Experiment 6: Newton's Second Law Part 1

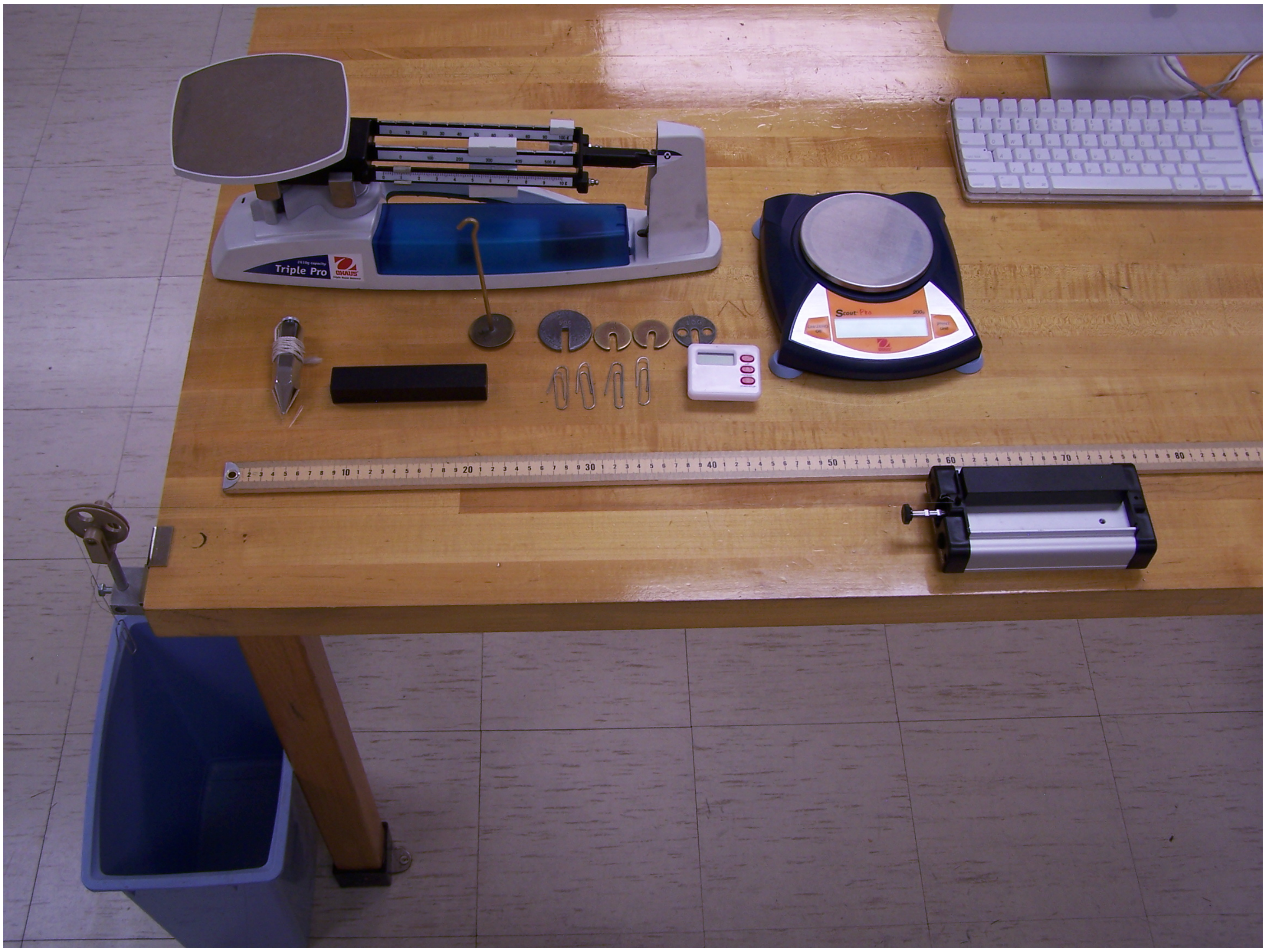


Figure 6.1: Newton's Second Law Setup

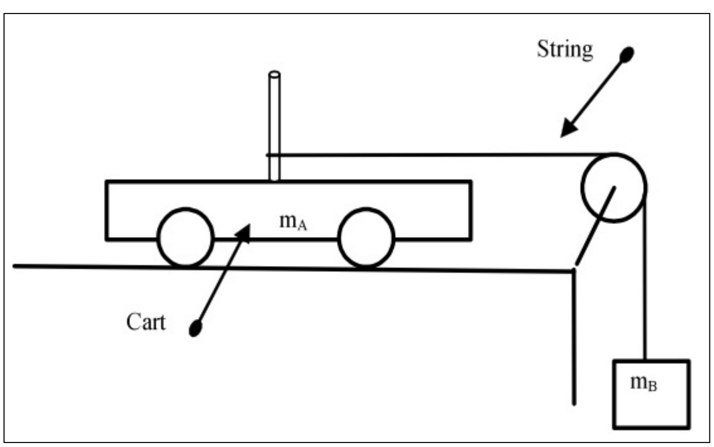


Figure 6.2: Note: String from cart to pulley must be horizontal and aligned with the pulley.

EQUIPMENT

Low-Friction Cart
Pulley and String
Triple-Beam Balance
Digital Balance
Stopwatch
Meter Stick
Mass Hanger
(1) 10 g Mass
(2) 20 g Masses
(1) 50 g Mass
Paper Clips (small masses)
Plumb Bob
Wastebasket

FREE-BODY DIAGRAM SOLUTION METHOD: INSTRUCTIONS

