Forces on an Inclined Plane Demonstrator

P4-1420

CONTENTS:

Inclined Plane Demonstrator

- Angle/Protractor Indicator
- Cart (to hold masses)
- Spring Scale
- Digital Scale
- Adjustable attachment for Spring Scale
- Adjustable attachment for Electronic Force Probe

Required but not included:

- Assortment of Masses (any configuration up to 650 grams)
- Calculator

TEACHER BACKGROUND KNOWLEDGE:

Throughout ancient civilizations, people have utilized the inclined plane understanding the value for moving things uphill, including 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 required to push or pull a weight (its mechanical advantage) up an inclined plane 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, Nemore. At the end of the 16th century, correct solutions were published by Galileo, including the inclined plane in his analysis of simple machines in Le Meccaniche ("On Mechanics") showing its underlying similarity to the other machines as a force “amplifier”. Leonardo da Vinci (1500’s) and Mathematician Leonhard Euler in 1750 addressed *sliding friction* on an inclined plane by calculating the coefficient of friction.

INTRODUCTION TO THE APPARATUS

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 his/her 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!).

INSTRUCTIONAL GUIDE:

The *Inclined Plane Demonstrator* can be used as a teacher demonstration or as a student-driven, lab-based device to teach the 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 Laws 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 BOTH the changing Force in Newtons or in Grams, if you wish your students to perform Mass-to-Force conversions.

2. The included, built-in 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 Angle/Protractor Indicator is attached by three thumbscrews to the inclined plane and its base. The “0” degrees 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 650 grams. 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 on 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 incline's 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.

GETTING FAMILIAR/SET-UP/EXPERIMENTING:

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 be completely level and sturdy during the experiments to insure accurate data.

2. Assemble the Angle/Protractor Indicator by attaching it to the base and the inclined plane by the three thumbscrews. The two base thumbscrews must be tightened throughout the experiments while the inclined plane thumbscrew will allow the student to set the angle of the incline and tighten when reaching the desired angle of the plane.

3. Depending on your selection of data collection device (Spring Scale or Digital Force Probes), 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 spring scale holder SLIDING piece, then slide spring scale into the opening and tighten the thumbscrews 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.

4. When placing the digital scale into the inclined plane, make sure you 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 4 screws (included).

5. 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 built-in digital balance. You are now ready to use the ***Inclined Plane Demonstrator.***

OBSERVATIONS AND TAKING DATA::

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 preparatory procedures should be similar in protocol.

As a Classroom Demonstration/In-Class Group Exercise or Student Lab Experiment Apparatus:

1. 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.
2. Place the cart on the scale and attach the spring scale or digital force probe's hook to the cart's "hitch".

3. At this point, you must Tare (zero the scale reading) the digital scale BEFORE placing masses into the cart.

4. Select the amount of known masses and place them into the cart. This amount of mass will remain constant throughout the experiment. The digital scale will now read the amount of mass ONLY in the cart. Students will convert the Mass to Newtons for determining the Weight (W or F_g) in the cart. The Weight Component will remain constant throughout the experiment and is the one Force in this experiment that does NOT change. Since the digital scale measures in grams, one option is to convert the gram reading to kilograms, allowing the student to use the standard value of the acceleration due to gravity at 9.81 m/s^2.

   Sample Calculation: W = mg

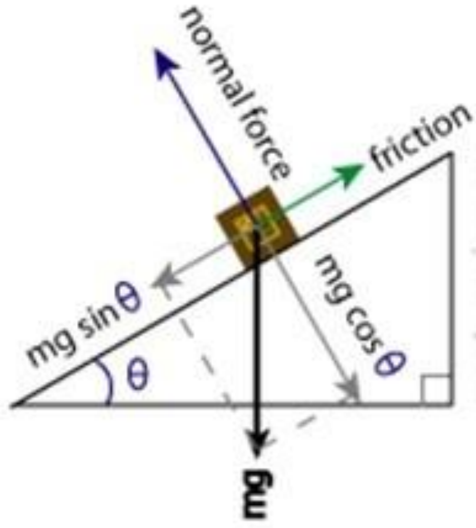
   <u>Where:</u>
   W = Weight (in Newtons)
   m = Mass (in Grams)
   g = 9.81 m/s^2 (Acceleration due to Gravity on Earth)

   <u>If m = 200 gms, then solve for Weight</u>
   W = (0.200 kg X 9.81 m/s^2)
   W = 1.96 Newtons

5. After determining the Weight (in Newtons) for the given mass in the cart, 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 Angle/Protractor Indicator 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 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 sale 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.

6. 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 a Digital Force Probe) does read in Newtons, there is no need to convert that data point. Again, conversion from the data 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 blance.



<u>To Determine the Force Components:</u>

Draw the schematic as shown in the Free-Body Diagram.

The Normal Force (F_n) is determined by (mg X Cos□)

The Parallel Force or Downhill Force (F_{II}) is determined by (mg X Sin□)

<u>Sample Calculation:</u>

If < = 30^o and the Weight = 1.96 Newtons, find the Force Components.

Normal Force (F_n) = 1.96N(Cos30^o) = 1.70N

Parallel Force (F_{II}) = 1.96N(Sin30^o) = 0.98N

CONCLUSIONS:

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 on-line 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^o 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 *<u>most important</u>* student outcome in using this device. Obviously, on-line 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.

BIO/ABOUT THE AUTHOR:

Buzz Putnam is a 31-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 is 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 is the keynote speaker at the 2016 STEAM Conference in Yuma, Arizona. He continues to promote learning science through demonstrations, music, humor and real-life scenarios.