

Introduction to Experiments

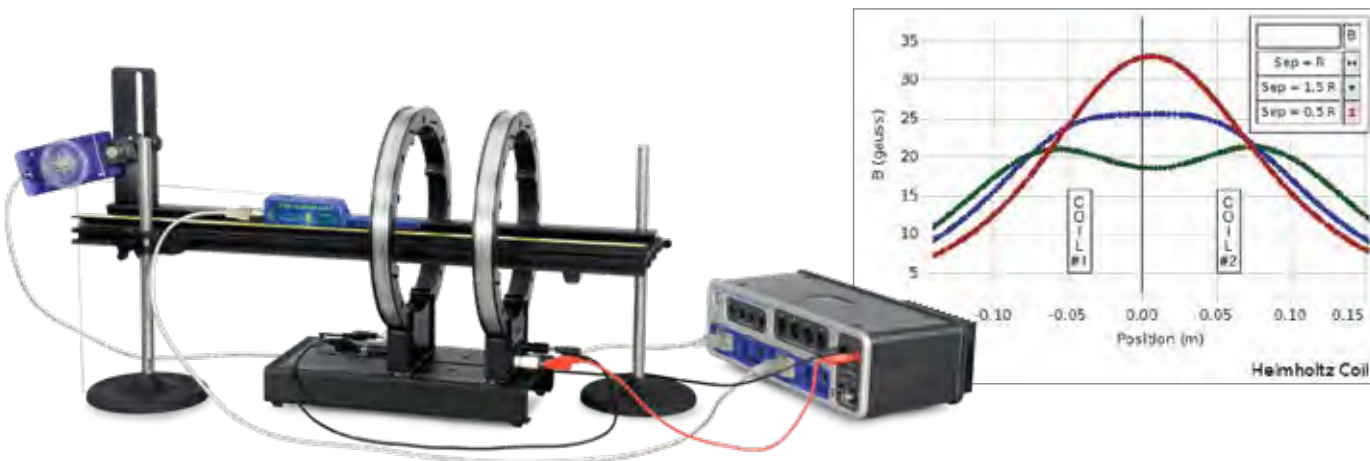
Download **FREE** PASCO Capstone Experiments

Over 60 classic physics experiments for use with PASCO equipment and software

The following pages present classic experiments in physics performed with PASCO apparatus.

Manuals can be downloaded at www.pasco.com. Interfaces and software, where indicated, should be ordered separately.

Everything else is included in the experiment: apparatus, sensors (when needed), and accessories.



Workbooks include all instructions needed to perform the experiment:

- ▶ Introduction and theory
- ▶ Detailed setup instructions including full-color photos
- ▶ Detailed analysis and summary questions
- ▶ Step-by-step instructions



Download This Experiment

Each experiment manual and the PASCO Capstone™ workbook files may be downloaded free at www.pasco.com/CapstoneExperiments

▶ Experiment Manual:

A detailed experiment manual helps ensure student success. An electronic Word® version is included for modification by the teacher.

▶ PASCO Capstone Workbook File:

PASCO Capstone workbook files are included for each experiment. These files contain workbooks with step-by-step instructions with embedded live data displays. Use these files with students. A file with sample data is also included.

| EXPERIMENT NUMBER | EXPERIMENT LIST | PAGE NO. |
|----------------------|-----------------------------------|----------|
| Mechanics | | |
| EX-5501 | Atwood's Machine | 330 |
| EX-5502 | Projectile Motion | 331 |
| EX-5503A | Newton's Law | 332 |
| EX-5504A | Hooke's Law | 333 |
| EX-5505A | Centripetal Force Pendulum | 334 |
| EX-5506 | Centripetal Force | 335 |
| EX-5508 | Sliding Friction | 336 |
| EX-5509A | Impulse | 336 |
| EX-5510B | Conservation of Momentum | 337 |
| EX-5511A | Ballistic Pendulum | 338 |
| EX-9935 | Conservation of Energy | 339 |
| EX-5512 | Conservation of Energy II | 340 |
| EX-5513A | Work Energy Theorem | 340 |
| EX-5550 | Universal Gravitational | 341 |
| Fluids | | |
| EX-5553 | Piping Systems | 342 |
| EX-5554 | Pumping Systems | 343 |
| EX-9909 | Archimedes Principle | 344 |
| Rotation | | |
| EX-5516B | Rotational Inertia | 345 |
| EX-5518A | Physical Pendulum | 346 |
| EX-5517C | Conservation of Angular Momentum | 347 |
| EX-5519A | Variable-g Pendulum | 348 |
| EX-5520A | Large Amplitude Pendulum | 348 |
| EX-5523A | Chaos | 349 |
| EX-5551 | Driven Damped Cart Oscillations | 350 |
| EX-5522A | Driven Damped Harmonic Oscillator | 351 |
| Structures | | |
| EX-5556 | Basic Bridges | 352 |
| EX-5555 | Shaking Tower Experiment | 353 |
| EX-5548 | Bridge Vibration | 354 |
| Materials | | |
| EX-5557 | Tensile Testing Metals | 355 |
| EX-5558 | Column Buckling | 356 |
| EX-5559 | Bending: 3-point and 4-point | 357 |

| EXPERIMENT NUMBER | EXPERIMENT LIST | PAGE NO. |
|---------------------------|----------------------------------|----------|
| Thermodynamics | | |
| EX-5524A | Specific Heat | 358 |
| EX-5525 | Electrical Equivalent of Heat | 359 |
| EX-5527 | Ideal Gas Laws | 360 |
| EX-5529A | Blackbody Radiation | 361 |
| EX-5530B | Heat Engine Cycle | 362 |
| EX-5531A | Ratio of Specific Heats of a Gas | 363 |
| Electromagnetism | | |
| EX-5532 | Electrostatic Charge | 364 |
| EX-9930B | Coulomb's Law | 365 |
| EX-9929A | Charge of an Electron | 366 |
| EX-5533 | Capacitance | 367 |
| EX-5534 | Resistivity | 368 |
| EX-5535 | Ohm's Law | 369 |
| EX-5538 | Kirchhoff's Circuit Law | 370 |
| EX-5536 | RC Circuit | 371 |
| EX-5537 | LRC Circuit | 372 |
| EX-5539A | Earth's Magnetic Field | 373 |
| EX-9933 | Magnetic Force on Wires | 374 |
| EX-5540A | Magnetic Fields of Coils | 375 |
| EX-5552 | Ampere's Law Experiment | 376 |
| EX-5541A | Faraday's Induction Law | 377 |
| Waves & Optics | | |
| EX-5542 | Vibrating Strings | 378 |
| EX-9952 | Mechanical Waves | 379 |
| EX-9987 | Reflection & Refraction | 380 |
| EX-9932A | Speed of Light | 381 |
| EX-9988 | Telescope/Microscope | 382 |
| EX-5547A | Light Intensity vs. Distance | 382 |
| EX-5545A | Interference & Diffraction | 383 |
| EX-5543A | Polarization | 384 |
| EX-5544A | Brewster's Angle | 385 |
| Quantum | | |
| EX-5546B | Atomic Spectra | 386 |
| EX-5549A | Photoelectric Effect | 387 |
| EX-5560 | Hall Effect | 388 |
| EX-5561 | Franck-Hertz | 389 |
| EX-5562 | Zeeman Effect | 390 |

Mechanics

Atwood's Machine

EX-5501

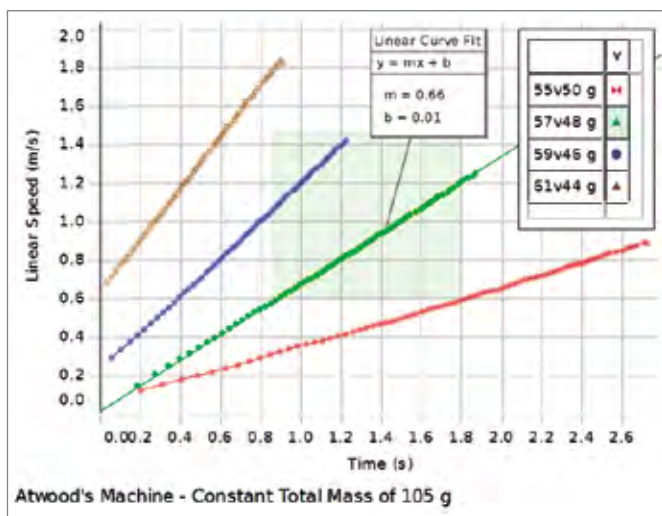
Concepts:

- ▶ Newton's Second Law of Motion
- ▶ Newton's Second Law of Rotational Motion
- ▶ Rotational Inertia

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ AirLink with Digital Adapter

In this classic experiment students use a very low mass/low friction pulley and measure the changing velocity of the unbalanced mass system. They interpret the slope of the velocity graph as acceleration. They examine the effect of the rotational inertia of the pulley and estimate the friction forces based on experimental data.



The acceleration of the weights is determined using the slope of the Velocity vs. Time graph. From this, the acceleration due to gravity can be found.

PASCO Advantage

The Super Pulley/Photogate System makes it easy for students to set up the apparatus and take data. Analysis includes accounting for friction and the rotational inertia of the pulley.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone™ workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Experiment Includes

- Photogate/Pulley System ME-6838A
- Mass and Hanger Set ME-8979
- Universal Table Clamp ME-9376B
- 60-cm Long Threaded Rod ME-8977
- Multi Clamp ME-9507
- Braided Physics String SE-8050



Order Information

Atwood's Machine EX-5501

Required:

550 or 850 Universal Interface* pp. 28-30
 PASCO Capstone Software..... pp. 72-75
 Balance or Scale..... p. 200
 Calipers SE-8710 p. 196

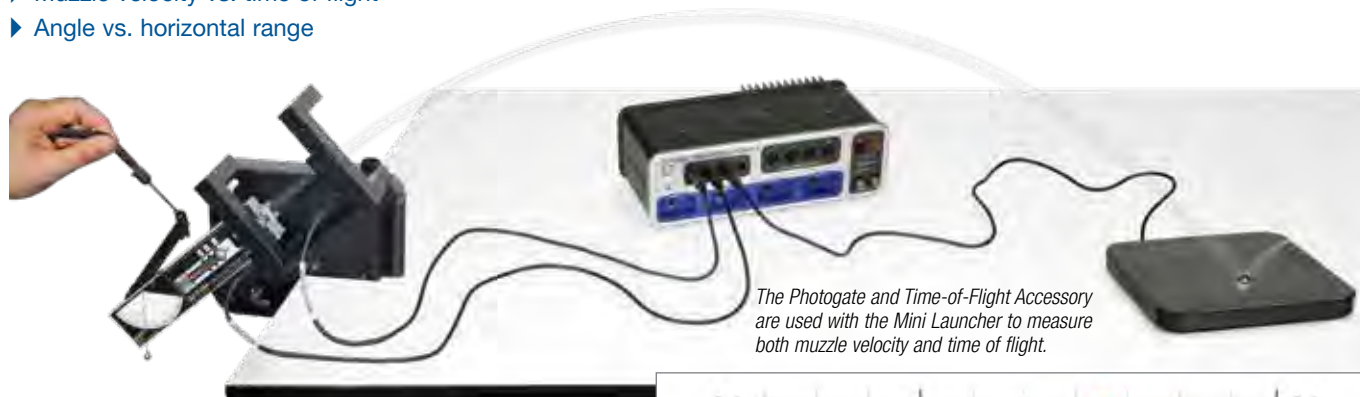
* This experiment can be performed using the 550 or 850 Universal Interface or AirLink with Digital Adapter.

Projectile Motion

EX-5502

Concepts:

- ▶ Independence of x- and y-motion
- ▶ Muzzle velocity vs. time of flight
- ▶ Angle vs. horizontal range



The Photogate and Time-of-Flight Accessory are used with the Mini Launcher to measure both muzzle velocity and time of flight.

Muzzle Velocity vs. Time of Flight

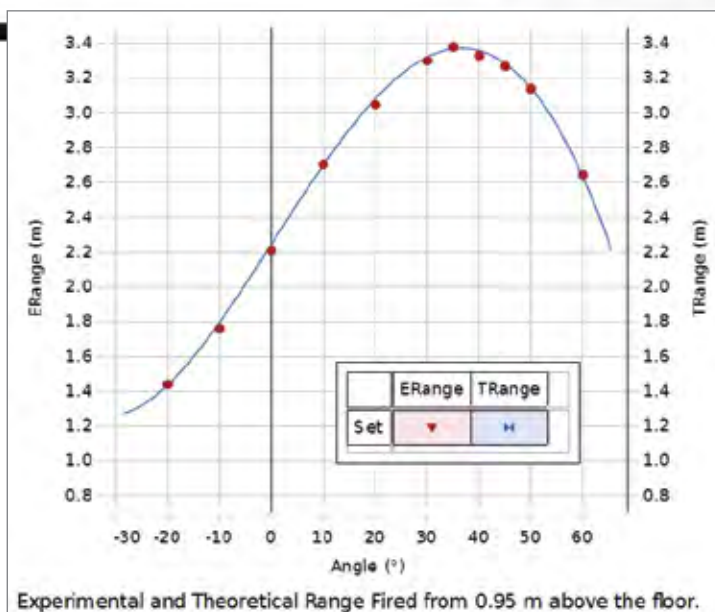
Students fire the projectile at three different velocities from the same height. The Photogate and Time-of-Flight Accessory are used to measure the time of flight at each muzzle velocity. Students are surprised to find that time of flight is not related to muzzle velocity at 0° launch angle.

Angle vs. Horizontal Range

The angle of launch is varied and the horizontal range measured for each angle. Students produce a graph of angle vs. horizontal range. The angle of maximum range can then be found. This experiment is conducted for two cases:

- ▶ Projectile is fired from a higher vertical position than its landing position
- ▶ Projectile is fired from the same vertical position as its landing position

Students are asked to use the kinematics equations to predict the horizontal range, given a launch angle and muzzle velocity. Carbon paper and a bulls-eye can then be used to test their hypothesis.



Experimental and Theoretical Range Fired from 0.95 m above the floor.

Students can use their data to determine which launch angle produces the maximum horizontal range.

PASCO Advantage

PASCO projectile launchers are designed for repeatable and accurate launches. In addition, photogates and other accessories are designed to work seamlessly with our projectile launchers. These features allow student predictions and calculations from the kinematics equations to be empirically verified.

Experiment Includes

- | | |
|-----------------------------|----------|
| • Mini Launcher | ME-6825A |
| • Time-of-Flight Accessory | ME-6810A |
| • Phone Jack Extender Cable | PI-8117 |
| • Photogate Head | ME-9498A |
| • Photogate Bracket | ME-6821A |
| • Carbon Paper | SE-8693 |
| • Large "C" Clamp (1) | SE-7284 |
| • Plumb Bob (need 1 only) | SE-8721 |
| • Metric Measuring Tape | SE-8712A |

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Projectile Motion..... EX-5502

Required:

850 or 550 Universal Interface* pp. 28-30
 PASCO Capstone Software pp. 72-75

* This experiment can be performed using the 850 Universal Interface, the 550 Universal Interface with 2 Digital Adapters, or any PASPORT interface with 2 ports and 2 Digital Adapters.

Mechanics

Newton's Laws

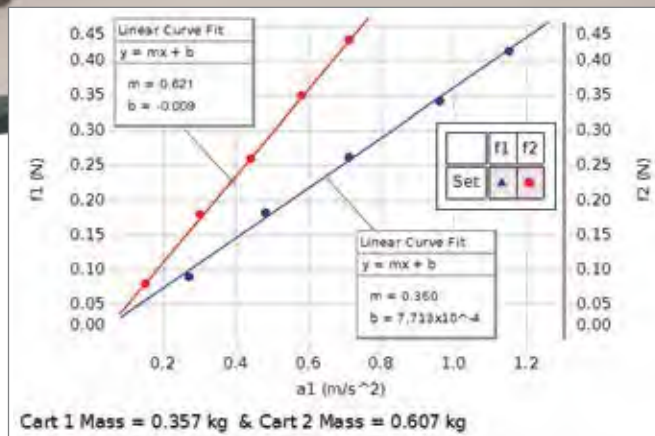
EX-5503B

► No interface required

Students can effectively study Newton's Second Law with a Dynamics System and Smart Cart.

Concepts:

- Newton's First Law (Inertia)
- Newton's Second Law ($F = ma$)
- Newton's Third Law ($F_{ab} = -F_{ba}$)



Force vs. acceleration data for the cart as it experiences changing net force

Method

Students use this collection of equipment to discover or experimentally determine all three of Newton's Laws.

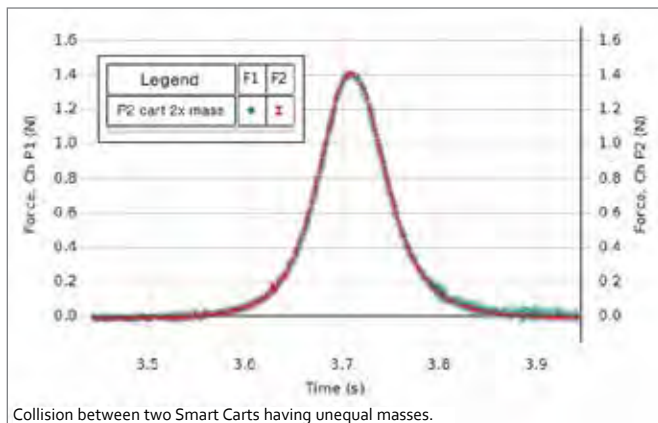
Newton's First Law – Students examine an object's motion to see if it changes when forces are applied or not.

Newton's Second Law – Students use the Smart Cart to discover the relationships between force, mass, and acceleration.

Newton's Third Law – Using two Smart Cart Force Sensors, students prove that forces between objects are equal in magnitude yet opposite in direction. These experiments include both tug-of-war exercises and collisions between cars.

PASCO Advantage

The Smart Cart has all the sensors required, which makes setup very quick and easy. The integration between the probeware and equipment helps students focus on the physics of each experiment.



Experiment Includes

- | | |
|---------------------------------|----------|
| • Smart Cart (red) | ME-1240 |
| • Smart Cart (blue) | ME-1241 |
| • Cart Mass (set of 2) | ME-6757A |
| • Dynamics Track Feet (2) | ME-8972 |
| • PASCO Mass and Hanger Set | ME-8979 |
| • Elastic Bumper | ME-8998 |
| • Super Pulley with Clamp | ME-9448B |
| • 1.2 m Aluminum Dynamics Track | ME-9493 |
| • Friction Block | ME-9807 |
| • Braided Physics String | SE-8050 |
| • Smart Cart Rod Stand Adapter | ME-1244 |

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Newton's Laws..... EX-5503B

Required:

Bluetooth 4.0 enabled computer

PASCO Capstone Software..... pp. 72-75

Hooke's Law and Energy Stored in a Spring

EX-5504A

Designed for use with any of the following:

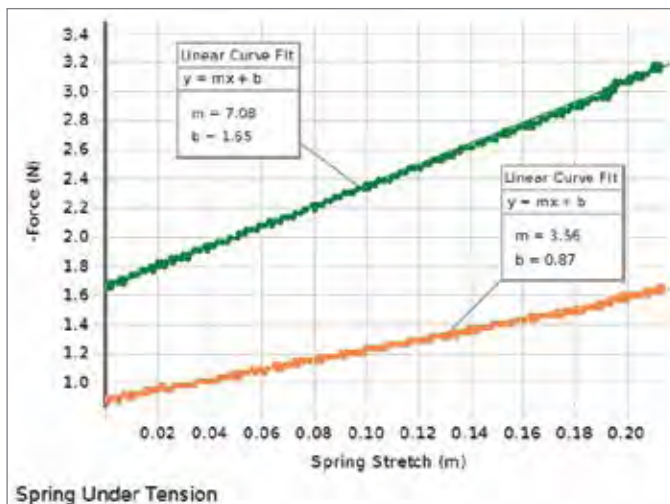
- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ Any PASPORT interface with 2 ports

Concepts:

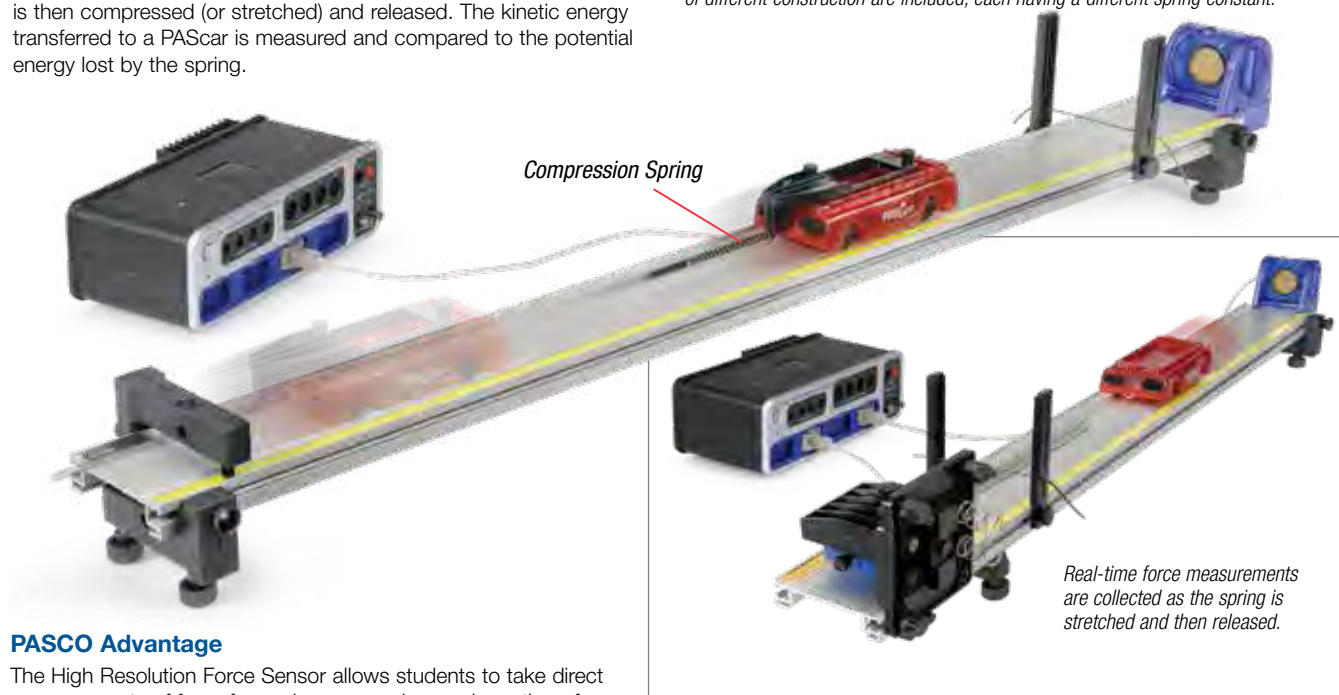
- ▶ Relationship between force and spring deformation
- ▶ Investigate both spring compression and extension
- ▶ Amount of energy stored in a spring

Method

In this experiment, students use a High Resolution Force Sensor to measure the force exerted to either compress or extend various springs, and a Motion Sensor to measure position and speed. Students create a Force vs. Stretch (or Compression) graph. The slope of this graph is known as the spring constant, while the vertical intercept is the initial loading force. Various springs of different construction are included, so students can better understand the physical meaning of the spring constant. The spring is then compressed (or stretched) and released. The kinetic energy transferred to a PAScar is measured and compared to the potential energy lost by the spring.



The slope of the Force vs. Stretch graph is known as the spring constant. Various springs of different construction are included, each having a different spring constant.



PASCO Advantage

The High Resolution Force Sensor allows students to take direct measurements of force for each compression or elongation of the spring. This is superior to using a hanging mass to apply a force, since students don't have to convert from mass to force. In addition, students are applying the forces to the springs and will have a better kinesthetic feel for the amount of force being applied in each case. Energy changes are easily measured and very visual.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Experiment Includes

- | | |
|--------------------------------|----------|
| • 1.2 m PAScar Dynamics System | ME-6955 |
| • Motion Sensor | PS-2103A |
| • Dynamics Track Spring Set | ME-8999 |
| • High Resolution Force Sensor | PS-2189 |
| • Force Bracket | ME-6622 |
| • Spring Cart Launcher | ME-6843 |
| • Elastic Bumper | ME-8998 |
| • Physics String | SE-8050 |

Order Information

Hooke's Law and Energy Stored in a Spring..... EX-5504A

Required:

550 or 850 Universal Interface* pp. 28-30
 PASCO Capstone Software..... pp. 72-75

* This experiment can be performed using the 550 or 850 Universal Interface or any PASPORT interface with 2 ports.

Mechanics

Centripetal Force on a Pendulum

EX-5505A

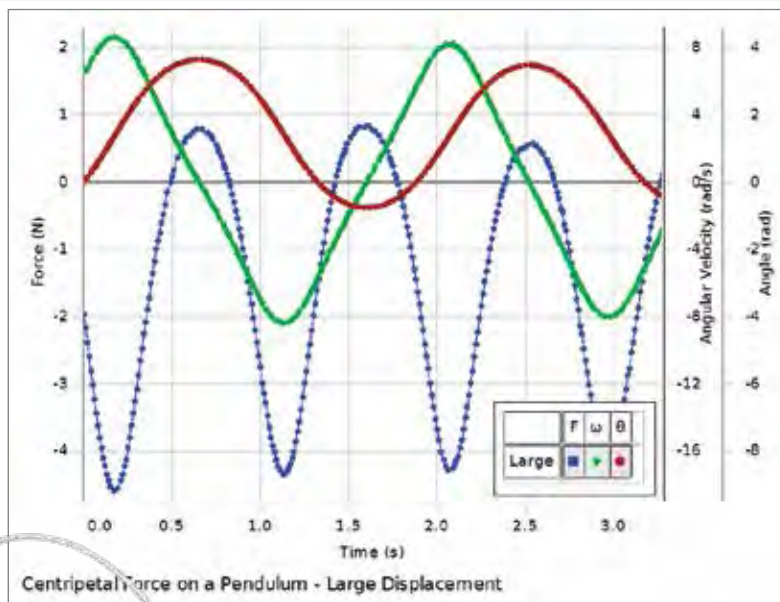
Concepts:

- ▶ Centripetal force
- ▶ Angular velocity
- ▶ Periodic motion

Designed for use with any of the following:

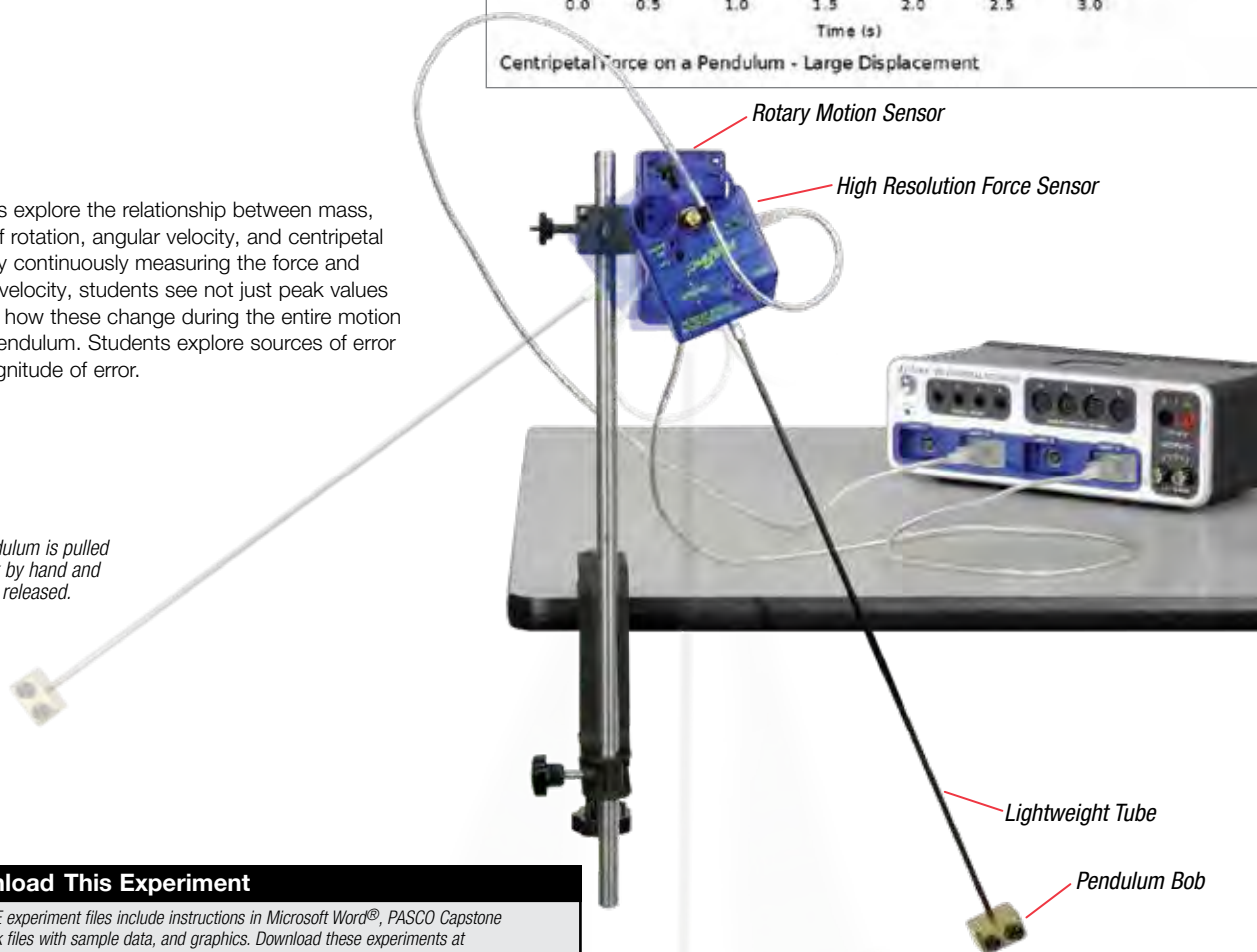
- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ Any PASPORT interface with 2 ports

The force, position, and velocity can be monitored for the entire range of motion. Note that the position and velocity are not sinusoidal for this large amplitude pendulum.



Students explore the relationship between mass, radius of rotation, angular velocity, and centripetal force. By continuously measuring the force and angular velocity, students see not just peak values but also how these change during the entire motion of the pendulum. Students explore sources of error and magnitude of error.

Pendulum is pulled back by hand and then released.



Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Experiment Includes

- High Resolution Force Sensor PS-2189
- Rotary Motion Sensor PS-2120A
- Centripetal Force Pendulum ME-9821
- Aluminum Table Clamp ME-8995
- Steel Rod 45 cm ME-8736

Order Information

Centripetal Force on a PendulumEX-5505A

Required:

550 or 850 Universal Interface* pp. 28-30
 PASCO Capstone Software pp. 72-75
 Balance or Scale p. 200

* This experiment can be performed using the 550 or 850 Universal Interface or any PASPORT interface with two ports.

