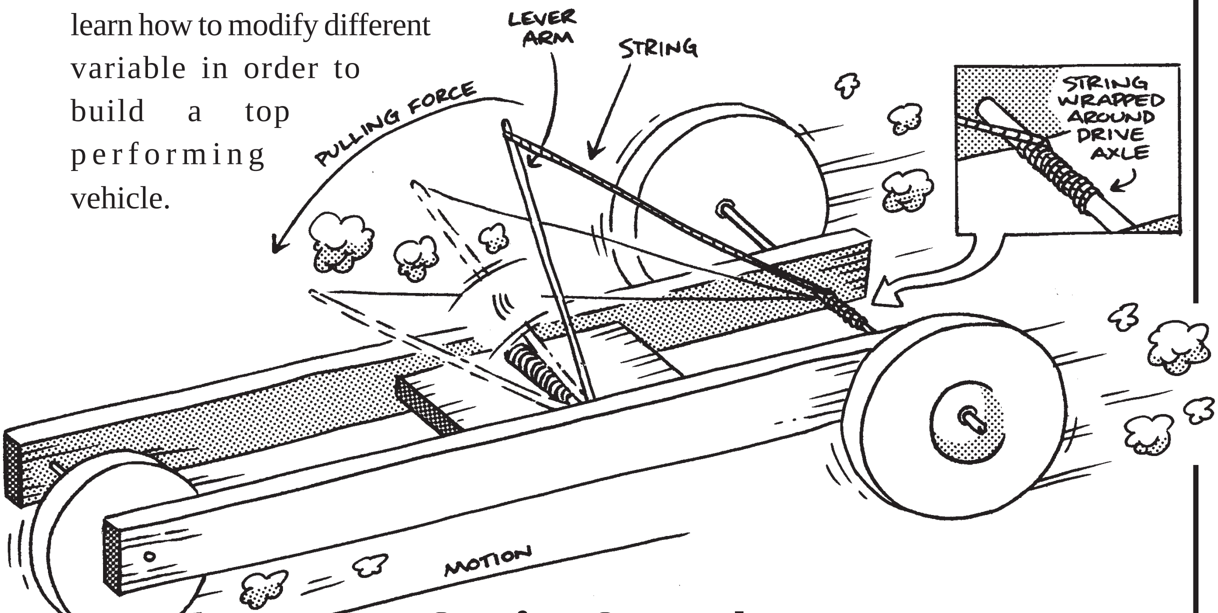
What is a Mouse-Trap Car and How does it Work?

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.



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!**

Motion

Motion occurs all around us yet it is hard to describe and explain. More than 2000 years ago the Greeks try to describe motion but failed because they did not understand the concept of **rate of change**. Today we describe motion as **rates of change** or some quantity divided by time. Speed is the measure of how fast something is traveling or the rate at which distance is being covered, another way of describing speed is to say that it is the distance that is being covered per time where the word **per** means divided by. In most cases, when you calculate the **speed** of a mousetrap racer you get an **average speed** over some distance, you begin timing at some predetermined starting point and then you stop timing at some predetermined ending point. This method does not tell you the **instantaneous speed** of your vehicle along any point of its motion it only tells you the **average speed** over your timing distance. In everyday conversations we tend to use the words speed and **velocity** interchangeably but it needs to be pointed out the speed and velocity are slightly different. Unlike speed velocity tells you direction; example, to say an objet is traveling at 55 mi/h is to give the objects speed only, to say an object is traveling at 55 mi/h due north is to give the object velocity. By adding the direction of an object motion we change it from speed to velocity. Why is this small distinction of direction important in the study of motion? If the velocity of an object is changing then there is another way to describe the objects motion and it is called **acceleration**, the rate at which velocity is changing. Velocity is changing when any of the following conditions occurs, there is a **change in speed**, or there is a **change in direction**. A car traveling in a circle at a constant speed has a changing direction so even though its speed is constant its direction is not, so it is accelerating. **Acceleration is something you can feel**, when you step on the gas pedal or break pedal in a car you feel yourself accelerate. Also, when you turn the steering wheel of a car you change your direction and you feel acceleration so we say that accelerations are changes in speed and direction.

Lab #2- The Force is Against You

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

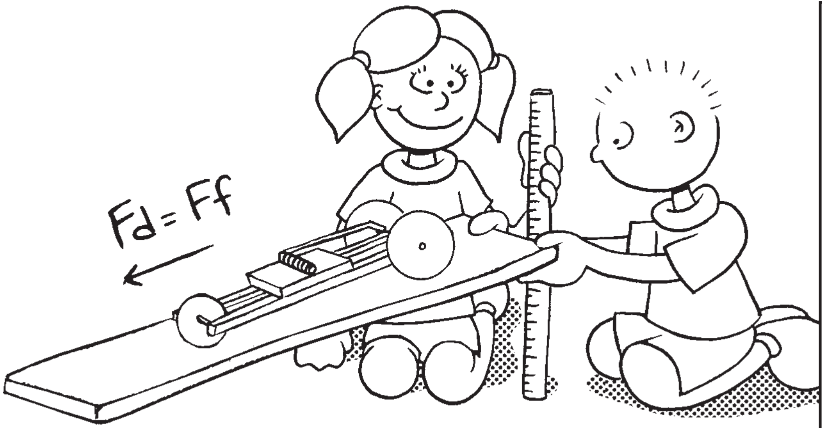
Variables needed from other labs
Total Potential Energy from Lab #5

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).



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.

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

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: $N = \cos\theta \cdot \mathrm{w}$

The normal force is the force that is perpendicularto the angled ramp.