Step 1: Sketch the problem/situation and specify the coordinate system for each object in your system.

Step 2: Draw all forces (arrows that represent these vectors) acting on *each object* in the system you are investigating. All forces should extend *away from* the object in the direction of the force. Remember that the length of the arrow is an indication of the magnitude of the force.

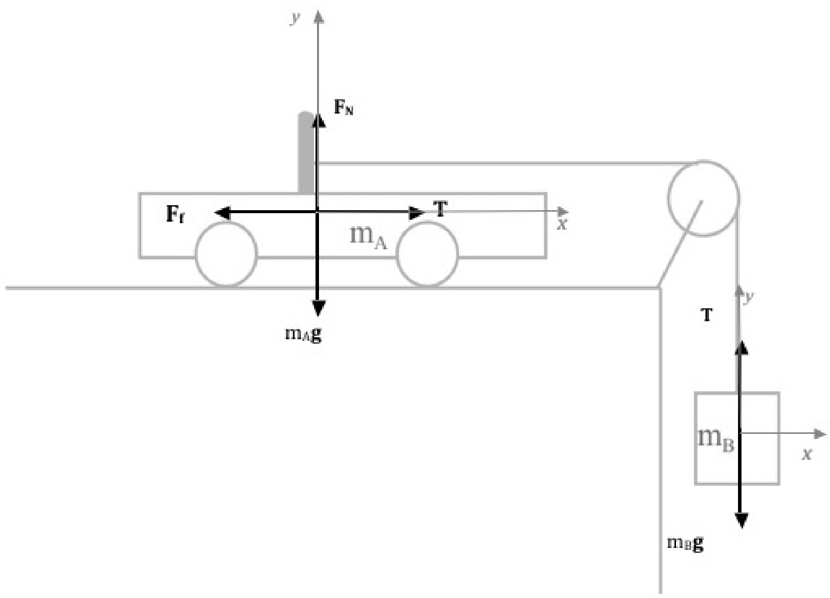


Figure 6.3: Free-Body Diagram of Modified Atwood's Machine (Example for $\vec{\mathbf{v}}$ constant, $\Sigma\vec{\mathbf{F}} = m\vec{\mathbf{a}} = 0.0$ N).

