

Laboratory Report Scoring and Cover Sheet

Title of Lab Newton's Laws

Course and Lab Section Number: PHY 1103 - 100 Date 23 Sept 2014

Principle Investigator Thomas Edison

Co-Investigator Nikola Tesla

	5	3-4	0-2	Comments
Format	N/A			
Title Page	N/A	N/A		
Abstract	N/A			
Introduction / Materials and Methods				

PI Score _____ + 15 = _____ / 30

Results				
Discussion: Data and Error Analysis				
Discussion: Conclusion				

Co-I Score _____ + 15 = _____ / 30

ABSTRACT

Newton's laws of motion describe interactions between objects via forces, and the objects' resulting motion. This experiment will examine Newton's laws separately, using conceptual questions and a modified Atwood device, in order to distinguish between them. By keeping the system mass constant, the relationship between net force and acceleration can be observed by changing net force and measuring acceleration. Acceleration will be measured with LoggerPro, and a graph of net force vs acceleration will be produced in Microsoft Excel. We hypothesize that the slope of this graph will be equal to the system mass obtained using a double pan balance, to within reasonable error. After performing the experiment, we obtained two values for the system mass that differed by 7.2%, which can be explained by sources of error such as air resistance and friction. These resistive forces were neglected in our predictions, and would both contribute to a measured acceleration slightly lower than expected. The effect would be to produce a force vs acceleration graph with a steeper slope than expected, as displayed by our data. In summary, we were able to successfully apply Newton's laws of motion to a physical system and interpret its behavior.

INTRODUCTION

Newton's laws of motion describe the effects of forces on an object's or system's motion. In brief, if the vector sum of all forces acting on a system is unbalanced, then the system will accelerate in a manner governed by the net force and the mass of the system.

First Law – Newton's first law states that, in the absence of a net force, a system will have no acceleration. For example, an object falling at terminal velocity is subject to two main forces; gravity exerts a force toward the earth's surface, and air resistance exerts a force in the opposite direction. At terminal velocity, the force from air resistance is equal in magnitude to the gravitational force and opposite in direction. Thus there is no net force on the falling object, and its velocity is constant.

Second Law – When a system is subject to a nonzero net force, it accelerates. Newton's second law describes this acceleration in terms of the mass of the system and the net force:

$$F_{net} = m_{system} \cdot a_{system} \quad \text{Eq. 1}$$

Thus, for a given mass, a larger force will produce a greater acceleration. Likewise, for a given force, a larger mass will experience a smaller acceleration.

Third Law – Forces do not materialize out of thin air; Newton's third law addresses this. The weight of a chair is a force acting on the floor beneath it. If the floor did not exert a force equal in magnitude and opposite in direction on the chair, the chair would accelerate in some direction, according to Newton's first law. Two objects that share a force in this manner may be called an action-reaction force pair.

This experiment used a modified Atwood device to examine Newton's laws of motion, as described below.

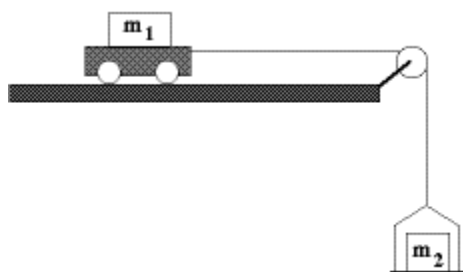


Figure 1a: Modified Atwood device

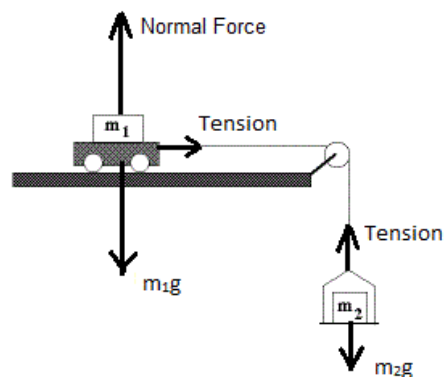


Figure 1b: Forces considered in this experiment

The modified Atwood device used consisted of a low-friction cart on a level track, connected to a hanging mass by a string. The string had a paper clip on either end, and was fed over a low-friction pulley, as shown in Figure 1a. The forces considered to be acting on the system are shown in Figure 1b above. Air resistance and friction were neglected.