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

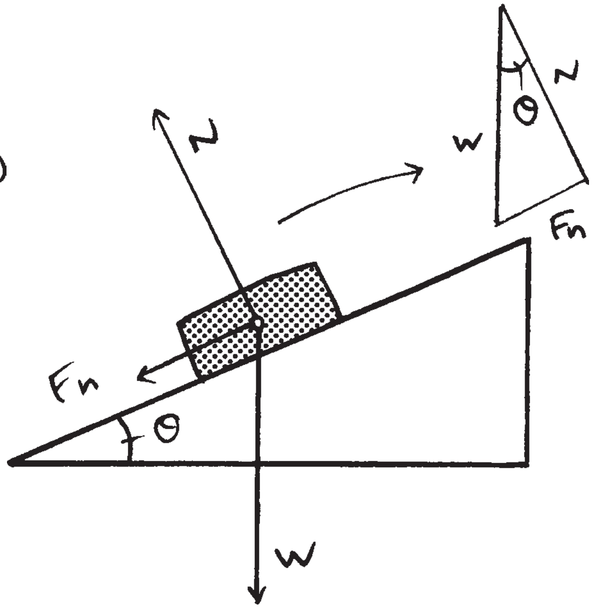
Resolving for the coefficient of friction from Formulas #3, #4 and #5

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

The coefficient of 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

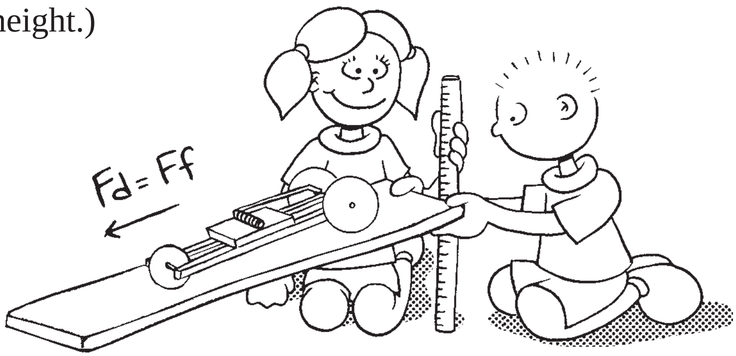
The angle of the ramp in this experiment forms a right triangle. The force due to gravity and the normal force of the ramp's surface cause a force directed down the ramp called "Force Down." These three forces form a right triangle which has the same angle as the base of the ramp. Knowing the angle of 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.

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.)

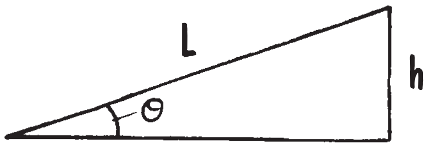


Data Table #1

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		$h=$	$\theta=$	$\mu=$	$f=$		$d=$

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.

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

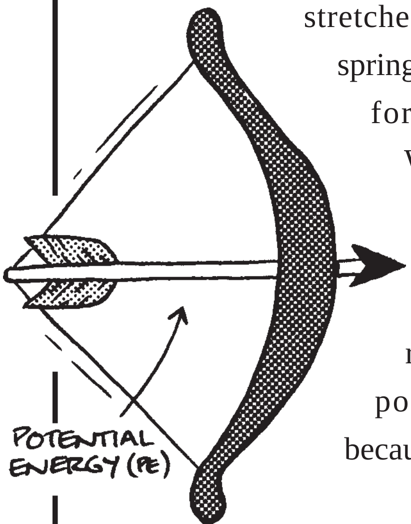
Step 7: Using the starting energy that you calculated in Lab #4 you can calculate the predicted travel distance by using the following:

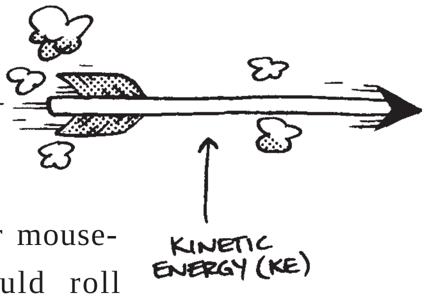
$$\text{Predicted Travel Distance} = \frac{\text{Total Potential Energy}}{\text{Rolling Friction}}$$

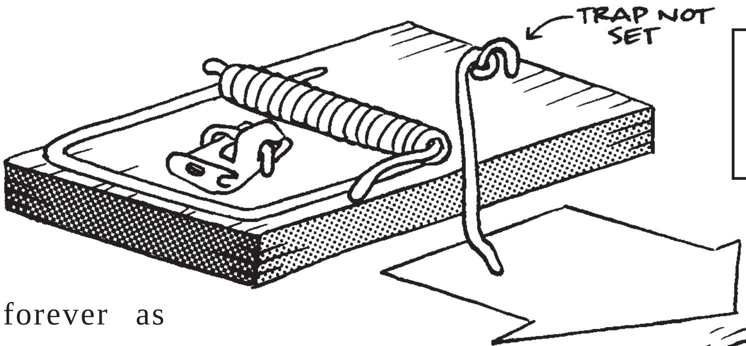
Energy

Perhaps the concept most central to building mouse-trap cars is **energy**. Energy is defined as having the ability to do work. Work is motion that result in something being done. Without energy, the universe would be motionless and without life. We usually observe energy only when it is happening or when it is being transformed. Energy can be classified in a number of ways. Most commonly energy is classified as **potential** and **kinetic**. The energy that is stored and held in readiness is called potential energy (PE) because in the stored state it has the potential to do work. For example, a stretched or compressed spring has the potential for doing work. When a bow is drawn, energy is stored in the bow. A stretched rubber band has potential energy because of its position and because in this position it is capable of doing work. Kinetic energy (KE) is energy of motion or the energy a moving object has. A baseball thrown through the air has kinetic energy because of its motion just as a moving car has energy because of its speed or motion.

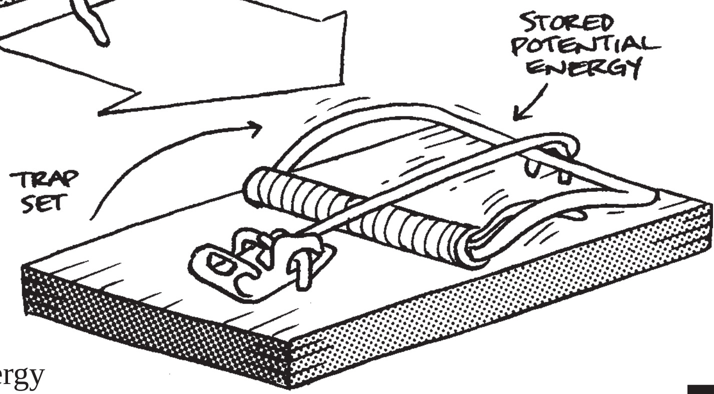
Energy, potential or kinetic, follows one basic rule called the Law of Conservation of Energy, stated: **Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes.** By winding the spring on your mouse-trap car, you store energy in the spring as potential energy. This stored potential energy will turn into kinetic energy as the mouse-trap car begins to move. In a perfect universe, your mouse-trap car should roll



