Atwood’s Machine

APPARATUS

1. The apparatus consists of two composite masses connected by a flexible wire that runs over two ball-bearing pulleys. The make up of the composite masses at the beginning of the experiment is:

<table>
<thead>
<tr>
<th>Left Side</th>
<th>Right Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 \times 1\ g</td>
<td>1 \times 250\ g</td>
</tr>
<tr>
<td>2 \times 2\ g</td>
<td>1 \times 250\ g</td>
</tr>
<tr>
<td>4 \times 5\ g</td>
<td>1 \times 500\ g</td>
</tr>
<tr>
<td>1 \times 10\ g</td>
<td>1 \times 1000\ g</td>
</tr>
<tr>
<td>1 \times 250\ g</td>
<td>1 \times 500\ g</td>
</tr>
<tr>
<td>1 \times 500\ g</td>
<td>1 \times 965\ g</td>
</tr>
<tr>
<td>1 \times 965\ g</td>
<td>1 \times 1000\ g</td>
</tr>
</tbody>
</table>

Total mass: 1750\ g 1750\ g

2. Stop clock
3. Pair of tweezers
4. Ruler

INTRODUCTION

This Atwood’s machine consists essentially of a wire passing over a pulley with a cylindrical mass attached to each end of the string. The cylinders are composed of three sections, the lower ones of 250\ g, and the middle ones of 500\ g. Note that the two top-most sections (the sections to which the wire is tied), do not have the same mass. The one on the left has a mass of 965\ g. The right hand one has a mass of 1000\ g. Each of these sections has eight vertical holes drilled into its top. When all the small masses are in the left cylinder, the two cylinders have the same mass and the force \((M_1 - M_2)g = 0\). In other words, there is no unbalanced force and the system remains at rest when the brake is released. The 10\ g mass is transferred from the left to the right hand cylinder, the difference between the two masses becomes \((M_1 - M_2) = 20\ g\), while the sum \((M_1 + M_2)\) remains unchanged. If now an additional 5\ g mass is transferred, the mass difference becomes 30\ g, while the sum is still unchanged, etc. With the small masses provided, it is possible to vary \((M_1 - M_2)\) in 2\ g steps from 0 to 70\ g.

A string, whose mass per unit length is approximately the as that of the wire, hangs from the two masses. It serves to keep the mass of the string plus wire on each side approximately constant as the system moves, therefore it keeps the accelerating force constant.
PRECAUTIONS

In order to obtain satisfactory results in this experiment and in order to prevent damage to the apparatus, it is necessary to observe the following precautions: Release the brake only when the difference in mass on the two sides is less than 70 g. Preparatory to taking a run, raise the right hand mass until it just touches the bumper. Make sure that it does not raise the movable plate. Always release the brake when moving the masses. Keep your feet away from the descending mass. Before releasing the brake, make sure that the left hand mass is not swinging.

Always stand clear of the suspended masses. The wire may break.

PROCEDURE

Start with a total load of 3500 g and all of the small masses on the left side. Move the left mass ($M_2$) to its lowest position, (see Fig. 1) Measure the displacement $s$, which is the distance from the top of the left mass to the bumper.

Transfer 10 g from the left to the right side (i.e. from $M_2$ to $M_1$, remember: if 10 g are transferred, then $M_1 - M_2$ will be 20 g). Make two determinations of the time of rise of the left hand mass through the measured distance. If the two time determinations differ by more than 5%, repeat the measurement until you obtain agreement within 5%. Compute the average acceleration using the average of the values of the time. It will be well to practice the timing before recording any results.

Increase the mass difference ($M_1 - M_2$) by about 10 g noting the time required in each case and compute the corresponding accelerations. At least six different mass differences should be used.

Setup the data table in the following way, do not forget to note $M_1 + M_2$:

<table>
<thead>
<tr>
<th>$M_1 - M_2$ [g]</th>
<th>time of rise [s]</th>
<th>displacement [m]</th>
<th>acceleration $a = 2s/t^2$ [m/s²]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>first</td>
<td>second</td>
<td>average</td>
</tr>
</tbody>
</table>

ANALYSIS

Applying Newton’s second law to the descending mass (see Fig. 1) we have,

$$M_1 g - T_1 = M_1 a$$

and to the ascending mass,

$$T_2 - M_2 g = M_2 a$$

Figure 1: Atwood’s machine
where $T_1$ is the tension in the wire above the descending mass, $T_2$ the tension in the wire above the ascending mass, and $g$ the acceleration due to gravity. $T_1$ will be greater than $T_2$ because there is friction and also because the wheels over which the wire runs are not without some mass, that means, a torque is required to accelerate them.

Adding (1) and (2) and solving for the acceleration we get

$$a = \frac{g}{M_1 + M_2} (M_1 - M_2) - \frac{T_1 - T_2}{M_1 + M_2} \quad (3)$$

where $(M_1 + M_2)$ is constant and $(T_1 - T_2)$ may also be considered as a constant if we assume that the friction remains constant as long as the total mass of the system does not change. If we plot the acceleration $a$ versus the mass differences $(M_1 - M_2)$, then equation (3) is represented by a straight line of slope $g/(M_1 + M_2)$ and intercept $(T_1 - T_2)/(M_1 + M_2)$.

Consult the introduction to this manual for instructions concerning the graphing of data. Plot mass differences on the x-axis and corresponding accelerations the y-axis. Plot the data obtained on graph paper and draw the regression line which best "fits" the points. From measurements of slope and intercept, calculate $g$ and $(T_1 - T_2)$. Your report should show your data table, graph, the method used to determine the slope and your calculations.

Questions (to be answered in your report):

1. What is the advantage of transferring mass from one side to the other, instead of adding mass to one side?

2. How would your results be changed if you gave the system an initial velocity other than zero?

3. Solve for the tension in the wire above the descending mass for the case of the largest acceleration. What would be the tension if $a = g$?