Investigating Newton's first law in a pulley system

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This experiment examined how force, mass, and acceleration relate in a one-mass pulley system. We measured the force acted upon a spring (Equivalent to the Tension in the spring) and compared it to the weight of the mass used in the experiment, factoring in Earth's gravity rounded to $-9.81\,\mathrm{m\,s^{-2}}$ By securing one end of the spring scale and the other end to the string attached to the mass, we tested whether the measured force matched what we expected based on the mass and gravity. Our results showed that the tension in the system changed depending on the total mass hanging. This supports the inverse relationship between mass and acceleration described by statics, e.g. $\sum F = 0$, which highlights how forces balance to prevent movement under certain conditions.

I. INTRODUCTION

This experiment explores Newton's first law, when the sum of all forces in a system is zero [1, 2]. We are using scenarios where we change masses. By securing one end of the spring scale to an object, and the other end to a string with the mass attached at a point beyond the pulley. The spring scale is calibrated by adding a known mass on the scale and zeroing it to be accurate. We can describe the relationship of force and mass with our results as they will, with this setup, illustrate how with an increase in mass there is a positive increase in force. If Newton's first law is correct, the spring scale will exert an equal and opposite force, resulting in equilibrium conditions with $\sum F = 0$ and no observable net movement.

To analyze the system, we use the equation:

$$T_1 = m_1 a_1 \tag{1}$$

where T_1 is the tension in the string (the force), m_1 is the mass of the various hanging masses, and a_1 is the Earth's gravitational acceleration. We will compare the theoretical results using a variety of masses, a_1 and this equation to create a theoretical force to compare with our experimental data; the force measured from the spring scale.

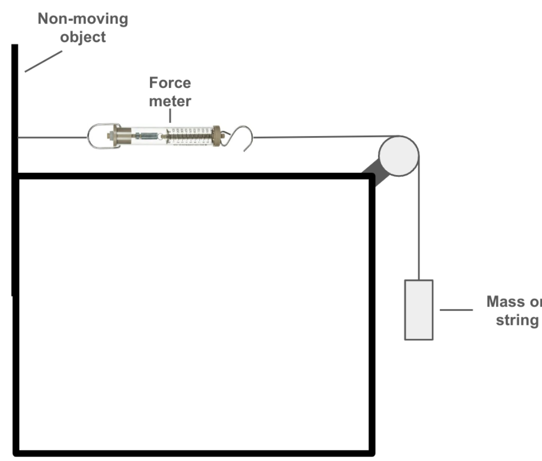

FIG. 1. Setup for the pulley system.

II. METHODS AND MATERIALS

Our tests were conducted using a spring, a hanging mass, and a pulley to change the direction of a string for added control of the objects (see Fig. 1). The materials used for this experimental setup were a complete scientific mass kit with a range of weights including 0.010 kg, 0.020 kg, 0.050 kg, 0.100 kg, 0.250 kg, 0.500 kg and 1.000 kg masses, a spring scale with a measurement range of 0 N to 20 N, an object that will not move to attach the force meter to, a pulley, an elevated surface about 0.8 m off the ground, and a string.

After calibrating the spring scale to provide a reliable number, we attached the pulley so that it is perpendicular to the surface. We anchored one end of the spring scale to a non-moving object and tied the other end to the string. The other end of the string was attached to a hanging mass, with the string fed over the pulley. These steps were repeated for each of the different masses used in the experimental trials.

To compare experimental and real-world values, we calculated the experimental force using (1). Plugging in our values, we obtained the tension in the string, representing the force on the spring scale, and then compared it to the recorded true value to check for consistency.

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TABLE I. Measured relationship between mass on the string and weight (tension).

Mass on string (kg)	Weight of mass on string (N)
0.100	0.8
0.350	3.2
0.500	4.4
0.750	7.2
1.000	9.9
1.500	15.2
1.570	15.9
2.000	20.0

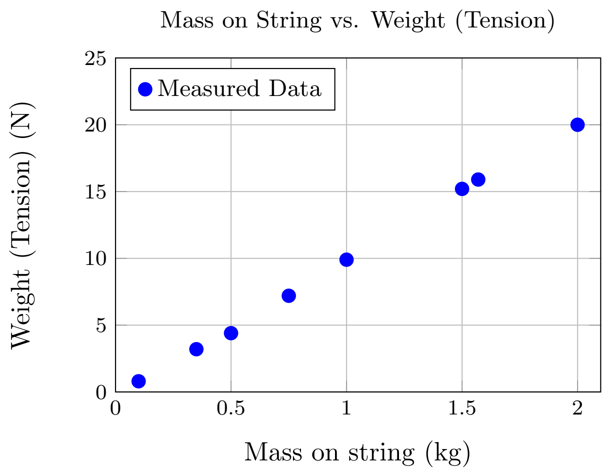

FIG. 2. Graph showing the roughly linear relationship between the mass on the string and the measured weight (tension).

III. RESULTS

Table I gives the measured relationship between the hanging mass on the string and the weight indicated by the spring scale, i.e. the tension in the string. These results are also shown in Fig. 2.

IV. DISCUSSION

Our results indicate that as the mass on the string increases the measured tension also increases in turn, confirming Newton's first law (Table I, Fig. 2). We observed a direct relationship between the mass and tension, as seen in Fig. 2. As the mass increased from 0.100 kg to 2.000 kg, the tension rose proportionally from 0.8 N to 20.0 N, confirming the predictions based on Newton's first law since the tension increases. The data is closely aligned with theoretical values of the weight force, showing consistent accuracy in the result. Minor deviations observed were due to to friction in the pulley and calibration imperfections in the spring scale, but had minimal impact on the overall trend. Overall, the findings support that, under constant gravitational acceleration, tension increases with mass.

Despite our attempts to simplify conditions, some factors may have affected our results, such as friction between the pulley and string (see Fig. 1) and slight differences in the expected and actual weights. Misalignment or reading errors with the spring scale may have also introduced inaccuracies. To reduce these issues in future experiments, recalibrating weights and lubricating surfaces would reduce the experimental error.

Overall, the results highlight how mass and force relate, showing that as mass increases, acceleration decreases under constant force. Real-world conditions, including reaction forces and limitations, should be considered to ensure accurate results.

V. ACKNOWLEDGMENTS

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[1] P. A. Tipler and G. Mosca, *Physics for Scientists and Engineers*, 5th ed. (W H Freeman and Company, New York, 2004).

[2] R. A. Pelcovits and J. Farkas, *Barron's AP Physics C Premium* (Kaplan North America, Fort Lauderdale, FL, 2024) .