Centripetal Force

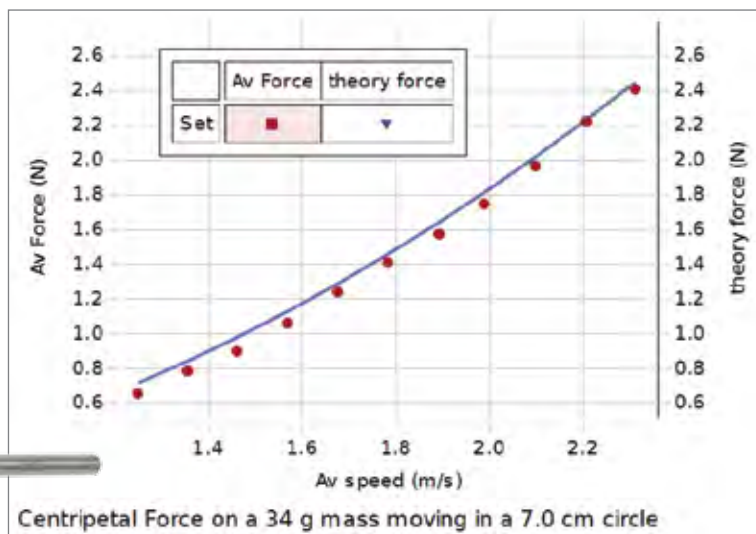
Designed for use with the 850 Universal Interface

EX-5506

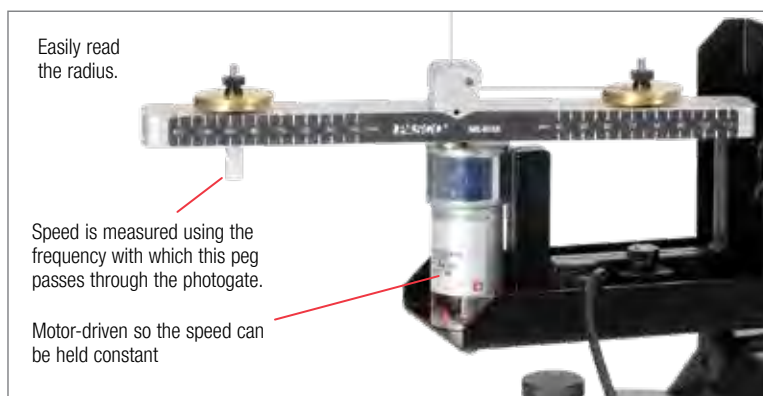
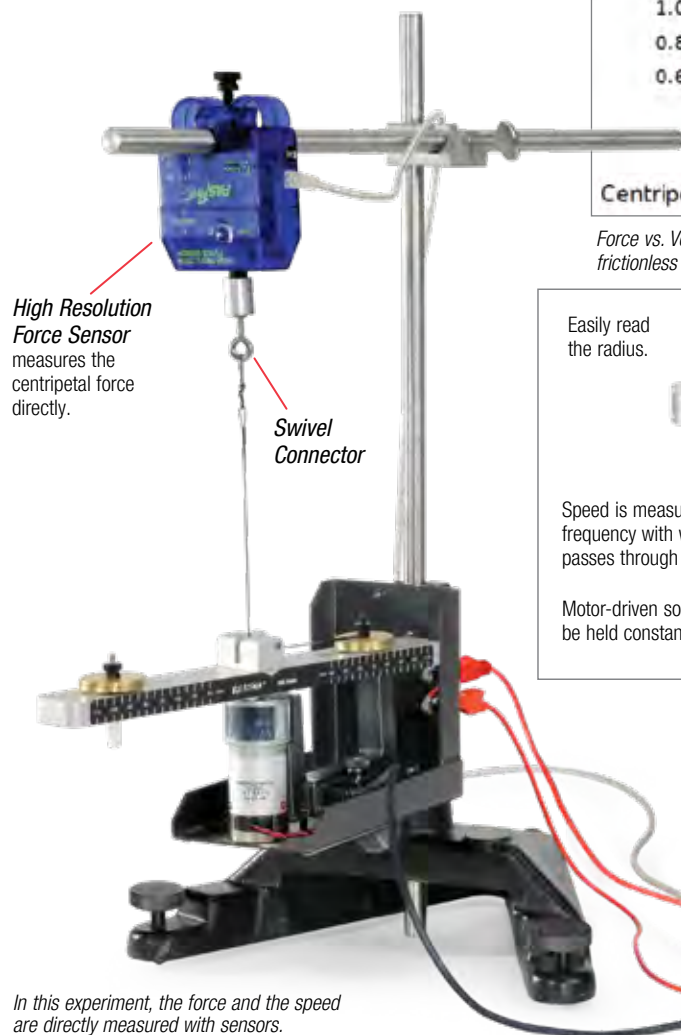
Concept:

- How centripetal force depends on radius, mass, and speed

Students explore the relationship between mass, radius of rotation, tangential speed, and centripetal force. By continuously measuring the force as the speed is varied, students clearly see the effect of speed on the centripetal force. The effect of changing the mass or radius is also investigated.



Force vs. Velocity data is shown above with a solid line representing the theoretical frictionless case.



In this experiment, the force and the speed are directly measured with sensors.

Experiment Includes

- Centripetal Force Apparatus ME-8088
- High Resolution Force Sensor PS-2189
- Photogate Head ME-9498A
- Large Rod Base ME-8735
- 90 cm Steel Rod ME-8738
- Multi-Clamp ME-9507
- 45 cm Steel Rod ME-8736
- Red Banana Plug Cord (5 pack) SE-9750

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Centripetal ForceEX-5506

Required:

850 Universal Interface.....pp. 28-30

PASCO Capstone Software.....pp. 72-75

Mechanics

Sliding Friction

EX-5508

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ Any PASPORT interface with 2 ports

Concepts:

- ▶ Relationship between frictional force and normal force
- ▶ Coefficients of friction (kinetic and static)

In this experiment, students use a High Resolution Force Sensor to discover frictional forces and their effect on the motion of an object. In addition, the coefficients of friction for various surface combinations can be empirically determined.

Experiment Includes

- Discover Friction Accessory ME-8574
- High Resolution Force Sensor PS-2189
- Motion Sensor PS-2103A
- 500 g Cart Masses (4) ME-6757
- Physics String SE-8050

Order Information

Sliding Friction.....EX-5508

Required:

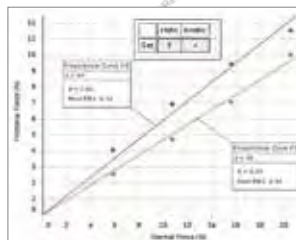
550 or 850 Universal Interface*p. 28-30

PASCO Capstone Software.....pp. 72-75

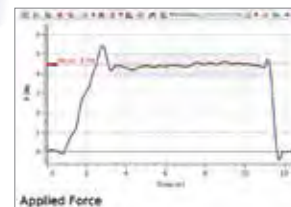
* This experiment can be performed using the 550 or 850 Universal Interface or any PASPORT interface with two ports.



Students pull the friction tray from rest to a constant velocity to measure both static and kinetic friction.



Students create a graph of Frictional Force vs. Normal Force to find the coefficients of static and kinetic friction.



The peak of the graph represents the maximum static frictional force. Once the friction tray begins to move, the kinetic frictional force is evident on the graph.

Impulse

EX-5509B

- ▶ Designed for use with the Smart Cart
- ▶ No interface required

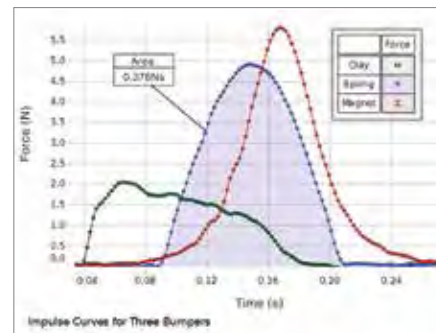
Concepts:

- ▶ Impulse: change in momentum
- ▶ Impulse: area under a Force vs. Time curve
- ▶ Different shaped force curves for elastic and inelastic collisions

In this experiment, the impulse on a cart is determined in two ways: by measuring the change in velocity and by finding the area under a Force vs. Time curve.

A Smart Cart runs down a slightly inclined track with its Force Sensor equipped with either a clay bumper, spring bumper, or magnetic bumper. The cart collides with the endstop. To determine the change in momentum (impulse), the velocities before and after the collision are recorded using the Smart Cart's encoder. To confirm the impulse, the force vs. time is plotted and the impulse is determined by finding the area under the curve.

Magnetic, Spring, and Clay Bumpers



The Force vs. Time is shown for three different bumpers: clay bumper in green, spring bumper in blue, and magnetic bumper in red.

The impulse of a collision is determined by two methods.

PASCO Advantage

Since the PASCO Smart Cart is capable of measuring both force and velocity, it eliminates the need for any external sensor. No interface is required. No wires interfere with the motion because the Smart Cart transmits the data over Bluetooth® 4.0.

Experiment Includes

- Force Sensor Bracket ME-6622
- PAScar Cart Mass (2) ME-6757A
- Smart Cart (red) ME-1240
- Dynamics Track Endstops (2) ME-8971
- Dynamics Track Feet (2) ME-8972
- 1.2 m Aluminum Dynamics Track ME-9493
- Smart Cart Rod Stand Adapter ME-1244

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

ImpulseEX-5509B

Required:

Bluetooth 4.0 enabled computer

PASCO Capstone Software.....pp. 72-75

Balance or Scale.....p. 200

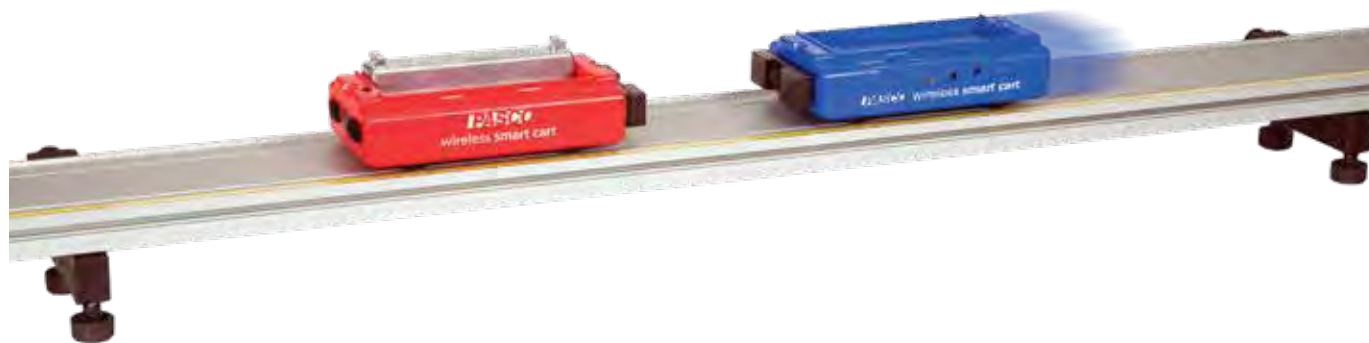
Conservation of Momentum

EX-5510C

- Designed for use with 2 Smart Carts
- No interface required

Concepts:

- Conservation of momentum in elastic and inelastic collisions
- Kinetic energy not conserved in inelastic collisions
- Kinetic energy temporarily stored as magnetic potential energy during elastic collisions using magnetic bumpers



The total momentum and total energy of carts undergoing elastic and inelastic collisions are measured. The values before and after the collisions are compared to verify that momentum is conserved in all collisions, while energy is only conserved in elastic collisions.

Elastic and inelastic collisions are performed with two dynamics carts of different masses. Magnetic bumpers are used in the elastic collision and Velcro® bumpers are used in the completely inelastic collision. In both cases, momentum is conserved.

Cart velocities are recorded using the encoders inside the Smart Carts. A real-time graph of Velocity vs. Time is obtained for each cart, clearly showing when the collision occurred. This enables the student to determine the cart velocities immediately before and after the collision.

The kinetic energy before and after the collision is also studied. Kinetic energy is not conserved for inelastic collisions. It is also demonstrated that kinetic energy momentarily decreases during the elastic collision and then returns to the original value after the collision.

PASCO Advantage

The magnitude and direction of the velocity of each cart is recorded continuously throughout the collision, which eliminates the problem in older methods of positioning photogates too close or too far from the point of collision.

Experiment Includes

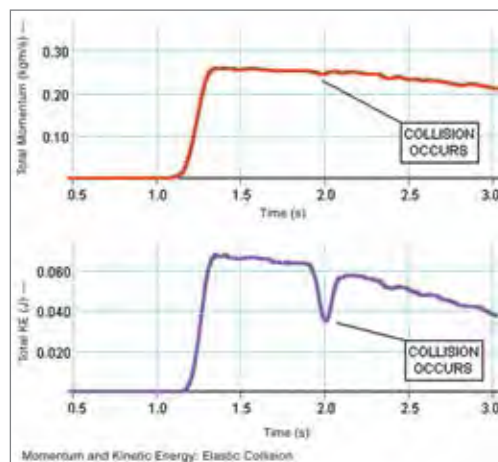
- | | |
|--------------------------------|----------|
| • 250 g Stackable Mass (2) | ME-6757A |
| • Smart Cart (red) | ME-1240 |
| • Smart Cart (blue) | ME-1241 |
| • Dynamics Track End Stops (2) | ME-8971 |
| • Dynamics Track Feet (2) | ME-8972 |
| • Starter Dynamics Track | ME-9493 |
| • Smart Cart Rod Stand Adapter | ME-1244 |

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.



A real-time graph of Velocity vs. Time is obtained for each cart, clearly showing when the elastic collision occurred.



The top graph of the total momentum for the 2-cart system (as calculated in PASCO Capstone) shows no change throughout the elastic collision. The total kinetic energy, shown in the bottom graph, momentarily decreases during the collision because energy is stored as magnetic potential energy.

Order Information

Conservation of Momentum.....EX-5510C

Required:

Bluetooth 4.0 enabled computer

PASCO Capstone Software..... pp. 72-75

Balance or Scale..... p. 200

Mechanics

Ballistic Pendulum

EX-5511A

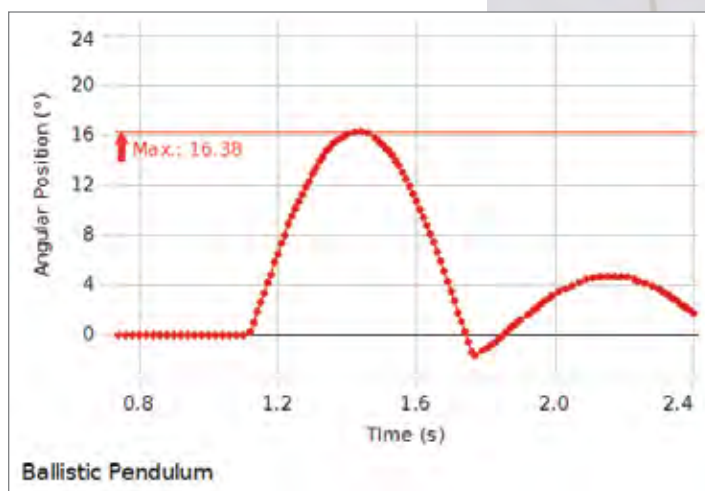
Concepts:

- ▶ Modern approach to a classic experiment
- ▶ View graph of entire pendulum swing
- ▶ Conservation of momentum
- ▶ Conservation of energy

PASCO's Rotary Motion Sensor is the heart of this modern approach to a classic physics experiment. The Mini Launcher (ME-6825B) fires a steel ball into the foam catcher of the Ballistic Pendulum Accessory (ME-6829) mounted on the Rotary Motion Sensor. The Rotary Motion Sensor measures the angular displacement of the pendulum and it is plotted in real-time in PASCO Capstone.

There is no need to catch the pendulum at its maximum height because the angle is continuously measured. Using the analysis tools in PASCO Capstone, students can find the maximum angle.

Using Conservation of Momentum and Conservation of Energy, students can determine the initial speed of the ball as it leaves the projectile launcher. The initial speed of the ball is confirmed by using two photogates to time the flight of the ball for a short distance.



This graph of the angle of the pendulum vs. time is plotted in real-time in PASCO Capstone. The maximum angle is displayed on the graph.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Experiment Includes

- | | |
|------------------------------------|----------|
| • Rotary Motion Sensor | PS-2120A |
| • Mini Launcher | ME-6825B |
| • Photogate Heads (2) | ME-9498A |
| • Photogate Mounting Bracket | ME-6821A |
| • Mini Launcher Ballistic Pendulum | ME-6829 |
| • Large "C" Clamp | SE-7285 |
| • 45 cm Steel Rod | ME-8736 |

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ AirLink



The ball is shot into a foam catcher at the end of a pendulum. The pendulum is mounted on a Rotary Motion Sensor to record the entire swing.

Order Information

Ballistic Pendulum EX-5511A

Required:

550 or 850 Universal Interface* pp. 28-30

PASCO Capstone Software pp. 72-75

* This experiment can be performed using the 550 or 850 Universal Interface or AirLink.

Conservation of Energy

EX-9935

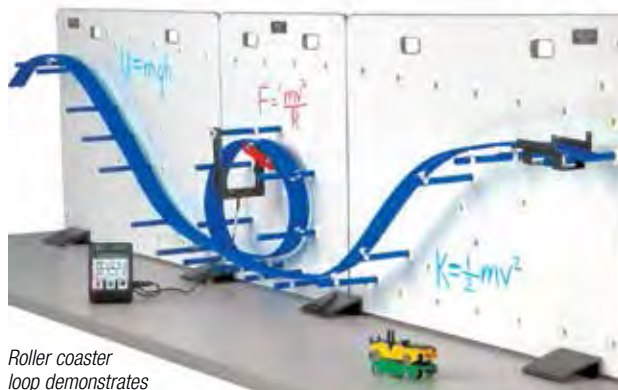
Concepts:

- ▶ Conservation of energy
- ▶ Centripetal acceleration
- ▶ Apparent weight

In this experiment, the Law of Conservation of Energy is verified by measuring the potential and kinetic energies of a car traveling over hills and loops on a curved track.

A car is started from rest on a variety of tracks (hills, valleys, loops, straight track). The speed of the car is measured at various points along the track using a photogate connected to a Smart Timer. The potential energy is calculated from the measured height and the kinetic energy is calculated from the speed. The total energy is calculated for two points on the track and compared.

The height from which the car must be released from rest to just make it over the top of the loop can be predicted from conservation of energy and the centripetal acceleration. Then the prediction can be tested on the roller coaster. If the car is released from the top of the hill so it easily makes it over the top of the loop, the speed of the car can be measured at the top of the loop and the centripetal acceleration as well as the apparent weight (normal force) on the car can be calculated.



Roller coaster loop demonstrates conservation of energy.

Experiment Includes

- Complete Roller Coaster System ME-9812
- Photogate Heads (2) ME-9498A
- Smart Timer ME-8930
- Conservation of Energy Experiment Manual

PASCO Advantage

The Roller Coaster can be configured in many ways. The whiteboard background is convenient for writing calculations or making marks for measuring heights. The PASCO Roller Coaster differs from conventional roller coaster toys in three ways:

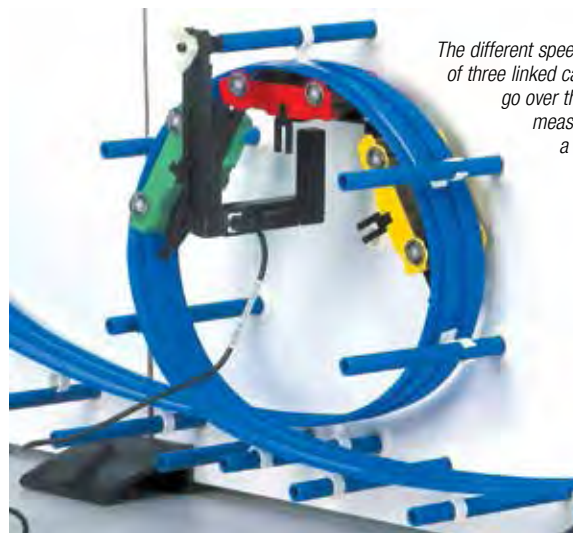
- ▶ Speed and height of the Roller Coaster car can be easily measured.
- ▶ Loss of energy due to friction is generally only about 5%.
- ▶ Cars will withstand repeated drops to the floor.



Conservation of energy for a car going over hills



Conservation of energy shows that the final speeds of these two cars are the same even though the red car takes much less time than the yellow car to reach the end of the track.



The different speeds of each of three linked cars as they go over the loop are measured using a photogate.

To Download This Experiment

Search for EX-9935 at www.pasco.com

Order Information

Conservation of Energy.....EX-9935

Mechanics

Conservation of Energy II

EX-5512

Concepts:

- ▶ Potential energy of a falling ball
- ▶ Kinetic energy of a falling ball
- ▶ Use different size balls to change friction

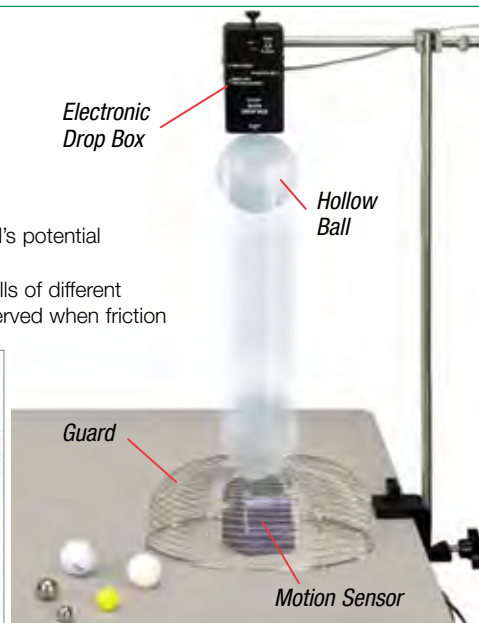
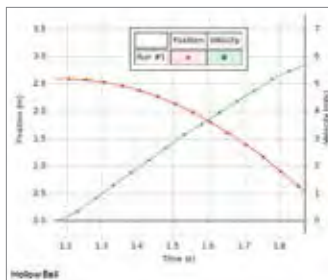
A ball is dropped from rest and its height and speed are recorded using a Motion Sensor. The ball's potential energy and kinetic energy are calculated at various points during the ball's fall.

The total energy of the ball is examined throughout the fall to determine if there is any change. Balls of different sizes are used to vary the amount of air friction, so that students can see that energy is not conserved when friction is appreciable.

Experiment Includes

- Motion Sensor PS-2103A
- Discover Freefall System ME-9889
- Large Rod Base ME-8735
- 120 cm Rod ME-8741
- Multi Clamp ME-9507
- 45 cm Rod ME-8736
- Motion Sensor Guard SE-7256

As the ball falls, its height and speed are recorded and displayed in PASCO Capstone software.



Order Information

Conservation of Energy II EX-5512

Required:

550 or 850 Universal Interface* p. 28-30

PASCO Capstone Software pp. 72-75

* This experiment can be performed using the 550 or 850 Universal Interface or AirLink.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Work Energy Theorem

EX-5513A

Concepts:

- ▶ Kinetic energy
- ▶ Potential energy
- ▶ Work energy theorem
- ▶ Conservation of mechanical energy

The total work done on an object is compared with the change in kinetic energy of the object. Using a High Resolution Force Sensor and a Motion Sensor, students record and display the force as a function of position.

The work done is the area under the Force vs. Position plot.

At any point during the experiment, kinetic energy is calculated from the velocity measured with the Motion Sensor. Students explore the meaning of dissipative forces.

PASCO Advantage

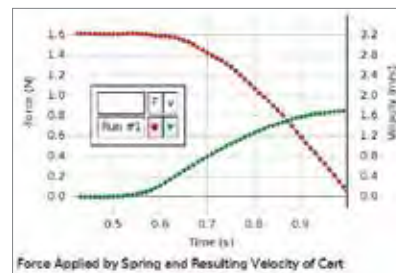
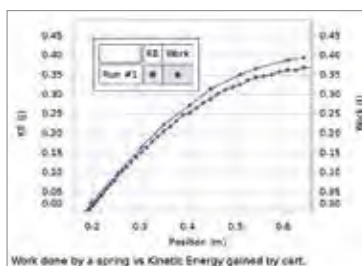
Instead of just focusing on the end points, real-time measurements of force, position, and velocity allow students to continuously examine the work done and the resulting kinetic energy of the cart during its entire trip down the track.

Experiment Includes

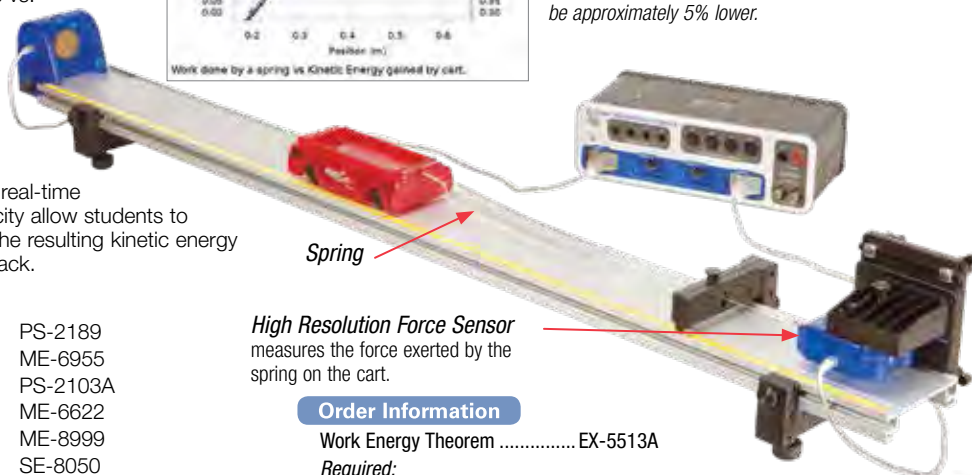
- High Resolution Force Sensor PS-2189
- 1.2 m PASCar Dynamics System ME-6955
- Motion Sensor PS-2103A
- Force Bracket ME-6622
- Dynamics Track Spring Set ME-8999
- Braided Physics String SE-8050

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ Any PASPORT interface with 2 ports



Work done by friction and ignoring the rotational kinetic energy of the wheels cause the cart kinetic energy to be approximately 5% lower.



Spring

High Resolution Force Sensor measures the force exerted by the spring on the cart.

Order Information

Work Energy Theorem EX-5513A

Required:

550 or 850 Universal Interface* pp. 28-30

PASCO Capstone Software pp. 72-75

Balance or Scale p. 200

* This experiment can be performed using the 550 or 850 Universal Interface or any PASPORT interface with two ports.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Universal Gravitational Constant

EX-5550

Concepts:

- ▶ Measure the Universal Gravitational Constant in less than three hours!
- ▶ Recreate Cavendish's historical experiment
- ▶ Uses PASCO Capstone Video Analysis

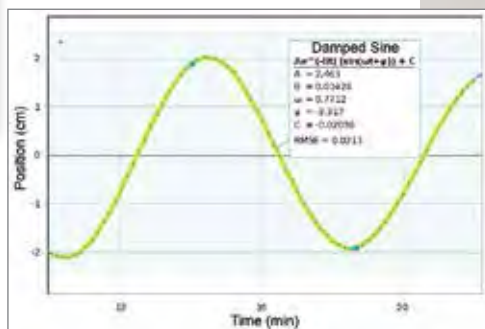
The attraction between a pair of small tungsten spheres and a pair of larger tungsten spheres is measured by the torsion of a beryllium ribbon. The large spheres are placed close to the small spheres and allowed to equilibrate. A laser is reflected from a mirror on the beryllium ribbon and shown on a screen or wall. The large spheres are then rotated through an angle to produce torque on the ribbon. The mirror rotates with the ribbon, so the laser reflection on the screen or wall is displaced. The displacement of the laser reflection is measured to find "G".

PASCO Advantage

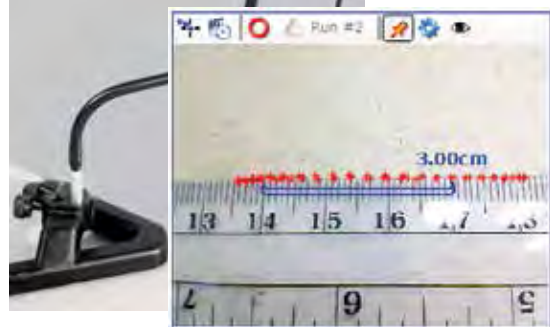
For the first time, the measurement of G using the Cavendish Balance can actually be performed in a three-hour lower division physics laboratory! Data collection is done using a webcam to video two periods of the oscillation for both ball positions in less than 45 minutes. The video data may then be transferred to the lab groups for analysis using the video analysis capability of PASCO Capstone. Fitting a damped sine curve to the video data allows an extremely precise determination of period of oscillation and where the final equilibrium positions would be. When analysis of small effects inherent in the method is included, an accuracy of better than 2% is possible.



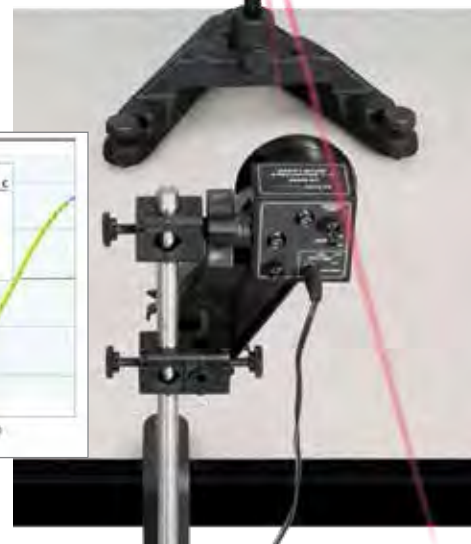
At left, the USB Camera Microscope records the oscillation of the laser beam.



In PASCO Capstone, a damped sine fit is applied to the data to determine the equilibrium point.



This is a screenshot of the video analysis points (red plus signs) in PASCO Capstone.



Experiment Includes

- | | |
|---------------------------------|----------|
| • Gravitational Torsion Balance | AP-8215A |
| • X-Y Adjustable Diode Laser | OS-8526A |
| • Large Rod Base | ME-9735 |
| • USB Camera Microscope | PS-2343 |
| • Polarizer Set | OS-8473 |
| • Rods and Clamps | |

NOTE: No interface is required.