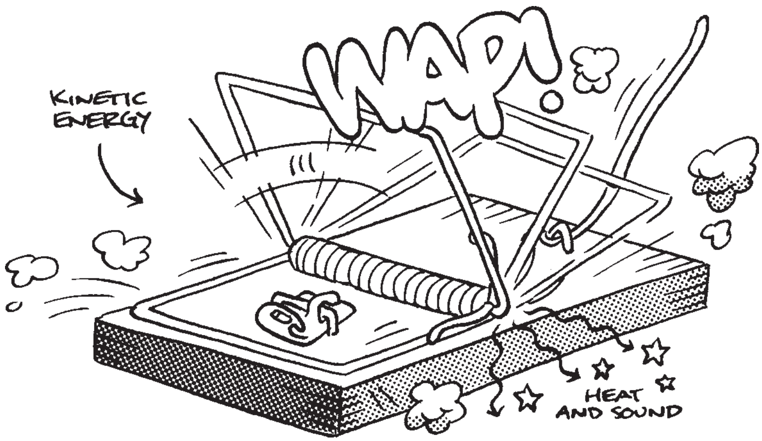




Potential Energy
Stored Energy



forever as the potential energy is changed into kinetic energy. But in our universe there is friction and in order to overcome friction you have to do work. Friction converts energy into **heat** and **sound** which removes energy from your motion, causing the vehicle to roll to a stop as its energy is removed. Your goal in building a good distance car is to produce a vehicle that loses energy at the lowest possible rate.



Kinetic Energy
Energy of Motion

Key Idea

When building mouse-trap cars, the objective is to transform the stored energy of the spring into **forward motion***. By reducing and eliminating friction, your vehicle will be more efficent at converting energy into motion.*

Lab #5 - All Wound Up

Purpose

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

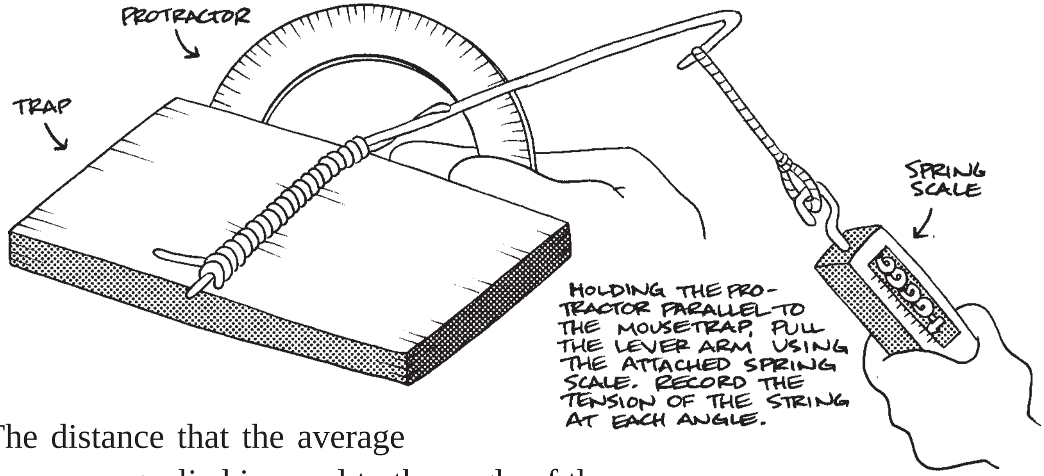
Equipment Needed

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.

The Set-up



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).

Formulas

What it All Means

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: $\text{degrees} \times \frac{\pi}{180^o} = \theta$

A formula used to change degrees into radians

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

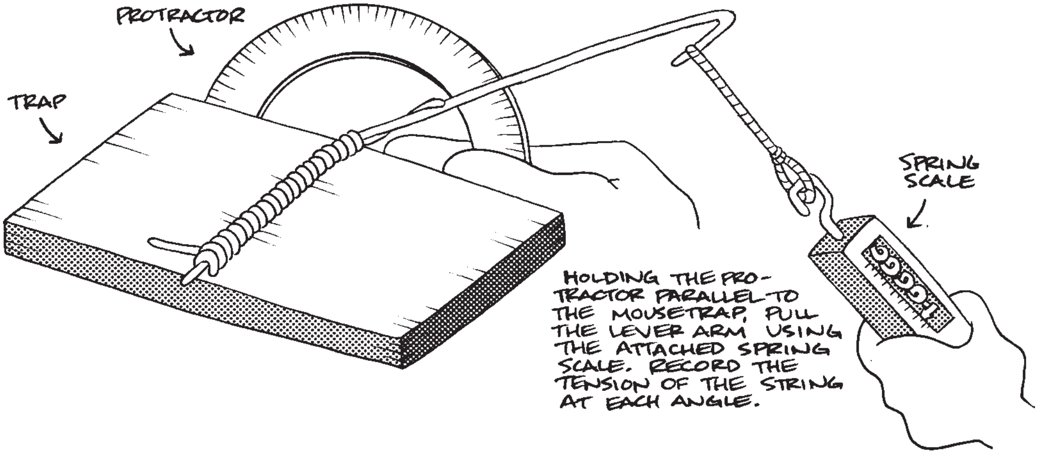
Formula #7: $PE = \frac{1}{2}kx^2$

Potential energy of a stretched or compressed spring

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

Potential energy of a stretched or compressed torsion spring

Pulling Your Weight



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.

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

Data Tables

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	

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.

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

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

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

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.