Several action-reaction force pairs are apparent from Figure 1b. First, the cart is pulled toward the earth via gravitation. Likewise, the earth is pulled toward the cart, but with a much smaller acceleration. Opposing the weight of the cart (although not its force pair) is the normal force exerted on the cart by the track. It is paired with an equal and opposite contact force exerted on the cart by the track. The two tension forces are also a third law pair, although they constitute an internal force, and are in effect equal and opposite.

Without the tension force acting horizontally on the cart, it remains stationary on the track. Thus the normal force and the weight (m_1g) of the cart must cancel. Both tension forces are internal, and cancel as well. Therefore the net force on the system is produced exclusively by the weight (m_2g) of the hanging mass. Substituting into Eq. 1:

$$m_2g = (m_1 + m_2) \cdot a \quad \text{Eq. 2}$$

The purpose of this experiment is to examine and verify Newton's laws of motion empirically. Eq. 2 above is in linear form $y = mx + b$, where dependent variable (y) is the net force (m_2g), slope (m) is the system mass ($m_1 + m_2$), independent variable (x) is the acceleration (a) of the system, and intercept (b) is zero. Force and acceleration are the independent and dependent variables, respectively, and would normally be graphed a vs. F . However, for this experiment they were graphed F vs. a , in order to have a slope equal to the system mass.

We hypothesize that we will be able to determine the system mass graphically in this manner, to within reasonable error, having measured the hanging mass and the acceleration of the system. We expect the vertical intercept to be zero; in the context of Newton's first law, zero net force will produce zero acceleration. We expect our calculated system mass to be slightly larger than the value obtained using a double pan balance, due mainly to air resistance and internal friction. These are neglected in Eq. 2 and will cause measured acceleration to be slightly less than expected, making the slope of the graph steeper.

MATERIALS

- computer with LoggerPro and Microsoft Excel
- Go!Motion Vernier motion detector
- low-friction cart with track
- low-friction pulley
- cotton string and two paper clips
- two 0.020 kg masses
- two 0.010 kg masses
- two 0.200 kg masses
- double pan balance

