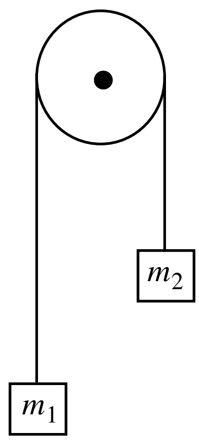
General Physics Lab: Atwood's Machine

Introduction

One may study Newton's second law using a device known as **Atwood's machine**, shown below. It consists of a pulley and two hanging masses. The difference in weight between the two hanging masses determines the net force acting on the system. This net force accelerates both of the hanging masses; the heavier mass is accelerated downward and the lighter mass is accelerated upward. This system is convenient for studying motion under constant acceleration because we can make the motion much slower, and easier to measure, than if we simply allowed objects to fall freely under the influence of gravity.



In the discussion which follows m_1 is less than m_2 so that m_1 accelerates upward and m_2 accelerates downward. According to Newton's Second Law, the net force on the entire system provides the acceleration for the entire system (m_1 and m_2 together). The forces acting on the two masses are mainly their weights, $m_1 g$ and $m_2 g$. Both of these forces act downward, but because of the pulley, they act in opposite directions as far as the motion of the masses and the string are concerned. There is also some friction in the pulley, which tends to oppose the motion. So

$$F_{net} = m_2 g - m_1 g - F_{fric} \tag{2}$$

We can measure the frictional force by first making m_1 and m_2 equal so the apparatus "balances", then adding just enough mass m_f to one side (use the m_1 side) to overcome the friction. Then

$$F_{fric} = m_f g \tag{3}$$

$$F_{net} = m_2 g - m_1 g - m_f g \tag{4}$$

$$F_{net} = \left(m_2 - m_1 - m_f\right) g \tag{5}$$

The total mass of the system is m1 + m2, so Newton's Second law predicts theoretically

$$a = \frac{F_{net}}{m_{total}} = \frac{\left(m_2 - m_1 - m_f\right) g}{m_1 + m_2} \tag{6}$$

In this experiment, you will determine the acceleration *a* experimentally for various combinations of m_1 and m_2, by measuring the time *t* requred for m_2 to "fall" a distance *y*, and using the familiar constant-acceleration equation

$$y = \tfrac{1}{2} at^2 \tag{7}$$

You will do this experiment in two stages. In the first stage, you will change the net force on the system (which consists of the pulley and the hanging masses) without changing the total mass of the system. In the second stage, you will change the total mass of the system while keeping constant the net force on the system.

In this experiment you will make your own data table. After reading the procedure and perhaps doing one or two trial runs, lay out a *neat* table (use a ruler!) with spaces for entering your data, then fill in the table as you take data.

Part I: Preliminary Measurements

1. Put masses on the hangers so that both m_1 and m_2 equal 500g. This should *include* the mass of the hangers. The system should now be in equilibrium.

2. Add small masses to m_2 to overcome friction, until a slight tap causes the system to move at constant speed. You will have to judge this by eye. The added mass is m_f in equation (5). Record this mass, then remove it from the system so that m_1 and m_2 are equal again.

3. With m_1 on the floor and m_2 near the pulley, measure the distance from the bottom of m_2 to the floor. This is the distance *y* that you will use in calculating the acceleration. Record it. It will be the same for all trials, unless you disturb the apparatus.

Part II: Total Mass Constant, Net Force Varying

4. Add 50g to m_2 so that m_1 = 500g and m_2 = 550g

5. Using the stopwatch, measure the time it takes for m_2 to “fall” the distance y. Repeat twice and find the average of the three time measurements, to get t. For best results, the same person should “drop” the mass and start the stopwatch (better coordination).

6. Calculate the “experimental” acceleration using equation (7) and the “theoretical” acceleration using equation (6). Find the percent difference between the two.

7. Calculate the net force on the system, sing equation (5).

8. Repeat steps 5—7 four more times, each time transferring 25g from m_1 to m_2. The sum of the two masses will remain the same, but the net force will change from one trial to the next.

Part III: Total Mass Varying, Net Force Constant

8. Start with m_1 = 450g and m_2 = 600g. Do steps 5—7 as before.

9. Repeat steps 5—7 four more times, each time adding 10g apiece to both m_1 and m_2. (The difference between m_1 and m_2, which determines the net force, therefore remains constant.)

Part IV: Analysis

10. Construct a graph of the net force (vertical axis) versus the acceleration (horizontal axis), using your measurements from Part II (in which the total mass is constant). Draw a best fit straight line, and measure its slope. What *should* this slope be equal to, based on your theoretical equations? (See the section on “Using the Results of a Linear Fit” in “Making and Analyzing Graphs” at the beginning of this manual.) Calculate the percent difference between the actual slope and its expected value.

11. Construct a graph of the acceleration (vertical axis) versus the reciprocal of the total mass (horizontal axis), using your measurements from Part III (in which the net force is constant). Draw a best fit straight line, and measure its slope. What *should* this slope be equal to, based on your theoretical equations? Calculate the percent difference between the actual slope and its expected value.

Problems

1. For *one* of your trials, calculate the upward force exerted by the string on m_1. Use the theoretical acceleration for that run, which you calculated in step 6.

2. For the same trial, calculate the upward force exerted by the string on m_2.

Advance Questions

These questions are worth 10% of the grade for this lab and must be completed before entering the lab.

1. When the net force on the system increases, with the total mass kept constant, should the acceleration increase, decrease or remain constant?

2. When total mass of the system increases, with the net force kept constant, should the acceleration increase, decrease, or remain constant?

3. How do we compensate for the frictional force exerted by the pulley?

4. How do we determine the acceleration of the apparatus, experimentally?

5. What is the advantage of using the Atwood's machine, versus simply letting an object fall freely and measuring its motion?