

OPERATING INSTRUCTIONS

Cart Acceleration Apparatus No. 32158

1. Purpose

Use the Cart Acceleration Apparatus to verify Newton's Second Law of Motion. The force-measuring scale on the apparatus is a part of the pulley system that applies a constant force. The force is therefore directly and easily measured.

2. Description

The apparatus is a pulley system that provides a way to give a steady acceleration to a moving body (see Fig. 1). The components of the pulley system are listed below.

- An aluminum stand, with a 1mm scale, that is 470mm high. It is labeled every centimeter for a length of 20 centimeters, to measure the tension applied to a moving body or cart.
- A coil holder attached to a spring coil that holds a dynamic pulley. You can move the coil holder to adjust the spring tension (or the tension on the pulley string) to zero.
- A dynamic pulley made of plastic, with a metal marker attached to indicate the movement of the cart on the stand's centimeter scale.
- A spring coil which is 20mm in diameter, with a spring constant of 32g/cm.
- Three static pulleys which control the string. They have a 25mm diameter.
- A bumper cushion. The carts can bump into it should they fail to stop before the falling weight that controls their motion reaches the floor.
- Four 50-gram weights, 46mm diameter x 4mm thickness, with a center hole for attaching string.
- Ten adjusters: five 5g-adjusters and five 1g-adjusters.
- A steel stand holder, 3mm x 105mm.
- A 230cm-long roll of string with a hook to attach to a cart. (An extra 5 meters of string are included.)

While it is not necessary to use our 32157 Dynamics Carts with Masses for the moving body, we recommend that you do so to obtain best results. The carts' center of gravity is clearly marked, and the ball-bearing action of their wheels is relatively friction-free. If you don't wish to use the carts, anything of appropriate mass on wheels can be used if you are willing to sacrifice some accuracy. We also recommend that you use the 32159 Acceleration Experiment Stand. It provides a straight track for the carts. You will need to have a spark recording device, such as our 32210 Compact

Spark Timer, to time the movement of the cart.

3. Setup

(See Fig. 1): Loosen the two parallel wing nuts on the stand holder and slide the square washers into the stand column. Tighten the wing nuts. Set the stand holder along the end of a sturdy table and clamp it. (C-Clamp 88056-01 opens to 3.5cm and is 8cm deep.) Be careful not to overtighten the clamp or you may damage the finish of the metal stand.

Fig. 1
Stand Assembly

4. Calculations

Newton's Second Law of Motion states that force is equal to mass times acceleration:

$$F = m \cdot a$$

which implies that acceleration is directly proportional to the force applied and that acceleration is inversely proportional to the mass being moved:

$$a \propto F$$

and

$$a \propto \frac{1}{m}$$

These two equations are tested with the Cart Acceleration Apparatus.

F	the force given to the cart
a	acceleration of the cart
m	mass of the cart
x	expansion of the spring
M	mass of the falling weight
M'	adjusting mass for M
T	tension of the string
g	gravity constant of Earth

The Cart Acceleration Apparatus generates the accelerating force by means of the falling mass **M**. This force is transmitted to the accelerating cart through spring tension **T**. During a cart acceleration, the spring tension is constant and is measured by the spring extension **x**. This motion is described by:

$$T = kx = ma \quad (1)$$

where **k** = the spring constant.

When falling masses are added, *the spring extension x will increase*. The tension is no longer a constant; in fact, the tension is increased according to the increased mass. Rewriting eq. (1) illustrates that the relationship between spring expansion **x** and cart acceleration **a** is linear

$$a = F(k,m) x \quad (2)$$

where the slope = k/m (see Fig. 6).

The increase in spring expansion can be explained by evaluating the entire kinetic equation for the experiment:

$$Mg - T = Ma \quad (3)$$

where **Mg** is the gravitational force on the falling mass, **T** is the upward tension on the falling mass by the spring, and **Ma** is the resultant force.

If $T = ma$ (from eq. 1), then

$$Mg - ma = Ma \quad (4)$$

Again from eq. (1):

$$T = kx = ma = F(mMg, M + m) \quad (5)$$

This illustrates that as the falling mass **M** is increased, **x** increases.

Equation 5 can also be written:

$$T = F(Mg, F(M,m) + 1) \quad (6)$$

which reduces to

$$T = Mg \quad \text{for } M \ll m \quad (7)$$

Therefore, if a small falling mass is used compared to the cart mass, eq. (1) can be extended to the case where the falling mass is kept constant and the cart mass increased:

$$a = (kx) \cdot F(1,m) \quad (8)$$

where the slope = kx (see Fig. 6).

If higher precision is desired, the falling mass can be adjusted by the following table (see Fig. 5)

<u>Cart Mass In Grams</u>	<u>Weight to Add to Falling Weight</u>
500	14
750	6
1000	2
1250	0

4. Operation

Fig. 2 Experiment Setup

Set up the Cart Acceleration Apparatus. Adjust the height of the cushion unit to match the height of the cart. Set the string as shown in Fig. 2.