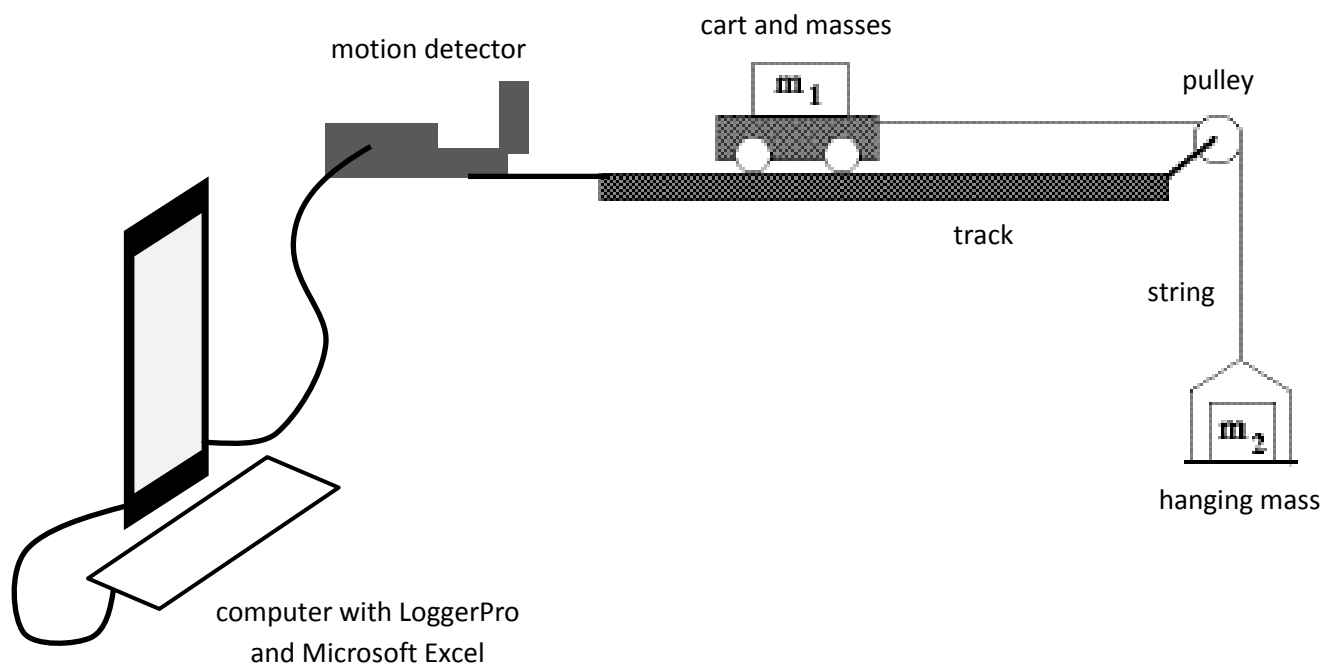


Figure 2: Experimental Setup for Modified Atwood Device

METHODS

Activity 1: Newton's First and Third Laws

The cart was placed on the track, and the four small masses and paper clips and string were placed atop it. The forces acting on the system were the gravitational force on the cart and objects atop it, and the normal force from the track opposing the cart's weight. The net force on the system was zero. Thus there was no imbalance of forces, and no acceleration.

One end of the string was attached to the cart with a paper clip, while the other end of the string was fed over the pulley. While keeping three masses atop the cart, one 0.020 kg mass was hung from the vertical end of the string with the second paper clip. It was observed that when released, the system accelerates (hanging mass toward the floor, cart toward the pulley). The forces acting on the system are those shown in Figure 1b above. The net force acting on the system is the weight of the hanging mass, given by $m_2g = (0.020 \text{ kg})(9.7953 \text{ m/s}^2) = 0.195906 \text{ N} = 0.20 \text{ N}$. The system is now accelerating because there is an imbalance of force, as described by Newton's first law.

The following questions, taken from the lab web page examine third law force pairs:

1. If not the normal force, what is the force that is equal and opposite to the gravitational force of the earth on the cart? – The pair of this force is the gravitational force of the cart on the earth. A misconception about gravity is that it creates a force that pulls things to Earth's surface. However, gravity is an attractive force between any two masses. An apple appears to fall to ground, rather than the ground leaping up to meet the apple, because the fruit's mass is many orders of magnitude smaller than Earth's. Since the forces are equal, the smaller mass must have the larger acceleration.

2. If not the gravitational force of the earth on the cart, what is the third law pair of the normal force? – The normal force is the contact force exerted by the track on the cart. By the same token, the cart exerts a contact force on the track. Another misconception is that this force is created by the cart's weight. However, the cart and track would attract each other gravitationally even if the earth were absent. The normal forces preventing the cart and track from occupying the same space simultaneously are due to material forces within each object.
3. Similarly, the gravitational force on the hanging mass (m_2g) and the tension in the string are not a Newton's 3rd Law pair. If not the string tension, what is the force that is equal and opposite to the gravitational force on m_2 ? – Similar to Question 1 above, the pair of the gravitational force of the earth on m_2 is the gravitational force of m_2 on the earth.
4. Is the tension less than, greater than, or equal in magnitude to the gravitational force on m_2 ? How do you know? – The tension in the string is less than the magnitude of the gravitational force acting on m_2 . This is evidenced by the mass accelerating in the direction of the gravitational force, rather than in the direction of the tension.