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

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

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

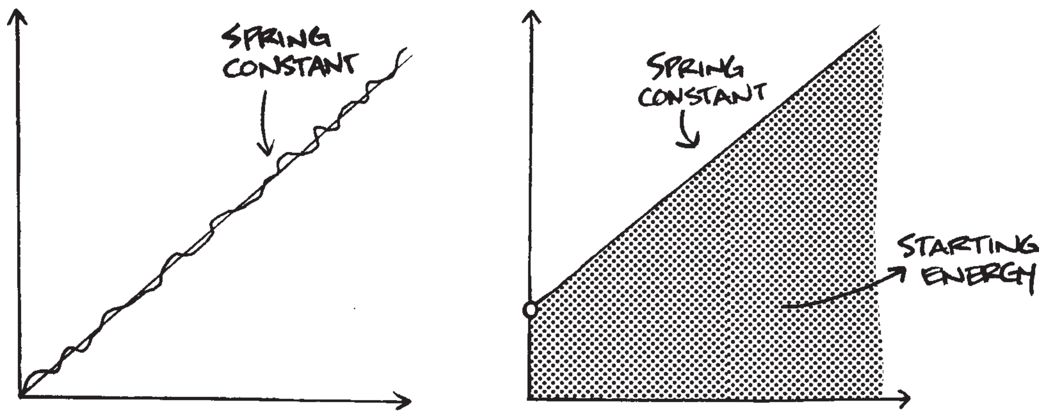
$$\kappa_3 = \frac{(F_3 - F_2)r_{\textit{arm}\text{ length}}}{\theta_{2,3}}$$

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.

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?

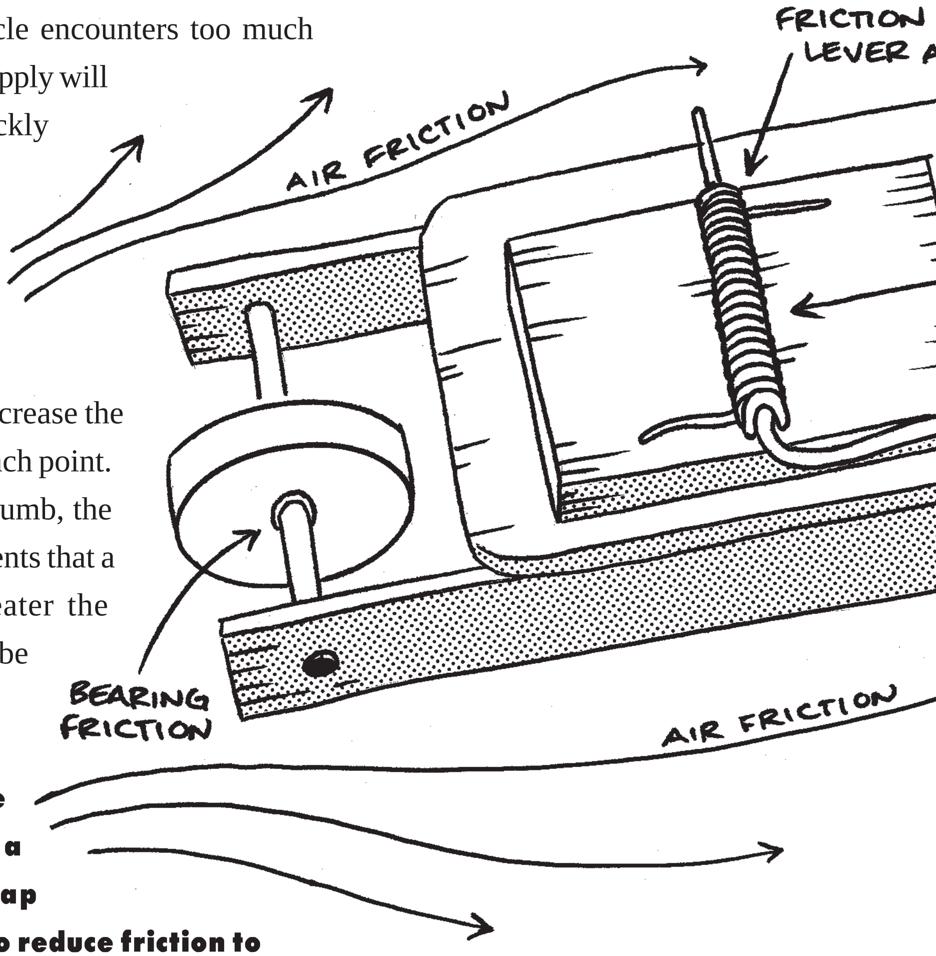
2. What does the slope of the line from each of your graphs tell you about the strength of your spring compared to other students' graphs?

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?

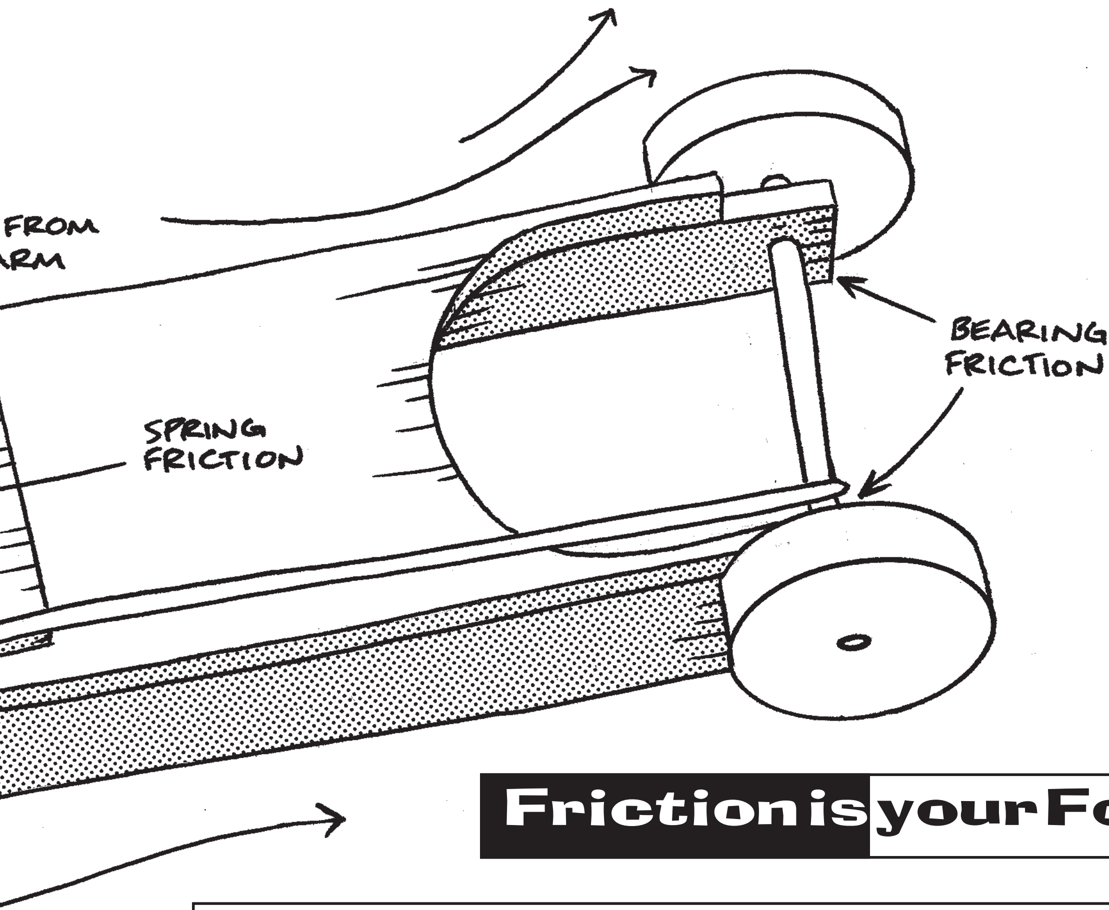
4. How does your potential energy compare to other students' potential energy in your class? Discuss.

