Phone: 417.374.7431
Fax: 417.374.7442
service@gosciencecrazy.com
2076 North James River Court
Nixa, Missouri 65714

Acceleration Trolley
#ACT01

Warning:

- **Not a toy; use only in a laboratory or educational setting.**
- **California Proposition 65 Warning: This product can expose you to chemicals including styrene, nickel, and lead, which are known to the State of California to cause cancer, birth defects, or other reproductive harm. For more information go to www.P65Warnings.ca.gov.**

Introduction

Newton's three laws of motion can be used to reliably describe the motion of an object of typical size and speed. Describing motion gets a lot more complicated when you observe very small and very large objects approaching the speed of light. Motion like this can only be explained using quantum mechanics and Einstein's theory of general relativity, respectively. This experiment will not come close to requiring either of those more complicated theories, however.

In this experiment, we will be describing the motion of a trolley suspended from two pulleys as it travels down a wire. The trolley has three holes in its body to give you the option to add weights. You may use a photogate to take accurate readings of the cart's velocity as it travels down the wire. Weights and photogate are **not included.**

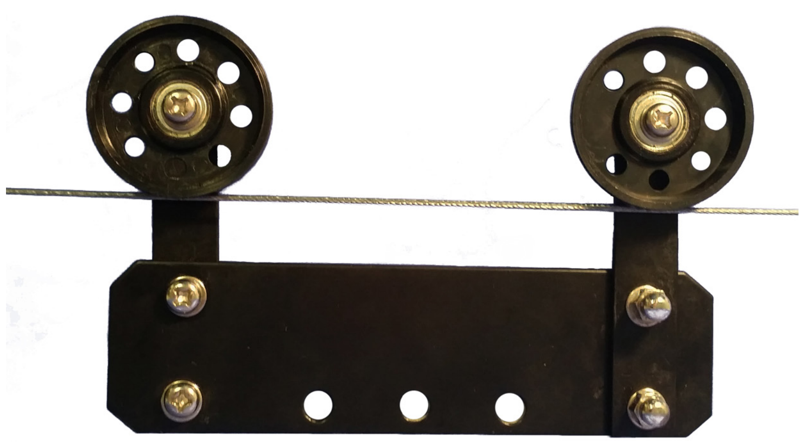
On pages 2 and 3 you can read about some of the math that goes into resolving the forces acting on the trolley, figuring out the coefficient of friction, and calculating the velocity and rate of acceleration. You can make mathematical approximations using this information to compare them with the readings from your photogate.

This kit comes with the following pieces:

- Trolley car with two pulleys
- Length of wire cable **(attachment hardware required and is not included)**

You can hang your wire however you find easiest. We recommend using **two eye hooks** and **two wire saddles.**

If you are wanting to compare mathematic approximations with photogate readings, you will need a calculator with trigonometry functions and a clinometer or protractor to find the angle of the wire.



Resolution of Forces in a Frictionless Environment

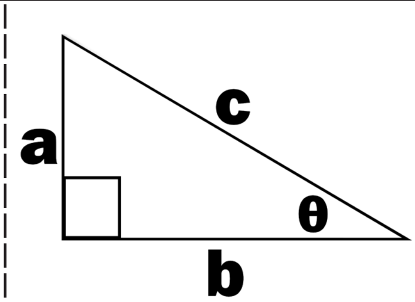
Forces, at their most basic, can be understood as either pushes or a pulls. If you apply a force to a frictionless object in a rightward direction, that object will move in a rightward direction until another force causes it to stop. In the real world, however, objects are almost never acted upon by only one force at a time. When a force quantity contains both a magnitude and a direction, it is known as a **vector.** Force vectors will combine with other force vectors acting on an object to create one quantity that expresses the net force acting on an object and the direction in which that net force is pushing or pulling it. To find out the net magnitude and direction of force vectors acting on an object, you will need to know how to **resolve forces**.

Resolving forces is a simple task of addition and subtraction on a hypothetical frictionless, two-dimensional system because you only need to worry about forwards and backwards forces. With an incline plane, however, its angle of incline creates a slightly more involved process that requires basic trigonometry to understand. If you need a trigonometry refresher, look below at the **sine function of a triangle** and the **cosine function of a triangle.** By knowing one reference angle on a right triangle and understanding the trigonometric functions on your calculator, you can use the sine function to calculate the length of the side opposite of the reference angle and the cosine function to calculate the length of the side adjacent to the reference angle.

