

INSTRUCTIONAL GUIDE

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Inclined Plane Demonstrator:

- [Protractor \(P4-1420-03\)](#)
- Cart (to hold masses)
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- Adjustable attachment for Spring Scale
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Background

Throughout history, people have utilized the inclined plane understanding its value for moving things uphill. Ancient applications include Stonehenge, the Egyptian pyramids, and even in ancient Greece where a 6 km paved ramp, the Diolkos, was built to drag ships overland across the Isthmus of Corinth.

The problem of calculating the force amplification provided by the inclined plane (mechanical advantage) was first attempted by Greek philosophers, but they ultimately got it wrong. The first correct calculations of the inclined plane appeared in the work of the 13th century author Jordanus de Nemore. At the end of the 16th century, correct solutions were published by many different Renaissance-era scientists including Galileo Galilei who incorporated the inclined plane in his analysis of simple machines in *Le Meccaniche* ("On Mechanics"). Leonardo da Vinci (1452-1529) was the first to synthesize the basic rules of friction as they relate to the inclined plane, but his discovery was unpublished. Mathematician Leonhard Euler in 1750 addressed sliding friction on an inclined plane by calculating the coefficient of friction

Introduction

The Inclined Plane Demonstrator is a device that can be used to determine the three forces (four forces if at rest) on an object resting on an angled surface. This engaging piece of lab/demonstration equipment makes the component theory of forces a tangible reality for every student. The Forces on Inclined Plane Demonstrator will allow the teacher and students to engage directly with these required concepts. The built-in digital balance will measure the changing normal force dependent upon the angle of the plane, and the spring scale attached to the cart will record the downhill parallel force component as the angle of the inclined plane is increased. With this device, your students can predetermine and calculate the normal and parallel forces exerted on the cart (and its masses) with each given angle.

With the Inclined Plane Demonstrator, seeing their force **calculations confirmed in “real-life”, without a simulation or digital re-creation, brings learning these necessary Physics concepts to a new level (...no pun intended!)**.

Instructions

The Inclined Plane Demonstrator can be used as a teacher demonstration or as a student-driven, lab-based device to teach the concept of component forces on an inclined plane, a required element for any physics classroom. Since the normal and parallel forces change with the angle of the plane, this device is an excellent addition for any Newton's lab involving forces and friction.

1. The included spring scale will measure the parallel applied force exerted on the cart (and its masses). As the inclined plane is raised, the scale will read the changing force in newtons (N) or in grams (g) if you wish your students to perform mass-to-force conversions.
2. The included digital balance will measure the normal (perpendicular) force exerted by the inclined plane on the cart (and its masses). As the inclined plane is raised, the scale will read the changing normal force. Since the balance reads in grams, your students will be required to perform mass-to-force conversions, as they might in any classroom physics problem exercise.
3. The protractor is attached by three thumbscrews to the inclined plane and its base. The 0° mark is engineered to line up exactly with the plane's surface. Expect a slight amount of error in the students' calculation due to the precision of the angle reading. A degree or two difference will cause a small variation in the force calculations.
4. The cart has been engineered to accept a variety of masses up to the digital balance's maximum limit of 800 g. It is important to keep the cart's wheelbase centered on the digital scale's pan at all times during the experiments to insure accurate readings of the digital balance.
5. There are two adjustable attachments included in the Inclined Plane Demonstrator kit. A two-piece (base with sliding piece) spring scale attachment is designed to allow for the spring scale to be moved up and down to ensure accurate placement of the cart on the center of the digital scale's pan as the angle is increased. The additional fixed (non-sliding) attachment has been designed to allow the use of an electronic force probe. Since electronic probes do not elongate throughout their data collection process, using an electronic probe will provide students with increased accuracy in their force data throughout the experiments.

