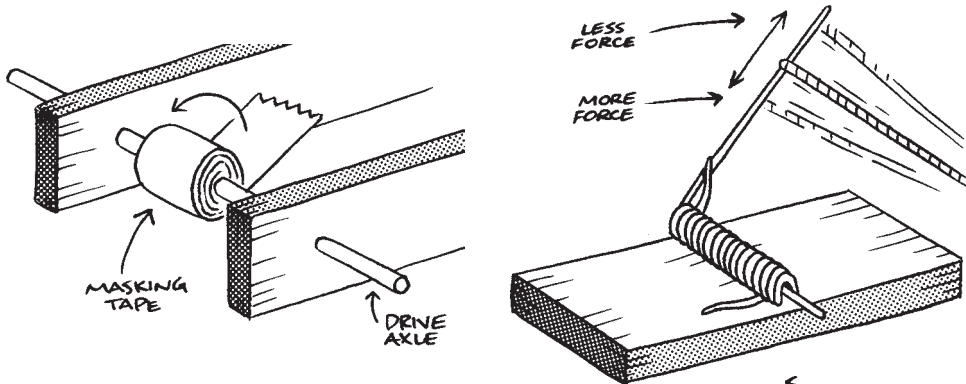
PROBLEM:

Mouse trap car does not travel straight.

    1. Wheels are not pointing in the same direction. The solution is to bring the wheels into alignment. If the vehicle is a three-wheeled vehicle you need to focus your efforts on the single wheel. Try to align it with the other two. This is not easy!

    2. This only applies to long distance cars that use one large wheel as the drive wheel. If the car travels straight when you push it without the tension of the lever arm, but turns once under the pulling tension of the trap, there is too much frame flex or the trap is pulling too hard on one side of the axle. Strengthen the frame or prevent the pulling side of the axle from giving too much at its holding points.
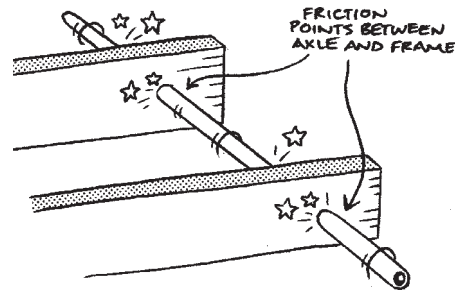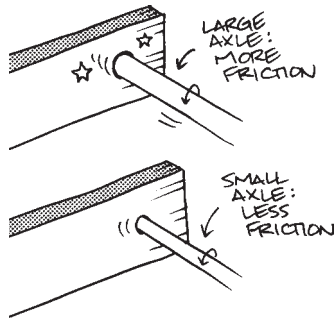
Technical Help

PROBLEM:

Mouse-trap car suddenly stops or slows quickly.

1. The string is not releasing from the drive axle because it is either glued to the axle or it is too long *or* the hook is too long and caching the string causing it to rewind.
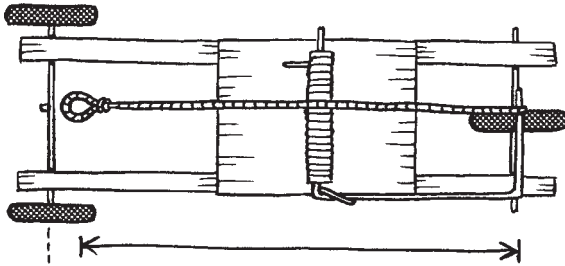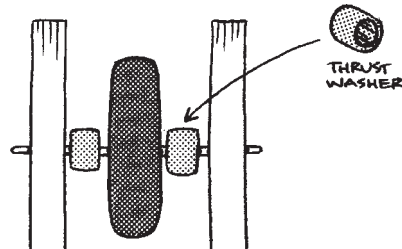

*Cut string a little bit **shorter** than what is needed in order to insure a proper release.*

2. There is too much friction at the rolling points. Re-work the bearings to reduce friction or try ball bearings. Try a small diameter axle.

3. Wheels are rubbing on the frame. Prevent wheels from rubbing with spacers or thrust washers.

Technical Help

The Great Mouse-Trap Car Distance Race Rules

OBJECTIVE:

Build a vehicle powered solely by the energy of one standard-sized mouse trap (1 3/4" X 3 7/8") that will travel the greatest linear distance.

By definition, a vehicle is "a device with wheels or runners used to carry something (e.g., car, bus, bicycle or sled)." Therefore, launching a ball (e.g., marble) from the mouse trap will be ruled illegal.