Order Information

Universal Gravitational ConstantEX-5550
 Required:
 PASCO Capstone Software.....pp. 72-75
 Transparent Ruler and Meter Stick

To Download This Experiment

Search for EX-5550 at www.pasco.com

Fluids

Piping Systems

EX-5553

Concepts:

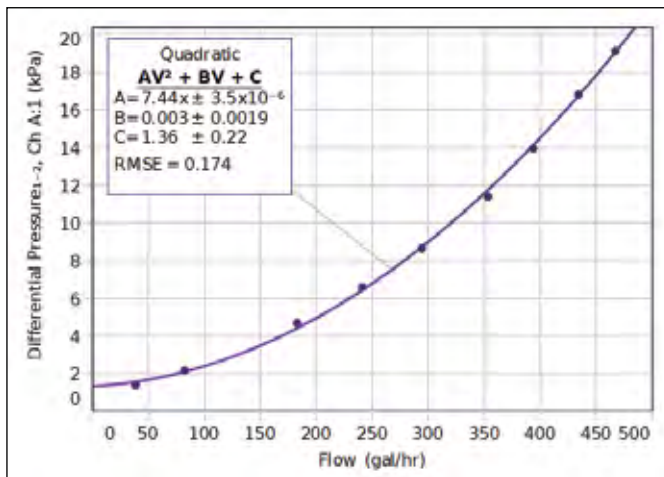
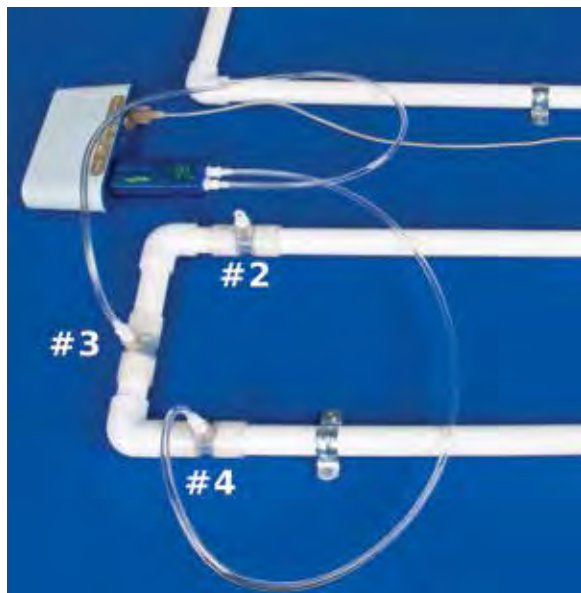
- ▶ Learn how to determine the friction factor.
- ▶ Estimate the energy loss of water flowing at a various flow rates through PVC pipe.
- ▶ Estimate the energy loss of water flowing through an elbow.
- ▶ Estimate the energy loss of water flowing through a valve.

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ Any PASPORT interface with 2 ports



In this experiment, students determine the major losses due to friction in pipes and the minor losses due to elbows and valves. The loss over a long distance is measured between pressure taps #1 and #5 (shown in the picture above). The water velocity is measured using the Venturi tube attached to the General Flow Sensor.



The water velocity is varied to explore the dependence of the losses on velocity (see graph above).

The minor losses due to elbows are found by comparing the pressure at tap #3 and tap #4, as shown at left.

Experiment Includes

- | | |
|--|---------------------|
| • General Flow Sensor | PS-2222 |
| • Venturi Tube | ME-2220 |
| • Dual Pressure Sensor | PS-2181 |
| • Pressure Taps (2 sets of 5 included) | ME-2224 |
| • Fast Temperature Probe | Included in PS-2011 |
| • Water Pump | SE-7727 |

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Piping Systems Experiment EX-5553

Required:

Bucket

Pipe Network (see pasco.com/engineering/pipes for details)

SPARKlink Air Interface PS-2011

PASCO Capstone Software pp. 72-75

* This experiment can be performed using the 550 or 850 Universal Interface or any PASPORT interface with two ports.

Pumping Systems

EX-5554

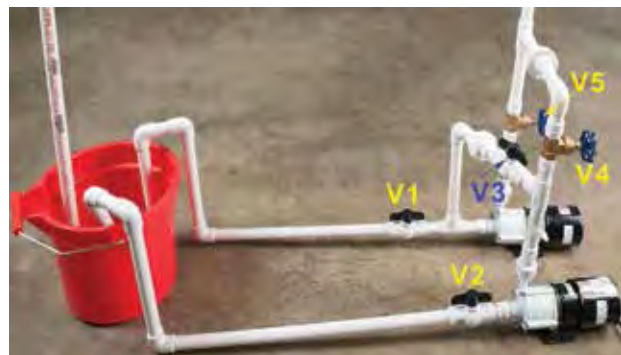
Designed for use with either of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface

Concepts:

- ▶ Find the relationship between pump head and flow rate.
- ▶ Creating pump performance curves:
 - Single pump
 - Pumps in parallel
 - Pumps in series

In this experiment, students determine the characteristic curves for two pumps and examine the impact of placing pumps in series and in parallel.



Two pumps are operated separately and then together in series and parallel.



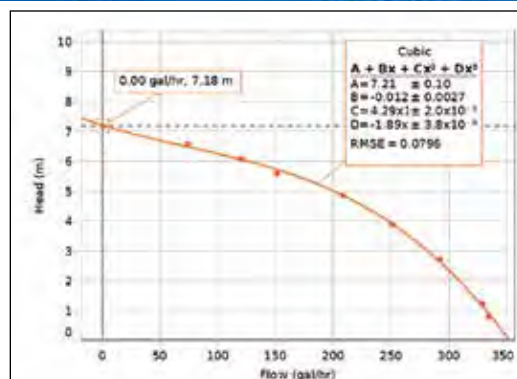
The pressure is measured just above the pump as the water velocity is varied.



For this experiment, the water is pumped through the short section of pipe through valves #6 and #8. The water velocity is measured using the Venturi tube attached to the General Flow sensor. The pressure at the pump is measured for different velocities and a pump curve is created (at right). The maximum head is recorded. Then two pumps are operated at the same time. The effects of pumps in series and in parallel are explored.

Experiment Includes

- | | |
|---|---------------------|
| • General Flow Sensor | PS-2222 |
| • Venturi Tube | ME-2220 |
| • Dual Pressure Sensor | PS-2181 |
| • Pressure Taps (2 sets of 5 included) | ME-2224 |
| • Fast Temperature Probe | Included in PS-2011 |
| • Water Pumps (2) | SE-7727 |



Order Information

Pumping Systems ExperimentEX-5554

Required:

Bucket

Pipe Network (see pasco.com/engineering/pipes for details) ..

SPARKlink Air InterfacePS-2011

PASCO Capstone Software.....pp. 72-75

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Fluids

Archimedes' Principle

EX-9909

Concepts:

- ▶ Archimedes' Principle
- ▶ Density
- ▶ Buoyant force

Archimedes' Principle states that the buoyant force on a submerged object is equal to the weight of the fluid that is displaced by the object.

The buoyant force on several objects is measured by weighing the water displaced by a submerged object. The buoyant force is also determined by measuring the difference between the object's weight in air and its apparent weight in water.

Some of the objects have the same density, some have the same volume, and some have the same mass. The density of each object is measured and the dependence of the buoyant force on density, mass, and volume is explored.



The buoyant force is measured by weighing the water displaced by the object.



The mass and volume are measured to determine the dependence of the buoyant force on mass, volume, and density.

Experiment Includes

- | | |
|---|---------|
| • Density Set | ME-8569 |
| • Overflow Can | SE-8568 |
| • Rod Base | ME-8735 |
| • 45 cm Steel Rod | ME-8736 |
| • Physics String | SE-8050 |
| • Triple-Beam Balance | SE-8707 |
| • Stainless Steel Calipers | SF-8711 |
| • 1000 ml Beaker | |
| • 100 ml Beaker | |
| • 50 ml Graduated Cylinder | |
| • Archimedes' Principle Experiment Manual | |

PASCO Advantage

The provided objects have related volumes, masses, and densities to demonstrate that only the volume of water displaced affects the buoyant force.

To Download This Experiment

Search for EX-9909 at www.pasco.com

Order Information

Archimedes' Principle EX-9909

Rotational Inertia

EX-5516B

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ AirLink

Concepts:

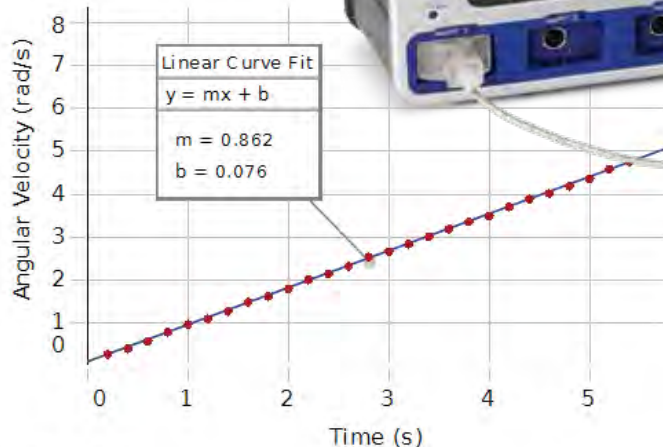
- ▶ Rotational inertia of a ring and a disk
- ▶ Torque

In this experiment, the rotational inertias of a ring and a disk are determined by applying a torque to the object and measuring the resulting angular acceleration.

A known torque is applied to the pulley on the Rotary Motion Sensor, causing a disk and ring to rotate. The resulting angular acceleration is measured using the slope of a graph of Angular Velocity vs. Time. The rotational inertia of the disk and ring combination is calculated from the torque and the angular acceleration. The procedure is repeated for the disk alone to find the rotational inertias of the ring and disk separately.



The Rotary Motion Sensor provides a sturdy, low-friction rotational platform for the Ring and Disk, in addition to measuring the resulting angular acceleration.



Disk & Ring

The rotational inertia of the ring and disk is calculated from the angular acceleration obtained from the slope of this Angular Velocity vs. Time graph.

A known torque is applied to the ring and disk by the weight hanging over the pulley. The rotational inertia of the ring and disk are determined from the resulting angular acceleration. The procedure is repeated for the disk alone.

PASCO Advantage

Friction can be neglected in this compact setup. The Rotary Motion Sensor is a versatile tool that can be used in a variety of other experiments.

Experiment Includes

- Large Rod Stand ME-8735
- 90 cm Long Steel Rod ME-8738
- Rotational Inertia Accessory ME-3420
- Mass Set (5 g resolution) ME-8979
- Rotary Motion Sensor PS-2120A

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Rotational Inertia EX-5516B

Required:

550 or 850 Universal Interface* pp. 28-30

PASCO Capstone Software pp. 72-75

Balance or Scale p. 200

Calipers SE-8710 p. 196

* This experiment can be performed using the 550 or 850 Universal Interface or AirLink.

Rotation

Physical Pendulum

EX-5518A

Designed for use with any of the following:

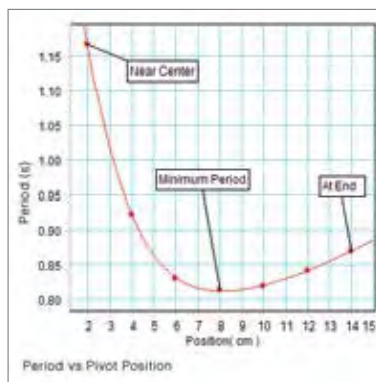
- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ AirLink

Concepts:

- ▶ Parallel Axis Theorem
- ▶ Period of a physical pendulum
- ▶ Computer modeling of a system
- ▶ Rotational inertia

In this experiment, the period of a physical pendulum, a narrow bar, is determined as a function of the distance of the pivot from the center of mass. A computer model of the system is developed, which allows the student to vary the physical parameters of the model (gravity, length, c.m. position) to match the data. This makes it possible to obtain values for the physical parameters without direct measurement.

A second experiment verifies the parallel axis theorem. It also uses superposition to find the rotational inertia of a disk with an off axis circular hole.



The Pendulum Bar has holes spaced at 2 cm intervals. A graph of Oscillation Period vs. Pivot Hole Position shows that there is a unique placement that gives a minimum period. This location can be verified using calculus.



Apply a known torque and measure the angular acceleration to calculate the moment of inertia of the object. Multiple holes in the plate allow investigation of the Parallel Axis Theorem.

Center hole is at center of mass.



Unique design allows pivot exactly at the edge. Measure the period of the thick ring oscillating at either the inner or outer radius.



Experiment Includes

- Large Rod Stand
- 45 cm Long Steel Rod
- Physical Pendulum Set
- Rotary Motion Sensor

ME-8735
ME-8736
ME-9833
PS-2120A

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Physical Pendulum EX-5518A

Required:

550 or 850 Universal Interface* pp. 28-30
PASCO Capstone Software pp. 72-75

* This experiment can be performed using the 550 or 850 Universal Interface or AirLink.

Conservation of Angular Momentum

EX-5517C

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ AirLink

Concepts:

- ▶ Conservation of angular momentum during collisions
- ▶ Easy determination of before and after points
- ▶ Calculation of energy lost during collision

The study of conservation of angular momentum during collisions is easy and fast using this system based on the Rotary Motion Sensor. The angular velocity of the spinning disk is graphed in real-time as a non-rotating ring is dropped onto it.

As a non-rotating ring is dropped onto a rotating disk, the angular velocity decreases to about 1/6th of its initial value since the ring has a large rotational inertia compared to the disk.



The Rotary Motion Sensor provides a sturdy, low-friction rotational platform for the Ring and Disk, in addition to measuring the resulting change in angular velocity.



PASCO Advantage

It is easy to measure the rotational speeds just before and after the collision since the entire collision is visible in the graph.

The rotational inertias of the ring and disk are calculated using the mass and dimensions of each. Then the total angular momentum before the collision is compared to the total angular momentum after the collision to show that it does not change.

The total kinetic energy before and after the collision is calculated to show the amount of energy lost during the inelastic collision.

Experiment Includes

- | | |
|--------------------------------|----------|
| • Rotary Motion Sensor | PS-2120A |
| • Rotational Inertia Accessory | ME-3420 |
| • Calipers | SF-8711 |
| • Large Rod Stand | ME-8735 |
| • 45 cm Long Steel Rod | ME-8736 |

Order Information

Conservation of Angular Momentum EX-5517C

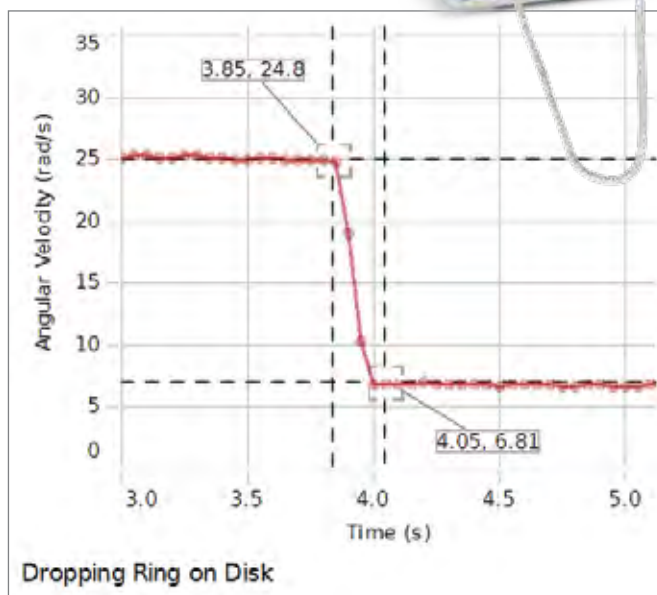
Required:

550 or 850 Universal Interface* pp. 28-30

PASCO Capstone Software pp. 72-75

Balance or Scale p. 200

* This experiment can be performed using the 550 or 850 Universal Interface or AirLink.



Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Rotation

Variable-g Pendulum

EX-5519A

Concepts:

- ▶ Period of a simple pendulum
- ▶ Effect of decreasing “g” on the pendulum period
- ▶ Large amplitude period
- ▶ Shape of displacement, velocity, and acceleration curves for large amplitude

This experiment explores the dependence of the period of a simple pendulum on the acceleration due to gravity and on the length and amplitude of the pendulum.

A simple rigid pendulum consists of a 35 cm long lightweight aluminum tube with masses at the end, mounted on a Rotary Motion Sensor. The pendulum is constrained to oscillate in a plane tilted at an angle from the vertical. This effectively reduces the acceleration due to gravity because the restoring force is decreased.

PASCO Advantage

The rigid pendulum can be assumed to be a simple pendulum: the actual period is approximately 99% of the period of a simple pendulum of the same length.

Experiment Includes

- Large Rod Stand ME-8735
- 45 cm Long Steel Rod ME-8736
- Angle Indicator ME-9495A
- Adjustable Angle Clamp ME-8744
- Pendulum Accessory ME-8969
- Rotary Motion Sensor PS-2120A

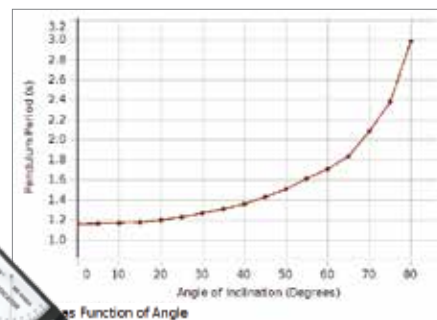
Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ AirLink

The period of the Variable-g Pendulum is plotted as a function of the angle of inclination to show the dependence of the period on g.



The period is measured for varying angles, simulating changing the acceleration due to gravity for the pendulum.

The Adjustable Angle Clamp makes it easy to adjust the angle from zero to 90 degrees, thus varying “g” from 9.8 m/s² to zero.

Order Information

Variable-g Pendulum EX-5519A

Required:

550 or 850 Universal Interface* pp. 28-30

PASCO Capstone Software pp. 72-75

* This experiment can be performed using the 550 or 850 Universal Interface or AirLink.

Large Amplitude Pendulum

EX-5520A

Concepts:

- ▶ Low amplitude approximation for the pendulum period
- ▶ Large amplitude period
- ▶ Shape of displacement, velocity, and acceleration curves for large amplitude

This experiment explores the dependence of the period of a simple pendulum on the amplitude of the oscillation. Also, the displacement, velocity, and acceleration for large amplitude are plotted vs. time to show the difference from the sinusoidal motion of low amplitude oscillations.

The period is measured as a function of the amplitude of the pendulum and compared to theory.

Experiment Includes

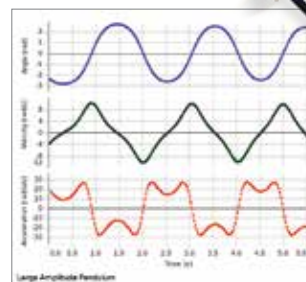
- Small “A” Base ME-8976
- 25 cm Long Threaded Steel Rod ME-8988
- Pendulum Accessory ME-8969
- Rotary Motion Sensor PS-2120A

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ AirLink



Graphs of angular displacement, velocity, and acceleration vs. time are displayed for a pendulum oscillating with large amplitude.

Order Information

Large Amplitude Pendulum EX-5520A

Required:

550 or 850 Universal Interface* pp. 28-30

PASCO Capstone Software pp. 72-75

* This experiment can be performed using the 550 or 850 Universal Interface or AirLink.

Chaos

EX-5523A

Designed for use with the 850 Universal Interface

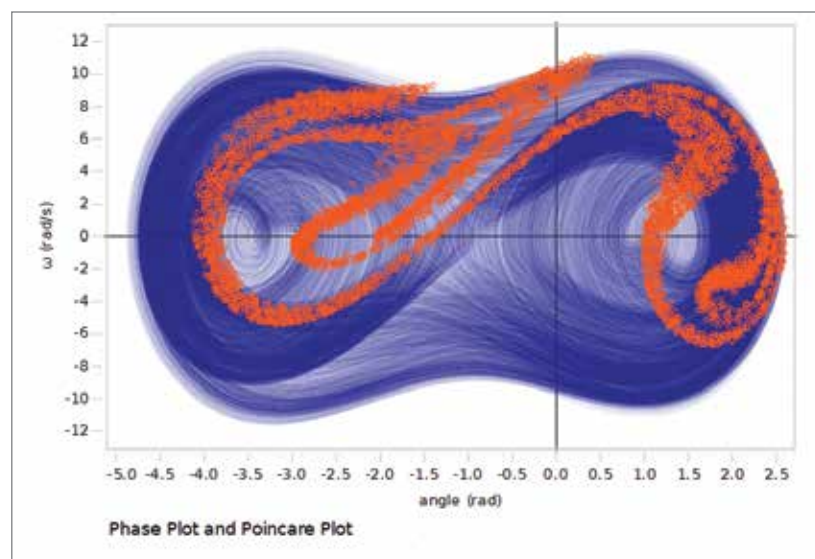
Concepts:

- ▶ Nonlinear oscillator
- ▶ Chaotic motion
- ▶ Phase space
- ▶ Poincare plot

The chaotic behavior of a driven nonlinear pendulum is explored by graphing its motion in phase space and by making a Poincare plot. These plots are compared to the motion of the pendulum when it is not chaotic.

The oscillator consists of an aluminum disk connected to two springs. A point mass on the edge of the aluminum disk makes the oscillator nonlinear. The frequency of the sinusoidal driver can be varied to investigate the progression from predictable motion to chaotic motion. Magnetic damping can be adjusted to change the character of the chaotic motion. The angular position and velocity of the disk are recorded as a function of time using a Rotary Motion Sensor. A real-time phase plot is made by graphing the angular velocity vs. the displacement angle of the oscillation.

The Poincare plot is also graphed in real time and superimposed on the phase plot. This is achieved by recording the point on the phase plot once every cycle of the driver arm as the driver arm blocks a photogate.



A graph in phase space and a Poincare plot are obtained to study the chaotic motion of this nonlinear oscillator.

The Poincare plot (in orange) shows the pendulum's velocity vs. position once per revolution of the driver. The purple background is the phase plot.

This phase plot (angular velocity vs. angle) is graphed in PASCO Capstone using partial opacity, so the trace gets darker as it traces back over itself.

Experiment Includes

- Large Rod Stand
- 120 cm Long Steel Rod (2)
- 45 cm Long Steel Rod
- Multi Clamps (2)
- Chaos/Driven Harmonic Accessory
- Mechanical Oscillator/Driver
- Rotary Motion Sensor
- Photogate Head

ME-8735
ME-8741
ME-8736
ME-9507
CI-6689A
ME-8750
PS-2120
ME-9498A

**PASCO Advantage**

PASCO Capstone can graph the motion in phase space and superimpose the Poincare plot in real time, showing students how the motion in phase space relates to actual motion of the oscillator.

Order Information

Chaos EX-5523A

Required:

850 Universal Interface pp. 28-30
PASCO Capstone Software pp. 72-75

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Oscillations

Driven Damped Cart Oscillations

EX-5551A

Concepts:

- ▶ Resonance curves
- ▶ Magnetic drag

Designed for use with:
▶ 850 Universal Interface



Magnets induce currents in the aluminum track and cause a drag force that is proportional to the cart velocity.

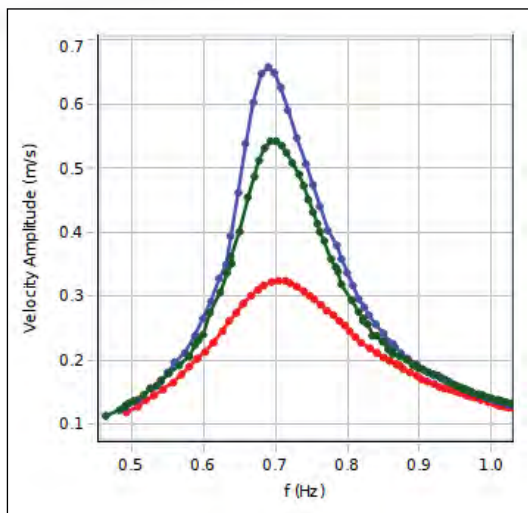


The oscillator consists of a Smart Cart attached to two springs. The damping is provided by magnets mounted on the Smart Cart that cause eddy currents in the aluminum track. The amplitude of the oscillation is plotted vs. the driving frequency for different amounts of magnetic damping. Increased damping is provided by moving adjustable magnets closer to the aluminum track.

$$\frac{d^2x}{dt^2} + \left(\frac{b}{m}\right) \frac{dx}{dt} + \left(\frac{k}{m}\right) x = F_0 \cos(\omega t)$$

$$x = \frac{F_0/m}{\sqrt{(\omega^2 - \omega_0^2)^2 + (b/m)^2 \omega^2}} \cos(\omega t - \phi)$$

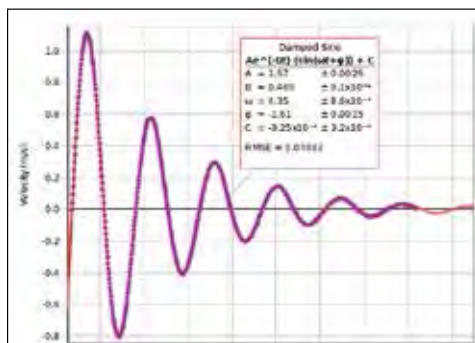
$$\omega = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$$



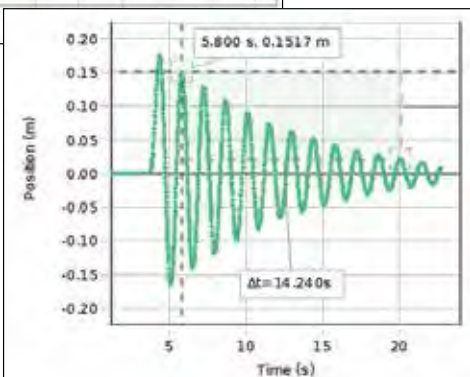
The amplitude of the cart's velocity is plotted vs. the driving frequency. The amount of drag is varied by changing the distance between the magnets and the track.

PASCO Advantage

The Smart Cart wirelessly measures the position and velocity of the cart as well as the magnetic drag, since the magnetic drag bumper is attached to the Smart Cart's force sensor.



In PASCO Capstone, a damped sine wave curve fit is applied to the data to determine the spring constant, period, and damping coefficient.



The period can be directly measured to determine the resonant frequency.

Experiment Includes

- Smart Cart ME-1240
- Mechanical Oscillator/Driver ME-8750
- Magnetic Damping Accessory ME-6828
- Dynamics Spring Set ME-8999
- Photogate Head ME-9498A
- Cart Mass (set of 2) ME-6757A
- 1.2 m Metal Dynamics Track ME-9493
- Dynamics Track End Stop (2 Pack) ME-8971
- Dynamics Track Feet (Pair) ME-8972
- Physics String SE-8050
- Smart Cart Rod Stand Adapter ME-1244

Required:

- Mass Balance SE-8707
- 850 Universal Interface UI-5000
- PASCO Capstone

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Driven Damped Cart Oscillations..... EX-5551A

Required:

Mass Balance SE-8707
850 Universal Interface..... UI-5000 pp. 28-29
PASCO Capstone Software..... pp. 72-75

Driven Damped Harmonic Oscillator

EX-5522A

Designed for use with:
 ▶ 850 Universal Interface

Concepts:

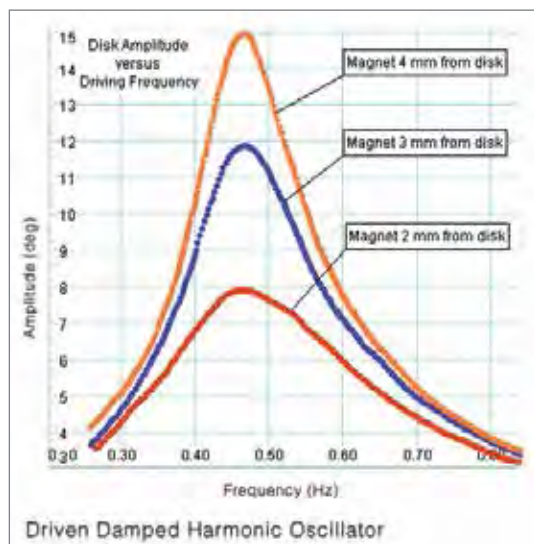
- ▶ Resonance curves for an oscillator: amplitude vs. frequency
- ▶ Resonant frequency
- ▶ Period of a pendulum
- ▶ Effect of magnetic damping on shape of resonance curve
- ▶ Phase difference between oscillator and driver at low, resonant, and high frequencies

In this experiment, the resonance of a driven damped harmonic oscillator is examined by plotting the oscillation amplitude vs. frequency for various amounts of damping.

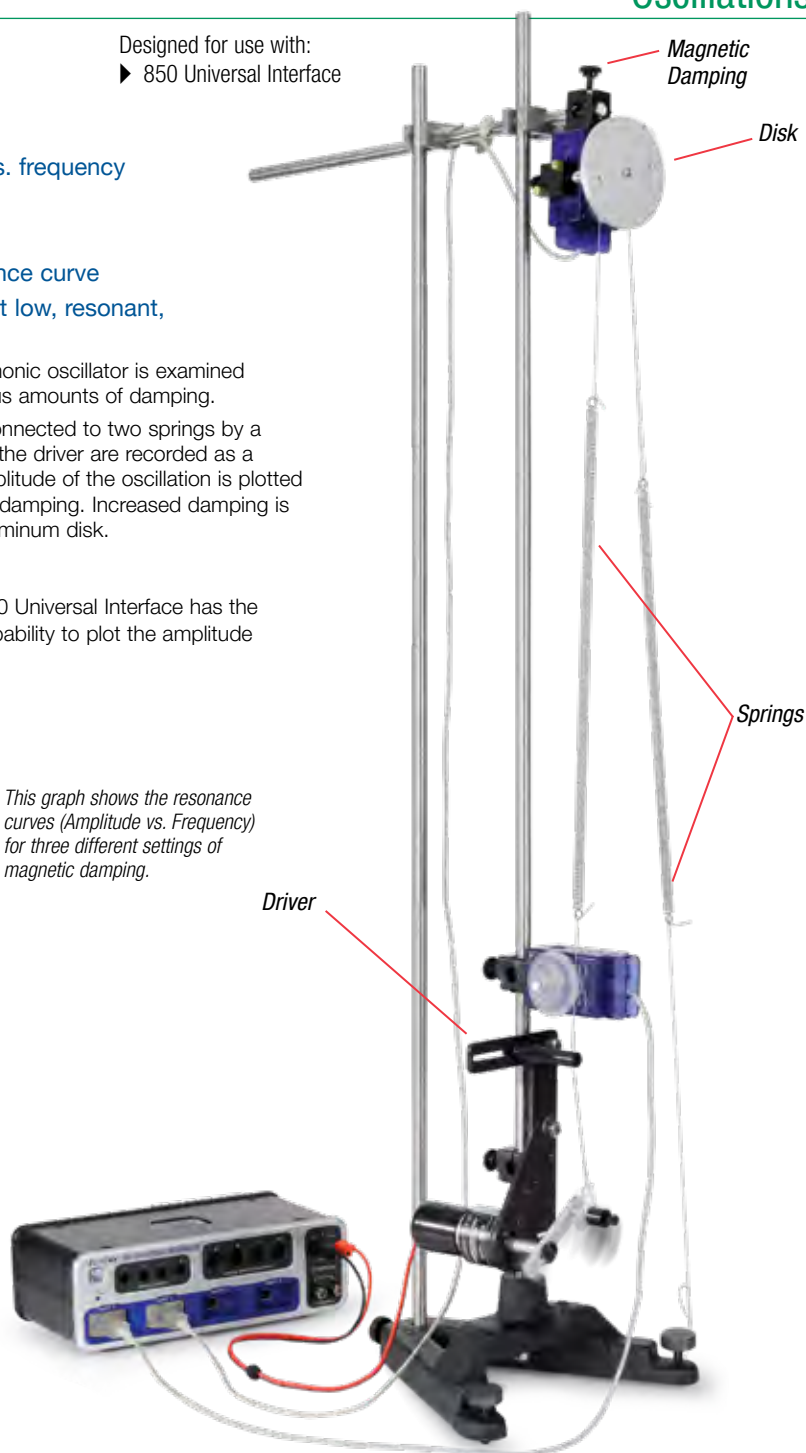
The oscillator consists of an aluminum disk with a pulley connected to two springs by a string. The angular positions and velocities of the disk and the driver are recorded as a function of time using two Rotary Motion Sensors. The amplitude of the oscillation is plotted vs. the driving frequency for different amounts of magnetic damping. Increased damping is provided by moving an adjustable magnet closer to the aluminum disk.

