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Newton's Second Law

Driving Question | Objective

What factors affect the acceleration of an object or system? Experimentally determine the relationship between an object's or system's mass, acceleration, and the net force being applied to the object or system.

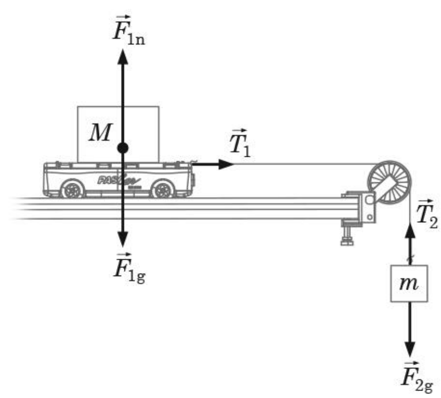
Materials and Equipment

- Data collection system
- PASCO Motion Sensor[1]
- PASCO Dynamics Track[2]
- PASCO Dynamics Cart[3]
- PASCO Dynamics Track End Stop[4]
- PASCO Super Pulley with Clamp[5]
- PASCO Compact Cart Mass (2), 500-g
- PASCO Mass and Hanger Set
- Thread
- Balance, 0.1-g resolution, 2,000-g capacity

Background

Often, several forces act on an object simultaneously. In such cases, it is the *net force*, or the vector sum of all the forces acting, that is important. Newton's First Law of Motion states that if no net force acts on an object, the velocity of the object remains unchanged. If the velocity is not changing, the object is not accelerating. Newton's Second Law relates to the effect of unbalanced forces acting on an object. If forces are unbalanced, there is a net force and the object accelerates.

Like Newton, you will observe a simple system to look for a relationship between net force, mass, and acceleration. The components of the system are shown in the diagram. The system consists of a cart attached by thread to a falling mass. The falling mass applies the force of gravity to the thread which is then translated through thread tension to the cart. Although the gravitational force on the cart is counteracted by the normal force from the track, the applied force from the falling mass has no counteraction (assuming frictional force in the cart's wheels is zero), resulting in a non-zero net force acting on the cart in the direction of the thread.



In this exploration you will investigate how this net force and the mass of the system are related to the system's acceleration.

Relevant Equations

$$\vec{a}_{\text{ave}} = \frac{\Delta \vec{v}}{\Delta t} \tag{1}$$

This equation states that the average acceleration of an object is equal to the change in the object's velocity $\Delta \vec{v}$ divided by the elapsed time Δt. If the object experiences constant acceleration (similar to acceleration from gravity), the linear slope of the object's velocity time graph will equal the object's constant acceleration.