REGULATIONS:

1. The device must be powered by a single "Victor" brand mouse trap (1 3/4" X 3 7/8"). Other brands may be used if permitted.
2. The mouse trap can not be physically altered except for the following: 4 holes can be drilled only to mount the mouse trap to the frame and a mouse-trap's spring can be removed only to adjust the length of its lever arm.
3. The device cannot have any additional potential or kinetic energy at the start other than what can be stored in the mouse-trap's spring itself. (This also means that you cannot push start your vehicle.)
4. The spring from the mouse trap cannot be altered or heat treated.
5. The spring cannot be wound more than its normal travel distance or 180 degrees.
6. Vehicles must be self-starting. Vehicles may not receive a push in the forward direction or side direction.
7. The vehicle must steer itself. Measurements of distance will not measure the total distance travele,d only the displacement distance.
8. Distance will be measured from the front of the tape at the starting line to the point of the vehicle that was closest to the start line at the time of release.
9. The instructor has the final decision as to the appropriateness of any additional items that might be used in the construction of the vehicle.

RUNNING THE CONTEST:

1. The race track can be any smooth level floor, a gymnasium or a non-carpeted hallway.
2. Each contestant will be given three attempts. The winner will be that vehicle which has obtained the greatest distance on any one of the three attempts. Any ties will be decided by a single run-off between the vehicles which tied.

OBJECTIVE:

Build a vehicle, powered solely by the energy of one standard-sized mouse trap (1 3/4" X 3 7/8") that will travel a 5-meter linear distance in the shortest amount of time.

By definition, a vehicle is "a device with wheels or runners used to carry something (e.g., a car, bus, bicycle, or sled)." Therefore, launching a ball (e.g., a marble) from the mouse trap will be ruled illegal.

REGULATIONS:

1. The device must be powered by a single "Victor" brand mouse trap (1 3/4" X 3 7/8") Other brands may be used if permitted.
2. The mouse trap can not be physically altered except for the following: 4 holes can be drilled only to mount the mouse trap to the frame and a mouse-trap's spring can be removed only to adjust the length of its lever arm.
3. The device cannot have any additional potential or kinetic energy at the start other than what can be stored in the mouse-trap's spring itself. (This also means that you cannot push start your vehicle.)
4. The spring from the mouse trap cannot be altered or heat treated.
5. The spring cannot be wound more than its normal travel distance or 180 degrees.
6. Vehicles must be self-starting. Vehicles may not receive a push in the forward direction or side direction.
7. The vehicle must steer itself. Measurements of distance will not measure the total distance traveled, only the displacement distance.
8. Vehicles can not recieve a running start and must start as close as posible to the start line. Time of run will begin when any part of the vehicle passes over the start line and will ends when that same point passes over the 5-meter mark.
9. The instructor has the final decision as to the appropriateness of any additional items that might be used in the construction of the vehicle.

RUNNING THE CONTEST:

1. The race track can be any smooth level floor, a gymnasium or a non-carpeted hallway.
2. Each contestant will be given three attempts. The winner will be that vehicle which has obtained the least amount of time on any one of the three attempts. Any ties will be decided by a single run-off between the vehicle which tied.

The Great Mouse-Trap Car Breaking Rules

OBJECTIVE:

Build a vehicle, powered solely by the energy of one standard-sized mouse trap, (1 3/4" X 3 7/8"), that will travel a 5-meter linear distance in the shortest amount of time AND stop as close to the 5 meter mark as possible without going over.

By definition, a vehicle is a device with wheels or runners used to carry something, as a car, bus, bicycle, or sled. Therefore, launching a ball, such as a marble from the mousetrap will be ruled illegal.

REGULATIONS:

1. The device must be powered by a single Victor brand mouse trap (1 3/4" X 3 7/8") Other brands may be used if permitted.
2. The mousetrap can not be physically altered except for the following: 4 holes can be drilled only to mount the mousetrap to the frame and a mousetrap's spring can be removed only to adjust the length of it's lever arm.
3. The device cannot have any additional potential or kinetic energy at the start other than what can be stored in the mouse trap's spring itself. (This also means that you cannot push start your vehicle.)
4. The spring from the mousetrap cannot be altered or heat treated.
5. The spring cannot be wound more than its normal travel distance or 180 degrees.
6. Vehicles must be self-starting. Racers may not receive a push in the forward direction or side direction.
7. The vehicle must steer itself. Measurements of distance will not measure the total distance traveled only the displacement distance.
8. Racers can not receive a running start and must start as close as possible to the start line. Time of run will begin when any part of the vehicle passes over the start line and will ends when that same point passes over the 5-meter mark.
9. The instructor has the final decision as to the appropriateness of any additional items that might be used in the construction of the vehicle.