PASCO Advantage

The combination of PASCO Capstone software and the 850 Universal Interface has the power to sweep through the driver frequencies and the capability to plot the amplitude vs. the driver frequency in real time.



This graph shows the resonance curves (Amplitude vs. Frequency) for three different settings of magnetic damping.



The magnetically damped oscillator is driven by a sinusoidal mechanical driver.

Experiment Includes

- | | |
|-----------------------------------|----------|
| • Rotary Motion Sensor (2) | PS-2120A |
| • Mechanical Oscillator/Driver | ME-8750 |
| • Chaos/Driven Harmonic Accessory | CI-6689A |
| • Large Rod Base | ME-8735 |
| • 120-cm Long Steel Rod (2) | ME-8741 |
| • 45-cm Long Steel Rod | ME-8736 |
| • Multi-Clamps (2) | ME-9507 |
| • Physics String | SE-8050 |

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

| | | |
|---|----------|-----------|
| Driven Damped Harmonic Oscillator | EX-5522A | |
| Required: | | |
| 850 Universal Interface..... | UI-5000 | pp. 28-29 |
| PASCO Capstone Software..... | | pp. 72-75 |
| Hooked Mass Set..... | SE-8759 | p. 201 |
| Calipers | SE-8710 | p. 196 |

Basic Bridges

EX-5556

Designed for use with:

- ▶ 850 Universal Interface,
- 550 Universal Interface
- or AirLink

Concepts:

- ▶ Learn about different types of bridges through hands-on exploration.
- ▶ Measure the tension/compression in beams for different bridge designs.

Rectangular Segments

First, students build a bridge with rectangular segments. Of course, bridges are never made this way but students will never understand why until they try it.

Triangular Segments

Next, students build a Warren bridge with triangular segments. This shows how much stronger triangular segments are than rectangular segments.

Effect of Scale

Students build a second Warren bridge on a different scale to discover how the forces change in this bridge that has twice the number of segments but spans the same distance.

Effect of Adding Verticals

Verticals are added to the larger Warren bridge. Students will find that the loads do not change when the verticals are added: So why are verticals used?

Full Warren Bridge vs. Pratt Bridge

Additional verticals are added to make a Full Warren bridge. Then the students change the Full Warren to a Pratt bridge. How are the forces different in a Pratt compared to a full Warren?

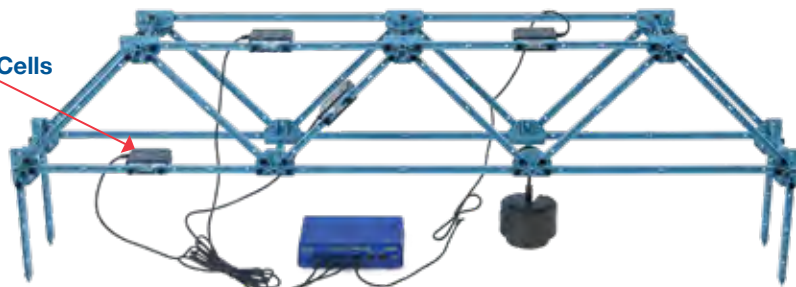
Experiment Includes

- | | |
|---------------------------|---------|
| • Truss Set Members (3) | ME-6993 |
| • Truss Set Screws (3) | ME-6994 |
| • #6 I-Beams (1) | ME-7008 |
| • 12 kg Mass Set | ME-7589 |
| • Load Cell Amplifier (1) | PS-2198 |
| • 100 N Load Cells (4) | PS-2200 |

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Load Cells

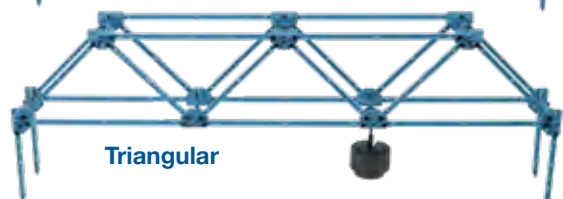


Measuring Loads

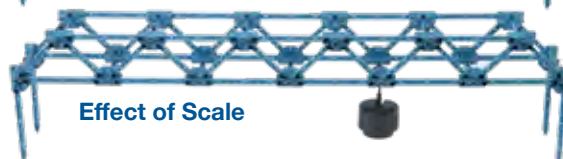
Each bridge is loaded by hanging a weight from the bridge. The tension and compression in the I-beams are measured with load cells. The load cells can be moved around to explore the load in every beam in the bridge.



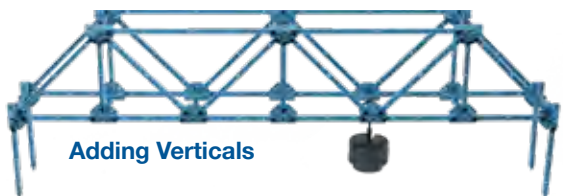
Rectangular



Triangular



Effect of Scale



Adding Verticals



Full Warren



Pratt

Order Information

| | |
|--------------------------------------|-----------|
| Basic Bridges | EX-5556 |
| <i>Required:</i> | |
| 550 or 850 Universal Interface | pp. 28-30 |
| OR | |
| AirLink..... | p. 26 |
| PASCO Capstone Software..... | pp. 72-75 |

Shaking Tower

EX-5555

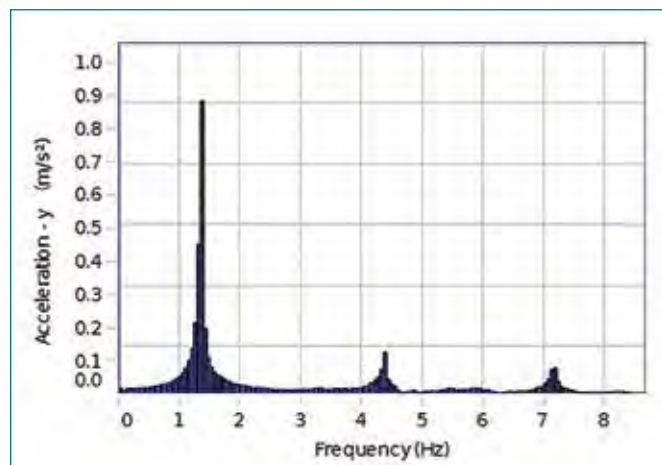
Designed for use with:

- 850 Universal Interface or Function Generator

Concepts:

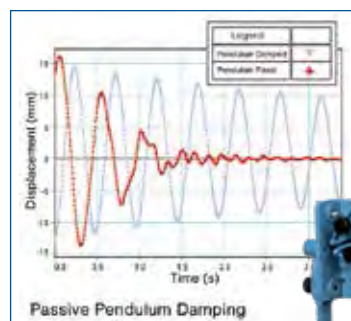
- Explore the resonance modes
- Measure accelerations with wireless sensors
- Demonstrate passive damping

Built from PASCO Structures beams, this tower is made to oscillate in its various resonance modes by a driver attached by a rubber band to the first floor of the tower. Wireless Load Cells with Accelerometers are attached to each floor to record how much shaking each floor experiences.

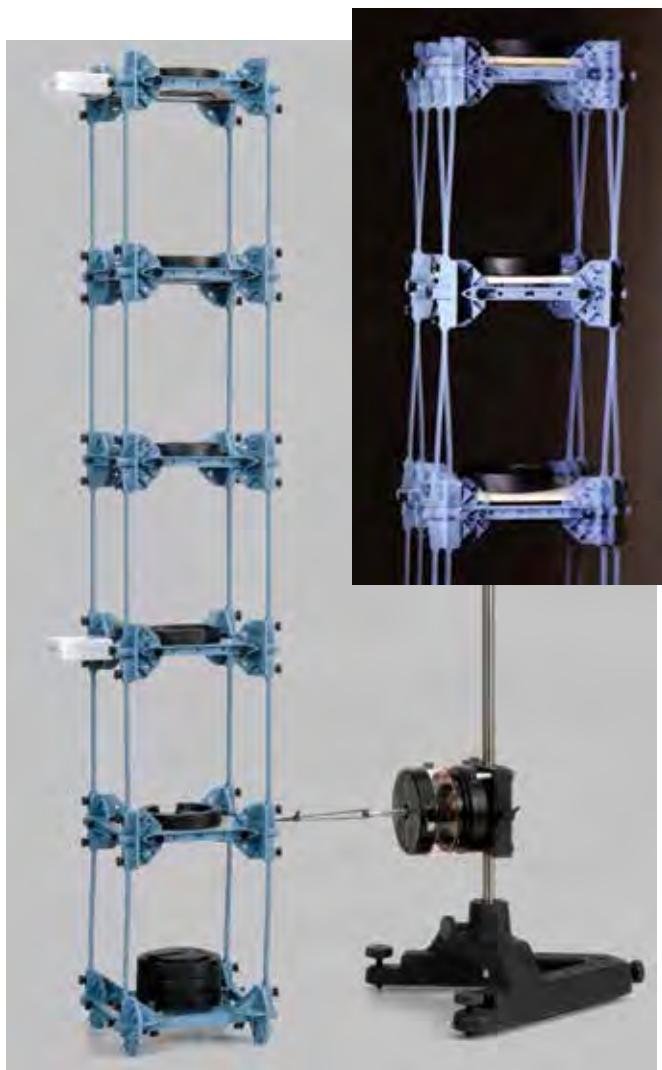
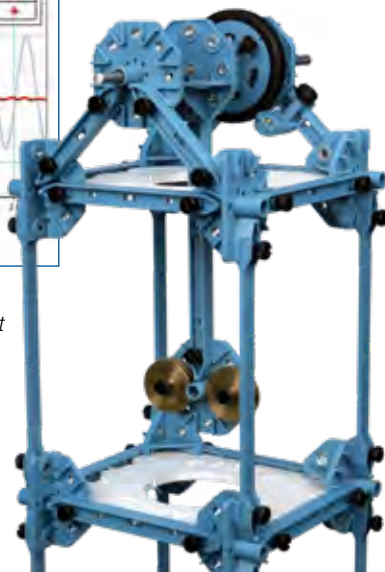


This FFT, generated in PASCO Capstone software, shows the frequency responses of the top Wireless Load Cell/Accelerometer.

In the second part of the experiment, a damping pendulum is installed on top of the tower. In modern buildings, passive damping mechanisms are installed to damp out oscillations during earthquakes. The damping pendulum in this tower quickly stops oscillations.



The gray graph, in PASCO Capstone software shows the oscillation without the pendulum. The red graph shows the damping caused when the pendulum is allowed to oscillate.



The tower is shaken by the Mechanical Wave Driver, which is powered by an 850 Universal Interface or Function Generator.

Experiment Includes

- Shaking Tower Kit (see p. 153) ME-7018
- Mechanical Wave Driver SF-9324
- 2 Meter Patch Cord Set SE-9415A
- Large Rod Base ME-8735
- Threaded Rod 25 cm ME-8988
- Large Slotted Mass Set ME-7566
- Wireless Load Cells (4) PS-3216

Masses required, but not included.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Shaking TowerEX-5555

Required:

850 Universal Interfacepp. 28-30

OR

Function Generator (PI-8127)p. 255

PASCO Capstone Softwarepp. 72-75

Structures

Bridge Vibrations

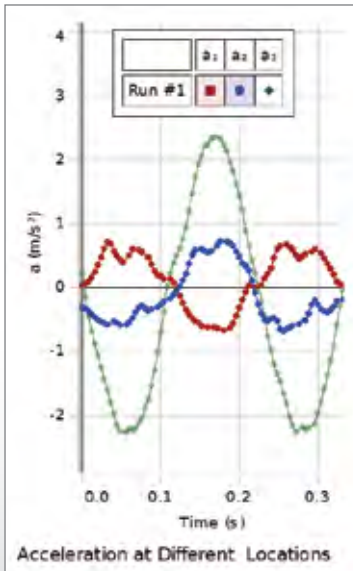
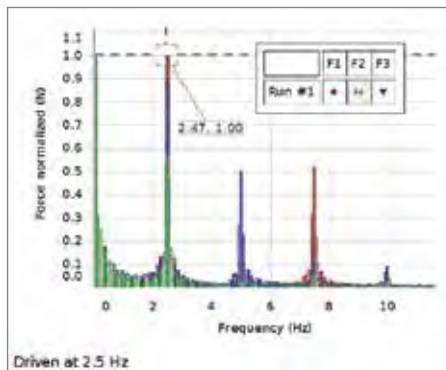
EX-5548

Concepts:

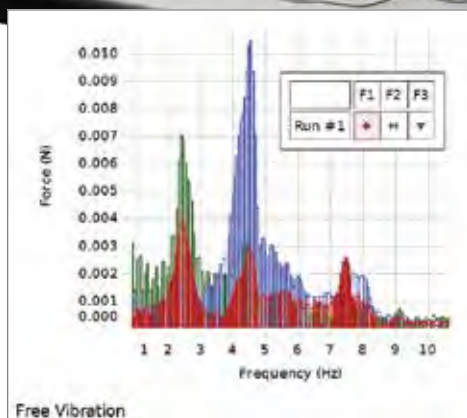
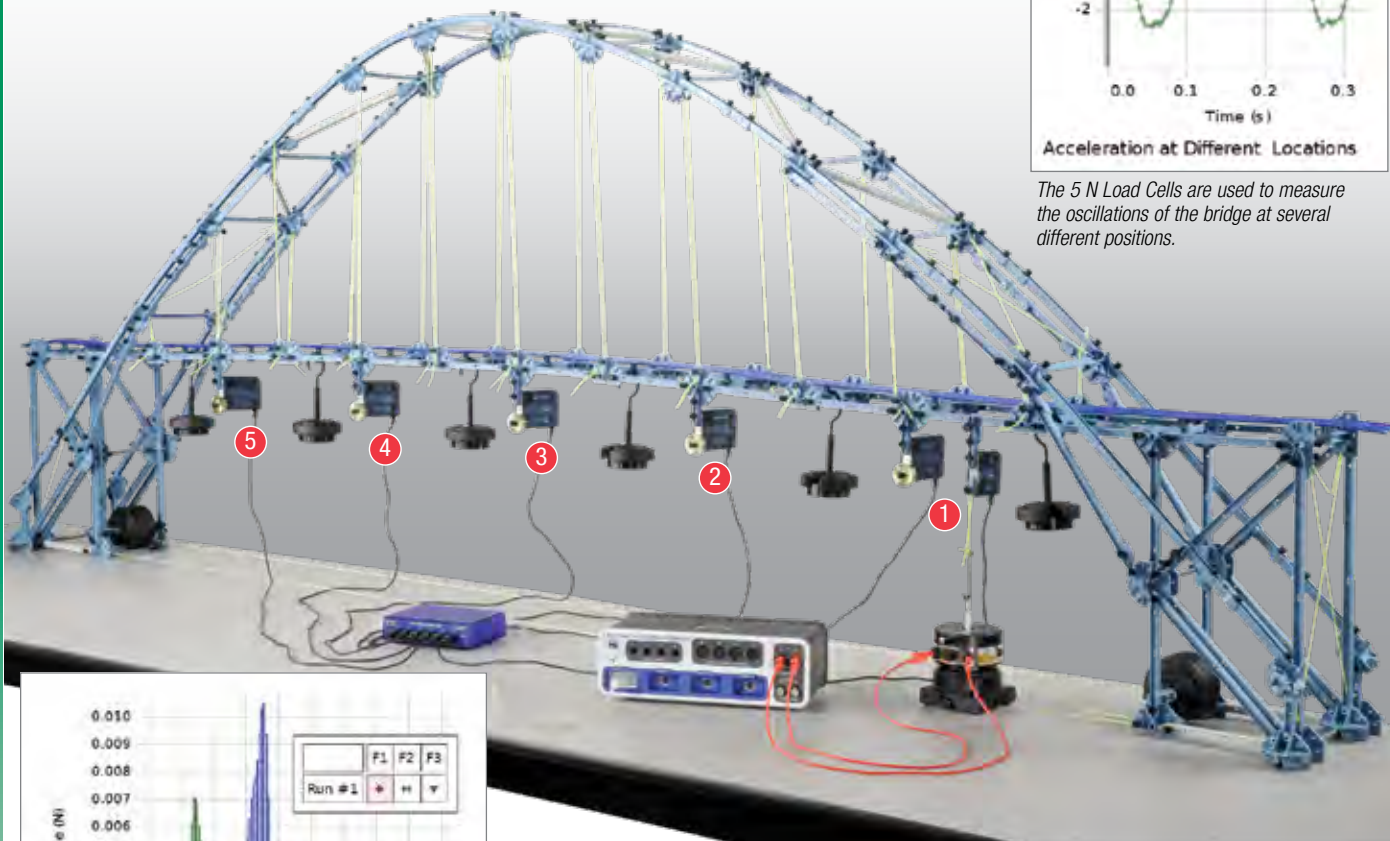
- Resonance in complex systems
- Driven vs. free vibrations

Designed for use with the
850 Universal Interface

The resonance of the bridge is characterized by driving the bridge at different resonant frequencies. Note how different the amplitudes are at different locations on the bridge.



The 5 N Load Cells are used to measure the oscillations of the bridge at several different positions.



The bridge is struck by hand and allowed to freely oscillate. Using PASCO Capstone™, the FFT shows that there are several resonant frequencies. Note how different the amplitudes are at different locations on the bridge.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Experiment Includes

- Large Structures Set
- Load Cell Amplifier
- 100 N Load Cell
- 5 N Load Cell (5)
- Mechanical Wave Driver
- Red 4 mm Banana Plug Cords
- Rubber Cord
- Large Slotted Mass Set (4)
- Short Mass Hanger (2)
- 20 g Masses (3 sets of 6)

ME-7003
PS-2198
PS-2200
PS-2201
SF-9324
SE-9750
ME-8986
ME-7589
ME-7590
ME-8983

Order Information

Bridge VibrationsEX-5548
Required:
850 Universal Interface..... pp. 28-29
PASCO Capstone Software..... pp. 72-75

Tensile Testing Metals

EX-5557

Designed for use with any of the following:

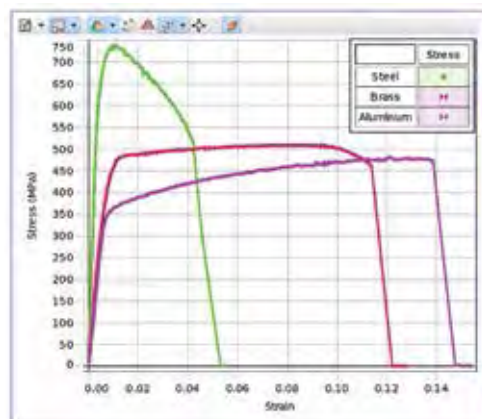
- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ AirLink

Concepts:

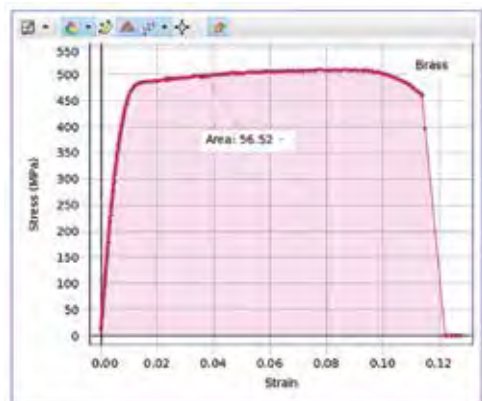
- ▶ Young's Modulus
- ▶ Ductility
- ▶ Yield Strength
- ▶ Modulus of Toughness
- ▶ Tensile Strength

The three metal tensile samples are made from 1018 Steel, 360 Brass and 2024-T3 Aluminum. The properties measured for these samples include Young's Modulus, Yield Strength, Tensile Strength, Ductility, and Modulus of Toughness. These properties are the same ones found in materials handbooks and databases and are used by engineers to design bridges, buildings, and machines.

1. Measure the slope in the linear portion of the Stress vs. Strain graph to find Young's Modulus for the material.
2. Estimate the Yield Strength by examining the Force vs. Position graph to see where the linear part of the curve ends.
3. Find the maximum stress on the graph to determine the Tensile Strength.
4. Find the maximum strain just before it breaks to determine the Ductility of the material.
5. Take the area under the Stress vs. Strain graph to determine the Modulus of Toughness for the material.

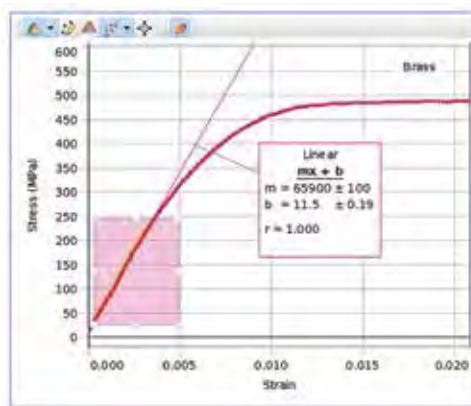


The Stress vs. Strain graph for three metals is displayed in real time and can be played back in PASCO Capstone software.



PASCO Advantage

The hand-cranked Materials Testing Machine allows students to feel the different forces required to break different samples. Data is recorded live and can be played back in PASCO Capstone software.



Young's Modulus for brass is determined from the slope of the line.

The toughness of brass is determined by taking the area under the Stress-Strain curve in PASCO Capstone software.

Experiment Includes

| | |
|------------------------------------|---------|
| Materials Testing Machine | ME-8236 |
| Tensile Samples (Aluminum, 10 ea.) | ME-8231 |
| Tensile Samples (Brass, 10 ea.) | ME-8232 |
| Tensile Samples (Steel, 10 ea.) | ME-8243 |
| Calipers | SE-8710 |

Order Information

| | |
|--------------------------------------|-----------|
| Tensile Testing Metals..... | EX-5557 |
| Required: | |
| AirLink..... | PS-3200 |
| 550 or 850 Universal Interface | pp. 28-30 |
| PASCO Capstone Software..... | pp. 72-75 |

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Materials

Column Buckling

EX-5558

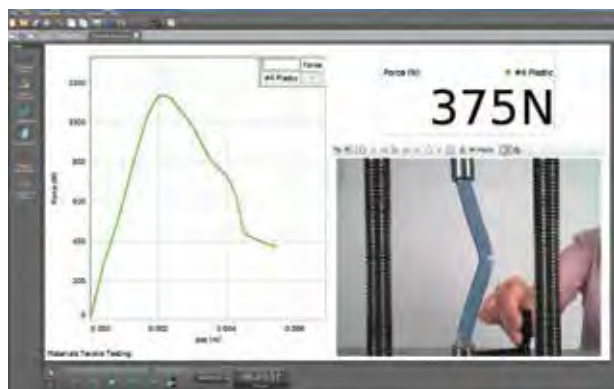
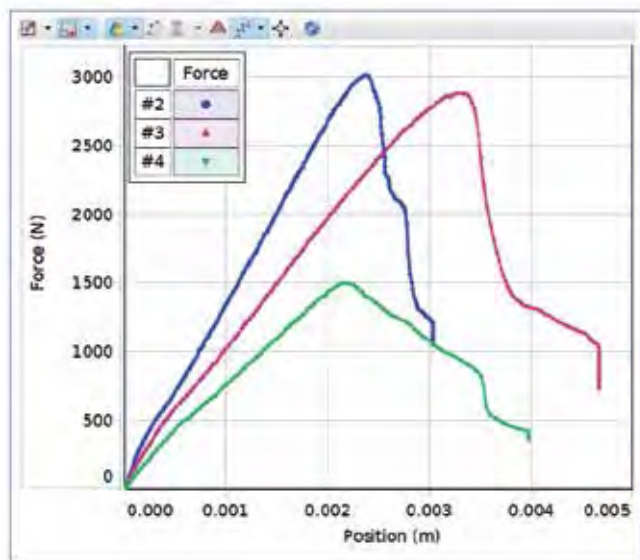
Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ AirLink

Concepts:

- ▶ Column Buckling of I-Beams
- ▶ Slenderness Ratio
- ▶ Euler Column Equation

In part one, three different length plastic I-beams are tested under compression to investigate their method of failure. The way in which a member fails (buckling or not) is determined by its Slenderness Ratio, and this ratio is calculated for each beam. Topics covered also include the Radius of Gyration and the Area Moment of Inertia.

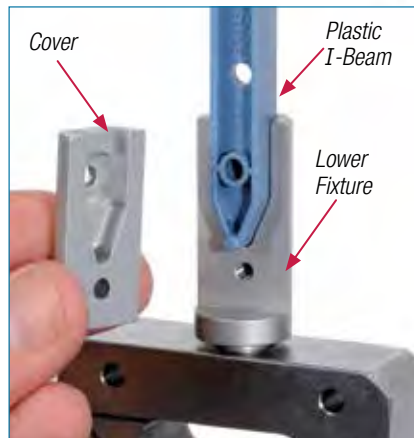


Experiment Includes

- Materials Testing Machine ME-8236
- Structures Beam Adapter ME-8242
- Structures Truss Set I-Beams ME-6993
- Structures Flat Beam ME-6987
- Structures Thin I-Beam ME-7012
- Calipers SE-8710

Required

- 550 or 850 Universal Interface or AirLink

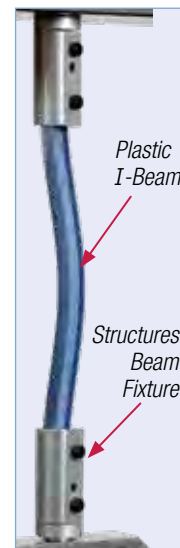


In part two, the critical force is predicted using the Euler Column Equation. When a compressive force is applied to a long straight column, it will elastically compress until a critical force (F_{crit}) is reached, and at this point the column will suddenly buckle. The relationship between this critical load and the column material and geometry is called the Euler Column Equation.

$$F_{crit} = \frac{4\pi^2 EI}{L^2}$$

PASCO Advantage

PASCO Capstone software has the ability to embed live video from a webcam and sync the Materials Tester data to the recorded video. Then you can play back the video along with the data on the graph, stepping through one frame at a time to see the exact breaking point



Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

- Column Buckling EX-5558
- Required:
- 550 or 850 Universal Interface or AirLink..... pp. 28-30
- PASCO Capstone Software..... pp. 72-75

3-Point and 4-Point Bending

EX-5559

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ AirLink

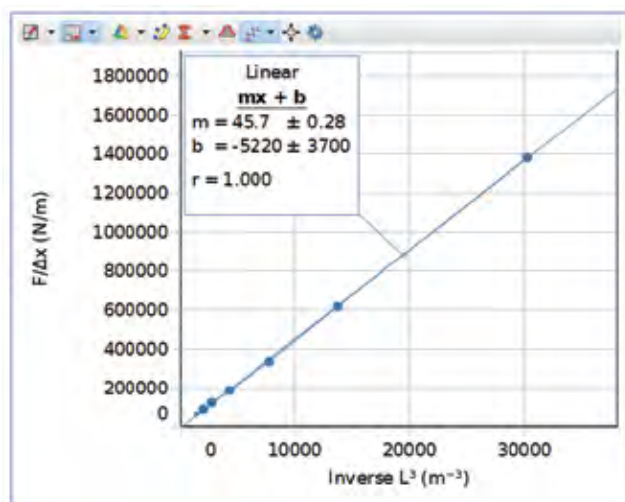
Concepts:

- ▶ 3-Point Bending
- ▶ 4-Point Bending
- ▶ Flexural Elastic Modulus

3-Point Bending

A Three-Point Bend test is performed on a round rod as shown. As a downward force (F) is applied in the middle of the rod, the flex (Δx) is recorded. The ratio ($F/\Delta x$) is the effective stiffness of the length of rod being tested.

The distance between the anvils is varied, and the resulting effect on the stiffness of the beam is measured. A graph of the resulting data yields the Flexural Elastic Modulus for the material.



4-Point Bending

A Four-Point Bend Test is performed on the ABS plastic beams from the PASCO Structures System. As a downward force (F) is applied in the middle of the beam, the flex (Δx) is recorded. The ratio ($F/\Delta x$) is the effective stiffness of the length of beam being tested, and is measured directly from the slope of the F vs. Δx graph. The Flexural Elastic Modulus for the material is then calculated.

Experiment Includes

- | | |
|-----------------------------|---------|
| • Materials Testing Machine | ME-8236 |
| • Bending Accessory | ME-8237 |
| • Shear Samples | ME-8240 |
| • Structures Flat Beams | ME-6987 |
| • Four-Point Load Anvil | ME-8249 |
| • Calipers | SE-8710 |

Required

- 550 or 850 Universal Interface or AirLink
- PASCO Capstone software

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.