Energy & Friction

When designing a mouse-trap powered car, there are two variables that truly determine the overall performance: **friction** and **energy**. Friction is what slows and stops your vehicle; energy is what moves your vehicle. If your vehicle encounters too much friction, your energy supply will be consumed too quickly and your vehicle will not travel very far or accelerate very fast. Evaluate every moving component on your vehicle and decrease the amount of friction at each point. As a general rule of thumb, the more moving components that a machine has, the greater the force of friction will be and the greater the energy consumption will be. **Your ultimate goal when building a distance mouse-trap powered vehicle is to reduce friction to the lowest possible force.** The smaller the frictional force, the farther your supply of energy will propel your vehicle. With this idea in mind, slow-moving vehicles will have a smaller force of air resistance acting against them and will travel farther than faster-moving vehicles.



Energy



Friction is your Foe

It can not be said enough! *Your ultimate goal when building a distance mouse-trap powered vehicle is to reduce friction to the lowest possible force. The smaller the frictional force, the further your supply of energy will propel your vehicle or the faster your vehicle will travel. If you are building a distace car, your vehicle should move as slow as possible without stopping as the spring releases its energy. Look your car over with a scrutinizing eye in order to reduce the total amount of friction acting on your vehicle.*

Lab #6 - The force Against you, Part II

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: $$d = \frac{PE}{f_{rf}}$$

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

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:

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

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

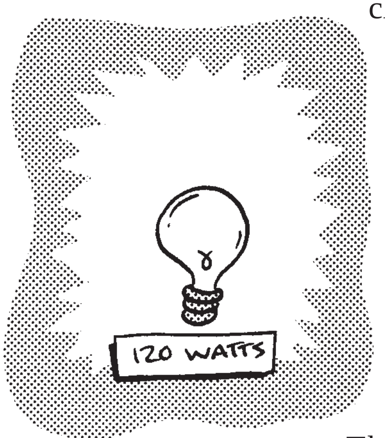
Step 3: You are going to calculate the coefficient of friction from the following formula. Note: For mass, remove the wheels and use ONLY the mass of the frame. It is the frame that rests on the bearings and presses the bearings' surfaces together. Therefore, you must remove the wheels and "mass" only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

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

Power Output

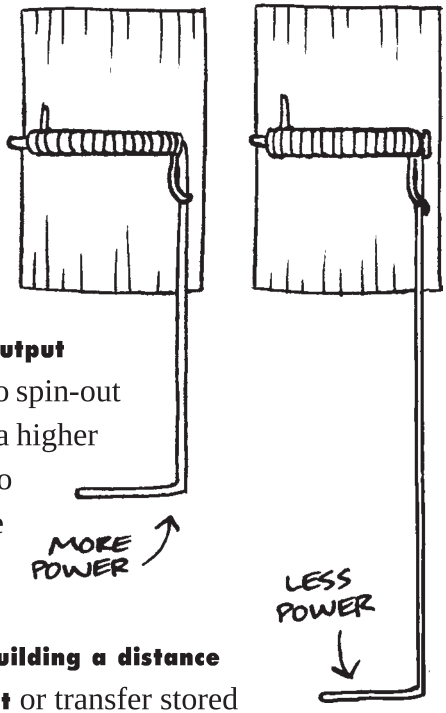
There is no difference in the amount of energy expended when you walk up a flight of stairs and when you run up a flight of stairs, but there is a difference in the amount of **power** output in the two situations. More power is expended running up the stairs. Power is the rate at which you do work or use energy. Because running up the stairs allows you to get to the top more quickly, you use energy at a higher rate.

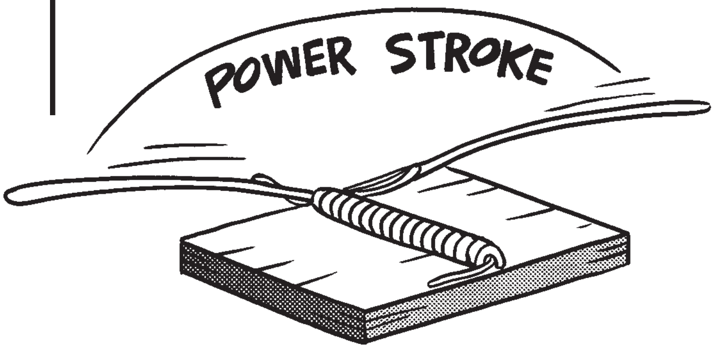
Higher power ratings mean that more work is being done per second when compared to smaller power ratings. A watt is the unit of measurement for power. A 120 watt light bulb uses twice the energy each second compared to a 60 watt light bulb. Usually higher rates of energy consumption will waste more energy to heat and sound than lower power outputs.



