1. **FREE-BODY DIAGRAM.**
   Pretend the dot at right is your mousetrap car.
   Draw and correctly label the four force vectors acting on the mouse cart.

2. Record the following in the data table below:

<table>
<thead>
<tr>
<th>Distance covered by mousetrap car x (in m)</th>
<th>Time, t (in sec), to cover the distance</th>
<th>Mass, m, of mousetrap car (in kg)</th>
<th>Length (in m) of mousetrap spring arm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force required to pull back mousetrap spring arm at tip (in N)</td>
<td>Actual/Estimated diameter of the wheel axle (in m) the string/rope is wrapped around</td>
<td>radius of rear car wheels (in m)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. **ENERGY. Use the WORD BANK to fill in the blanks below.**

<table>
<thead>
<tr>
<th>nowhere</th>
<th>photosynthesis</th>
<th>distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>work</td>
<td>sun</td>
<td>food</td>
</tr>
</tbody>
</table>

   In order for the mousetrap car to gain energy, somebody has to do ________________ on it. In other words, somebody has to apply a force to the mousetrap car arm through a ________________ (in m). The energy that “somebody” used to pull back the mousetrap car arm didn’t come out of ________________. It actually comes from the ________________ you eat which gets its energy from a processs called ________________. In other words, if you go back far enough, the mousetrap car is really powered by the ____________________.
4. **CALCULATE WORK (W)**. The work done on the mousetrap arm is found using the formula \( W = F \times d \), where \( F \) is the force (in Newtons) applied to the mousetrap car spring arm and \( d \) is the distance (in m) through which the force is applied.

You found the **force** applied using a spring scale and should have it in the table above.

To find the **distance** you pulled back you have to use the length of the mousetrap arm that you also recorded in the table above. Write it here: ___________.

We need to find out what part of the circumference of a circle the force was applied to the mousetrap arm. The maximum would be half a circle if the mousetrap started at one end and completely unwound to the other end.

If it didn’t (and probably it didn’t go through 180 degrees), we need to find out how much it did go through.

**STEP 1:** Find out the circumference of the circle the mousetrap arm would make if it made an entire rotation. \( C = 2\pi r = \) ____________ m

**STEP 2:** Divide your circumference by 2: \( C \div 2 = \) ____________ m

**STEP 3:** Now if it didn’t go through the entire half circle, estimate how much of the half-circle the arm goes through before it stops. Choose one of the following percentages:

- [ ] 10%
- [ ] 20%
- [ ] 30%
- [ ] 40%
- [ ] 50%
- [ ] 60%
- [ ] 70%
- [ ] 80%
- [ ] 90%

**STEP 4:** Now multiply your half-circumference value by the decimal equivalent of the percentage. **EX:** If your mousetrap car arm went through 20% of the half circle (see picture at right), then your final distance, \( d \), will be \( C \div 2 \times 0.20 \)

Write your distance here: \( d = \) ____________ m

**STEP 5:** Now find the work done by you to move the mousetrap arm into position.

\[
W = F \times d = \text{ ____________ Joules (the unit of work and energy)}
\]
5. **ENERGY TRANSFORMATIONS.** Use the WORD BANK to fill in the blanks below.

<table>
<thead>
<tr>
<th>Translational Kinetic</th>
<th>Elastic potential</th>
<th>Heat</th>
<th>Chemical Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
<td>out</td>
<td>Rotational Kinetic</td>
<td>friction</td>
</tr>
</tbody>
</table>

Initially then, you ate food which contained __________ _____________ energy (in Calories). Then you did ________________ (in Joules) on the mousetrap spring arm to pull it back.

Now the mousetrap has ________________ _______________ energy (in Joules) stored in the coils of its spring. Once the mousetrap arm is released, the rope/string it is attached to spins the axle the wheels are attached to giving them ________________ _______________ energy (in Joules). Then the “rubber meets the road” and the spinning action of the wheels makes the car move forward in a straight line (translate forward), turning the energy now into ________________ _______________ energy (in Joules). Unfortunately, not all the energy put IN becomes useful energy ___________. There is ________________ in the spring, the axle, the wheels, even the air that slows the car down. So some of the energy is working against this force and eventually turns into _______________ (in Joules).

6. **ELASTIC POTENTIAL ENERGY (EPE).** The energy stored in a mousetrap spring is found using the formula: \[ E_{PE} = \frac{1}{2} k \theta^2 \], where \( k \) is spring constant of the mousetrap spring, a measure of how “tough” the spring is and \( \theta \) is the angle (in radians) the torsional mousetrap spring compresses. Let’s find how much of the work (W) that we put in from Part 4 actually ended up as \( E_{PE} \) in the mousetrap spring.

**STEP 1:** To find \( \theta \), the angle through which the mousetrap spring compressed, we can just find the angle through which the mousetrap arm went through. They are the same.

The formula for the angle is \( \theta = \frac{s}{r} \), where \( s \) is the part of the circumference that the mousetrap car arm went through from Part 4 above and \( r \) is the radius of the mousetrap car arm which you recorded in your data Table on p. 1.

\[ \theta = \frac{\text{angle}}{\text{radius}} \]

**STEP 2:** The spring constant “\( k \)” of a mousetrap is about 1.3 N/m.

Now find your mousetrap’s \( E_{PE} \): \( E_{PE} = \frac{1}{2} k \theta^2 = \frac{1}{2} \times 1.3 \times (\text{angle})^2 \) Joules
7. **FRICTIONAL LOSSES.** At this point, some of our initial energy has converted into heat due to frictional losses. The amount of heat generated is simply the difference between our initial energy input into the mousetrap as Work and the EPE that the mousetrap has. Find it here: \[ \text{Heat} = \text{Work} - \text{EPE} = \text{______________________________} \text{ Joules} \]

8. **SIMPLE MACHINES.**

**MULTIPLE CHOICE.** There are two main simple machines at work in our mousetrap car. They are:

A. Lever and screw  
B. Lever and wheel and axle  
C. Inclined plane and wheel and axle  
D. Wedge and screw

Use the WORD BANK to fill in the blanks below.