Order Information

3-Point and 4-Point Bending.....EX-5559

Required:

550 or 850 Universal Interface or AirLink.....pp. 28-30
 PASCO Capstone Software.....pp. 72-75

Thermodynamics

Specific Heat

EX-5524A

Concepts:

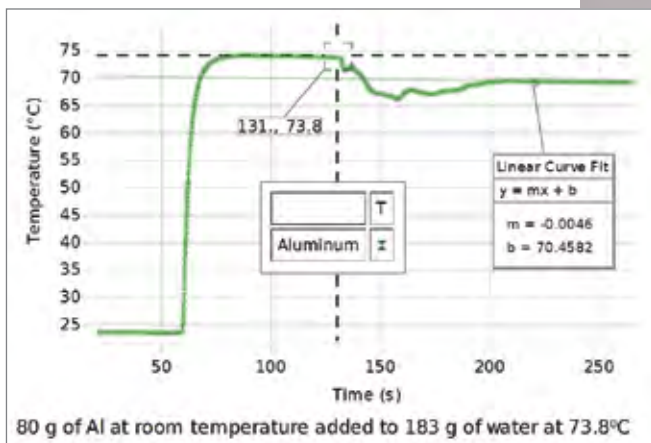
- ▶ Thermal energy
- ▶ Equilibrium temperature
- ▶ Specific heat

Students learn that materials can be identified using specific heat as a measurable characteristic. A known mass of water is used and the unknown material is placed in the water. The initial temperature of the water and the unknown material are measured. The equilibrium temperature is found and from this the specific heat of the unknown material is derived.

By performing this experiment in two ways (water warming, water cooling) students explore how experiment design may alter results. Finally students explore sources of error and magnitude of error.

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ AirLink



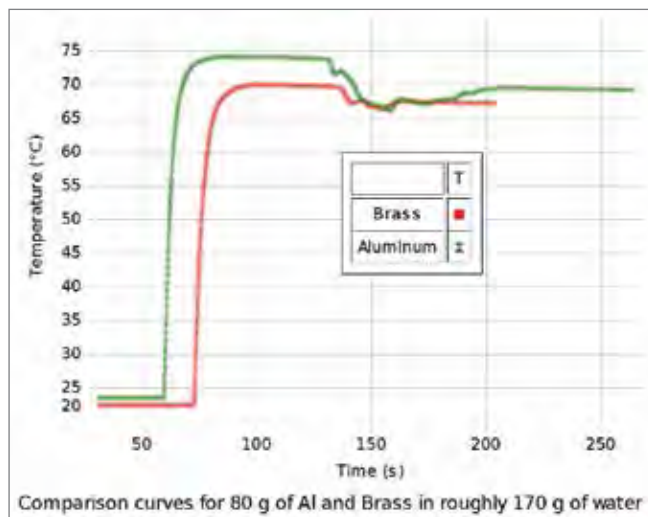
Room temperature A1 is added to hot water. After 210 s, the system has come to equilibrium and is slowly cooling. A linear fit to the cooling curve allows extrapolation back to find the equilibrium temperature that would have occurred at 131 s when the A1 was added if the system had come to equilibrium instantaneously. This allows measurement of the specific heat within at approximately 10%.

Experiment Includes

- Temperature Sensor PS-2125
- Calorimetry Cup with Lid PS-3401
- Heater Stirrer SE-8723
- Balance
- Graduated Cylinder, 50 mL
- 1000-mL Beaker
- Braided Physics String SE-8050

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone™ workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.



Comparison of a similar system shows that A1 causes about twice the drop in water temperature as does brass. The cooling slopes before and after support Newton's Law of Cooling.

Order Information

Specific Heat EX-5524A

Required:

550 or 850 Universal Interface* p. 28-30

PASCO Capstone Software pp. 72-75

* This experiment can be performed using the 550 or 850 Universal Interface or AirLink.

Electrical Equivalent of Heat

EX-5525

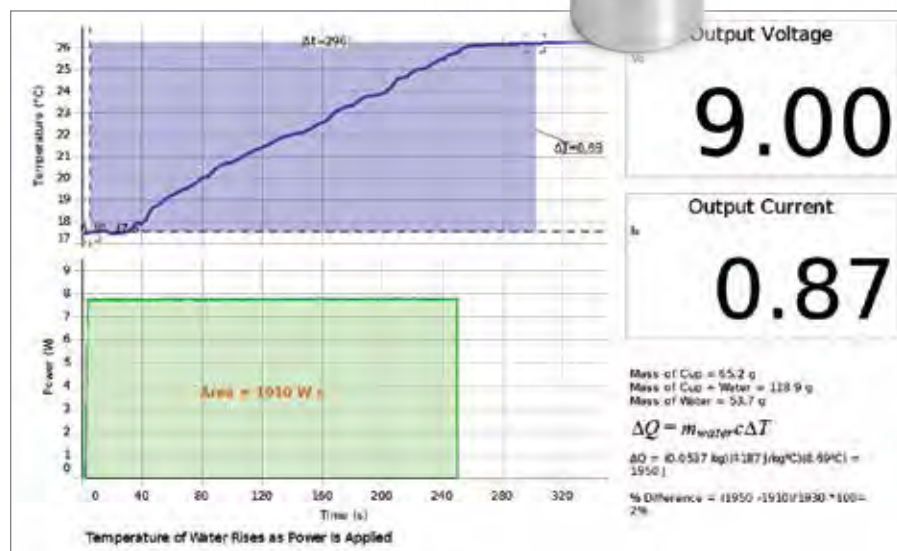
Designed for use with the 850 Universal Interface

Concept:

- Compare electrical energy input to changes in internal energy

The double wall of the aluminum Calorimeter Cup ensures good insulation. Energy is added to the system using the 10 Ω Heating Resistor, powered by the 850 Universal Interface. The voltage, current, power, and resulting increase in temperature are monitored and displayed continuously.

The amount of electrical energy used to heat the water (and the inner cup) is equal to the area under the Power vs. Time curve. The amount of heat delivered to the water (and the inner cup) can be calculated using the increase in temperature and the mass of the water. The comparison of the electrical energy to the heat results in a value for the number of joules in a calorie.



The bottom graph displays the power output from the generator and the top graph the increase in temperature. The amount of electrical energy used to heat the water is determined by finding the area under the Power vs. Time curve.

Experiment Includes

- | | |
|-------------------------------|---------|
| • Energy Transfer-Calorimeter | ET-8499 |
| • Temperature Sensor | PS-2125 |
| • Mass Scale | SE-8707 |

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

| | |
|-------------------------------------|-----------|
| Electrical Equivalent of Heat | EX-5525 |
| Required: | |
| 850 Universal Interface..... | p. 28-30 |
| PASCO Capstone Software..... | pp. 72-75 |

Thermodynamics

Ideal Gas Law

EX-5527

Concepts:

- ▶ Ideal Gas Law
- ▶ Boyle's Law
- ▶ Gay-Lussac's Law

The temperature, volume, and pressure of a gas are measured simultaneously to show that they change according to the Ideal Gas Law. Two special cases of the Ideal Gas Law are also examined: constant volume (Gay-Lussac's Law) and constant temperature (Boyle's Law). A syringe is used to vary the volume at constant temperature. A sphere of constant volume is immersed in different temperature water baths to show the change in pressure.

PASCO Advantage

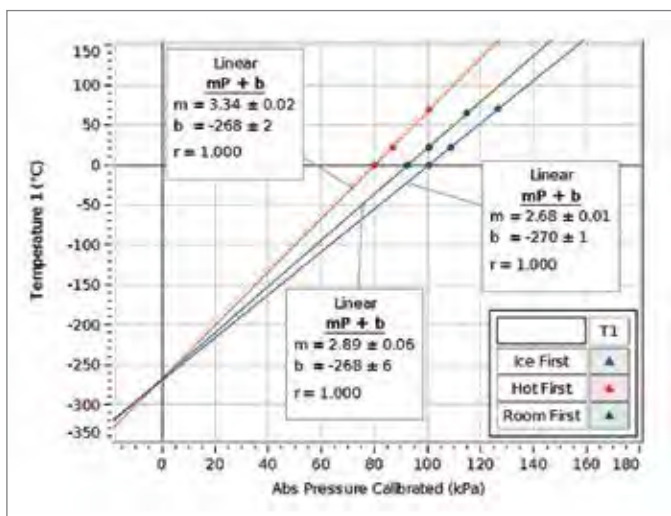
The Ideal Gas Syringe and Absolute Zero Sphere have a thermistor with small mass that responds quickly to temperature changes.

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ AirLink



For the Ideal Gas Syringe (shown above) the Slope of the Volume vs. $\frac{1}{P}$ graph equals nR .



For the Absolute Zero Apparatus (shown at right), which has constant volume, the Pressure vs. Temperature graphs have different slopes corresponding to the different number of moles in the container.



Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Experiment Includes

- Ideal Gas Law Syringe TD-8596A
- Pressure/Temperature Sensor PS-2146
- Absolute Zero Apparatus TD-8595
- Plastic Containers (2) ME-7559

Order Information

Ideal Gas Law EX-5527

Required:

550 or 850 Universal Interface* pp. 28-30
 PASCO Capstone Software pp. 72-75
 Calipers SE-8710 p. 196

* This experiment can be performed using the 550 or 850 Universal Interface or AirLink.

Blackbody Radiation

EX-5529A

Designed for use with the
850 Universal Interface

Concepts:

- ▶ Blackbody spectrum
- ▶ Peak wavelength vs. temperature

The classic blackbody spectrum of light intensity vs. wavelength is obtained for a light bulb, and the shift in the peak wavelength is demonstrated for different bulb temperatures.

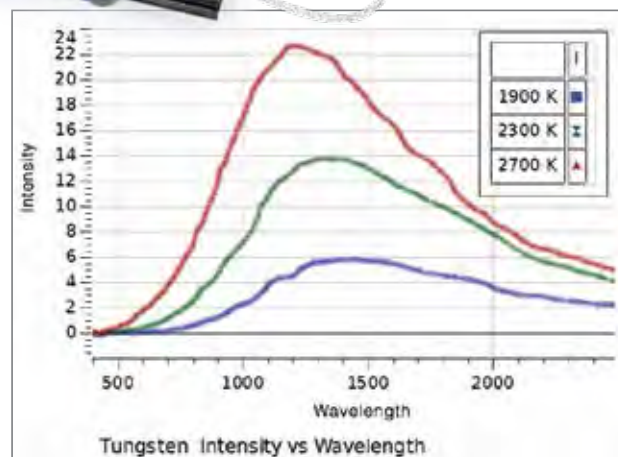
The continuous blackbody spectrum is scanned using a prism spectrophotometer.



The spectrum of an incandescent light bulb is scanned by hand using a prism spectrophotometer, which measures relative light intensity as a function of angle. A Broad Spectrum Light Sensor is used with a prism, so the entire spectrum from approximately 400 nm to 2500 nm can be scanned without the overlapping orders caused by a grating. The wavelengths corresponding to the angles are calculated using the equations for a prism spectrophotometer. The relative light intensity can then be plotted as a function of wavelength as the spectrum is scanned, resulting in the characteristic blackbody curve. The intensity of the light bulb is reduced, which reduces the temperature, and the scan is repeated to show how the curves nest with a shift in the peak wavelength.

The temperature of the bulb's filament can then be measured indirectly by determining the resistance of the bulb from the measured voltage and current. From the temperature, the theoretical peak wavelength can be calculated and compared to the measured peak wavelength.

Note: Results are qualitative and suitable for introductory classes only.



Classic textbook diagram of the intensity vs. wavelength blackbody curves can be produced with real data. In this graph, the peak wavelength in the blackbody curve shifts as the source temperature is decreased.

PASCO Advantage

All the complex calculations for the angle-to-wavelength conversion are stored in the setup file supplied for PASCO Capstone.

Experiment Includes

- | | |
|------------------------------------|----------|
| • Prism Spectrophotometer Kit | OS-8544 |
| • Optics Bench (60 cm) | OS-8541 |
| • Spectrophotometer Accessory Kit | OS-8537 |
| • Aperture Bracket | OS-8534A |
| • Broad Spectrum Light Sensor | PS-2150 |
| • Rotary Motion Sensor | PS-2120A |
| • Voltage Sensor | UI-5100 |
| • Replacement Bulb (10 pk) | SE-8509 |
| • Black Banana Plug Cords (5 pack) | SE-9751 |

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Blackbody RadiationEX-5529A

Required:

850 Universal Interface..... pp. 28-29
PASCO Capstone Software..... pp. 72-75

Thermodynamics

Heat Engine Cycle

EX-5530B

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ Any PASPORT interface with 3 ports

Concepts:

- ▶ Heat engine efficiency
- ▶ Isothermal processes
- ▶ Isobaric processes
- ▶ Ideal Gas Law

A P-V diagram is generated as a heat engine is taken through a cycle. From this diagram, the heat added to the gas and the work done by the engine are measured to determine the efficiency of the engine. This actual efficiency is compared to the theoretical maximum efficiency.

The heat engine consists of air inside a cylinder that expands when an attached can is immersed in hot water. The expanding air pushes on a piston and does work by lifting a weight. The heat engine cycle is completed by immersing the can in cold water, which returns the air pressure and volume to the starting values.

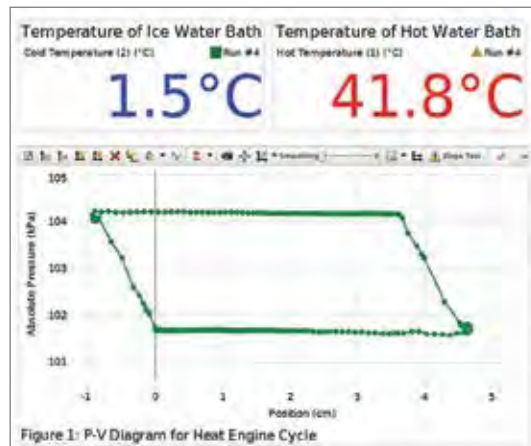


Figure 1: P-V Diagram for Heat Engine Cycle
The PASCO Capstone™ graph shows an isobaric/isothermal heat engine cycle operating between a cold water bath at 1.5°C and a hot water bath at 41.8°C.

The actual efficiency is determined for a heat engine that lifts a weight as heat is added to the gas.

PASCO Advantage

This operating heat engine shows how a difference in temperature can be used to do work. Each part of the cycle is easily identifiable, and the actual efficiency as well as the maximum possible efficiency can be easily determined.

The cycle is performed as follows:

1. With the can in the cold bath, the 200 g mass is placed on the platform.
2. The can is moved from the cold bath to the hot bath.
3. The 200 g mass is removed from the platform.
4. The can is moved from the hot bath to the cold bath.

The change in pressure is measured with a Low Pressure Sensor. The change in piston height is measured by the attached string over the Rotary Motion Sensor pulley. The change in volume is calculated by multiplying the change in piston height by the piston cross-sectional area.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Experiment Includes

- | | |
|---------------------------------|----------|
| • Heat Engine/Gas Law Apparatus | TD-8572A |
| • Large Rod Stand | ME-8735 |
| • Slotted Mass (200 g) | SE-8811 |
| • Mass & Hanger Set | ME-8979 |
| • Plastic containers (2) | ME-7559 |
| • Thread | |
| • 90 cm Long Steel Rod | ME-8738 |
| • Rotary Motion Sensor | PS-2120A |
| • Quad Temperature Sensor | PS-2143 |
| • Dual Pressure Sensor | PS-2181 |

Order Information

Heat Engine Cycle.....EX-5530B

Required:

550 or 850 Universal Interface* pp. 28-30
PASCO Capstone Software..... pp. 72-75

* This experiment can be performed using the 850 Universal Interface or any PASPORT interface with three ports.

Ratio of Specific Heats

EX-5531A

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ AirLink

Concepts:

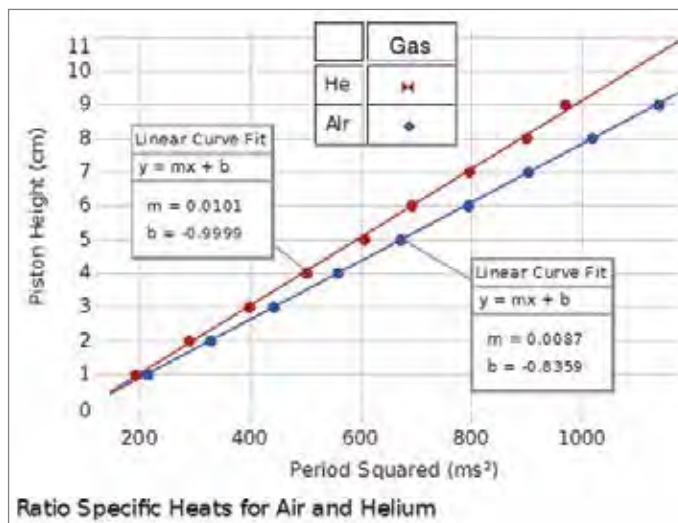
- ▶ C_p/C_v for a gas
- ▶ Ruchardt's method of measuring the ratio of specific heats
- ▶ Adiabatic process

In this experiment, the ratio of specific heat capacities for air is determined using Ruchardt's method of measuring the period of oscillation of the piston in a cylinder filled with air.

A cylinder is filled with air and a Pressure Sensor is attached. The piston is plucked by hand and allowed to oscillate. The oscillating pressure is recorded as a function of time and the period is determined. The ratio of specific heat capacities is calculated using the period of oscillation, according to Ruchardt's method.

PASCO Advantage

Since the oscillations are plotted, it is easy to accurately measure the period of oscillation.



A plot of the Piston Height vs. the Period Squared shows that the period increases as the gas volume increases. The slope of the line is related to the ratio of specific heats (C_p/C_v) and is different for the two gases.



The pressure oscillates after the piston is plucked by hand.

Experiment Includes

- Heat Engine/Gas Law Apparatus TD-8572A
- Large Rod Stand ME-8735
- 45 cm Long Steel Rod ME-8736
- Dual Pressure Sensor PS-2181

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Ratio of Specific Heats.....EX-5531A

Required:

550 or 850 Universal Interface* pp. 28-30

PASCO Capstone Software..... pp. 72-75

* This experiment can be performed using the 550 or 850 Universal Interface or AirLink.

Electromagnetism

Electrostatic Charge

EX-5532

Concepts:

- ▶ Methods of charging
- ▶ Charge distribution
- ▶ Conservation of charge

Using classic equipment (a Faraday Ice Pail and Conductive Spheres), students learn to charge objects by direct contact and by induction. The charge is measured using a high impedance electrometer.

Students explore the distribution of charge on different shaped conductive shapes. A sphere with a hole in it is provided to show that no charge resides on the inner surface of the conductor when it is charged.



New Digital Readout



Experiment Includes

- | | |
|------------------------------------|----------|
| • Basic Electrometer | ES-9078A |
| • Charge Producers and Proof Plane | ES-9057C |
| • Faraday Ice Pail and Shield | ES-9042A |
| • Conductive Spheres, 13 cm | ES-9059C |
| • Conductive Shapes | ES-9061 |
| • Electrostatics Voltage Source | ES-9077 |

Order Information

Electrostatic Charge.....EX-5532

Required:

PASCO Capstone Software.....pp. 72-75
(No interface required.)

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

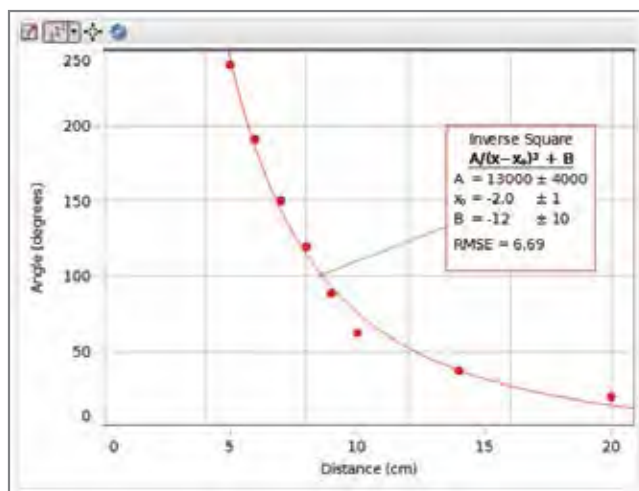
Coulomb's Law

EX-9930B

Concepts:

- ▶ Verify the Inverse Square Law: $F \sim 1/R^2$
- ▶ Verify the Force/Charge Relationship: $F \sim q_1 q_2$
- ▶ Determine Coulomb's Constant: $k = 9.0 \times 10^9 \text{ Nm}^2/\text{C}^2$

A conductive sphere is mounted on the end of an insulating counterbalanced rod and suspended from a very thin torsion wire. An identical sphere is mounted on a calibrated linear track and can be positioned at various distances from the first sphere. When the conductive spheres are charged, the force between them is proportional to the twist of the torsion wire that is required to bring the balance back to its equilibrium position. Introductory physics students can determine the Inverse Square Law in a simple experiment, while advanced students can perform investigations into all the variables involved in electrostatic repulsion.



Electrostatic force is directly proportional to the angle of twist, and the angle of twist is proportional to the inverse square of the separation of the balls.



When an electrostatic force is applied, the torsion wire is twisted to return the balance to equilibrium. The twist of the wire is proportional to the electrostatic repulsion force.

Experiment Includes

- | | |
|------------------------------------|----------|
| • Coulomb's Law Apparatus | ES-9070 |
| • Kilovolt Power Supply | SF-9586B |
| • Basic Electrometer | ES-9078A |
| • Faraday Ice Pail | ES-9042A |
| • Charge Producers and Proof Plane | ES-9057C |
| • Coulomb's Law Experiment Manual | |

Order Information

Coulomb's Law..... EX-9930B
(No interface required.)

To Download This Experiment

Search for EX-9930B at www.pasco.com

Electromagnetism

Charge of an Electron

EX-9929A

Concepts:

- ▶ Accurately measure the charge of a single electron
- ▶ Recreate Robert Millikan's historical experiment

Small droplets of oil are introduced into a chamber where an electric field of known strength is present. Using the viewing scope and a stopwatch, the velocity of a falling oil droplet is measured and recorded. Next, the electric field in the chamber is increased, causing the oil droplet to move upward. This allows the measurement of the force on the droplet and, ultimately, the charge of the droplet. By measuring the charge of several different oil droplets, the smallest difference in charge between them can be equated to the charge of an electron.



PASCO Advantage

PASCO's Charge of an Electron Experiment features a 30x, bright-field, erect-image microscope for clear viewing of the oil droplets. The droplet viewing chamber utilizes a special condenser to minimize droplet drift typically caused by droplet illumination and outside air currents. An ionization source allows the droplet charge to be changed.

Experiment Includes

- | | |
|---|----------|
| • Millikan Oil Drop Apparatus | AP-8210 |
| • Basic Digital Multimeter | SE-9786A |
| • High Voltage Power Supply | SF-9585A |
| • Large Rod Base | ME-8735 |
| • 45 cm Steel Rod (2) | ME-8736 |
| • Red Banana Plug Cords (5 Pack) | SE-9750 |
| • Black Banana Plug Cords (5 Pack) | SE-9751 |
| • Charge of an Electron Experiment Manual | |

Easy Cleaning

The condenser system easily disassembles for cleaning and inspection.

Condenser Housing

Minimum Electric Field Distortion

A 0.5 mm diameter droplet entry hole in the top capacitor plate has a negligible effect on the electric field.

Ionization Source

The thorium-232 alpha source can be activated by the switch on the side of the chamber. The source allows the charge on the oil droplets to be changed.

Droplet Hole Cover

Prevents additional droplets from entering the chamber once the experiment has started.

Polished Surfaces

Polished surfaces on the plate spacer minimize absorption of light (and heat) through the chamber walls.

Electrical Connection

Electrical connection to the top plate

Condenser Assembly

To Download This Experiment

Search for EX-9929A at www.pasco.com

Order Information

Charge of an ElectronEX-9929A
(No interface required.)

Capacitance

EX-5533

Designed for use with any of the following:

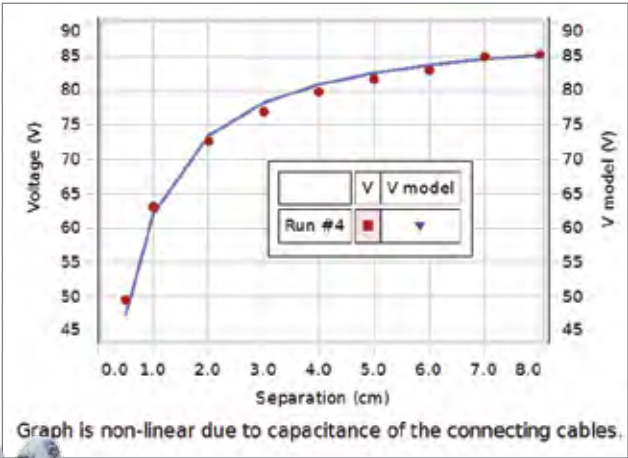
- ▶ 850 Universal Interface
- ▶ 550 Universal Interface

Concepts:

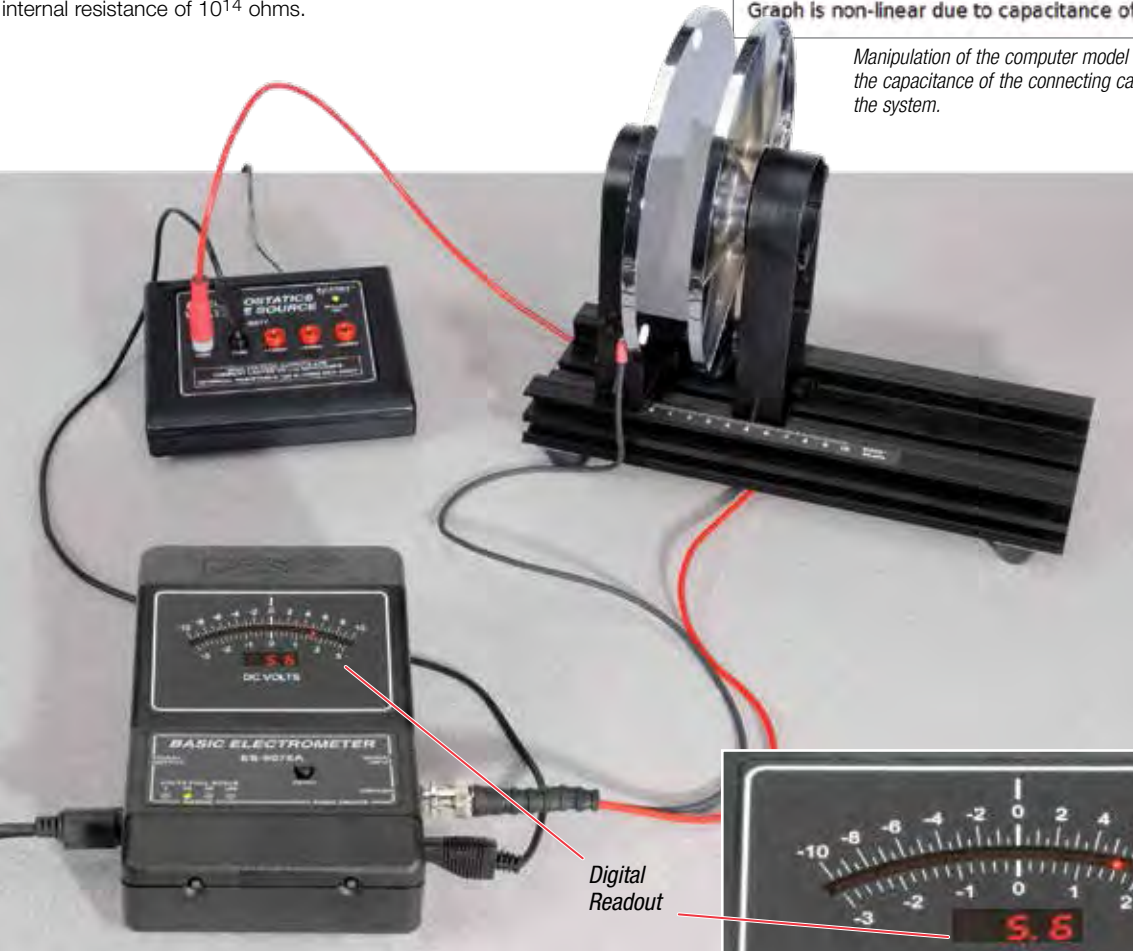
- ▶ Capacitance
- ▶ Parallel plate capacitor
- ▶ Factors affecting capacitance

This lab explores the effect of varying the plate distance and insulating dielectric materials in a variable flat plate capacitor.

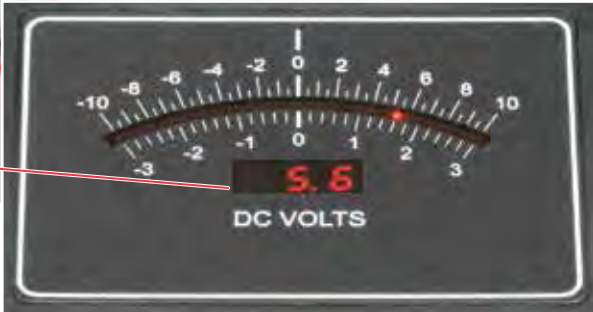
The electrometer used in this experiment makes it possible to measure the voltage across the capacitor plates without discharging the capacitor, since it has an internal resistance of 10^{14} ohms.



Manipulation of the computer model allows measurement of the capacitance of the connecting cables and the charge on the system.