RUNNING THE CONTEST:

1. The race track can be any smooth level floor, a gymnasium or a non-carpeted hallway.
2. Each contestant will be given three attempts. The winner will be that racer which has obtained the lowest score on any one of the three attempts. Any ties will be decided by a single run off between the racers that tied.

SCORING: lowest score wins:

Score = (time in seconds) + (distance from 5 meter mark in centimeters) + (distance OVER 5 meter mark in centimeters)
Note: the penalty for going over the mark is the distance from the line being added twice, if a car does not go past the line then the distance over the line is zero.

The Great Mouse-Trap Boat Race Rules

OBJECTIVE:

Build a vehicle, powered solely by the energy of one standard-sized mouse trap
(1 3/4" X 3 7/8") that will travel a 3-meter linear distance in the shortest amount of time.

By definition, a vehicle is "a device that floats such as a boat." Therefore, launching a ball
(e.g., a marble) from the mouse trap will be ruled illegal.

REGULATIONS:

1. The device must be powered by a single "Victor" brand mouse trap (1 3/4" X 3 7/8")
   Other brands may be used if permitted.
2. The mouse trap can not be physically altered except for the following: 4 holes can be
   drilled only to mount the mouse trap to the frame and a mouse-trap's spring can be
   removed only to adjust the length of its lever arm.
3. The device cannot have any additional potential or kinetic energy at the start other than
   what can be stored in the mouse-trap's spring itself. (This also means that you cannot
   push start your vehicle.)
4. The spring from the mouse trap cannot be altered or heat treated.
5. The spring cannot be wound more than its normal travel distance or 180 degrees.
6. Vehicles must be self-starting. Vehicles may not receive a push in the forward direction
   or side direction.
7. The vehicle must steer itself. Measurements of distance will not measure the total
   distance traveled, only the displacement distance.
8. Vehicles can not recieve a running start and must start as close as posible to the start
   line. Time of run will begin when any part of the vehicle passes over the start line and
   will ends when that same point passes over the 3-meter mark.
9. The instructor has the final decision as to the appropriateness of any additional items
   that might be used in the construction of the vehicle.

RUNNING THE CONTEST:

1. The race track can be any boady of water that is greater than 3-meters.
2. Each contestant will be given three attempts. The winner will be that vehicle which has
   obtained the least time on any one of the three attempts. Any ties will be decided by a
   single run-off between the vehicle which tied.

Mouse-Trap Car Worksheet

[ ] What is the diameter of your vehicles drive wheels?

[ ] What is the circumference of the drive wheels?
The circumference is calculated by multiplying the drive wheel diameter by Pi or 3.14.

[ ] How far will your vehicle travel in one rotation of the drive wheels?
A vehicle will travel the same distance as the circumference for each turn of the drive wheel.

[ ] What is the diameter of the drive axle?

[ ] What is the circumference of the drive axle?
The circumference is calculated by multiplying the drive axle diameter by Pi or 3.14.

[ ] How much string is used during one complete turn of the drive wheel?
In one turn of the axle, the length of srting used is the same as the circumference.

[ ] What is the length of your vehicles power stroke?

[ ] For your vehicles power stroke, how many times would the string wind around the drive axle? (Note, the string should always be as long or a little shorter than the power stroke.)
The number time that the drive axle turns durring the power stroke is calculated by deviding the length of the power stroke by the amount of string needed for one turn of the axle.

[ ] How many turns will the drive wheel(s) make during the power stroke?
same number as the turns of string around the axle

[ ] How far will your vehicle travel durring the power stroke?
Multiply the drive wheel circumference by the turns of string.

Mouse-Trap Car Worksheet

☐	Mouse-Trap Car's Mass
☐	Mouse-Trap Car's Weight
☐	Normal Force on non-drive wheel(s)
☐	Normal force on drive wheel(s)
☐	Position of center of mass from non-drive wheel(s)
☐	Rotational inertia of non-drive wheel(s)
☐	Rotational inertia of drive wheel(s)
☐	Wheel grip or traction force
☐	Coefficient of Traction
☐	Coefficient of rolling friction
☐	Friction force of non-drive wheel(s)
☐	Maximum Acceleration
☐	Drive Wheel Axle Radius
☐	Drive Wheel Radius
☐	String Tension at start
☐	Potential energy of wound mouse-trap
☐	Predicted travel distance
☐	Actual travel distance
☐	Speed over 5 meters