When you build a mouse-trap car for distance, you want a small energy consumption per second or a small power usage. **Smaller power outputs will produce less wasted energy and greater efficiency**. When you build a vehicle for speed, you want to use your energy quickly or at a high power ratio. You can change the power ratio of your vehicle by changing one or all of the following: where the string attaches to the mouse-trap's lever arm, the drive wheel diameter, or the drive axle diameter.

The amount of energy used by a short lever arm and a long lever arm are the same, but the distance that the energy is used determines that rate of energy consumption or the power. Long lever arms decrease the pulling force but increase the pulling distance, thereby decreasing the power. Short lever arms increase the pulling force and decrease the pulling distance, thereby increasing the power. **If you are building a mouse-trap car for speed, you will want the maximum power output** just before the point where the wheels begin to spin-out on the floor. Maximum power output means a higher rate of stored energy is being transferred into energy of motion or greater acceleration of the vehicle. Greater acceleration can be achieved by having a short length lever arm or by having a small axle to a large wheel. **If you are building a distance vehicle, you want to minimize the power output** or transfer stored energy into energy of motion at a slow rate. This usually mean having a long lever arm and a large axle-to-wheel ratio. If you make the lever arm too long, you may not have enough torque through the entire pulling distance to keep the vehicle moving, in which case you will have to attach the string to a lower point or change the axle-to-wheel ratio.

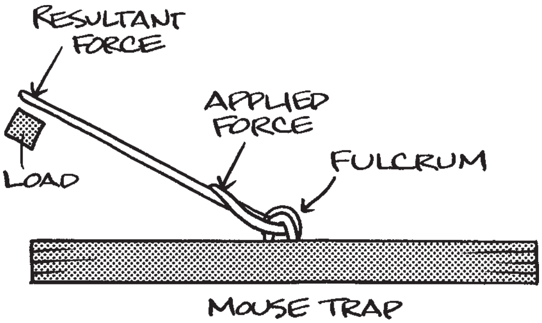




Power

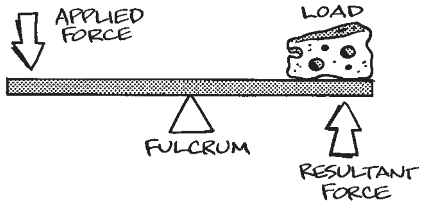
When the string is wound around the axle, the spring of the trap is under maximum tension and has the most potential energy. As the mousetrap's arm is released, the mousetrap converts potential energy into kinetic energy. The ***power stroke*** *represents the range of the lever arms movement and the total available energy.*

Mechanical Advantage

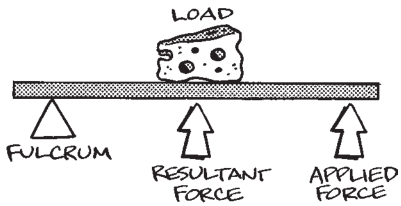


A Mousetrap is a Third-class lever

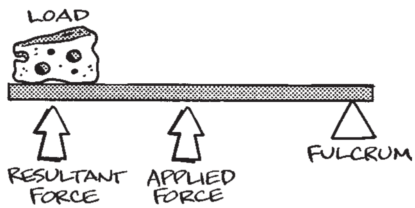
First-class lever



Second-class lever



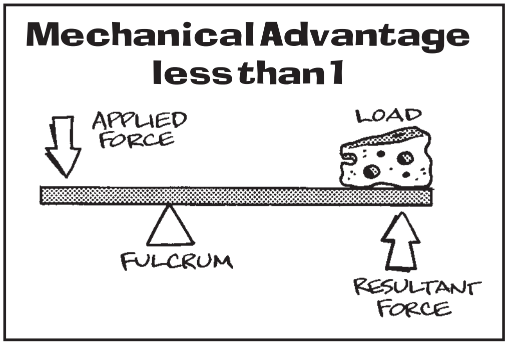
Third-class lever



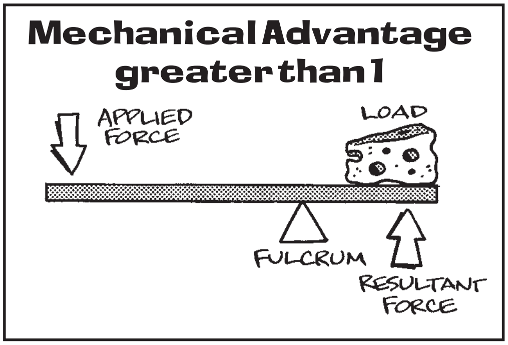
Mechanical advantage **comparison between the force put into a machine and the force out of a machine**. Mechanical advantage calculated from the resultant force divided by the applied force. An example of a "simple" machine is a lever. With a lever you have four important elements that you must identify: the applied force, the resultant force, the fulcrum, and the load. The applied force is put into the machine and the resultant force is what comes out of the machine. The load is what the machine is doing the work on and the fulcrum is where a lever pivots or rotates. A machine can be used to reduce the input force that is needed to lift an object. By changing the position of the applied force, load, and fulcrum of a lever the mechanical advantage of the system is changed.

There are three classes of levers that are determined based on the position and direction of the applied force, resultant force, and the fulcrum. Pliers would be considered two connecting first-class levers. A wheelbarrow would be considered a second-class lever. A mousetrap would be considered a third-class lever.

Like everything, you can not get something for anything and energy is no different when it comes to a machine. **You can only get the same amount of energy out of a machine as you put into the machine.** Any energy you put into a system is equal to the energy you get out of that system. With friction, some of the input energy is converted into heat and sound. Because of friction, some of the input energy is lost and the amount of energy that is actual used to do work determines the efficiency of the machine.

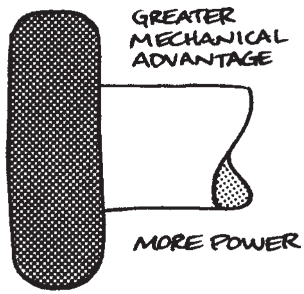


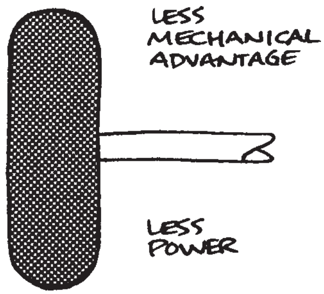
Energy is the product of an applied force through a distance. With a lever, when one force is smaller than another force, the smaller force must travel a greater distance than the larger force so that the energy input on the system is equal to the output energy of the system. When the mechanical advantage is greater than 1, the input force (applied force) is smaller than the output force (resultant force) and the applied force is applied over a greater distance than the load's travel distance. When the mechanical advantage is less than 1, the input force is greater than the output force and the load travels a greater distance than the effort force's distance of travel.