Digital Readout



Experiment Includes

- Basic Electrometer ES-9078A
- Basic Variable Capacitor ES-9079
- Electrostatics Voltage Source ES-9077

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Capacitance..... EX-5533

Required:

550 or 850 Universal Interface pp. 28-30
PASCO Capstone Software..... pp. 72-75

Electromagnetism

Resistivity

EX-5534

Designed for use with the
850 Universal Interface

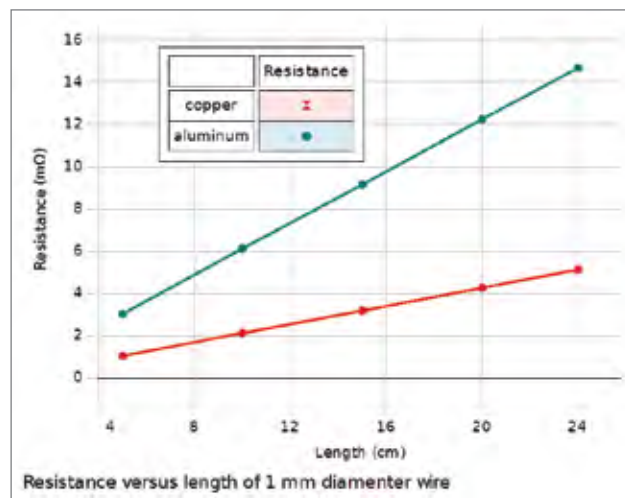
Concepts:

- Relate resistance to wire length
- Determine resistivity of different materials

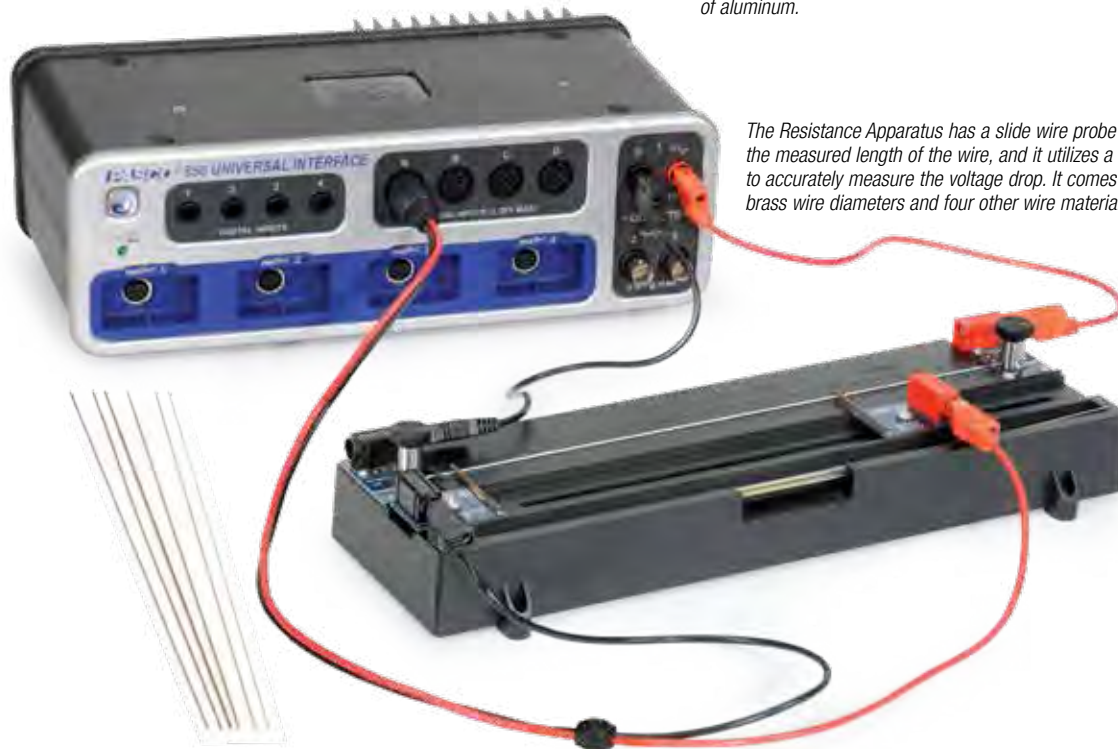
Discover the relationship between the resistance of a wire and its length, diameter, and the resistivity of the metal.

The current is measured directly by the 850 Universal Interface, and the voltage drop over the selected section of wire is measured by the Voltage Sensor. This allows easy calculation of the resistance of the length of wire. The resistance is plotted vs. the length of the wire, and the slope of the resulting straight line is used to determine the resistivity.

Using wires of the same diameter made of different materials allows examination of the effect of resistivity. Using brass wires with various diameters allows examination of the effect diameter has on resistance.



Since both wires have the same diameter, the resistivity is directly proportional to the slope. The graph shows that the resistivity of copper is about one-third that of aluminum.



The Resistance Apparatus has a slide wire probe to easily change the measured length of the wire, and it utilizes a four wire hook-up to accurately measure the voltage drop. It comes with four different brass wire diameters and four other wire materials.

PASCO Advantage

The Resistance Apparatus has a slide-wire probe to easily change the measured length of the wire. It utilizes a four-wire hook-up to accurately measure the voltage drop.

The 850 Universal Interface Power Amplifier makes it possible to scan the voltages, allowing more time to examine wires made of different metals and with different diameters.

Experiment Includes

- Resistance Apparatus EM-8812
- Voltage Sensor UI-5100
- Patch cords (set of 5) SE-9750

Order Information

Resistivity EX-5534

Required:

850 Universal Interface pp. 28-29
PASCO Capstone Software pp. 72-75
Micrometer p. 196

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Ohm's Law

EX-5535

Designed for use with any of the following:

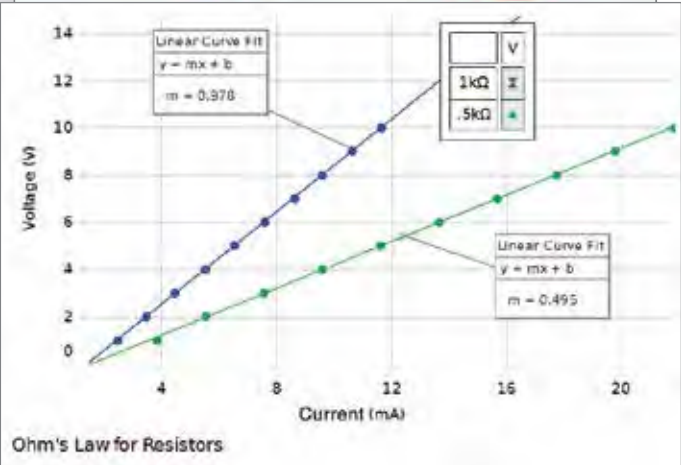
- ▶ 850 Universal Interface
- ▶ 550 Universal Interface

Concepts:

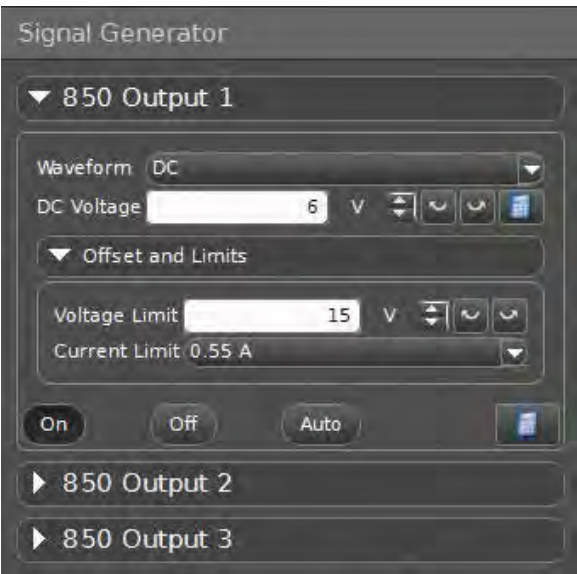
- ▶ Relationship between voltage and current

Method

In this experiment, students simultaneously measure both current and voltage for a simple DC circuit. The relationship between current and voltage is explored for different resistors in parallel. Voltage is graphed vs. current to verify Ohm's Law and recognize the physical meaning of slope.



The relationship between voltage and current varies for different circuit resistance.



Students control output from the 850 signal generators directly from the user interface in PASCO Capstone.

Experiment Includes

- Resistive/Capacitive/Inductive Network UI-5210
- Short Patch Cords (set of 8) SE-7123

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

- Ohm's Law EX-5535
- Required:
- 550 or 850 Universal Interface pp. 28-30
- PASCO Capstone Software..... pp. 72-75

Electromagnetism

Kirchhoff's Circuit Law

EX-5538

Designed for use with any of the following:

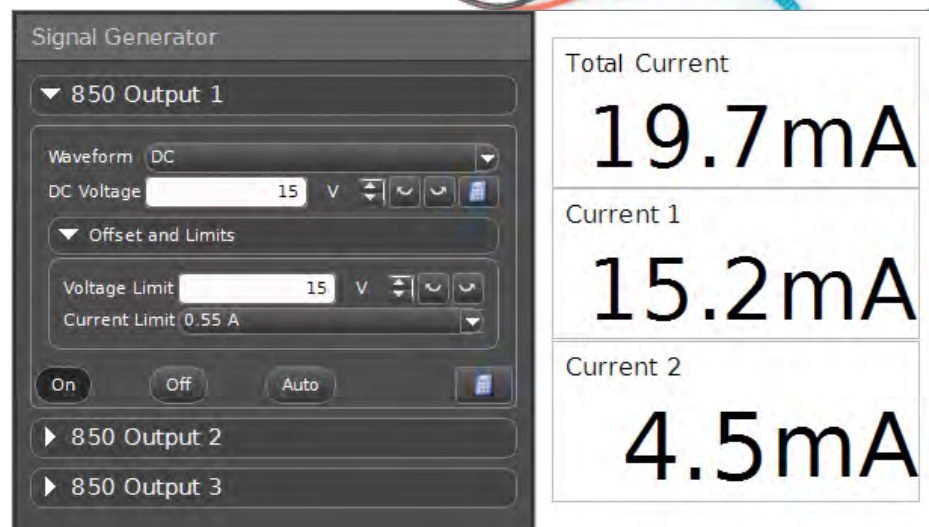
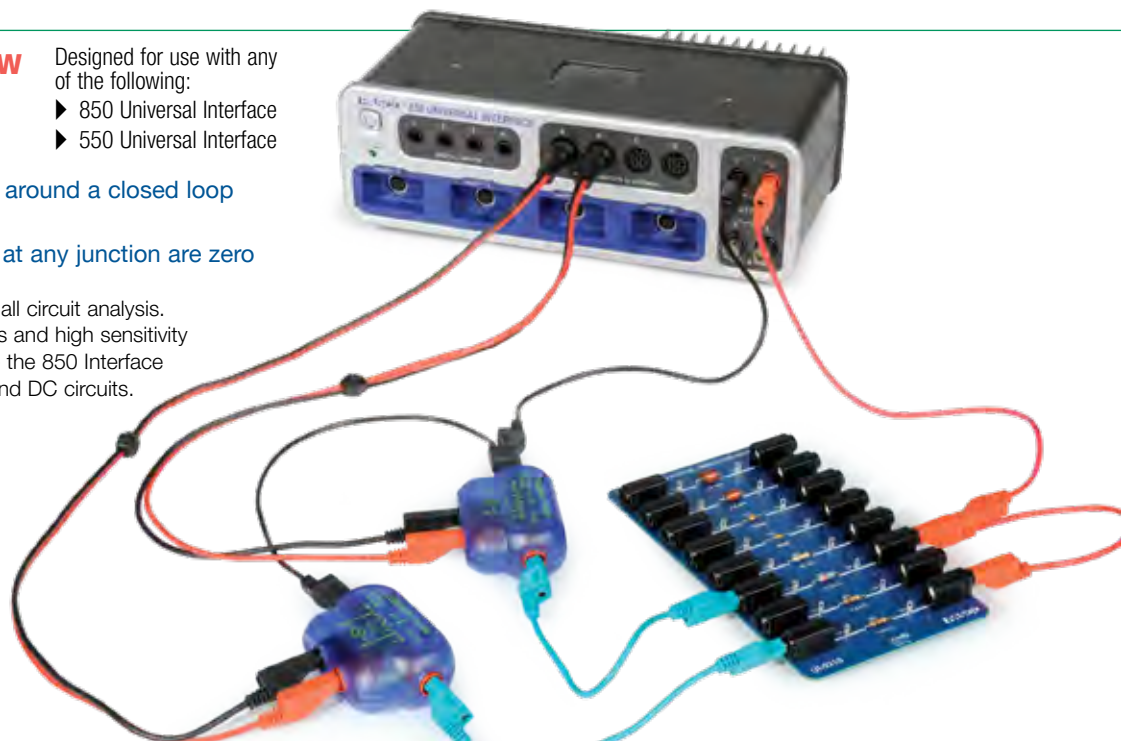
- ▶ 850 Universal Interface
- ▶ 550 Universal Interface

Concepts:

- ▶ Summation of the voltages around a closed loop are zero at any instant
- ▶ Summation of the currents at any junction are zero

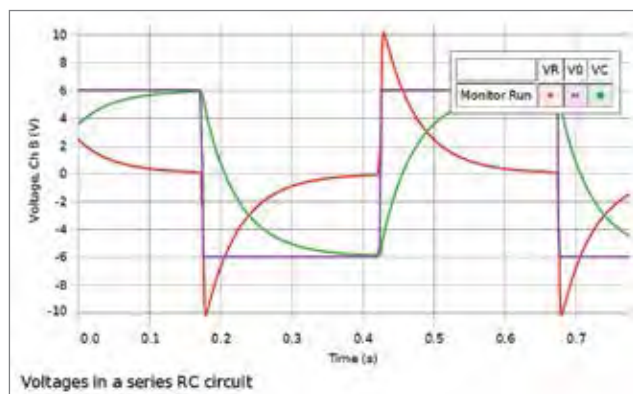
Kirchhoff's Laws form the basis of all circuit analysis. The high speed for AC applications and high sensitivity (0.1 mA) for DC applications make the 850 Interface an ideal tool for investigating AC and DC circuits.

Students control output from the 850 signal generators directly from the user interface in PASCO Capstone.



Measurement of voltages and currents in series-parallel DC circuits demonstrates the validity of Kirchhoff's Laws. The use of multiple current probes avoids student confusion that can arise when rearranging the circuit to measure currents at different points.

Students compare the current flow through each resistor to the total current output from the 850.



The high speed of the 850 Universal Interface, in scope mode, allows the examination of time varying voltages in an RC circuit to verify that Kirchhoff's loop theorem holds even when voltage is not constant.

Experiment Includes

- Resistive/Capacitive/Inductive Network UI-5210
- Voltage Sensors (3) UI-5100
- Current Probe (2) PS-2184
- Short Patch Cords (set of 8) SE-7123

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Kirchhoff's Circuit Law EX-5538

Required:

550 or 850 Universal Interface pp. 28-30

PASCO Capstone Software..... pp. 72-75

RC Circuit

EX-5536

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface

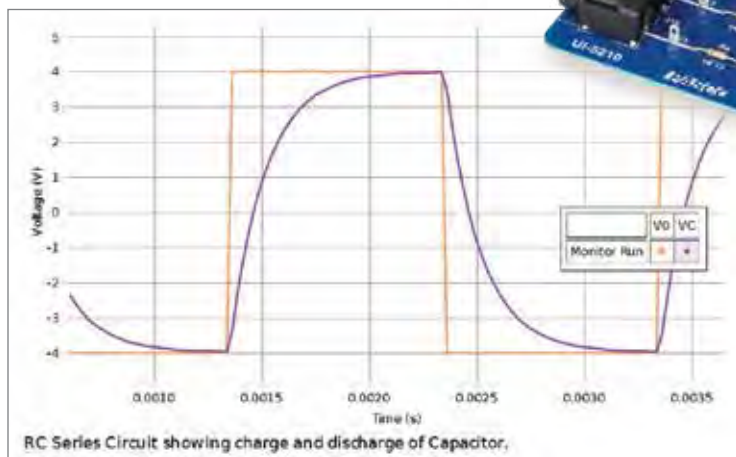
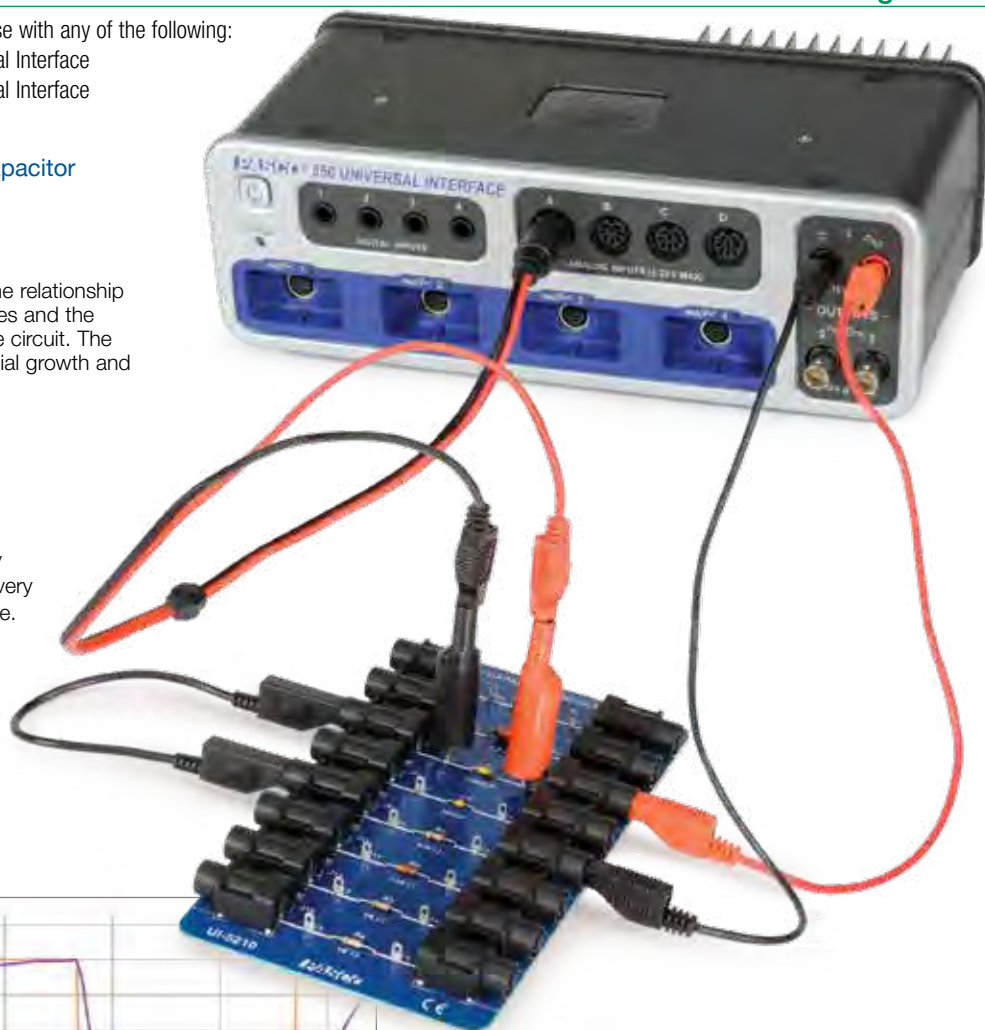
Concepts:

- ▶ Charging and discharging a capacitor
- ▶ Exponential growth and decay
- ▶ Time constants

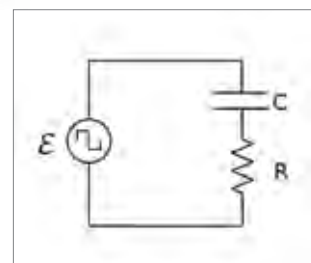
Students collect data to understand the relationship between charging and discharging rates and the capacitance and resistance in a simple circuit. The time constant is derived and exponential growth and decay are explored.

PASCO Advantage

The RC Circuit experiment is extremely simple and transparent to set up. It is very easy to measure the time to half charge. It is also easy to verify that the curve is exponential using the curve-fitting capability of PASCO Capstone software.



The actual capacitance is determined from the charge/discharge curve.



The 850 Universal Interface provides a very clean square wave to the series RC circuit.

Experiment Includes

- | | |
|--|---------|
| • Resistive/Capacitive/Inductive Network | UI-5210 |
| • Voltage Sensor | UI-5100 |
| • Short Patch Cords (set of 8) | SE-7123 |

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

RC Circuit EX-5536

Required:

550 or 850 Universal Interface pp. 28-30
 PASCO Capstone Software pp. 72-75

Electromagnetism

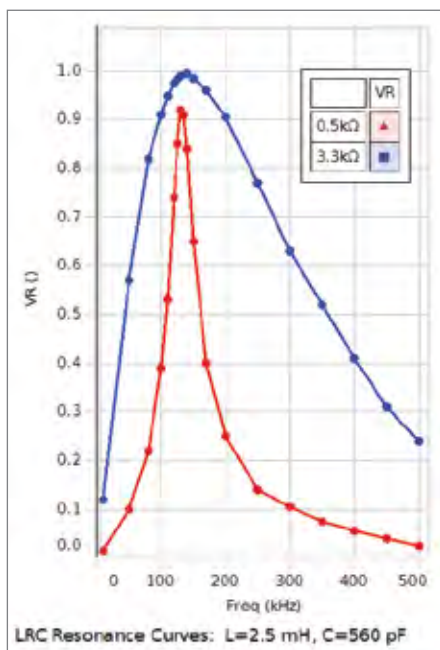
LRC Circuit

Designed for use with the 850 Universal Interface
EX-5537

Concepts:

- ▶ LC oscillations
- ▶ Inductive, capacitive, and resistive AC circuits
- ▶ LRC resonant frequency

The response of a series LRC circuit is examined at driving frequencies above, below, and at the resonant frequency. A sinusoidal voltage is applied individually to a resistor, a capacitor, and an inductor. The amplitude of the current and the phase difference between the applied voltage and the current are measured in each of the three circuits to see the effect each component has on the current. Finally, a sinusoidal voltage is applied to an inductor, resistor, and capacitor in series. The amplitude of the current and the phase difference between the applied voltage and the current are measured and compared to theory.



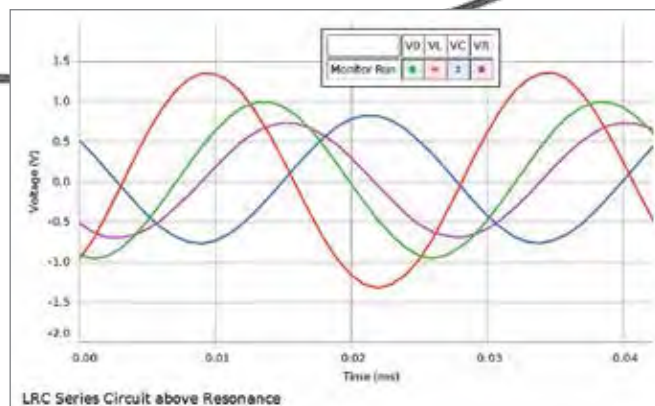
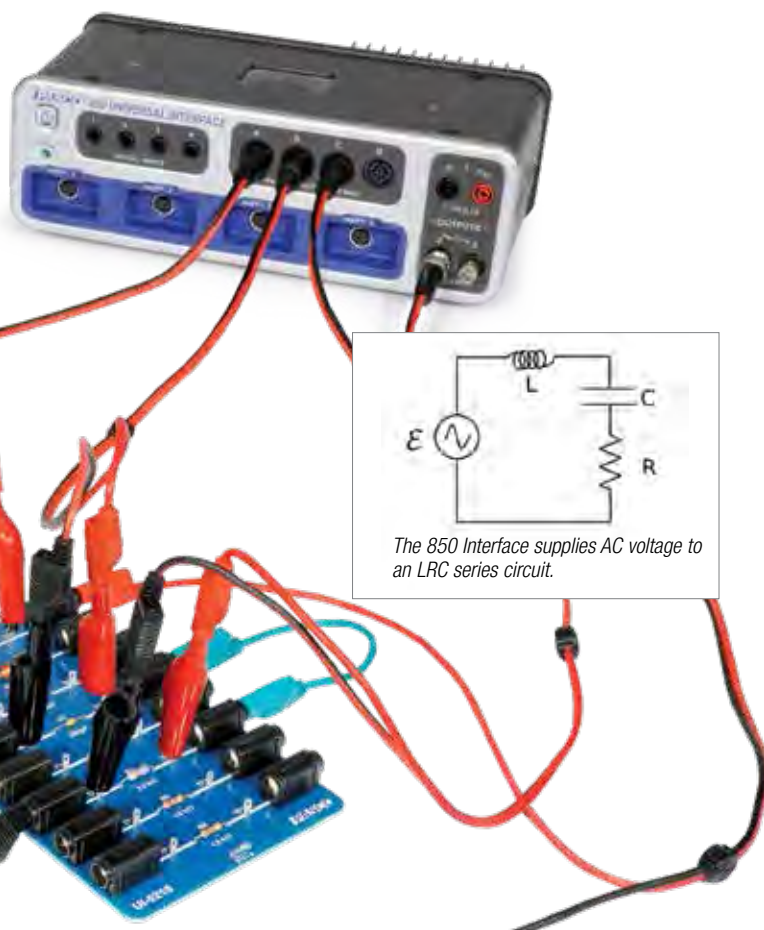
The effect of circuit resistance on peak width is clear and leads to an understanding of how to design a filter for a circuit.

Experiment Includes

- Resistive/Capacitive/Inductive Network UI-5210
- Voltage Sensors (3) UI-5100
- Short Patch Cords (set of 8) SE-7123
- BNC-to-Banana Output Cable UI-5119

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.



The oscilloscope display in PASCO Capstone is used to simultaneously display the voltages across the inductor, capacitor, and resistor, as well as the source voltage.

Order Information

LRC Circuit EX-5537

Required:

850 Universal Interface..... pp. 28-29

PASCO Capstone Software..... pp. 72-75

Earth's Magnetic Field

EX-5539A

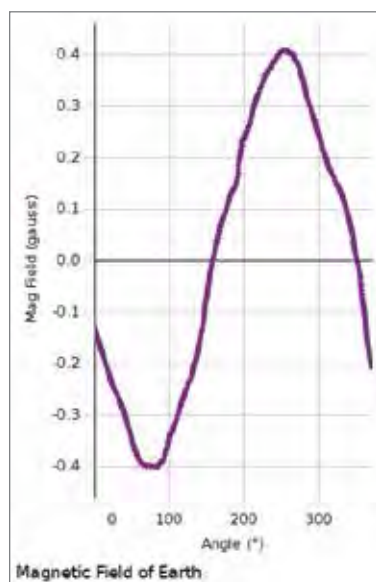
Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ Any PASPORT interface with 2 ports

Concepts:

- ▶ Magnitude of the earth's magnetic field
- ▶ Direction of earth's magnetic field
- ▶ Dip angle

The magnitude and direction of the Earth's magnetic field are measured using a Magnetic Field Sensor mounted on a Rotary Motion Sensor. The Magnetic Field Sensor is rotated through 360 degrees by rotating the Rotary Motion Sensor pulley by hand. The Magnetic Field Sensor is zeroed using the Zero Gauss Chamber, the walls of which are made of a highly permeable material that redirects the magnetic field around the chamber.



The Earth's magnetic field is measured as the Magnetic Field Sensor is rotated 360 degrees in the Earth's field.

PASCO Advantage

The sensitive Magnetic Field Sensor combined with the Rotary Motion Sensor enables the measurement of the magnetic field strength as a function of angle from North. It is essentially a computerized compass that can measure both the direction and the magnitude of the field.



The Magnetic Field Sensor is mounted on a Rotary Motion Sensor to measure the magnitude and direction of the Earth's magnetic field.

Experiment Includes

- | | |
|--|----------|
| • 2-Axis Magnetic Field Sensor | PS-2162 |
| • Zero Gauss Chamber | EM-8652 |
| • Rotary Motion Sensor | PS-2120A |
| • Dip Needle | SF-8619 |
| • Aluminum Table Clamp | ME-8995 |
| • 25 cm Stainless Steel Rod (threaded) | ME-8988 |
| • Adjustable Angle Clamp | ME-8744 |
| • Angle Indicator | ME-9495A |

Order Information

Earth's Magnetic Field EX-5539A

Required:

550 or 850 Universal Interface* pp. 28-30
 PASCO Capstone Software pp. 72-75

* This experiment can be performed using the 850 or 550 Universal Interface or any PASPORT interface with two ports.

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

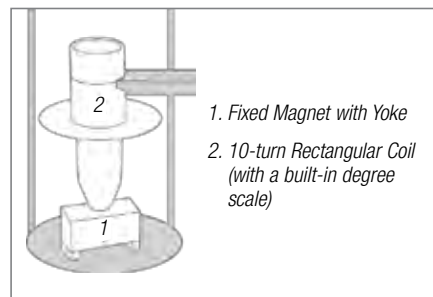
Electromagnetism

Magnetic Forces on Wires

EX-9933

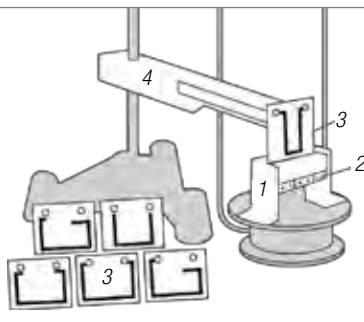
Concepts:

- ▶ Examine the relationships between: force and current, force and length of wire, force and magnetic field strength, and force and angle



1. Fixed Magnet with Yoke
2. 10-turn Rectangular Coil (with a built-in degree scale)

1. Iron Yoke (holds magnets)
2. Removable Magnets (six)
3. Six Conductors (1, 2, 3, 4, 6 and 8 cm in length)
4. Mount (for holding/positioning conductors)

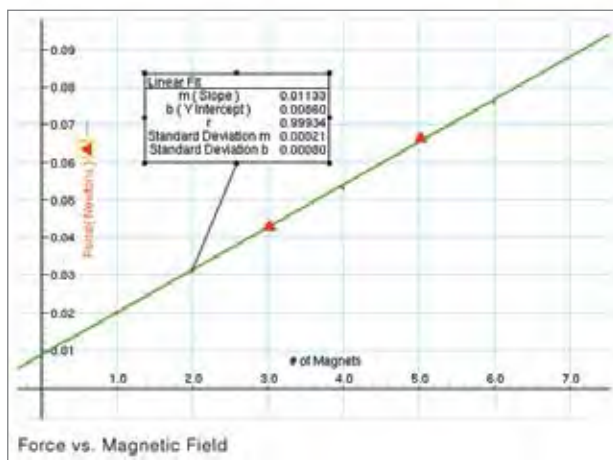


Magnets are mounted on an iron yoke and placed on a balance (resolution of at least 0.01 g). One of the conducting paths is suspended between the magnets. The balance is used to measure the mass of the magnets and yoke prior to any current passing through the conducting path. Current is then passed through the conducting path, producing a force. The change in reading on the balance can be converted to find the magnetic force between the conductor and magnetic field.

Conductors of different lengths are included to measure the effect of length on magnetic force. Magnetic field can be varied by changing the number of magnets in the yoke. The power source is used to change the current supplied to the conductor. The Current Balance Accessory includes all the components needed to test the effect of angle on magnetic force.

PASCO Advantage

PASCO's Magnetic Forces on Wires Experiment allows students to study the key variables (conductor length, current, magnetic field strength, and angle) that affect magnetic force.



Graph illustrates the direct relationship between magnetic field and magnetic force.

Experiment Includes

- Basic Current Balance SF-8607
- Current Balance Accessory SF-8608
- Ohaus Cent-o-Gram Balance SE-8725
- Low Voltage AC/DC Power Supply SF-9584B
- Large Base and Support Rod ME-9355
- Red Banana Plug Cords (5 pack) SE-9750
- Black Banana Plug Cords (5 pack) SE-9751
- Magnetic Forces on Wires Experiment Manual

To Download This Experiment

Search for EX-9933 at www.pasco.com

Order Information

Magnetic Forces on Wires.....EX-9933

No interface required.

