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Incline Plane Friction Set #IPFRIC-811

Warning:

- **Not a toy; use only in a laboratory or educational setting.**
- **California Proposition 65 Warning: This product can expose you to chemicals including 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

An **incline plane** is an example of a **simple machine,** the other's being levers, wheels and axles, pulleys, inclined planes, wedges, and screws. Simple machines are among the oldest and most basic tools used by humans to make doing work easier by changing the direction or magnitude of an applied force. With incline planes, we are able to move objects vertical distances with less force than it would take to lift that object straight up by applying that smaller force over a longer distance.

By studying an incline plane, you can observe multiple essential concepts of mechanical physics such as **resolving force vectors**, finding the **potential energy** of an elevated object, and viewing **accelerated motion.**

This kit comes with the following pieces:

- Incline Plane
- Adjustable Protractor
- Friction Blocks (3x)
- Weight Pan with String

Some **additional supplies** are recommended for full usage of your incline plane:

- Weight Set
- Spring Scale
- Pen and paper
- Calculator with trigonometric functions
- Marble, Hall's Carriage, or other rolling item

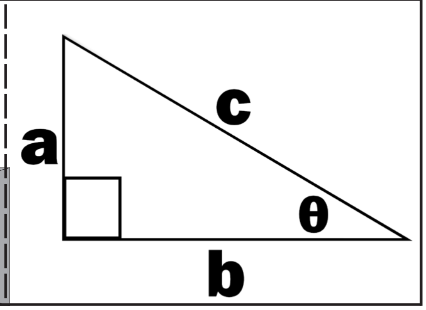
Resolution of Forces in a Frictionless Environment

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**.

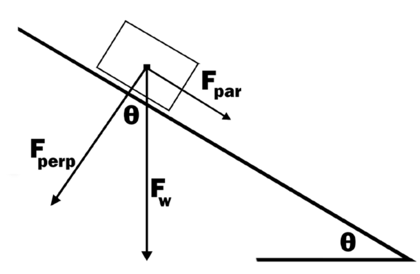
Resolving forces is a simple task of addition and subtraction on a hypothetical frictionless, two-dimensional system because you only need to worry about forwards and backwards forces. With an incline plane, however, its angle of incline creates a slightly more involved process that requires basic trigonometry 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**

$$a = c \sin\theta$$



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:

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

Potential Energy

Potential energy refers to the energy stored by an object. In the case of an object on an incline plane, it is a byproduct of the object's mass and the height it is suspended from a surface. You can calculate gravitational potential energy using the following formula:

$$PE_{grav} = m\,g\,h$$

How to Use

Below you will find instructions on how to properly use your incline plane in order to observe the concepts that you have learned from the last two pages:

Setting Up Your Incline Plane

1. Remove the pieces of your kit from their packaging.
2. Gather your protractor and you incline plane together.
3. Place the incline plane on a flat surface with the board containing the pulley on top.
4. Align the two notches on the bottom of the protractor's short side with the two screws on the bottom board of the incline plane.
5. Tighten the screws around these two notches so that the protractor is firmly fixed to the incline plane. **(Note:** A screwdriver may be necessary. The numbers of the protractor should be visible to you, which means the curved side of it should be curving towards the pulley and the open end of the incline plane.**)**
6. Tighten the wing-nut on the top board of the incline plane so that the angle of inclination is set to what you desire. Use the pointer beside the wing-nut to observe your angle.

Observing Potential Energy

1. Set up your incline plane with your angle at 20°.
2. Roll a ball or a car from the top of the incline plane.
3. Repeat steps 2 and 3 several times, increasing the angle each time.
4. Calculate the potential energy the ball or car at each angle. **(Note:** Since PE here is a product of mass, gravitational acceleration, and height, and because you're only changing the angle of incline, you will need to take note of the incline plane's height each time before calculating.**)** Take note that your marble will roll faster when it is dropped from a higher height. As you will see when you do your calculations, the more potential energy an object possesses, the more kinetic energy it releases when it is rolled.

Resolving Forces

1. Set up your incline plane with your angle at 20°.
2. Calculate your coefficient of friction using the tangent of your angle.
3. Choose any friction board to use for this experiment. Find its mass in kilograms.
4. Use this mass to calculate the weight ($\mathbf{F}_w$).
5. Using your weight ($\mathbf{F}_w$) and the angle of incline, solve for the natural force ($\mathbf{N} = \mathbf{F}_{perp}$)and the frictional force ($\mathbf{F}_f = \mathbf{F}_{par}$). Draw a free body diagram to illustrate the force vectors you've found.
6. Weigh your weight pan, tie the loose end of its string to your friction board, and thread the string through your pulley.
7. Calculate how much weight you will need to add to your weight pan so that the $\mathbf{F}_{par}$ vector pointing down the ramp is neutralized by the force coming off of the pulley. If your calculations were correct **(Hint:** Use the formula $\mathbf{F = m\ g}$**)**, the friction board will stay in place. If you added too much weight, the board will accelerate towards the pulley. Conversely, if you didn't add enough weight, your board will accelerate down the incline plane.
8. Repeat this experiment using different friction boards and different angles.