The scale should read "zero" when there is no tension applied to the string. You can move the coil holder if necessary.

The cart should be set on a table or counter or on the Cart Acceleration Stand (Cenco No. 32159) with spark timer tape attached. Pull the cart away from the Cart Acceleration Apparatus until the falling masses are elevated far enough off the floor for a good data run. Continue to hold onto the cart and turn the spark timer on. After the spring and falling mass are completely still, gradually let go of the cart. (You can hold your finger in front of the cart while you let it begin to move, and then withdraw your finger.) If your movements are slow and gradual you will avoid spring oscillation and obtain good experiment results.

Caution! A little observation and practice is necessary to prevent overshooting the length of the string or sudden acceleration of the cart, especially if you are using the Cart Acceleration Stand. Overshooting could cause the cart to bounce or fall and pit the track of the stand. To prevent this kind of overshoot, determine the proper length of string to use and gradually release the cart.

Read the scale when the scale mark is stable. (The stable scale mark will be slightly smaller than that which exists right before the cart is released.) The string must be short enough and the cart at a proper distance for the scale to reach stability before the weight falls on the ground or the cart bumps into the cushion. The cushion is provided as a precaution to protect the cart.

Record the spring expansion x .

Calculate the acceleration of the cart by recording tape analysis. About 5 data points length will suffice, preferably 5 mid run points.

Repeat the experiment, changing the mass of the falling weight. Compile a chart describing the relation of force and acceleration. Transpose the data onto a graph. Hooke's Law is assumed for the expansion of the spring coil. A sample data chart and graph are shown in Fig. 3 and 4.

Experiment Trial	1	2	3	4
Falling Weight M (g)	50	100	150	200
Spring Expansion x (mm)	20	46	70	94
Cart Acceleration a (mm/sec ²)	1.7	4.5	6.8	9.1

Fig. 3 Spring Expansion & Cart Acceleration Data

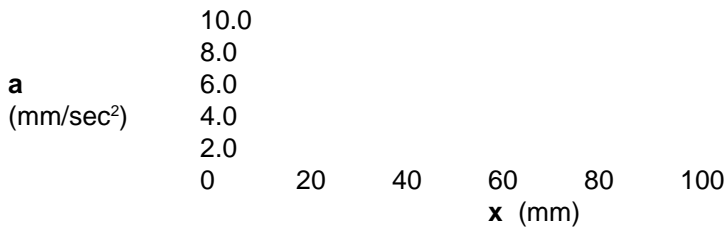


Fig. 4 Acceleration/Spring Expansion (Force)

Repeat the experiment again, varying the mass of the cart, but keeping the pulling force of the falling weight constant. Compile a data chart showing the indirect relationship between mass and acceleration. Transpose the data onto a graph. (See Fig. 5 and 6.)

Experiment Trial	1	2	3	4
*Falling Weight M + M' (g)	114	106	102	100
Spring Expansion x (mm)	47	49	48	47
Cart Mass m (g)	500	750	1000	1250
F(1,m) x 10⁻³	2	1.3	1	0.8
Cart Acceleration a (mm/sec ²)	8.9	6.3	4.9	4.3

Note: **M'** is an adjustment factor for the tension of the spring.

Fig. 5 Inverse of Cart Mass/Cart Acceleration Data

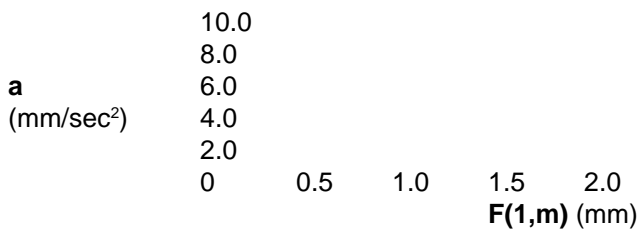


Fig. 6 Acceleration/Inverse of Cart Mass

Exploring Newton's Second Law of Motion is but one of the experiments you can do using the Dynamics Carts with Masses. This apparatus is also used to demonstrate Hooke's Law, friction experiments, and other motion experiments such as constant acceleration in linear motion, conservation of momentum, cart docking, elastic collisions, and force balancing on a slope. Please refer to the instructions for the Dynamics Carts with Masses (Cenco No. 32157) and the Acceleration Experiment Stand (Cenco No. 32159) for experiment diagrams and details, or consult any good physics textbook.

6. Maintenance

The Cart Acceleration Apparatus needs no special maintenance. If you should experience any difficulty with a Cart Acceleration Apparatus, please contact Central Scientific Company, giving details of the problem. To ensure better service, please do not return any apparatus to Central Scientific Company until we have sent you authorization.

7. Accessories

<u>Description</u>	<u>Catalog No.</u>
Dynamics Carts with Masses	32157
Acceleration Experiment Stand	32159
Compact Spark Timer	32210

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