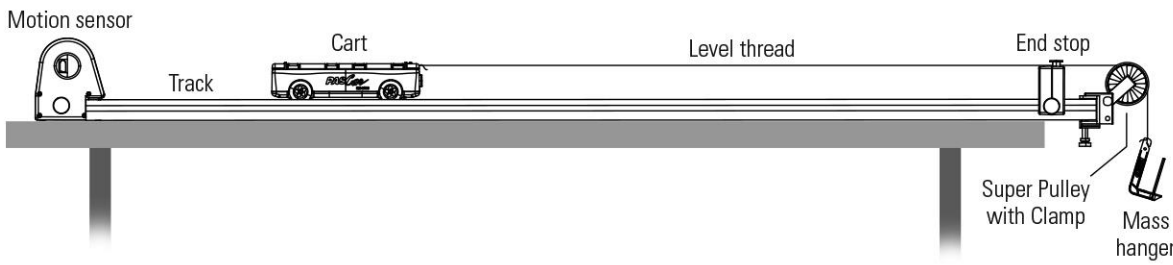
Procedure

Part 1 – Constant Net Force, Varying System Mass

SET UP

1. The mass of the cart is 500 g. Record this value in kilograms into Table 1 in the Data Analysis section below.

2. Set up the equipment, as shown in the diagram. Follow the guidelines below as you set up this system:



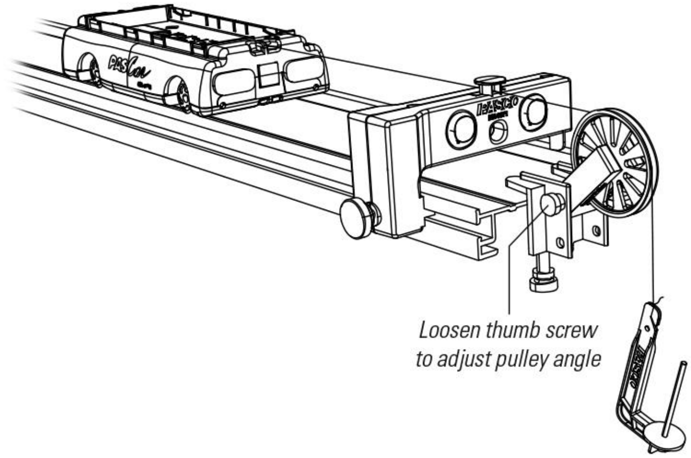
   a. Be sure the track is level, and mount the end stop to the track just in front of the pulley.

   b. Adjust the angle of the pulley so that the thread is parallel to the track, as pictured.

3. Add an additional 500 g of masses from the mass set into the cart.

4. Hang 20 g of mass on the 5-g mass hanger, for a total hanging mass of 25 g.

5. On the data collection system, create a graph display of velocity versus time, and then adjust the sample rate to 25 Hz. Both position and velocity should be checked.



COLLECT DATA

7. In Table 1, record the total mass of the system for Trial 1:

   Total mass of system = mass of cart + mass in the cart + hanging mass

8. Pull the cart away from the end stop, toward the motion sensor, until the mass hanger hangs just below the pulley.

9. Set the delayed start position above .4 m and the automatic stop position above .9 m. Begin recording data.

10. When the cart reaches the end stop, stop recording data. Do not allow the cart to run into the end stop.

11. Remove 100 g of mass from the cart, and then follow the same steps to record a second run of data. Record the total system mass for Trial 2 into Table 1.

12. Repeat the same data collection steps three additional times, decreasing the amount of mass in the cart by 100 g in each trial. Record the total system mass for each trial into Table 1.

13. Use a line of best fit applied to the velocity data only when the system was in motion. The slope of the best fit line is equal to the acceleration of the system. Record this data into Table 1 for each trial.

Part 2 – Constant System Mass, Varying Net Force

SET UP

14. Use the same Part 1 setup: hang 20 g of mass on the 5-g mass hanger, for a total hanging mass of 25 g; place 500 g of masses from the mass set into the cart. Since the mass of the cart is 500 g, the total mass of the system is 1000 g.

COLLECT DATA

15. In Table 2, record the current amount of hanging mass for Trial 1 in the Part 2 Data Analysis section below.

16. Repeat procedures 9 to 10.

17. Take 20 g of mass out of the cart and add the mass you just removed from the cart to the mass hanger, for a total of 45 g of hanging mass. This technique keeps the total mass of the cart-masses-mass-hanger-system constant.

18. In Table 2, record the current amount of hanging mass for Trial 2.

19. Pull the cart away from the end stop until the mass hanger hangs just below the pulley, and then record another run of data as you release the cart.

20. Repeat the same data collection steps three additional times, removing 20 g of mass from the cart and adding it to the mass hanger in each trial. Record the hanging mass in each trial in Table 2.

21. Use the tools on your data collection system to determine the acceleration of the system after it was released in each trial. Record this data into Table 2.