Activity 2: Graphical Representation of Newton's Second Law – Net Force vs Acceleration

To examine the relationship between net force, system mass, and acceleration, one variable must be held constant. In this experiment, system mass was held constant by keeping all masses either hanging on the end of the string over the pulley, or else sitting atop the cart. When taking data, net force was the independent variable, since it could be controlled by adjusting the hanging mass. Acceleration was the dependent variable.

We positioned the motion detector at the end of the track opposite the pulley. It was activated using LoggerPro, and the cart was allowed to accelerate toward the pulley. From the motion detector data, LoggerPro produced a velocity vs. time graph:

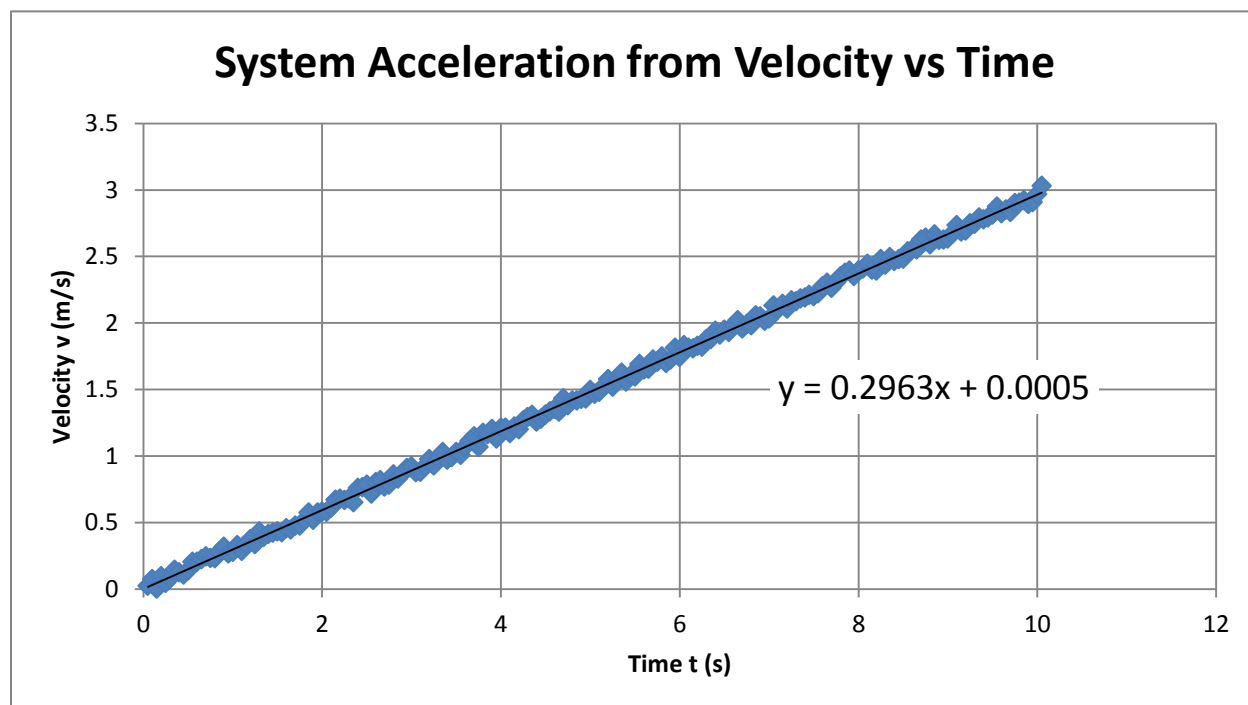


Figure 3: System Acceleration from Velocity vs Time

The graph suggests that acceleration was roughly constant as the cart moved along the track toward the pulley, as expected. The acceleration was determined experimentally, from a linear fit to the velocity vs time data, to be $a = 0.2969 \text{ m/s}^2$.