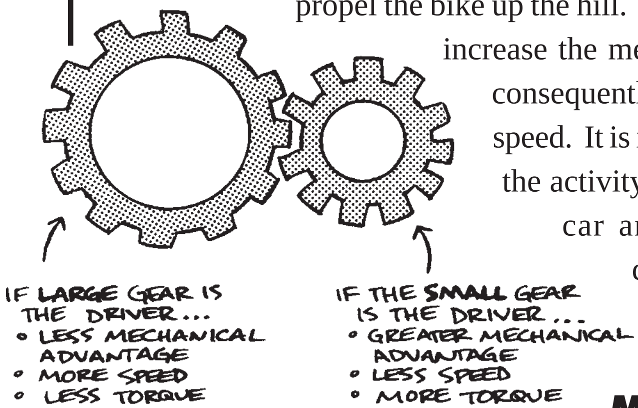
Changing the diameter of either the wheel(s) or the axle controls the mechanical advantage of a wheel-axle system. When the ratios of the length of string used per turn divided by the distance traveled is less than 1, the mechanical advantage is small and the car travels slow and far. When the ratios of the length of string used per turn divided by the distance traveled is greater than 1 the car accelerates very quickly and uses only a small amount of string.

Transmission

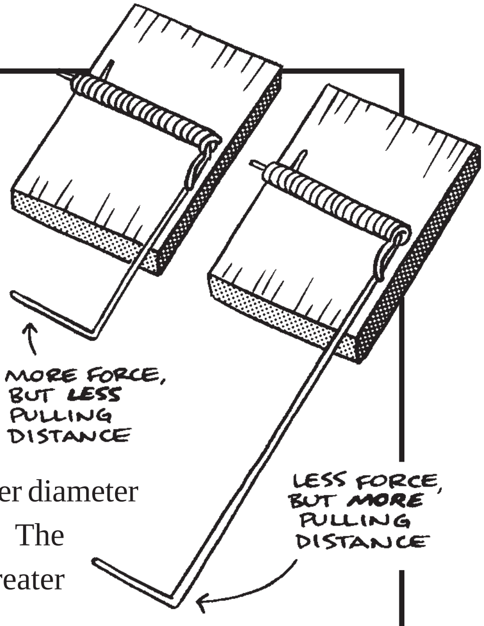


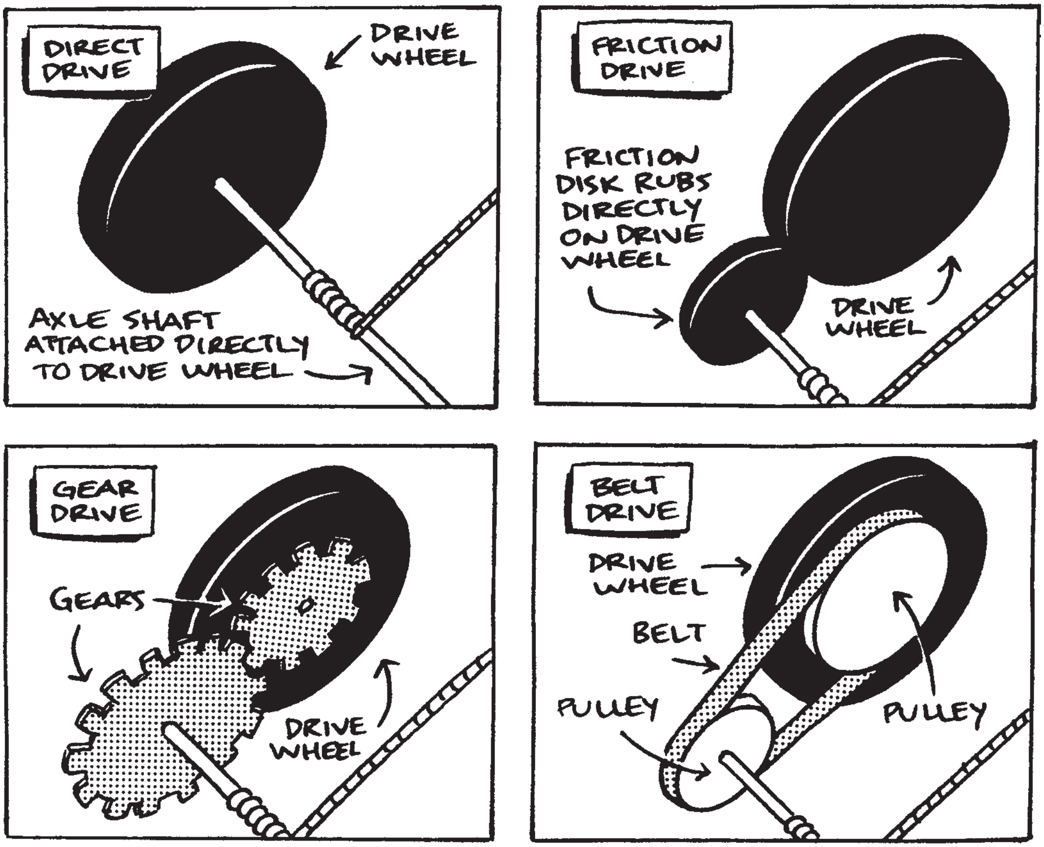


The diameters of your drive wheel and drive axle represent your **gearing** or **transmission**. A transmission is any device that transmits mechanical energy from one place to another. With a mouse-trap car, power is transferred to the wheels via the transmission. In addition to getting energy from one place to another, the transmission can be used to trade speed for torque or torque for speed. Some of the common ways to transfer power to the drive wheels are direct drive, gear drive, belt drive, and friction drive. Not all are best used on a mouse-trap car. Gear and pulley ratios are used to describe the mechanical advantage. One gear or pulley is called the “drive” and the other the “driven.” The diameter or **ratio** of the drive and driven components of a transmission determines the force and speed that will result. Obviously, there are tradeoffs that you need to understand. When a large gear or pulley is driven by a smaller gear or pulley, there is an increase in torque and a decrease in top speed. When a smaller gear or pulley is driven by a larger gear or pulley, there is a decrease in torque and an increase in top speed. Think of pedaling a multispeed bike. When the rear gear on a bike is as small as possible (i.e., it’s in high gear), the bike can go the fastest on a level road, but as the road begins to slant upwards the bike begins to slow. More torque is required to propel the bike up the hill. By putting the bike into a lower gear, you increase the mechanical advantage of your gearing and consequently get more torque, but at the cost of less speed. It is important to match your transmission with the activity you need to perform. A Formula 1 race car and a tractor both have transmissions designed for the tasks they perform. A tractor needs more torque than a race car