Data Analysis

Part 1 – Constant Net Force, Varying System Mass

Mass of Cart (kg): 500g

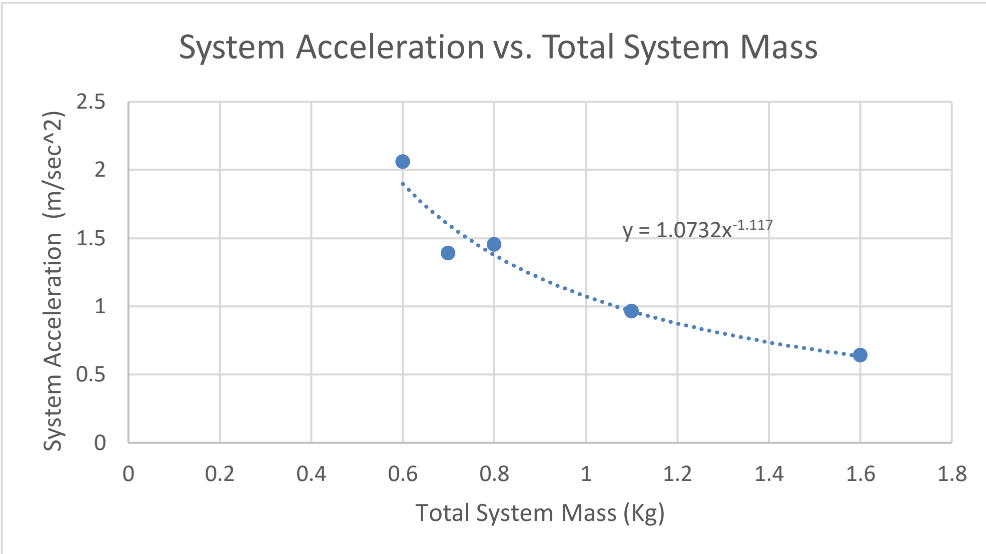
Table 1: Acceleration of a system with varying mass and constant net force

Trial	Total System Mass (kg)	System Acceleration (m/s^2)	1/Mass (kg^{-1})
1	0.8kg	1.45 m/s^2	1.25
2	0.6kg	2.06 m/s^2	1.67
3	0.7kg	1.39 m/s^2	1.43
4	1.1kg	0.963 m/s^2	0.59
5	1.6kg	0.64 m/s^2	0.625

1. Plot a graph of *system acceleration* versus *total system mass* in the blank Graph 1 axes. Be sure to label both axes with the correct scale and units.

Graph 1: Acceleration versus mass for a system experiencing constant net force

Insert graph here



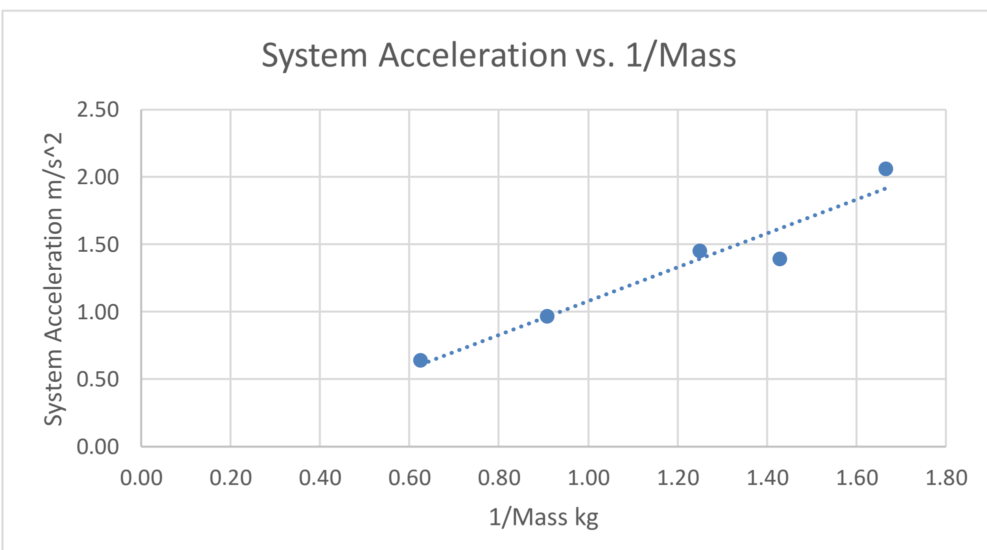
2. *Linearize* your System Acceleration versus Total System Mass data:

   a. Calculate 1/Total System Mass for each system mass value in Table 1. Record the results into Table 1 (1/Mass).

   b. Plot a graph of *system acceleration* versus *1/mass* in the blank Graph 2 axes. Be sure to label both axes with the correct scale and units and give the graph a title.