Magnetic Fields of Coils

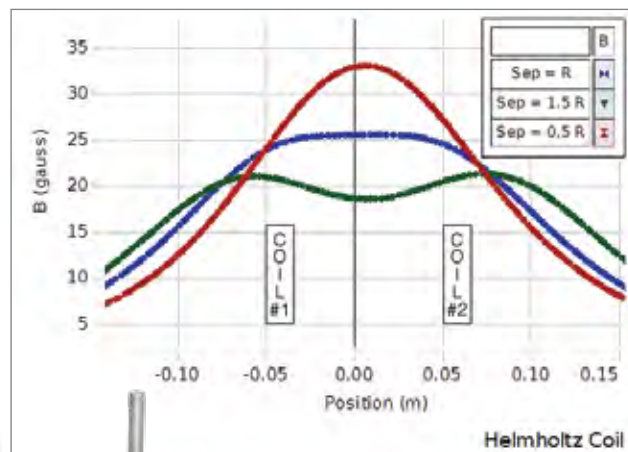
EX-5540A

Designed for use with the
850 Universal Interface

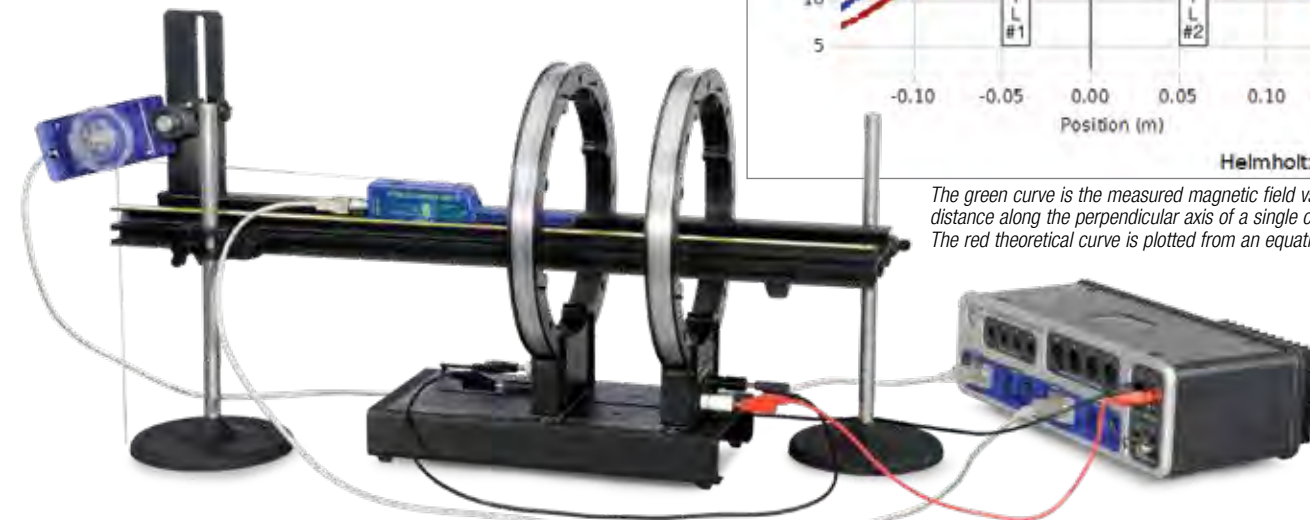
Concepts:

- ▶ Magnetic fields of:
single coil
Helmholtz coils
inside a solenoid

This plot shows the magnetic field strength along the axis of Helmholtz coils for three different coil separations. The green data is for coils with the proper separation (the coil radius); the red data is for the coils too close together; and the blue data is for the coils too far apart.



The green curve is the measured magnetic field vs. distance along the perpendicular axis of a single coil. The red theoretical curve is plotted from an equation.



The dependence of the magnetic field strength of current-carrying coils on the distance from the coil along the perpendicular axis is determined and compared to the theoretical curve. In addition, the effect of varying the coil separation on the shape of the magnetic field between the Helmholtz coils is examined.

The magnetic fields of various coils are plotted vs. position as the Magnetic Field Sensor is passed through the coils, guided by a track. The position is recorded by a string attached to the Magnetic Field Sensor that passes over the Rotary Motion Sensor pulley to a hanging mass. It is particularly interesting to compare the field from Helmholtz coils at the proper separation of the coil radius to the field from coils separated at less than or more than the coil radius.

The magnetic field inside a solenoid can be examined in both the radial and axial directions.

The magnetic field inside a solenoid is measured in the radial and axial directions.

The magnetic field of Helmholtz coils is measured as a function of distance along the perpendicular axis.



PASCO Advantage

Using the PASCO Capstone™ curve fit, the theoretical equation for the magnetic field can be plotted on the same graph.

Experiment Includes

| | |
|--------------------------------------|----------|
| • Helmholtz Coil Base | EM-6715 |
| • Field Coil (2) (500 turn) | EM-6723 |
| • Primary and Secondary Coils | SE-8653 |
| • Red Patch Cords (set of 5) | SE-9750 |
| • Black Patch Cords (set of 5) | SE-9751 |
| • 60 cm Optics Bench | OS-8541 |
| • Dynamics Track Mount | CI-6692 |
| • 20 g Hooked Mass (Hooked Mass Set) | SE-8759 |
| • Round Base with Rod (2 of each) | ME-8270 |
| • Optics Bench Rod Clamps (set of 2) | OS-8479 |
| • 2-Axis Magnetic Field Sensor | PS-2162 |
| • Rotary Motion Sensor | PS-2120A |

Order Information

Magnetic Fields of Coils..... EX-5540A

Required:

850 Universal Interface..... pp. 28-29
PASCO Capstone Software..... pp. 72-75

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Electromagnetism

Ampere's Law Experiment

EX-5552

Concepts:

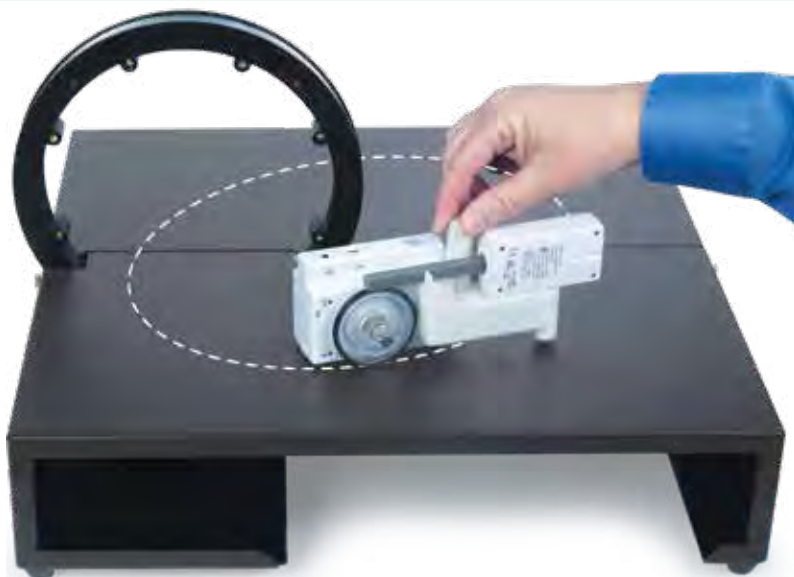
- ▶ Verify Ampere's Law
- ▶ Plot magnetic field tangent to path
- ▶ Closed integral is area under B vs. Distance plot
- ▶ Choose to enclose current in path or not

Students can verify Ampere's Law experimentally by graphing the magnetic field strength that is tangent to the path taken along a closed path that encloses a current source.

The magnetic field strength is measured with a Wireless Magnetic Field Sensor which rides on a Rotary Motion Sensor. The student pushes the Rotary Motion Sensor, which rolls on its wheel, along a closed path.

PASCO Advantage

The Wireless 3-Axis Magnetic Field and Rotary Motion sensors allow the students to move in any shaped path without wires getting wrapped around the coil. Students can choose any path they want; you don't have to follow a circular path because the sensors are recording the field tangent to any path.



*The path taken can be any shape, provided that it is a closed path.
The suggested dotted path shown is not marked on the apparatus.*

Ampere's Law

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 NI$$

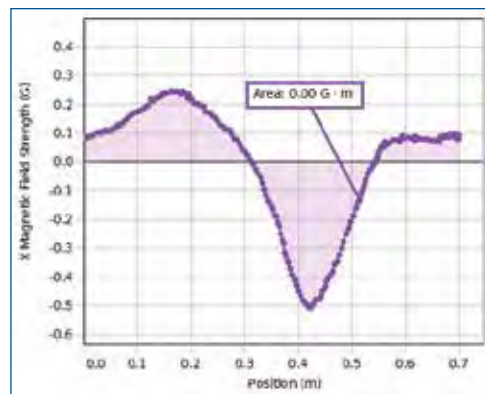
Area under B vs. Distance curve = μ_0 (# of coil turns enclosed in path) (Current)

The key to making this work is that the Magnetic Field Sensor element is positioned tangent to the Rotary Motion Sensor's wheel. This accomplishes the dot product in Ampere's Law because only the component of the magnetic field that is tangent to the path is recorded.

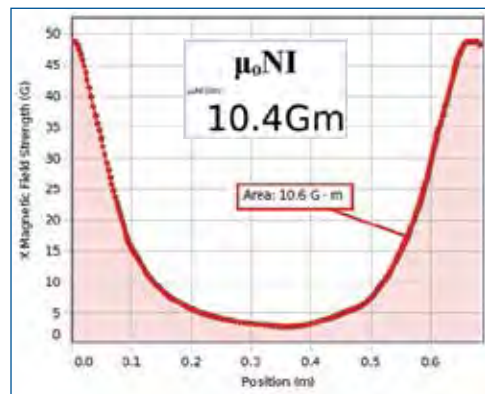
If you traverse a path that does not enclose any current source, the area under the curve is zero. The magnetic field of the Earth or any nearby source is measured but they will cancel out in a closed loop that encloses no current.

Includes

- | | |
|---|---------|
| • Ampere's Law Accessory | EM-6720 |
| • Wireless 3-Axis Magnetic Field Sensor | PS-3221 |
| • Wireless Rotary Motion Sensor | PS-3220 |
| • Field Coil (500-turn) | EM-6723 |
| • Zero Gauss Chamber | EM-8652 |



No current enclosed: Area is zero.



Current enclosed: Area is $\mu_0 NI$.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Ampere's Law EX-5552

Required:

PASCO Capstone Software pp. 72-75

Faraday's Law of Induction

EX-5541A

Designed for use with any of the following:

- 850 Universal Interface
- 550 Universal Interface

Concepts:

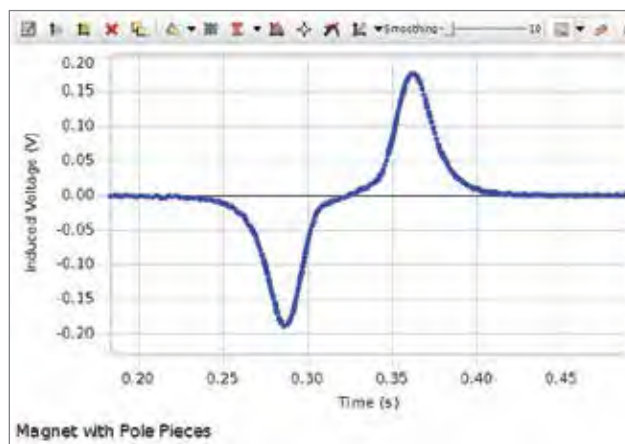
- Magnetic flux
- Faraday's Law of Induction
- Lenz's Law
- Conservation of energy
- Electrical power

A voltage is induced in a coil swinging through a magnetic field. Faraday's Law and Lenz's Law are examined and the energy dissipated in a load resistor is compared to the loss of energy of the coil pendulum.

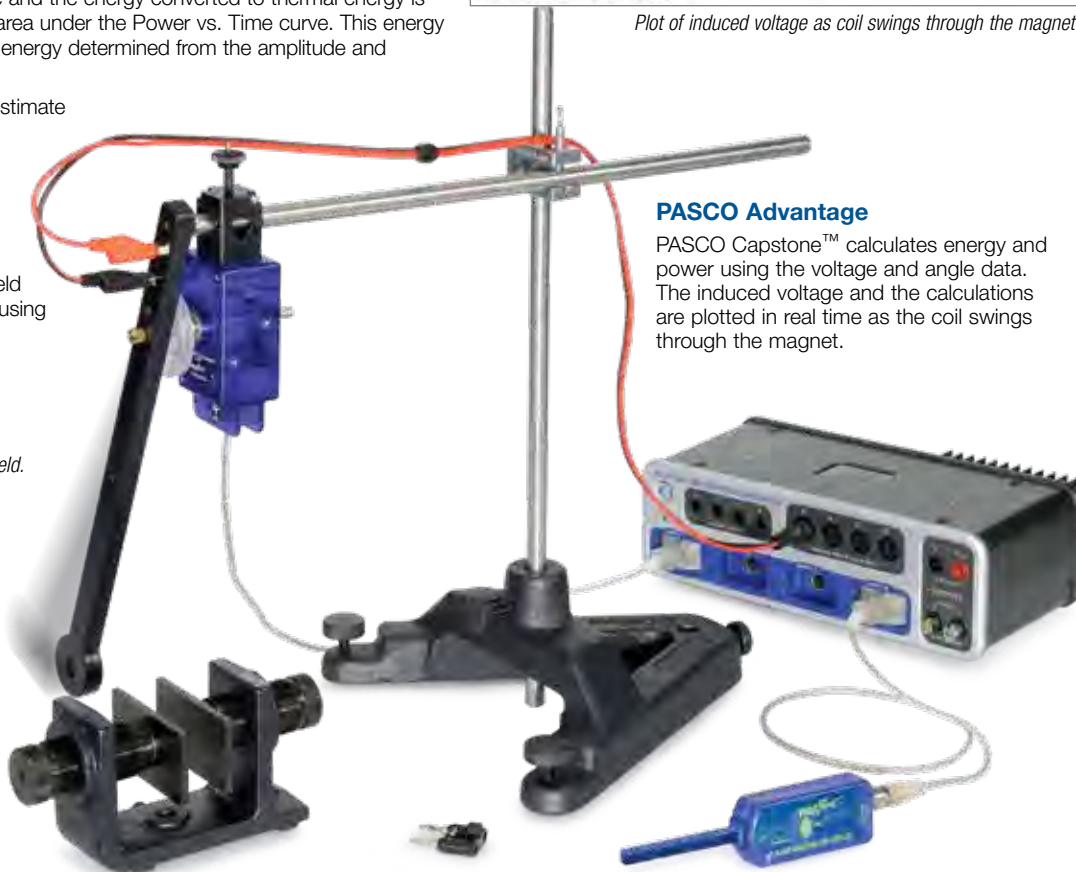
A rigid pendulum with a coil at its end swings through a horseshoe magnet. A resistive load is connected across the coil and the induced voltage is recorded using a Voltage Sensor. The angle is measured with a Rotary Motion Sensor, which also acts as a pivot for the pendulum. The induced voltage is plotted vs. time and angle. The power dissipated in the resistor is calculated from the voltage and the energy converted to thermal energy is determined by finding the area under the Power vs. Time curve. This energy is compared to the loss of energy determined from the amplitude and speed of the pendulum.

Faraday's Law is used to estimate the magnetic field of the magnet from the maximum induced voltage. Also, the direction of the induced voltage as the coil enters and leaves the magnetic field is examined and analyzed using Lenz's Law.

A voltage is induced in a coil swinging through a magnetic field.



Plot of induced voltage as coil swings through the magnet



PASCO Advantage

PASCO Capstone™ calculates energy and power using the voltage and angle data. The induced voltage and the calculations are plotted in real time as the coil swings through the magnet.

Experiment Includes

- Induction Wand EM-8099
- Variable Gap Lab Magnet EM-8641
- Large Rod Base ME-8735
- 45 cm Steel Rod (2) ME-8736
- Multi Clamp ME-9507
- Voltage Sensor UI-5100
- 2-Axis Magnetic Field Sensor PS-2162
- Rotary Motion Sensor PS-2120A

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Faraday's Law of Induction.....EX-5541A

Required:

550 or 850 Universal Interface pp. 28-30
PASCO Capstone Software..... pp. 72-75

Waves and Optics

Vibrating String

EX-5542

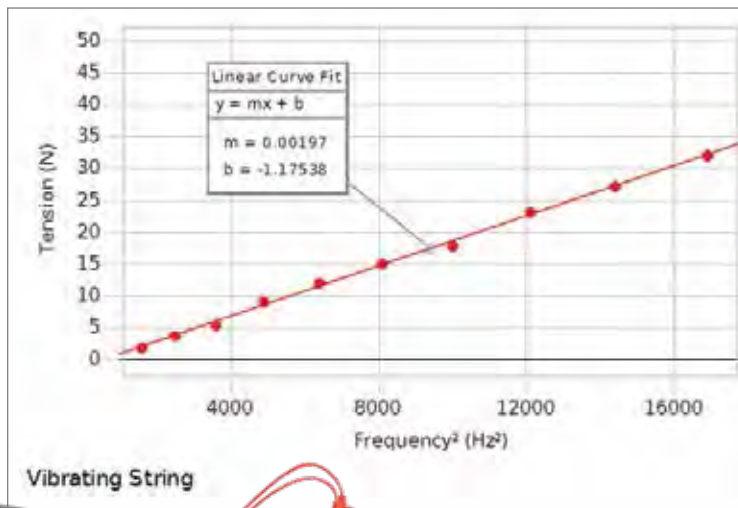
Designed for use with the
850 Universal Interface

Concepts:

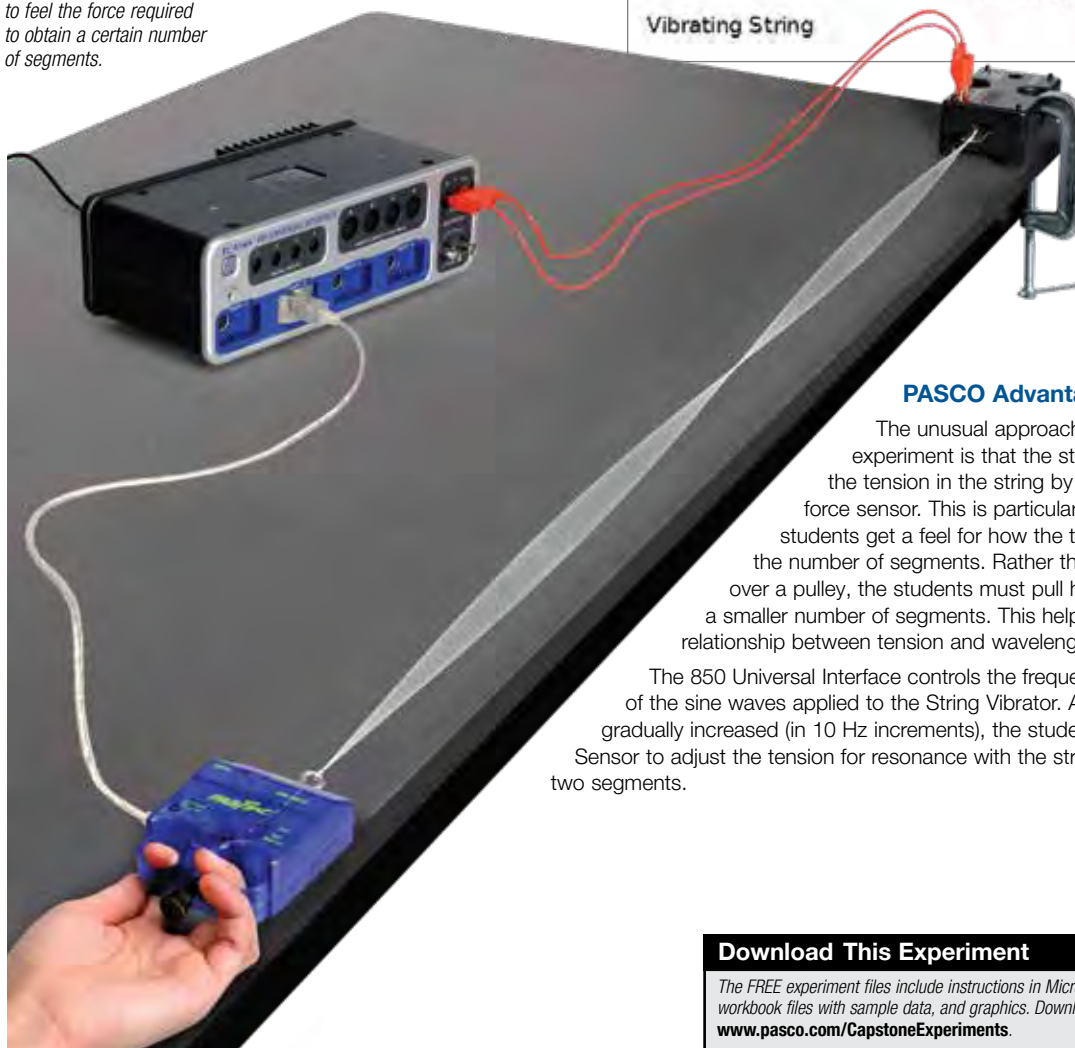
- Investigate standing waves
- Pull string to adjust number of segments
- Vary frequency of vibration

Study standing waves in a string by varying the driver frequency and keeping the number of segments constant. The String Vibrator is powered by the 850 Universal Interface. Students vary both the frequency and amplitude.

The string tension is measured directly with a Force Sensor, enabling students to feel the force required to obtain a certain number of segments of segments.



A graph of force vs. the square of the frequency shows a linear relationship. The slope of this line is related to the length and density of the string.



PASCO Advantage

The unusual approach in this version of the experiment is that the students actually provide the tension in the string by pulling directly on the force sensor. This is particularly instructive because the students get a feel for how the tension must change to vary the number of segments. Rather than hanging more weight over a pulley, the students must pull harder to achieve a smaller number of segments. This helps them remember the relationship between tension and wavelength.

The 850 Universal Interface controls the frequency and amplitude of the sine waves applied to the String Vibrator. As the frequency is gradually increased (in 10 Hz increments), the student pulls on the Force Sensor to adjust the tension for resonance with the string vibrating in two segments.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Experiment Includes

- | | |
|--------------------------------|----------|
| • String Vibrator | WA-9857 |
| • Physics String | SE-8050 |
| • High Resolution Force Sensor | PS-2189 |
| • Large "C" Clamp | |
| • Patch Cords (set of 5) | SE-9750 |
| • Tape Measure | SE-8712A |

Order Information

Vibrating String..... EX-5542

Required:

850 Universal Interface..... pp. 28-29
 PASCO Capstone Software..... pp. 72-75

Waves

EX-9952

Concepts:

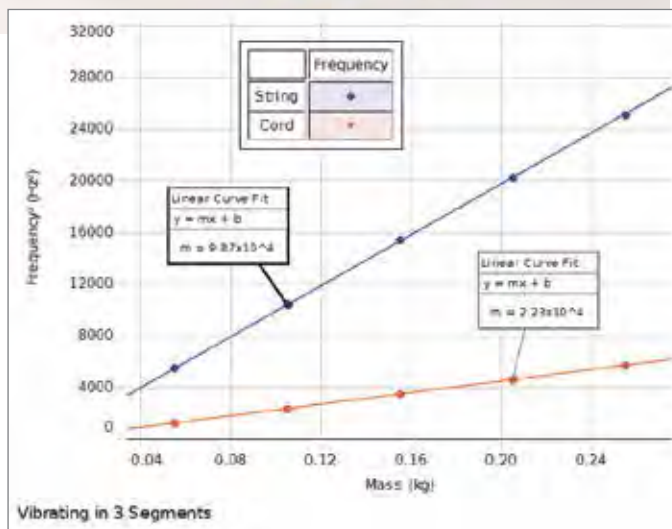
- Speed of waves in a string
- Resonance in strings and air columns
- Speed of sound in air
- Harmonics



Standing waves in strings and air columns are studied. Using a sine wave generator to drive a string vibrator, the driving frequency, length, density, and tension of the string are varied to explore standing waves in strings and to determine the speed of the wave. For the sound waves in the air column, a speaker is used to drive a resonance tube. The driving frequency and the length of the tube are varied for both open and closed tubes. The relationship between resonant frequency modes and tube length is determined for closed vs. open tubes.

Experiment Includes

- String Vibrator WA-9857
- Sine Wave Generator WA-9867
- Open Speaker WA-9900
- Economy Resonance Tube WA-9495
- Elastic Wave Cord SE-9409
- Physics String SE-8050
- Yellow Braided Cord 699-067
- Mass and Hanger Set ME-8979
- Universal Table Clamp (2) ME-9376B
- Adjustable Angle Clamp ME-8744
- Super Pulley ME-9450
- Pulley Mounting Rod SA-9242
- 45 cm Rod (2) ME-8736
- Red Banana Plug Cord Set SE-9750
- Waves Experiment Manual



Graphs of the square of the frequency vs. the hanging mass for two different types of strings have different slopes corresponding to different string densities.

PASCO Advantage

The frequency of the vibration of the string is not limited to the line frequency, so the frequency can be varied as well as the length and the tension.

To Download The Manual

Search for EX-9952 at www.pasco.com

Order Information

Waves.....EX-9952

Waves and Optics

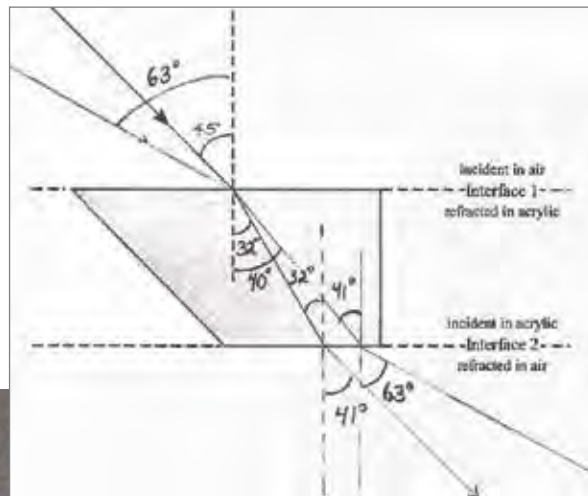
Reflection and Refraction

EX-9987

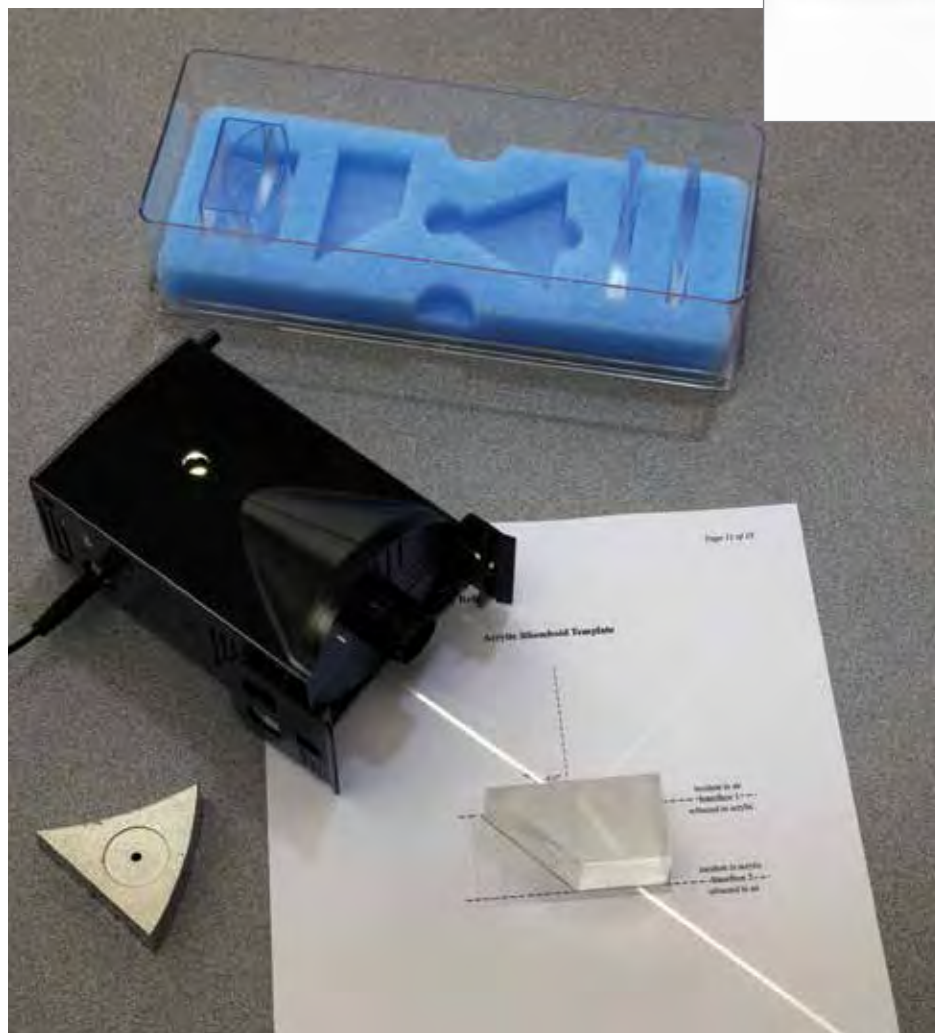
Concepts:

- ▶ Reflection and refraction
- ▶ Index of refraction

Students experimentally derive the Law of Reflection for curved and flat mirrors. Snell's Law is explored and the index of refraction for a piece of acrylic material is found.



Sample of student work, showing the path of two different rays passing through the acrylic rhomboid.



PASCO Advantage

Students trace the rays on the provided templates and make angle measurements directly from their drawing. This reinforces the connection between the real rays they can see in the lab and the type of ray diagrams seen in the classroom.

Experiment Includes

- Ray Optics Kit OS-8516A
- Basic Optics Light Source OS-8470
- Reflection and Refraction Experiment Manual

Order Information

Reflection and Refraction.....EX-9987

Required:

Protractor and Ruler

To Download The Manual

Search for EX-9987 at www.pasco.com

Speed of Light

EX-9932A

Concepts:

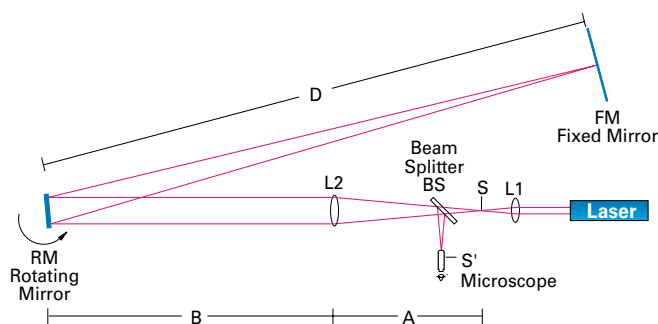
- ▶ Determine the Speed of Light in Air
- ▶ Recreate Foucault's Historical Experiment

CLASS II LASER PRODUCT
LASER RADIATION – DO NOT STARE INTO BEAM OR VIEW
DIRECTLY WITH OPTICAL INSTRUMENTS



The Speed of Light Experiment uses laser light and a high-speed rotating mirror to determine this fundamental constant using the Foucault method.