<table>
<thead>
<tr>
<th>Distance</th>
<th>force</th>
<th>great</th>
<th>lever</th>
<th>small</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical advantage</td>
<td>minimum</td>
<td>axle</td>
<td>nothing</td>
<td>out</td>
</tr>
</tbody>
</table>

If we use our mousetrap as is, it will simply not move through enough distance to make our car go the ________________ distance required. So we used a simple machine, a ________________ that allowed the mousetrap spring force to move through a greater amount of ________________ (in m). Simple machines give the user what is called ________________, a “bionic benefit”, so to speak, for using them that they would not otherwise get. The user puts IN very little ________________ (in N) and gets a lot of force ________________ in exchange.

You never get something for ________________, however. The price for applying such a small input force is that you have to apply it through a ________________ distance.

In the case of our mousetrap car, the mousetrap lever arm is very long and moves through a great amount of distance. Therefore, only a ________________ amount of force is required to move it at the tip. The rope that comes off the lever arm wraps around a tiny ________________ that the wheels are attached to. Because the axle spins through such a small distance, a great amount of Force (in N) is available to spin the wheels.
CALCULATING THE FORCE AT THE WHEELS.

We now will find out how much force is accelerating the car forward initially. You might be tempted to think it is the force that you measured with the spring scale and recorded in your data table on p. 1. But this is just the force at the tip of the lever arm. We must use the principles of **mechanical advantage** to find what force, ideally, made it to back wheels.

**STEP 1:** Mechanical advantage (M.A.) is all about ratios and proportions. The ratio for M.A. is between the force applied ($F_1$) and the distance over which it is applied ($d_1$) compared to the force output ($F_2$) and the distance over which it is applied ($d_2$).

Look at the picture below:

![Diagram showing mechanical advantage](image)

The ratio set up comes from the Law of Conservation of energy and the work formula. The Law of Conservation of Energy states that the amount of work in must equal the work out.

$$W_{in} = W_{out}$$

$$F_1 \cdot d_1 = F_2 \cdot d_2$$

Substituting the formula for work.

In Table 1 we have the values of $F_1$ (the force on the mousetrap spring lever arm), $d_1$ (the length of the mousetrap spring lever arm), and $d_2$ (the estimated/actual radius of the axle).

We can solve for $F_2$ then and get the force turning the rear axle.

$$\frac{F_1 \cdot d_1}{d_2} = F_2$$

Go ahead and find your $F_2$: _____________________ N

**STEP 2:** Now we need to do the process again for the wheel and axle. The axle transmits its force ($F_2$) to the wheel ($F_3$). The axle has a small radius ($d_2$) and the wheel has a big radius ($d_3$). So we will lose a little bit of mechanical advantage going from axle to wheel.

Calculating again...

$$\frac{F_2 \cdot d_2}{d_3} = F_3$$

Go ahead and find your $F_3$: _____________________ N
10. FORCES AND MOTION. Use the WORD BANK to fill in the blanks below.

<table>
<thead>
<tr>
<th>forward</th>
<th>3rd</th>
<th>accelerate</th>
</tr>
</thead>
<tbody>
<tr>
<td>force</td>
<td>reaction</td>
<td>friction</td>
</tr>
</tbody>
</table>

According to Newton’s 2\textsuperscript{nd} Law, when a \underline{force} \ (in \text{N}) is applied to a mass, that mass will \underline{accelerate} \ (in \text{m/s}^2).

The wheels are pushing on the ground with a force $F_3$ that we found in Part 9. By Newton’s \underline{reaction} Law, for every action there is an equal and opposite \underline{friction}. So the ground pushes back on the mousetrap car making it go \underline{forward}.

Let’s find the initial acceleration of the car using Newton’s 2\textsuperscript{nd} Law assuming none of the energy has been lost due to \underline{friction}.

$$F_3 = m \cdot a \rightarrow a = \frac{F_3}{m} = \underline{\text{m/s}^2}$$ (where $F_3$ is the force at the wheels, and $m$ is the mass of the mousetrap cart (in kg))

11. IDEAL DISTANCE VS. REAL DISTANCE TRAVELLED. Now we will compare the ideal distance that the mousetrap car should have travelled (without frictional losses) vs. the distance it actually travelled in real life.

To find the theoretical (ideal) distance, $d_{\text{ideal}}$, we go back to a formula from the past:

$$d_{\text{ideal}} = \frac{1}{2} \cdot a \cdot t^2$$ where $a$ is the acceleration you just found in Step 10, and $t$ is the time you recorded in your data table on page. 1.

Find $d_{\text{ideal}}$ now: $d_{\text{ideal}} = \underline{\text{m}}$

Now compare $d_{\text{ideal}}$ with $d_{\text{real}}$, the distance you recorded in the table on p. 1.

12. WORK DONE AGAINST FRICTION. As a final step, we will find the work done against friction by comparing $W_{\text{ideal}}$ with $W_{\text{real}}$.

$$W_{\text{frict}} = \Delta W = W_{\text{ideal}} - W_{\text{real}} = F_3 \cdot d_{\text{ideal}} - F_3 \cdot d_{\text{real}} = \underline{\text{J}}$$

This is the work that the mousetrap car did against friction!!!