Set-Up

1. Remove the Inclined Plane Demonstrator parts from the box and set the device on a level, clean and solid surface. It is important that your desk or lab table can be completely level and sturdy during the experiments to ensure accurate data.
2. Assemble the protractor by attaching it to the base and the inclined plane by the three thumbscrews. The two base thumbscrews must remain tightened throughout the experiment while the inclined plane thumbscrew will allow the student to set the angle of the incline by tightening the screw when the desired angle of the plane is reached.
3. Depending on your selection of data collection device (spring scale or digital force probe), secure the appropriate holder on the inclined plane. The spring scale holder has two pieces—the base and its sliding component. After attaching the spring scale holder base, connect the sliding component of the spring scale holder, then slide spring scale into the opening and tighten the thumb screws to hold the spring scale in place. If you are going to use a digital force probe, attach the digital scale holder (the piece with the short post) with the thumbscrews on the inclined plane.

- When placing the digital scale into the inclined plane, make sure to insert it from the bottom up and push to secure. Make sure you remove the battery protector tab. Place the foam spacers between the scale and the clear acrylic plate and secure with the circular tabs.
- Place the cart and selected masses on the inclined plane, attaching the cart to the spring scale or digital force probe. Adjust the spring scale slider to allow the cart to be positioned in the center of the digital balance. You are now ready to use the Inclined Plane Demonstrator.

Data Collection

At this point, your Inclined Plane Demonstrator should be completely assembled and ready to use. Whether you are using the apparatus for a classroom demonstration or placed on individual lab tables as part of a laboratory investigation with your students, the following steps can be followed to collect data.

- When you are ready to begin the experiment, place the assembled Inclined Plane Demonstrator on a level, solid surface and turn on the digital scale. Be certain to select the unit of measurement you want the scale to read.
- Place the cart on the scale and attach the spring scale or digital force probe's good to the cart's "hitch."
- At this point, you have an option to:
 - Tare (zero the scale reading) the digital scale BEFORE placing the masses into the cart. If you select this option, your force calculations throughout the experiment will include ONLY the masses you place in the cart.
 - Tare the digital scale AFTER placing the masses into the cart. If you select this option, your force calculations throughout the experiment will include the mass of the cart AND the masses you place in the cart.
- Since the digital scale measures in grams, you will need to convert the measurement into kilograms, allowing the student to use the standard value of the acceleration due to gravity at 9.81 m/s^2 or at an accepted value of 10 m/s^2 , which is sufficiently accurate for most physics calculations at the high school level. Students should convert the mass to newtons for determining the weight (W or F_g) for the mass or cart/mass system. Since the amount of mass will remain constant throughout the experiment, the weight component will also remain constant throughout the experiment and is the one force in this experiment that does NOT change.

Take a look at this sample calculation to see how acceleration of gravity times mass gives weight:

$$W = m \cdot g$$

Where W is weight in Newtons (N) m is mass in kilograms (kg) and g is the acceleration due to gravity on Earth with a constant value of 9.81 m/s^2 .

So, if $m = 200 \text{ g}$, solve for its weight on Earth. *Remember to convert g to kg!*

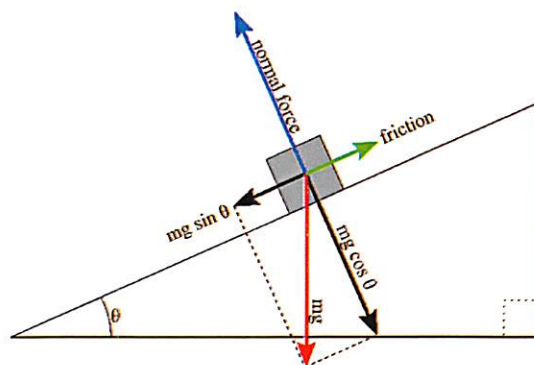
$$W = 0.200 \text{ kg} \cdot 9.81 \text{ m/s}^2$$

$$W = 1.96 \text{ N}$$

- After determining the Weight (in Newtons) for the given mass in the car, it is now time to set the Inclined Plane at the desired angle for the experiment. Select an angle by loosening the single thumbscrew on the protractor and once the angle is determined, tighten the thumbscrew to ensure the Inclined Plane is locked in place. Remember that the selected angle is set by the