To construct a force vs acceleration graph, the previous procedure was repeated for various different hanging masses. In each case, an experimental acceleration was obtained from a linear fit to the velocity vs time graph produced by LoggerPro. The net force acting on the accelerating system was calculated by multiplying the hanging mass m_2 by the acceleration of gravity $g = 9.7953 \text{ m/s}^2$. These data are presented in Table 1 in the Appendix.

A graph of net force vs acceleration was created in Microsoft Excel with the data from Table 1. A linear regression was applied to the graph, giving a graphically-determined value for the system mass. This graph is displayed in the Results section as Figure 4. Another experimental value for the system mass was obtained using the double pan balance. After calibrating it as well as possible, the cart, small masses, and string and paper clips were placed on one pan. The two 0.200 kg masses were placed on the other pan, as a counterbalance to the rather heavy cart (the balance can measure 0.110 kg without counterbalance). This measured system mass is provided in the Results section. It was compared to the graphically-obtained value using percent difference.

The slope of this graph represents the mass of the accelerating system on the modified Atwood device. It has units of kilograms, as expected of mass. These units can also be obtained by interpreting slope as rise over run, or change in y over change in x , and dividing Newtons (equivalent to kilograms times meters per second squared) by meters per second squared, leaving kilograms.

RESULTS

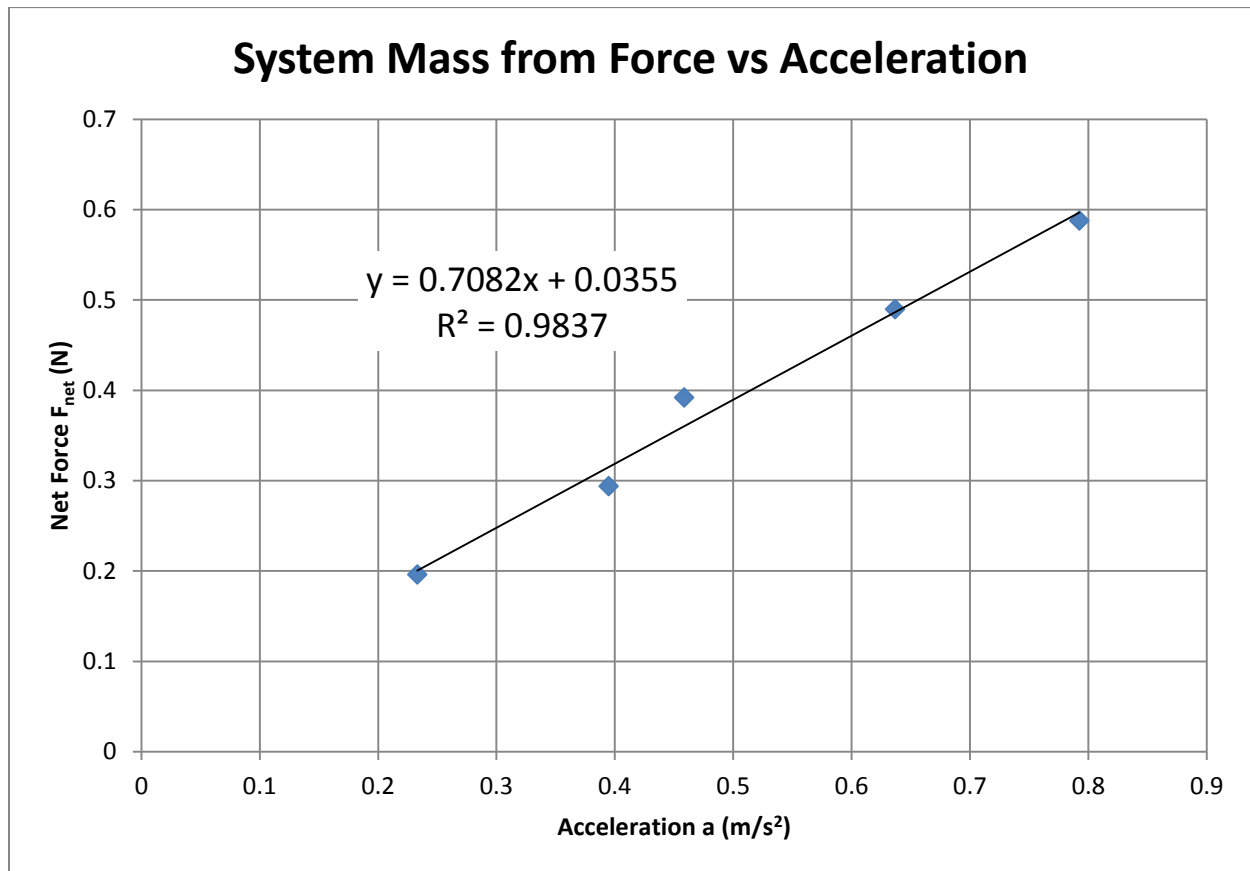


Figure 4: System Mass from Force vs Acceleration. Please see the appendix for the table of raw data.

The linear fit to the Force vs Acceleration data can be rewritten as:

$$F_{net} (N) = 0.7082 (kg) \cdot a (m/s^2) + 0.0355 (N) \quad \text{Eq. 3}$$

This gave a graphical value for the system mass of $m_2 = 0.7082$ kg. The measured system mass obtained using the double pan balance was $m_2 = 0.6592 \text{ kg} \pm 0.0002 \text{ kg}$. These values were compared using percent difference:

$$\begin{aligned} \%difference &= \frac{|experimental1 - experimental2|}{average} \cdot 100\% \quad \text{Eq. 4} \\ &= \frac{|0.7082 \text{ kg} - 0.6592 \text{ kg}|}{(0.7082 \text{ kg} + 0.6592 \text{ kg})/2} \cdot 100\% = 7.2\% \end{aligned}$$

DISCUSSION

Data Analysis