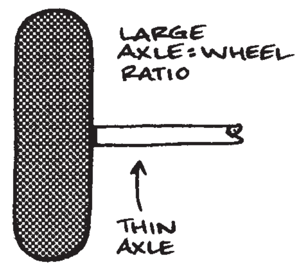
but with the tradeoff of speed. Test your mouse-trap car by running the car in your hand. If you place your vehicle on the ground and the mouse-trap lever does not pull off the start or stops part of the way through its motion, you do not have enough torque. If you do not have enough torque you should increase the mechanical advantage by doing one of the following: making the length of the lever arm smaller, using smaller diameter drive wheels, or using a larger diameter drive axle. The larger the diameter of the driven gear or pulley, the greater the mechanical advantage or torque.





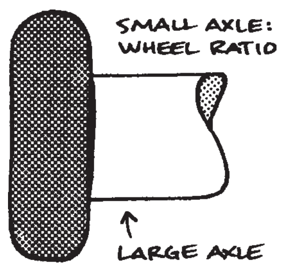
Wheel-to-Axle Ratio

By increasing or decreasing the wheel-to-axle ratio, you will change the **mechanical advantage** of your mouse-trap car. Keep in mind, changing the **mechanical advantage does not increase the work you get from your mouse trap; it only changes the size of the force and the distance the force is applied**. With distance vehicles, you want a small force over a long distance; therefore, use a large wheel with a small axle (i.e., a large wheel-to-axle ratio). A large wheel with a small axle will cover more distance per each turn of the axle when compared to a smaller wheel with the same axle. There is a trade-off for having a large wheel-to-axle ratio. The trade-off is that it takes more force to accelerate the vehicle to the same speed in the same time as a vehicle that has a small wheel-to-axle ratio, but this is okay because distance cars should not be fast in order to cut down on air resistance. It is essential that a vehicle with a large wheel-to-axle ratio has a small rotational inertia wheel, since low rotational inertia wheels will be much easier to rotate than large rotational inertia wheels.



Use a large wheel-to-axle ratio with distance vehicales

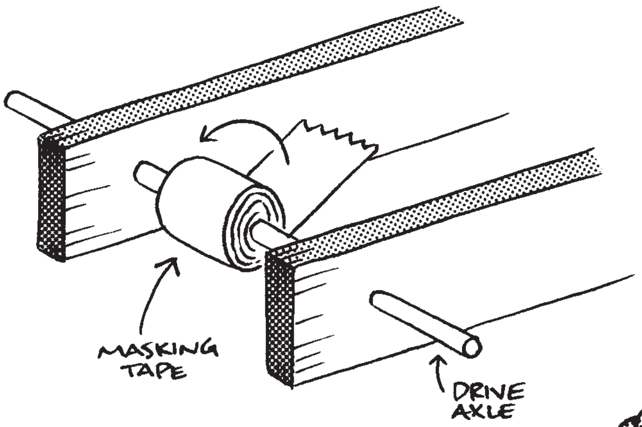
For quicker accelerations, a large axle size means a larger force is transferred to the ground, causing greater acceleration. By decreasing the wheel-to-axle ratio, you will increase the torque but at the cost of decreasing the distance that the force is being applied. To achieve quicker accelerations with a speed car, use a wheel or wheels with a large axle or a smaller wheel-to-axle ratio than with your distance car. Again, a tapered axle can be designed to distribute larger forces at the start and then decrease the force once the car is in motion.



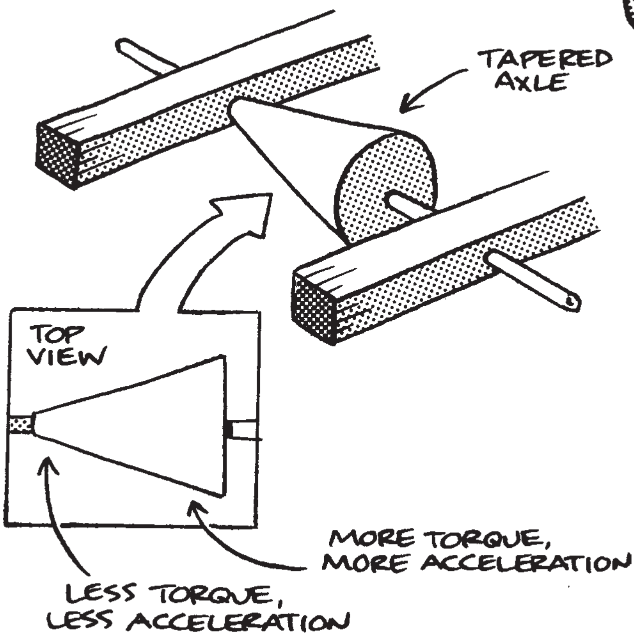
Use a small wheel-to-axle ratio with speed vehicles

Construction Tip

Changing the Torque with Axle Size



If your vehicle does not have enough torque in order to move off the start, it will not travel the full length of the pulling distance without stopping. Try wrapping **tape** *around the drive axle in order to increase the* **diameter** *and increase the* **torque**.



Brain Tip

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A tapered axle will act like a **transmission** *and change the torque or the* **gearing** *of the drive axle. If you need more torque off the start and less torque towards the end of travel, start winding the string at the thinner part of the gearing so that it starts to unwind from the thicker diameter at the beginning of its travel. If you need more torque towards the end of the vehicle's motion, start winding the string around the thicker part so that it starts to unwind from the smaller diameter.*