Step 3: Write Newton's 2^{nd} Law ($\Sigma\vec{\mathbf{F}} = m\vec{\mathbf{a}}$) in component form ($\Sigma F_x = ma_x$ and $\Sigma F_y = ma_y$) for *each* object in the system. For this example, m_A and m_B:

m_A: $\Sigma F_{A_x} = m_A a_{A_x}$
$\Sigma F_{A_y} = m_A a_{A_y}$

m_B: $\Sigma F_{B_x} = m_B a_{B_x}$
$\Sigma F_{B_y} = m_B a_{B_y}$

Step 4:
Refer to your diagram to sum the forces for each object as instructed by Sir Isaac Newton. For this example:

$\Sigma F_{A_x} = m_A a_{A_x} = T - F_f$

$\Sigma F_{A_y} = m_A a_{A_y} = F_N - m_A g = 0.0$ N
(a_{A_y}: Constant velocity means this acceleration equals 0.0 m/s^2)

$\Sigma F_{B_x} = m_B a_{B_x} = 0.0$ N
(m_B: No forces acting in the horizontal direction.)

$\Sigma F_{B_y} = m_B a_{B_y} = T - m_B g$
(Note that since m_A and m_B are connected and moving together, T is the same for each object, and $a_{A_x} = -a_{B_y}$.)

Step 5:
Write the known quantities. Write the question.
Always write equations algebraically first, then insert the known values.
Now do the math! That's all there is to it.

Advance Reading

Text: Newton's Second Law, acceleration, velocity, displacement, vectors.

Objective

The objective of this lab is to explore and analyze the relationship between force, mass, and acceleration.

Theory

According to Newton's Second Law, the acceleration, $\vec{\mathbf{a}}$, of a body is directly proportional to the vector sum of the forces, $\Sigma\vec{\mathbf{F}}$, applied to the body:

$$\Sigma\vec{\mathbf{F}} = m\vec{\mathbf{a}} \tag{6.1}$$

where m is the mass of the body.

A force T (tension) will be applied to the cart, m_A, by means of a string with an attached mass, m_B. If one can ignore the force of friction acting on the cart, then if the unbalanced force acting on the system is increased while the mass of the accelerating system is held constant, the acceleration of the system will increase proportionately.

This analysis assumes a frictionless environment.

The added mass, m_B, exerts a force equal to its weight on the cart/mass system.

When the cart is accelerating, deriving a of the cart is found with the following equation:

$$a = \frac{m_B \cdot g}{m_A + m_B} \tag{6.2}$$

We will compare this calculated acceleration to the acceleration obtained from the kinematic equations for constant acceleration.

In this experiment, acceleration will be found experimentally tracking the cart's motion across a set distance. The time of travel will be carefully measured using a stopwatch.

Note that since the cart and m_B are connected, their acceleration, velocity, and distance traveled are equal at all times. Thus, the horizontal distance the cart travels, Δx, is equal to the vertical drop of the attached mass, Δy.

$$x = x_0 + v_{0_x}t + \frac{1}{2}a_x t^2 \tag{6.3}$$

We now define calculated and measured accelerations as $a_{Theo.}$ and $a_{Meas.}$:

$a_{Theo.}$ is determined by Eq 6.2;
$a_{Meas.}$ is determined by Eq 6.3.

Name: ____

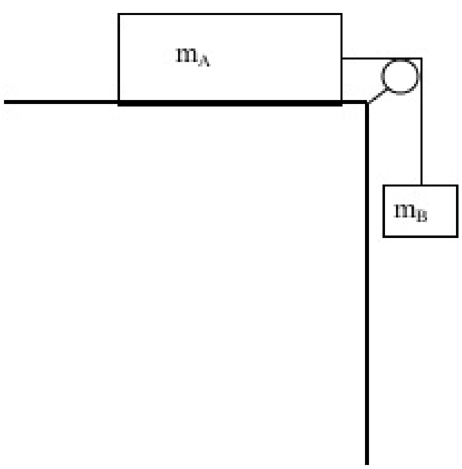
1. State Newton's First and Second Laws (qualitative explanations). (20 pts)