The graphed data in Figure 4 are described well by a linear fit, which has an R^2 value of 0.9837. As explained in Methods for Activity 2, the slope of this graph represents the mass of the accelerating system. This graphically-determined mass was 7.2% greater than the mass measurement obtained using the double pan balance. This error could be due to neglecting air resistance and friction in our predictions. Both provide small forces that resist motion; thus in this experiment, both would act opposite to the net force, since the system moves in the direction of that force. This would not change the calculated values of net force in Table 1, but it would decrease the observed acceleration measured by LoggerPro. In context of the force vs acceleration graph, the same force would produce a smaller acceleration. Since acceleration is on the horizontal axis, air resistance and friction would therefore result in a steeper slope than expected. This agrees with our experimental results.

To reduce friction within the modified Atwood device, the cart wheels and pulley were checked and adjusted to minimize friction as much as possible. We also wiped any debris from the cart wheels and track before starting the experiment. Without using a more aerodynamically-optimized apparatus, we cannot do much to reduce air resistance.

One might also expect the small masses used in the experiment to have slightly less mass than advertised, due to abrasion from normal use over time. This would have made our calculated values of net force slightly larger than actual. The effect of this error would be to produce a smaller acceleration than expected, also resulting in a steeper slope for the force vs acceleration graph. This agrees with our experimental results.

The intercept of the force vs acceleration graph was 0.0355, which is reasonably close to the expected value of zero. The difference could be caused by the entire graph being shifted vertically by a positive systematic error, or by random errors on each data point.

Another source of error comes from the mass of the string. The string between the cart and pulley provides a force resisting the motion, while the string between the pulley and hanging mass adds to the net force acting on the system. The string and paper clips had a mass of about 3 g, roughly 0.5% of the total system mass, and their effect on the system's motion was probably miniscule. However, the variable forces they produce were ignored during the experiment, and therefore contributed in some way to the error in our results.