human eye and there may be a small amount of error in the student's calculations due to this. After setting the angle, be certain that the cart containing the masses is centered on the digital scale pan to ensure the most accurate reading. You can do this by manipulating the sliding part of the spring scale holder so that the scale secures the cart in the centered position. Loosen the thumbscrews on the spring scale holder and move the spring scale so that the cart is free to move parallel to the plane as you adjust the spring scale. The spring scale holder is designed to allow "play" in the position of the cart since the cart WILL cause the spring to stretch as the angle is increased. This will NOT be a factor if you choose to use a digital force probe because of the non-elastic nature of these devices. NOTE: if the cart rests on the edge of the pan, the digital balance measurement will not produce the desired reading for your experiment.

- Once the angle is set and the cart adjusted to the center of the pan, your students can calculate the normal force and the parallel force components for the set-up. Since the spring scale (or digital force probe) does read in Newtons, there is no need to convert units. Again, conversion from the reading on the digital scale will be necessary since the units must be in Newtons for consistency in the students' calculations. Using the students' initial calculations for the set-up, the teacher should then compare and correlate student results with the readings from the Inclined Plane Demonstrator. You will find that their results will compare well with the readings from the spring scale/digital force probe and the digital balance.



Remember to "zero" the spring scale and "tare" the digital balance for *each angle* before placing the cart and mass on the ramp. The spring scale and digital balance will not read accurate values at different angles unless this step is included.

Use the free body diagram above to determine the force components of this system. The normal force, F_n , which is always perpendicular to the surface the body is sitting on, is determined by $mg \cdot \cos\theta$. The parallel force, $F_{||}$ is determined by $mg \cdot \sin\theta$. If $\theta = 30^\circ$ and the weight is 1.96 N, find the force components:

$$F_n = 1.96 \text{ N} \cdot \cos 30^\circ = 1.70 \text{ N}$$

$$F_{||} = 1.96 \text{ N} \cdot \sin 30^\circ = 0.98 \text{ N}$$

Conclusion

The Inclined Plane Demonstrator can be used as a classroom demonstration during a group sample problem or as a laboratory stand-alone/lab station. The teacher has an unlimited number of angle settings and experimental mass variations to be used at every lab station. Remember that the Inclined Plane Demonstrator is designed with the highest specifications, but despite every effort to reduce frictional forces, the apparatus can produce error when compared to the "perfect" answers in student calculations or online simulations. In practice, students can expect ~10% error in their calculations compared to the readings with the Inclined plane Demonstrator. In addition, increasing the angle of the Inclined Plane to more than 45° can cause larger errors in the digital scale measurements (normal force) due to the cart placement on the digital scale pan. In the author's opinion, the process of setting up the apparatus and the calculation protocol is the most important student outcome in using this device. Obviously, online simulations will result in "perfect" answers to their problems, but direct

observations by your students to mass/angle changes with the Inclined Plane Demonstrator will prove invaluable to their students' learning process.

Related Products

Force Table (P3-3537) Study the equilibrium of force with this superbly designed, highly functional table. Precision pulleys, force rings, weights and instructions included. A must-have to study vector physics!

Inclined Plane (P3-3541) A versatile and sturdy inclined plane that attaches easily to a stand (not included) and adjusts to any height.

Four-Sided Friction Block (P3-3608) Our 4-sided Friction Block makes friction experiments quick and easy. Surfaces include paper, wood, sandpaper and vinyl. Threaded brass post allows for easy addition of slotted masses.

Acknowledgement

Buzz Putnam is a 35-year Physics and Nanotechnology teacher in Upstate New York and has worked with Arbor Scientific as an annual Presenter at NSTA, Texas, New York, New Jersey Science Conferences and as a Consultant/Product Developer since 1999. He was a New York State Master Teacher Award winner, a member of the Cornell Institute for Physics Teachers (CIPT) Lab Development team, Presenter at the Fibonacci STEAM Project through his "Mad About Science" travelling science show and was the 2017 Yale University Physics Teacher of the year. He continues to promote learning science through demonstrations, music, humor and real-life scenarios.