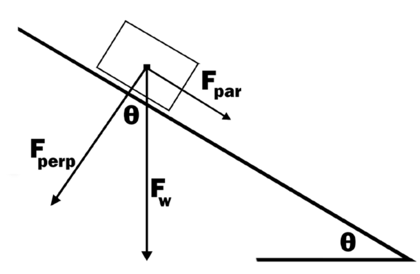
- **θ = Reference Angle**
- **a = Opposite Side**
- **b = Adjacent Side**
- **c = Hypotenuse**

$$a = c \sin\theta$$

$$b = c \cos\theta$$



To expand off of this basic trigonometry, take a look at how it can be applied to the free body diagram below. (A **free body diagram** is a line drawing used when resolving forces to visualize the individual vectors in the system.) When an object is placed onto an incline plane, its weight ($\mathbf{F_w}$) exerts a force straight down that is equal to the product of its mass (in kilograms) and 9.8m/s^2, or the acceleration of gravity on Earth ($\mathbf{F_w = m\ g}$). This downward force can be resolved into two vectors: the parallel and the perpendicular force. As their names suggest, the **parallel force** acts in a direction parallel to the slope of the incline, and the **perpendicular force** acts in a direction perpendicular to the slope of the incline. Since geometry tells us that the angle of incline is the same as the angle present between the $\mathbf{F_w}$ and $\mathbf{F_{perp}}$ vectors, trigonometry can be applied just as it was with the triangle above. Using the weight vector ($\mathbf{F_w}$) as the triangle's hypotenuse, you can consider the parallel force ($\mathbf{F_{par}}$) as the opposite side (**a**) of the triangle and the perpendicular for ($\mathbf{F_{perp}}$) as the adjacent side (**b**). Take a look below to see how the basic trigonometry explained earlier can be re-written to explain how forces function on an incline plane:



$$F_{par} = F_w \sin\theta$$

$$F_{perp} = F_w \cos\theta$$

- **θ = Angle of Incline**
- **F_{par} = Parallel Force**
- **F_{perp} = Perpendicular Force**
- **F_w = Weight**

Including Friction when Resolving Forces

The previous page laid out free body diagrams showing how force vectors operate on a frictionless weight on an incline plane. Friction-free environments are absent almost entirely from the natural world, however. Friction is a force that opposes movement. As two pieces of matter come into contact with each other, their surfaces grip onto each other and slow movement. **Frictional force** (F_f) is measured in Newtons, but the amount of friction inherent to a particular object is measured by the **coefficient of friction (COF) μ,** which is a magnitude of the **normal force.**

Normal force (**N**) is the name given to the force exerted upward by a surface onto any object resting on top of it. **Frictional force** is the name given to the force working in opposition to the parallel force on the incline plane. Because we know that the normal and frictional forces act equally in opposition to other forces, we know that the normal force and the perpendicular force are equal to each other and that the same goes for the frictional force and the parallel force:

$$N = F_{perp}$$

$$F_f = F_{par}$$

The **COF** can calculated by dividing the frictional force by the normal force. Because we know that the normal force equals the perpendicular force and the frictional force equals the parallel force, we are able to condense the formula for finding the COF into a simple trigonometric function of tangent:

$$\mu = \frac{F_f}{N} = \frac{F_w \sin\theta}{F_w \cos\theta} = \tan\theta$$

After finding the COF, you can easily calculate the acceleration of the object on the incline plane using the following equation:

$$acc = g\sin\theta - \mu\cos\theta$$

Velocity

The formula below can be used to find the velocity **(v)** of an object on any point of a path so long as you know its rate of acceleration **(a)** and the distance its has traveled **(s)**:

$$V_f^2 - V_i^2 = 2as$$

How to Use

Your Acceleration Trolley will allow you to observe motion on an incline plane. Follow the instructions below:

Observing Motion on an Incline Plane

1. Find at least two, but preferably three, people for this experiment.
2. Attach one end of your wire to a position that is about eye level. Have one volunteer hold the loose end of the wire at the other end of the room so that it is taut. The loose end should be lower than the fastened end, and its position should be held at a consistent height until instructed to change.
3. Measure the wire's angle of incline. This can be done with a clinometer, a protractor, or with volunteers using a yardstick and some trigonometry.
4. Instruct one volunteer to attach the trolley to the wire near the fastened end by threading it into the grooves of the trolley's pulleys.
5. Release the trolley near the top of the wire. Instruct the volunteer holding the loose end to catch the trolley when it reaches the end.
6. Repeat step five several times. Vary the experiment by adding weights to the trolley and increasing the angle of incline. Observe the velocity of the trolley increase as its weight and angle of incline increase.

Confirming the Math Behind Motion on an Incline Plane

1. Attach one end of your wire to a position that is about eye level. Attach the other end of your wire to a lower point across the room so that the wire is taut.
2. Measure the wire's angle of incline. This can be done with a clinometer, a protractor, or with volunteers using a yardstick and some trigonometry.
3. Record the mass of your trolley.
4. Using your angle of incline and the mass of the trolley, calculate the velocity that you expect the trolley to travel past a point on the wire a predetermined distance away from the starting point. The equations on pages 2 and 3 will help you with your math.
5. Attach the trolley to the wire near the elevated end by threading it into the grooves of the trolley's pulleys.
6. Find one person to hold onto the trolley until it's ready to release, another person to hold a photogate in position, and another to catch the trolley at the far end of the wire.
7. Set your photogate so that it records velocity.
8. Release the trolley down the wire.
9. Compare your estimated velocity with the one you recorded with the photogate. How close was your estimate?
10. Repeat steps 1 through 9 using various angles of incline and trolley masses. Observe how these factors influence motion.