2. How is tension applied to the system in this experiment? (15 pts)

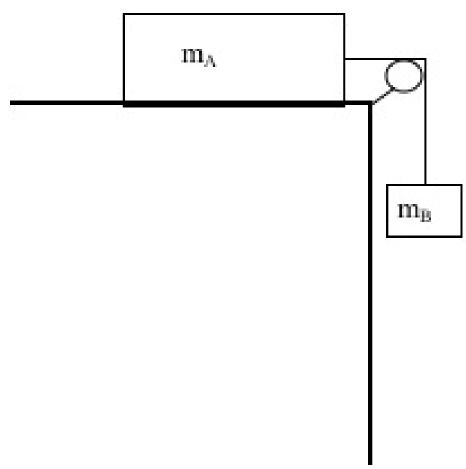
3. Should the acceleration determined in any part of this experiment be greater than, less than, or equal to the acceleration of gravity? Explain. Assume friction is negligible. (20 pts)

4. Complete the free-body diagrams for the two situations shown below. Draw to scale (*i.e.*, your diagrams should delineate between $\Sigma\vec{\mathbf{F}} = m\vec{\mathbf{a}} = 0.0$ N and $\Sigma\vec{\mathbf{F}} = m\vec{\mathbf{a}} > 0.0$ N). (30 pts)

Situation 1: $\Sigma\vec{\mathbf{F}} = m\vec{\mathbf{a}} = 0.0$ N



Situation 2: $\Sigma\vec{\mathbf{F}} = m\vec{\mathbf{a}} > 0.0$ N



PROCEDURE

PART 1: Part 1: Vary the Applied Force

Trial #1

1. Measure the mass of the cart using the triple beam balance (turning it upside down will keep it from rolling off). Add the large masses (you may assume they are 500g each) and two 20g masses on the cart. Record the total mass as m_A in the table on the back.

2. Attach m_B (a 50g mass hanger) to the end of the string and record the mass in the diagram and the table on the back.

3. Use a stopwatch to measure the time it takes for the cart to travel a distance Δx (or for m_B to fall the same distance Δy). Your data will be more accurate if Δx is as large as possible. ***Do not allow the cart to hit the pulley!*** Record this time three times in the table below, average those times, and record the average time and the distance in the table on the back.

4. Calculate the acceleration of the cart during this motion using the following equations and record both in the table on the back (an example of this calculation should appear in your report).

$$a_{Theo.} = m_B \cdot g/(m_A + m_B)$$
$$a_{Meas.} = 2 \cdot \Delta y/t^2$$

Trial #2

5. Remove one of the 20g masses from the cart and place it on the mass hanger. Record the new m_A and m_B in the table.

6. Repeat steps 3 and 4 for the altered system.

Trial #3

7. Remove the remaining 20g mass from the cart and place it on the mass hanger. Record the new m_A and m_B in the table.

8. Repeat steps 3 and 4 for the altered system.

Part 2: Graphing

The entire cart/hanging mass system follows the same law, $\Sigma F = ma$. This means that plotting force vs. acceleration yields a linear relationship (of the form $y = mx$).

9. Open Graphical Analysis. Graph force ($m_B g$) vs. acceleration ($a_{Meas.}$) for the *Varying Force* trials (be sure to include (0,0)). Apply a linear fit to the data. You will need these graphs for your lab report.

10. Create a similar graph of $m_B g$ *vs.* $a_{Theo.}$.

QUESTIONS

1. Was each slope close to the mass ($m_A + m_B$) of the system? What were some sources of uncertainty that could cause them to be different?

2. Qualitatively sketch the cart's motion with respect to time. How would you expect each of these graphs to be affected if a lighter cart were used? Sketch the changes with dotted lines (in some way, indicate to your TA which are the original lines, and which are indicating a lighter cart.)

3. Were any forces ignored in this experiment? What are they? Do you believe they may have significantly altered your result