Graph 2: Acceleration versus 1/mass for a system experiencing a constant net force

Insert graph here



- 3. What does the slope of a best fit line on your Acceleration versus 1/Mass graph represent? *Hint: the units for slope are* $kg \cdot m/s^2$.

The best fit line on our Acceleration versus 1/Mass graph represents the net force of the system.

Part 2 – Constant System Mass, Varying Net Force

Table 2: Acceleration of a system with varying net force and constant mass

Trial	Hanging Mass (kg)	System Acceleration (m/s^2)	Net Force (N)
1	0.11	0.513	1.078
2	0.12	0.548	1.176
3	0.2	0.618	1.96
4	0.5	2.42	4.9
5	0.1	0.379	0.98

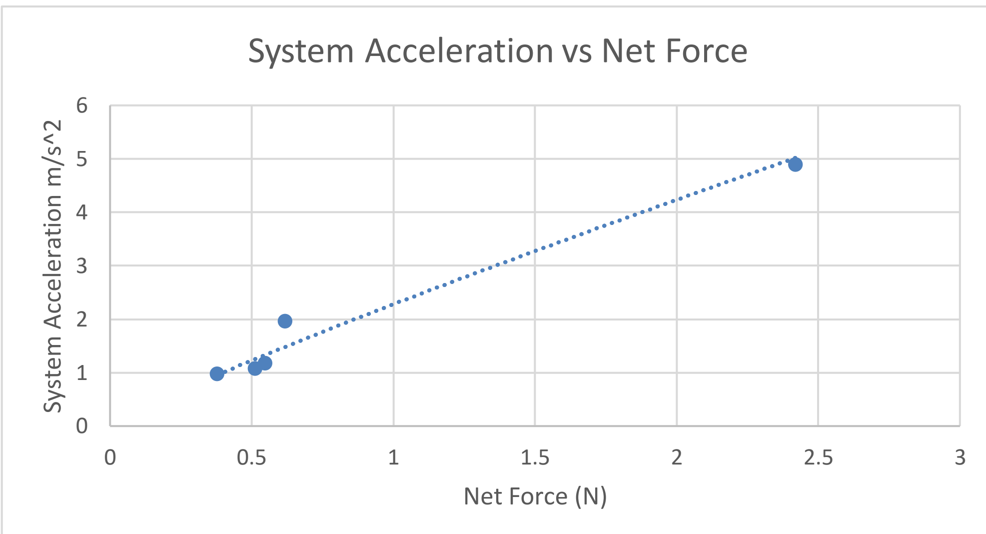
4. Calculate the magnitude of the net force $\left|\vec{F}_{\text{net}}\right|$ acting on the system in each trial:

$$\left|\vec{F}_{\text{net}}\right| = mg$$

where m is the amount of hanging mass in each trial and g is earth's gravitational constant (g = 9.8 m/s^2). Record your results in Table 2.

5. Plot a graph of *system acceleration* versus *net force* in the blank Graph 3 axes. Be sure to label both axes with the correct scale and units.

Graph 3: Acceleration versus net force for a system with constant mass



Analysis Questions

- 1. Qualitatively, what effect did your object's or system's mass have on its acceleration? Support your answer with data.

As the system mass increased, the acceleration increased. For example, when the hanging weight increased from 0.11kg to 0.12kg the system acceleration increased from 0.513 m/s^2 to 0.548 m/s^2

- 2. What is the relationship (inverse, proportional, equal, squared, et cetera) between the mass of your object or system and its acceleration? How do you know?

It would be an inverse relationship because as the mass of the system increases the acceleration decreases.

- 3. Qualitatively, what was the effect on your object's or system's acceleration as the net force acting on it increased? Support your answer with data.

As the net force of the object increased then the system acceleration increased, when the net force of the object was 1.078N the system acceleration was 0.513 m/s^2 and when the net force is 1.176N the system acceleration is 0.548 m/s^2

- 4. What is the relationship (inverse, proportional, equal, squared, et cetera) between your object's or system's acceleration and the net force acting on it? How do you know?

