Force and Motion

In this experiment, you will explore the relationship between force and motion. You are given a car with tabs, a string, a pully, a weight hanger, some weights, and the laser gate you used in previous experiments. The force on the car is a result of weights hanging at the end of the string. The laser gate measures the motion of the car (speed versus time).

Setting up the Equipment

Hardware:
Each lab bench has a laser gate, and each gate is connected to a computer. The laser gate consists of a laser and a detector. The laser should be set up so that its beam shines through the spokes of the pully and directly on the detector.

Each group of 2 students will be given a car, which will travel on the table. A string should be attached to the car, then pass over the pully to a 5 g weight hanger. See the figure. Note: **The cars are expensive since they have little friction. Do not let the cars fall off the table and hit the ground!!!**

Software:
You can use the program "atwood". Click once on the icon to start the program. The menu should be self-explanatory.

1. To check if the laser gate is working, type "t". The program samples the detector once every second and displays if the gate is blocked (the laser beam doesn't hit the detector) or unblocked (the laser shines on the detector).

2. To set the number of data points that will be collected, type"n".

3. To take data, press "d".

4. To see a graph of v versus t press "g".

The interface measures the time that the laser gate is blocked and unblocked. After the run is over, the times and velocities are displayed on the screen. Velocity calibration is done automatically from the preprogrammed value for the circumference of the pulley.

Designing and carrying out the Experiment

Before you begin, be sure that the string is not rubbing on anything, i.e. the table or stand. Also be sure that the string runs parallel to the table top from the car to the pulley.

A. What kind of motion does a constant force produce?

1. Design an experiment to measure the velocity as a function of time for the system when there is 20 g on the weight holder..

2. From your time and velocity data determine whether the car moves with constant acceleration. Explain!

B. How does the acceleration depend on the net force if the total mass of the system is held constant?

1. Vary the hanging mass between 5 g (the hanger) and 30 g keeping the total mass of the system constant. Measure the acceleration for each situation (**check the graph to insure that the acceleration is constant in each case**).

2. Make an appropriate graph of the data you obtained to determine the relationship between force and motion. You should make the graph first by hand and then using the linefit program on the computer.

3. What is the meaning slope?

4. Does the graph go through the origin? Explain

5. From your graph determine the effective mass of the pulley, and the effective net frictional force.

6. What law of physics have you demonstrated?

Design Problem

You want the car, with total mass $\approx 500\ g$ to have an acceleration of exactly 50 cm/s^2. Calculate how much mass you need to hang so that the car (with total mass 500 g) has this acceleration.. Test your prediction.

Equation of Force and Motion

Since the car, hanging weight, and pully all move together, we can consider all three of these objects as one system. This is only true if the string does not slip on the pulley. In this case, we have:

$$a = \frac{F_{net}}{M_{tot}} \tag{1}$$

For our setup, $F_{net} = m_h g - f$, where m_h is the total hanging mass, and f is the net friction. M_{tot} is the total (effective) mass that is moving, $M_{tot} = m_h + m_{car} + m_{pulley}$. m_{pulley} is the effective mass of the pulley. Substituting in the equation above we have

$$a = \frac{g}{m_{car} + m_h + m_{pulley}} m_h + \frac{f}{M_{tot}} \tag{2}$$

To get an idea of what the effective mass of the pulley, m_{pulley}, should be, one can apply Newton's law of motion to each object: the hanging mass, the car, and the pulley. Let T_1 be the tension in the string from the pulley to the hanging mass, and let T_2 be the tension in the string from the car to the pulley. Then we have:

$$\begin{aligned} m_h g - T_1 &= m_h a \ (for\ hanging\ mass) \\ T_2 - f_c &= m_{car} a \ (for\ car) \\ r(T_1 - T_2) - r f_p &= I\alpha (for\ pulley) \end{aligned}$$

The last equation is a result of applying Newton's laws to rotation about a fixed axis. α is the angular acceleration of the pulley, and $\alpha = a/r$ if the string doesn't slip on the pulley. With this substitution, we have

$$\begin{aligned} m_h g - T_1 &= m_h a \ (for\ hanging\ mass) \\ T_2 - f_c &= m_{car} a \ (for\ car) \\ T_1 - T_2 - f_p &= \frac{I}{r^2} a \ (for\ pulley) \end{aligned}$$

Adding these three equations yields

$$\begin{aligned} m_h g - f &= (m_{car} + m_h + I/r^2) a \\ a &= \frac{g}{m_{car} + m_h + I/r^2} m_h + \frac{f}{M_{tot}} \end{aligned}$$

which is the same as before with $m_{pulley} \to I/r^2$, f is the net friction, and I is the rotational inertia of the pulley about it's axis.