Purpose: To demonstrate that for a system of fixed (i.e. constant) total mass, the ratio of the net external force to the acceleration is a constant. In SI units this constant is just the total mass in kg. To estimate the friction present in the pulley.

Discussion: An ideal (i.e. frictionless and massless) pulley serves merely to redirect the one-dimensional motion of the string and attached masses, without affecting the tension in the string or otherwise interfering with the motion. With this in mind, we can view the Atwood's machine system as being driven by an external force \( F \) equal in magnitude to the difference between the two weights. If \( m_1 \) is the larger mass and \( m_2 \) is the smaller mass, then \( F_{\text{ext}} = (m_1 - m_2)g \). The total inertia of the system is given by the total mass \((m_1 + m_2)\).

The real pulleys used in the lab have some friction, which we will try to include in our analysis of the experiment. They also have a mass of 10 g, which introduces a small amount of 'rotational inertia'. Rotational inertia will be discussed later in the course, but it will be neglected in this experiment. The equation of motion for the system is,

\[
F_{\text{ext}} = (m_1 + m_2)\frac{a}{f} + f
\]

where \( a \) is the one-dimensional acceleration of the masses, and \( f \) is assumed to be a constant friction due to the pulley. For a specific value of \( F_{\text{ext}} \), we expect the acceleration to be a constant. Rearranging the equation of motion,

\[
F_{\text{ext}} = (m_1 + m_2)a + f
\]

We will vary \( F_{\text{ext}} \) by changing \( m_1 \) and \( m_2 \), and at the same time keep the total mass \((m_1 + m_2)\) constant. A graph of \( F_{\text{ext}} \) vs. \( a \) should be a straight line with slope \((m_1 + m_2)\) and intercept \( f \).

For given values of \( m_1 \) and \( m_2 \), you are going to measure the time \( t \) it takes \( m_1 \) to fall from some known height \( h \) to the floor. If \( m_1 \) is released with \( v_0 = 0 \) and we assume a constant acceleration (as expected), then the equations of uniformly accelerated motion predict \( h = \frac{a}{2}t^2 \). Solving for the acceleration, \( a = \frac{2h}{t^2} \).

Note: Use m, kg, N, and s in your calculations throughout this experiment.

Procedure:

1. Set up the equipment as instructed. You should make \( h \) at least 1.00 m. It is recommended that you use a total mass of approximately 0.600 kg (i.e. 600 g), and that \( m_1 \) and \( m_2 \) initially differ by approximately 0.010 kg (i.e. 10 g). The small masses should initially be part of \( m_2 \), since you are going to gradually decrease \( m_2 \) and increase \( m_1 \) by transferring these small masses.

2. Measure the time \( t \) it takes \( m_1 \) to fall the known height \( h \). It is extremely important that you obtain accurate times. Be prepared to repeat the motion many times, until you obtain consistent results. Use \( t \) to calculate the acceleration of the system in m/s^2.

3. Transfer mass from \( m_2 \) to \( m_1 \), and repeat step 2. The initial recommendation is that you transfer mass in 0.001 kg (i.e. 1 g) increments, which means that the difference \( m_1 - m_2 \) will increase in 0.002 kg (i.e. 2
g) increments. Notice that the total mass \((m_1 + m_2)\) remains constant. Continue in this way until you have obtained accelerations for eight or more mass distributions.

4. Make a graph of \(F_{\text{ext}}\) vs. \(a\). If the points on your graph appear to be on a straight line, you have partially verified Newton's second law. Draw the best line through your data.

5. Determine the slope (in kg) and intercept (in N) of your line. The slope should correspond to the total mass, and the intercept should correspond to the friction \(f\).

6. Calculate the percentage difference between your slope and the known total mass of the system \((m_1 + m_2)\).

\[
\% \text{ difference} = \left(\frac{\text{slope} - \text{mass}}{\text{mass}}\right) \times 100.
\]

If this percentage is small, you have further verified Newton's second law. Do not be alarmed if your slope is not too close to the expected value.

7. There is no predicted value of \(f\), to which you can compare your experimental value.