The relationship between a system's acceleration and its net force is that they are directly proportional with one another. As the net fore increases so does the system's acceleration.

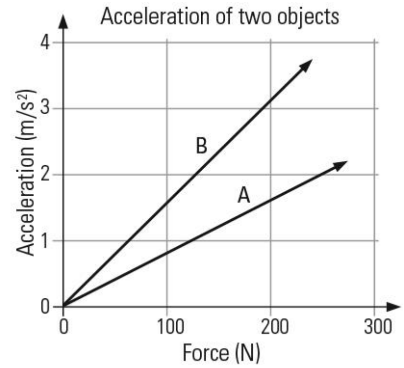
- 5. There are two common mathematical expressions for Newton's Second Law. One of these expressions is given below. How does your data support this mathematical relationship?

$$\vec{a} = \frac{\vec{F}_{\text{net}}}{m}$$

The net force of our system was proven by multiplying the mass of our system by an acceleration of 9.8m/s^2 therefore proving the relationships demonstrated in this equation to be true.

Synthesis Questions

- 1. Two different carts are accelerated by a net force. The graph shows their respective accelerations as a function of this net force. What can you conclude about the mass of cart A compared to the mass of cart B? How do you know?



We know that force is equal to mass times acceleration where the mass is the mass of a system and the acceleration is the acceleration of a body. This means that the slope of a Acceleration vs Force graph gives us 1/mass and since B has a larger slope it will be a larger 1/x number therefore making it less than the mass of Object A

- 2. We know from experience that the harder we throw a ball (apply more force), the faster it will be moving (greater initial velocity resulting from acceleration). If you throw a 1 kg softball as hard as you can, and it is traveling at 20 m/s when it leaves your hand, how fast do you think a 5 kg shot put

As a ball is thrown as hard as it can be the mv will remain constant between both objects, thus if the mass increases then the velocity of the objects will decrease.
M1=1Kg, V1=20ms^-1 V2=?, M2=5kg
V2=4ms^-1

would travel with the same throw?

- 3. If we launch a rocket that has been designed to produce a constant force, will the acceleration at initial launch be the same as the acceleration just before the fuel is completely expended? Explain your answer.

Force (F) in rocket is constant and force is equal to mass times acceleration, therefore as fuel builds up it changes as the mass decreases and the acceleration increases.

- 4. A 1,000.0 kg rocket is traveling straight up with its engine producing a force of 39,240 N. If the rocket experiences a retarding force from air resistance equal to –1,227 N, what is its acceleration?

The mass of the rocket is 1000Kg and the force produced by the engine is 39240N and the retarding force is -1227N. So if mass times acceleration equals the net force than the net force is equal to the engine force plus the retarding force. Then 1000Xa=39240-1227 and acceleration is equal to 38.013ms^-2

- 5. A teacher challenges her students to find the mass of their physics book using the system shown at right and their understanding of Newton's Second Law. A motion sensor measures the cart's acceleration due to three different hanging masses: 0.020 kg, 0.040 kg, and 0.060 kg. The acceleration and force data are provided in the table. The mass of the cart is 0.300 kg. Use the provided information to find the mass of the physics book. Show all of your work and explain your reasoning and process for deriving the book's mass.

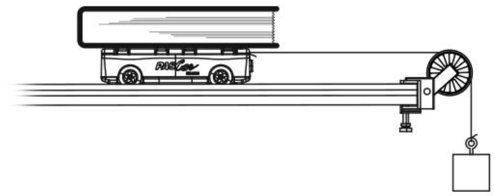


Table: Acceleration of a cart with varying net force and constant mass

Trial	Net Force Acting on the Cart (N)	Acceleration of the Cart (m/s^2)
1	0.196	0.131
2	0.392	0.261
3	0.588	0.392

Take a picture of your work and attach it below.

slope of force vs. acceleration = mass

$y = 1.5x - 0.0$

∴ slope = mass = 1.5kg