Conclusion

We hypothesized that we would be able to determine the system mass graphically, to within reasonable error, using Newton's second law in the form of Eq. 2. Our difference of 7.2% supports that hypothesis, but suggests that sources of error were not negligible. As discussed in the Data Analysis section, air resistance, internal friction, and normal wear on the small masses used in the experiment would all produce a steeper force vs acceleration graph than expected. Thus we accept our original hypothesis, with the caveat that these sources of error were significant, and should somehow be taken into account.

We hypothesized that the vertical intercept of the force vs acceleration graph would be zero, based on Newton's first law; in the absence of a net force, an object will not accelerate. We accept this hypothesis, given that the intercept is close to zero, and taking into account possible systematic and random errors.

We hypothesized that the system mass obtained graphically would be slightly higher than the measured mass obtained using the double pan balance, due to friction and air resistance. We accept this hypothesis, based on our graphically-determined system mass being 7.2% greater than our measured system mass. The caveat in this case is that our prediction did not account for the small masses having slightly less mass than expected.

This experiment allowed us to distinguish between Newton's laws of motion, by applying them separately to a physical experiment. Clearly, when the cart is stationary on the track, there is no net force acting on it, and its acceleration is zero. This verifies Newton's first law. And since neither the cart nor track moves the other, Newton's third law is also verified; the cart and track act on each other with an equal and opposite contact force. Activity 2 demonstrated Newton's second law accurately, considering the sources of error discussed in the Data Analysis section. In that respect, we learned that Newton's laws can be used to predict the motion of a system, but also that air resistance and friction cannot always be neglected.

One improvement to the experiment design that could be performed easily would be to measure the small masses individually on the double pan balance, to obtain a more precise value for each. This would minimize error due to wear on the masses.

Using a sleeker apparatus would reduce air resistance. However an easier method of minimizing the effect of air resistance would be to use a larger system mass, perhaps by placing the two 0.200 kg masses on the cart for the acceleration trials.

Friction on the pulley axis and cart axles cannot be reduced much, but minor adjustments can be made to both to minimize friction. The cart wheels and the track can be

cleaned before performing the experiment; this would also reduce friction. Alternatively, if the experiment were performed in a vacuum, air resistance could be neglected with confidence.

APPENDIX

Hanging Mass m_2 (kg)	Net Force F_{net} (N)	Acceleration a (m/s^2)
0.020	0.20	0.2331
0.030	0.29	0.3950
0.040	0.39	0.4586
0.050	0.49	0.6367
0.060	0.59	0.7925

Table 1: Acceleration Measurements for Constant System Mass

REFERENCES

“Error Analysis,” Department of Physics and Astronomy, Appalachian State University,

<http://physics.appstate.edu/undergraduate-programs/laboratory/resources/error-analysis>, 6 Oct 2014

“Free Fall 2,” Department of Physics and Astronomy, Appalachian State University,

<http://physics.appstate.edu/laboratory/quick-guides/free-fall-2>, 6 Oct 2014

“Laboratory Report,” Department of Physics and Astronomy, Appalachian State University,

<http://physics.appstate.edu/undergraduate-programs/laboratory/resources/laboratory-report>, 6 Oct 2014

“Motion Detector 2,” Department of Physics and Astronomy, Appalachian State University,

http://physics.appstate.edu/sites/physics.appstate.edu/files/motion_detector.pdf, 6 Oct 2014

“Newton’s Laws,” Department of Physics and Astronomy, Appalachian State University,

<http://physics.appstate.edu/laboratory/quick-guides/newtons-laws>, 6 Oct 2014

“Significant Figures,” Department of Physics and Astronomy, Appalachian State University,

<http://physics.appstate.edu/undergraduate-programs/laboratory/resources/significant-figures>, 6 Oct 2014