Laser light passes through a series of lenses to produce an image of the light source at a measured position. The light is then directed to a rotating mirror, which reflects the light to a fixed mirror at a known distance from the rotating mirror. The laser light is reflected back through its original path and a new image is formed at a slightly different position. The difference between final/initial positions, angular velocity of the rotating mirror, and distance traveled by the light are then used to calculate the speed of light in air.



PASCO Advantage

PASCO's Speed of Light Experiment allows students to experimentally measure the speed of light within 5% of the accepted value. In addition, the experiment can be performed on a desktop or in a hallway.

- Complete Speed of Light Apparatus
- Speed of Light Experiment Manual

OS-9261B

To Download This Experiment

Search for EX-9932A at www.pasco.com

Order Information

Speed of Light.....EX-9932A

Waves and Optics

Telescope/Microscope

EX-9988

Concepts:

- ▶ Multiple lens systems
- ▶ Parallax
- ▶ Magnification
- ▶ Description of images

Students construct an astronomical telescope, a Galilean telescope, and a compound microscope on the optical bench. Using a viewing screen with grid, they find and describe the ways in which images are changed by the multiple lens systems.

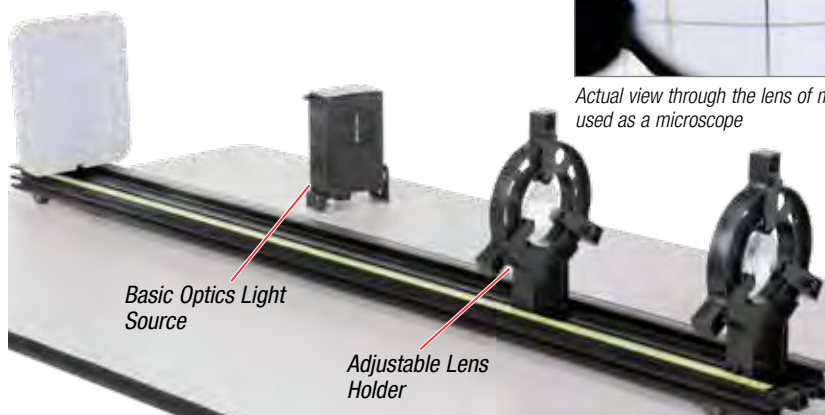
The parallax method is used to locate virtual images. Students draw ray diagrams and measure the magnification of the instruments.

PASCO Advantage

Using the Basic Optics Track and Adjustable Lens Holders makes it easy for students to quickly build each of the instruments. Open construction means that all students can see the location and types of lenses used.

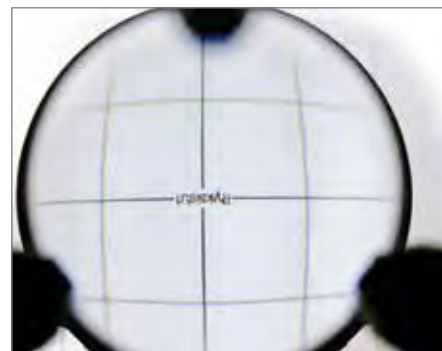
Experiment Includes

- Beginning Optics System OS-8459
 - Includes:
 - Basic Optics Light Source OS-8470
 - Adjustable Lens Holders (2) OS-8474
 - Geometric Lens Set OS-8466A
 - Viewing Screen OS-8460
 - 1.2 m Optics Bench OS-8508



Basic Optics Light Source

Adjustable Lens Holder



Actual view through the lens of magnified screen when used as a microscope

To Download This Experiment

Search for EX-9988 at www.pasco.com

Order Information

Telescope and Microscope.....EX-9988

Required:

Rubber Bands and Ruler

Light Intensity vs. Distance

EX-5547A

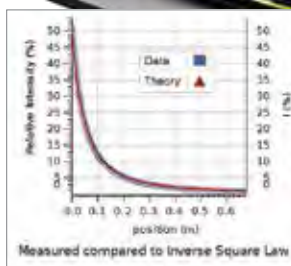
In this experiment the student measures intensity as a function of distance from a point of source and from an extended (5 cm x 5 cm) source. Manipulation of a computer model verifies that for the point source, the intensity drops off like an inverse square. But for the extended source the data cannot be fit by an inverse square relationship.

PASCO Advantage

As the student slides the light sensor away from the Light Source, the Optics Track keeps everything aligned. The Rotary Motion Sensor measures the position, allowing the Intensity vs. Distance graph to be plotted in real time. Students immediately see the relationship between distance and intensity of light.

Experiment Includes

- 120 cm Optics Bench OS-8508
- Basic Optics Light Source OS-8470
- Aperture Bracket OS-8534A
- 20 g Hooked Mass (Hooked Mass Set) SE-8759
- Thread 699-011
- High Sensitivity Light Sensor PS-2176
- Rotary Motion Sensor PS-2120A
- Dynamics Track Mount CI-6692



Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ Any PASPORT interface with 2 ports

Order Information

Light Intensity vs. Distance.....EX-5547A

Required:

550 or 850 Universal Interface*pp. 28-30
PASCO Capstone Software.....pp. 72-75

* This experiment can be performed using the 550 or 850 Universal Interface or any PASPORT interface with two ports.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Interference and Diffraction of Light

EX-5545A

Concepts:

- ▶ Two-slit interference
- ▶ Multiple-slit minor maxima
- ▶ Single-slit diffraction
- ▶ Slit vs. line diffraction

Interference and diffraction patterns from laser light passing through various single-slits and multiple-slits are scanned and plotted in real time. These patterns are then examined for similarities and differences.

The distances between the central maximum and the diffraction minima for a single slit are measured by scanning the laser pattern with a Light Sensor and plotting light intensity vs. distance. Also, the distances between interference maxima for two or more slits are measured. These measurements are compared to theoretical values. Differences and similarities between interference and diffraction patterns are examined.

PASCO Advantage

Since the Linear Translator tracks the position of the Light Sensor, it is not necessary to move the Light Sensor at a constant speed. The Intensity vs. Distance graph is plotted in real time, showing the connection between the intensity pattern and the actual laser pattern. Adjustment of the slit size on the Light Sensor mask gives the resolution required to see detail in the interference patterns.

Designed for use with any of the following:

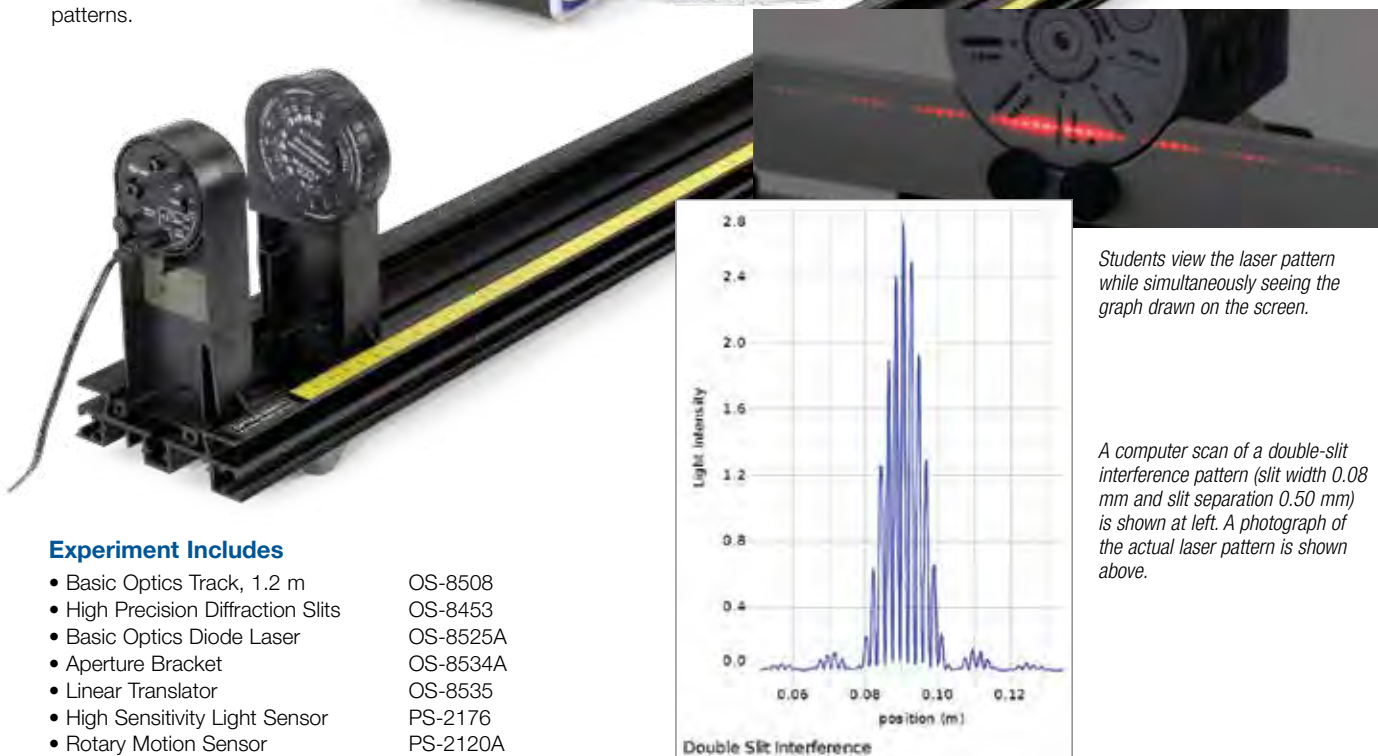
- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ Any PASPORT interface with 2 ports



The laser interference pattern is scanned by hand with a Light Sensor on a Linear Translator.



CLASS 2 LASER PRODUCT
LASER LIGHT – DO NOT STARE
INTO BEAM



Students view the laser pattern while simultaneously seeing the graph drawn on the screen.

A computer scan of a double-slit interference pattern (slit width 0.08 mm and slit separation 0.50 mm) is shown at left. A photograph of the actual laser pattern is shown above.

Experiment Includes

- Basic Optics Track, 1.2 m OS-8508
- High Precision Diffraction Slits OS-8453
- Basic Optics Diode Laser OS-8525A
- Aperture Bracket OS-8534A
- Linear Translator OS-8535
- High Sensitivity Light Sensor PS-2176
- Rotary Motion Sensor PS-2120A

Order Information

Interference and Diffraction of Light.....EX-5545A

Required:

550 or 850 Universal Interface* pp. 28-30
PASCO Capstone Software..... pp. 72-75

* This experiment can be performed using the 550 or 850 Universal Interface or any PASPORT interface with two ports.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Waves and Optics

Polarization of Light

EX-5543A

Concept:

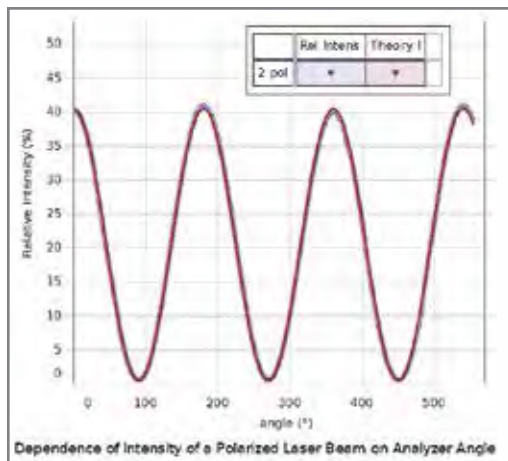
► Malus' Law of Polarization

In this experiment, Malus' Law of Polarization is verified by showing that the intensity of light passed through two polarizers depends on the square of the cosine of the angle between the two polarization axes.

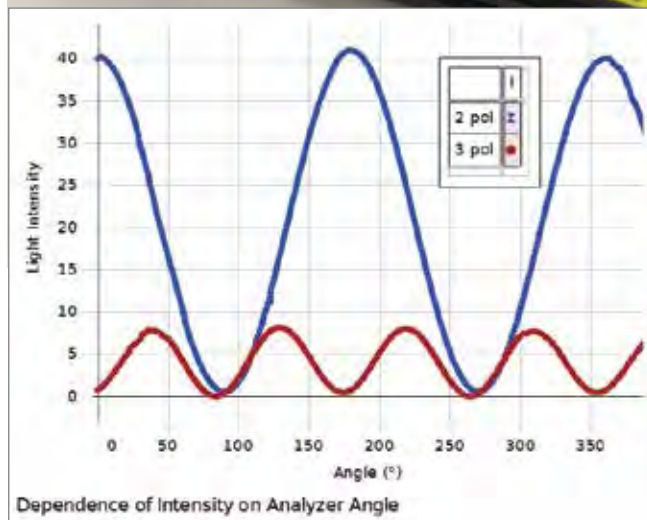
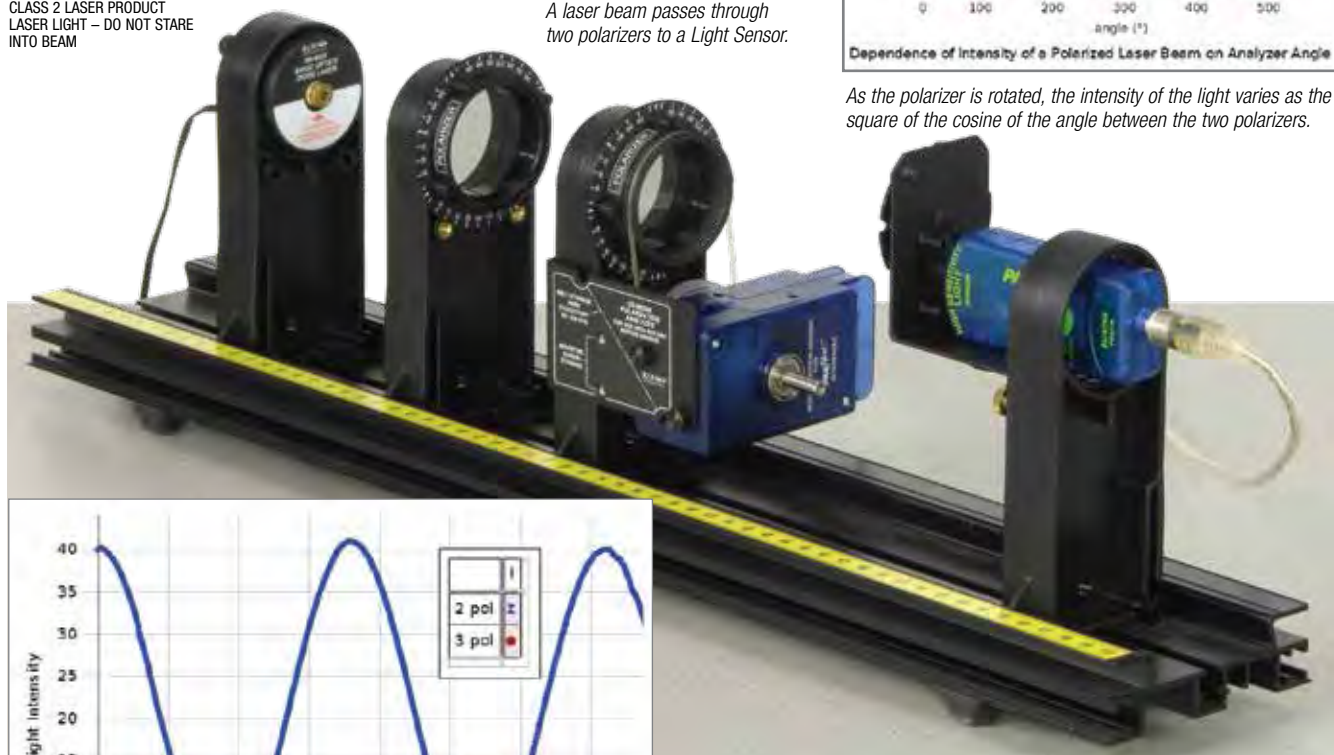
Laser light (peak wavelength = 650 nm) is passed through two polarizers. As the second polarizer (the analyzer) is rotated by hand, the relative light intensity is recorded as a function of the angle between the axes of polarization of the two polarizers. The angle is obtained using a Rotary Motion Sensor coupled to the polarizer with a drive belt. The plot of light intensity vs. angle can be fitted to the square of the cosine of the angle.

CLASS 2 LASER PRODUCT
LASER LIGHT – DO NOT STARE
INTO BEAM

A laser beam passes through two polarizers to a Light Sensor.



As the polarizer is rotated, the intensity of the light varies as the square of the cosine of the angle between the two polarizers.



A three-polarizer system can be produced using the fact that the laser is polarized. The data (red trace) at left shows that there are four oscillations per full rotation for a three-polarizer system.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

PASCO Advantage

Laser light is used in this experiment because its wavelength is more completely extinguished by the crossed polarizers.

Experiment Includes

- Polarization Analyzer OS-8533A
- Basic Optics Bench (60 cm) OS-8541
- Red Diode Laser OS-8525A
- High Sensitivity Light Sensor PS-2176
- Rotary Motion Sensor PS-2120A

Order Information

Polarization of Light..... EX-5543A

Required:

550 or 850 Universal Interface* pp. 28-30
PASCO Capstone Software..... pp. 72-75

** This experiment can be performed using the 550 or 850 Universal Interface or any PASPORT interface with two ports.*

Brewster's Angle

EX-5544A

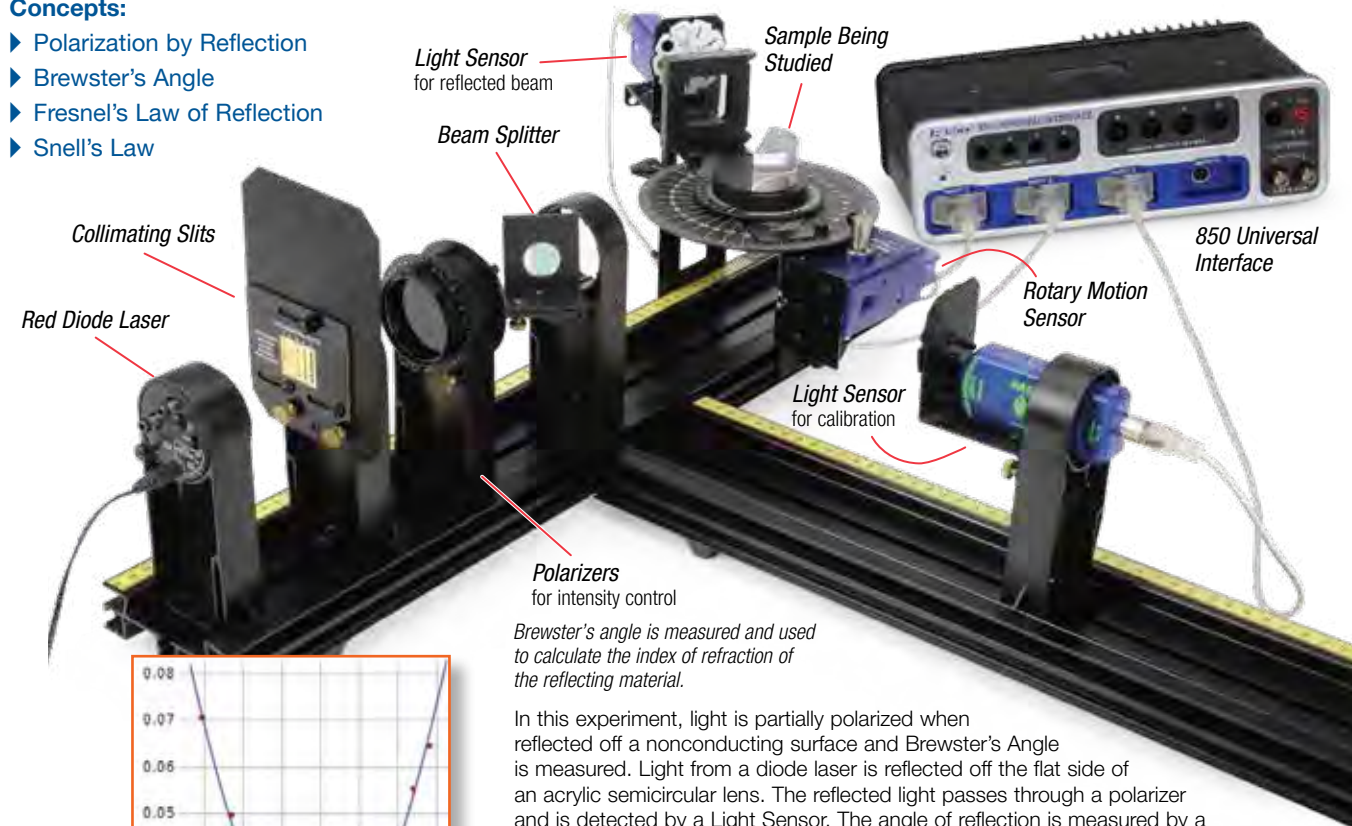
Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ Any PASPORT interface with 3 ports

CLASS 2 LASER PRODUCT
LASER LIGHT – DO NOT STARE INTO BEAM

Concepts:

- ▶ Polarization by Reflection
- ▶ Brewster's Angle
- ▶ Fresnel's Law of Reflection
- ▶ Snell's Law


Polarizers
for intensity control

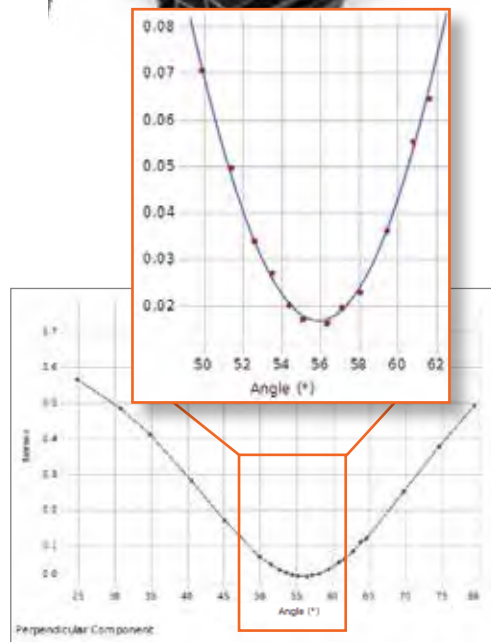
Brewster's angle is measured and used
to calculate the index of refraction of
the reflecting material.

In this experiment, light is partially polarized when reflected off a nonconducting surface and Brewster's Angle is measured. Light from a diode laser is reflected off the flat side of an acrylic semicircular lens. The reflected light passes through a polarizer and is detected by a Light Sensor. The angle of reflection is measured by a Rotary Motion Sensor mounted on the Spectrophotometer table. The intensity of the reflected polarized light vs. reflected angle is graphed to determine the angle at which the light intensity is a minimum. This is Brewster's Angle, which is used to calculate the index of refraction of acrylic.

PASCO Advantage

It is possible to determine the difference in index of refraction for different wavelengths of light. This is accomplished by using a beam-splitter and a second light sensor to compensate for the variation of the laser intensity. The reflected beam intensity is normalized by the intensity of the laser. This modification to the experiment was suggested by Cristian Bahrim and Wei-Tai Hsu in the *American Journal of Physics* article: "Precise Measurement of the Refractive Indices for Dielectrics Using an Improved Brewster Angle Method", Vol. 77, page 337 (2009).

Developed using original ideas from P.J. Ouseph, Professor of Physics at University of Louisville, KY: "Polarization of Light by Reflection and the Brewster Angle" by P.J. Ouseph, Kevin Driver, and John Conklin, *Am. J. Phys.* 69, 1166 (2001).



Brewster's Angle is determined by finding the angle at which no light is transmitted through the analyzing polarizer.

Experiment Includes

- Brewster's Angle Accessory OS-8170A
- Spectrophotometer Accessory Kit OS-8537
- Optics Bench (60 cm) (2) OS-8541
- Rotary Motion Sensor PS-2120A
- High Sensitivity Light Sensor (2) PS-2176
- Aperture Bracket for Light Sensor (2) OS-8534A
- Red Diode Laser OS-8525A
- Polarizer Set OS-8473

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Brewster's Angle EX-5544A

Required:

850 Universal Interface* pp. 28-29
PASCO Capstone Software pp. 72-75

* This experiment can be performed using the 850 Universal Interface or any PASPORT interface with three ports.

Quantum

Atomic Spectra

EX-5546B

Concepts:

- ▶ Hydrogen balmer series
- ▶ Helium spectrum
- ▶ Mercury doublet

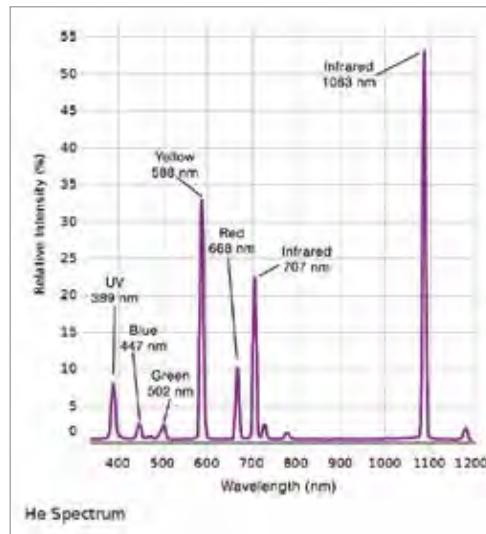
The wavelengths of the discrete lines of the atomic spectra of various gases are measured using a grating spectrophotometer.

The atomic spectra of hydrogen, helium, and mercury are scanned by hand using a grating spectrophotometer, which measures relative light intensity as a function of angle. From the resulting graph, the wavelengths of the spectral lines are determined by measuring the angle from the central maximum to each line. First and second order lines are examined.

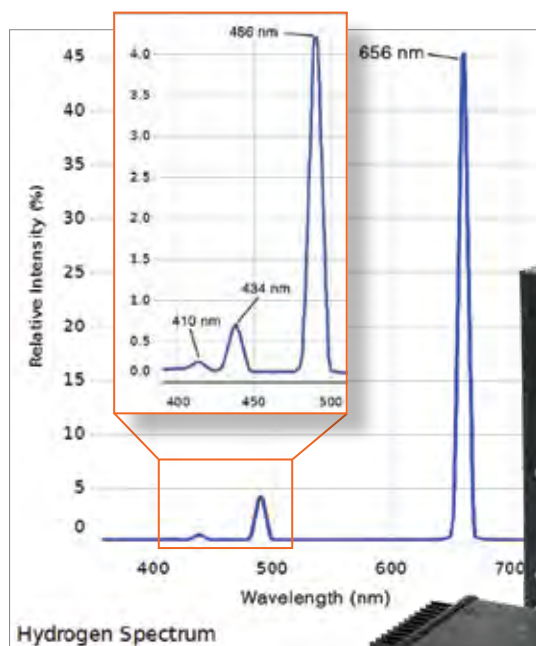
The wavelengths of the spectral lines are compared to the accepted values and, in the case of hydrogen, the electron orbit transitions corresponding to the lines are identified.

Designed for use with any of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface
- ▶ Any PASPORT interface with 2 ports



The spectral lines of helium are scanned.

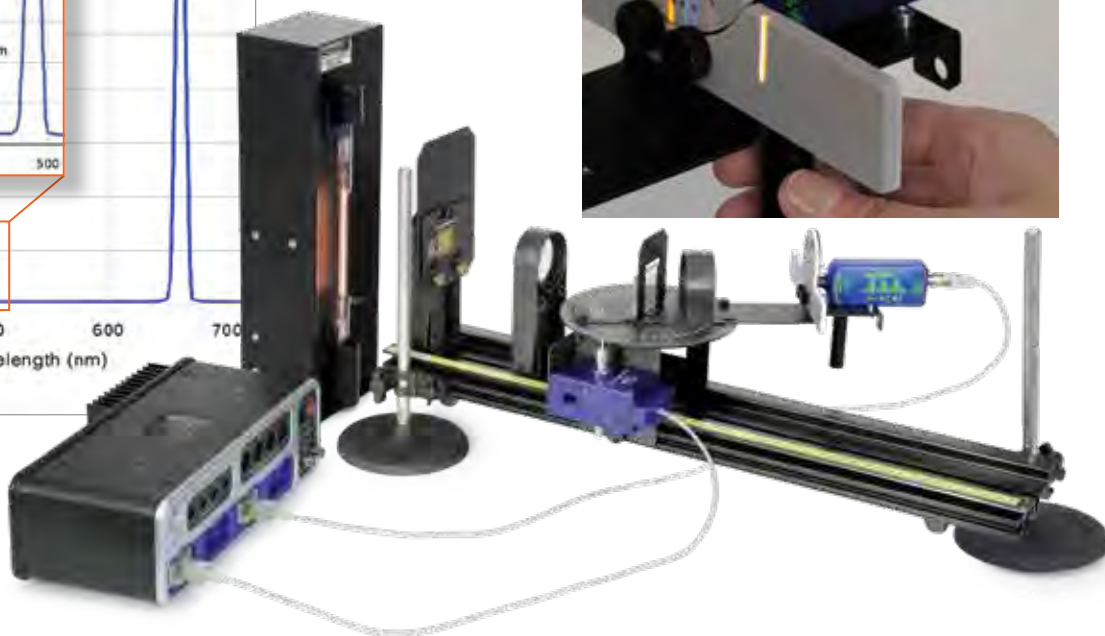


The four brightest lines of the Balmer series for hydrogen



PASCO Advantage

The open construction of the spectrophotometer allows the entire spectrum to be seen, while the intensity vs. angle is graphed in real time.



Experiment Includes

- Spectrophotometer Accessory Kit
- 60 cm Optics Bench
- Aperture Bracket
- High Sensitivity Light Sensor
- Rotary Motion Sensor
- Round Base with Rod (2)
- Spectral Tube Power Supply and Mount
- Hydrogen Spectral Tube
- Helium Spectral Tube
- Mercury Spectral Tube

- OS-8537
- OS-8541
- OS-8534A
- PS-2176
- PS-2120A
- ME-8270
- SE-9460
- SE-9461
- SE-9462
- SE-9466

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Atomic Spectra..... EX-5546B

Required:

550 or 850 Universal Interface* pp. 28-30

PASCO Capstone Software..... pp. 72-75

* This experiment can be performed using the 550 or 850 Universal Interface or any PASPORT interface with two ports.

Photoelectric Effect

EX-5549A

Designed for use with either of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface

Concepts:

- ▶ Connects to the 850 Universal Interface for data collection in PASCO Capstone
- ▶ Find Planck's Constant to within 5%
- ▶ Verify that stopping voltage is independent of intensity
- ▶ Find characteristics of the photodiode

The Photoelectric Effect System is used to perform the photoelectric experiment, determining Planck's Constant to within 5%. This apparatus uses the conventional method of determining Planck's Constant. The metal plate in the photodiode is illuminated with various frequencies of light, selected from a mercury lamp using filters. The voltage is then adjusted to stop the photoelectric current. The stopping voltage is plotted vs. the frequency, and Planck's Constant is determined from the slope of the graph.

The concept that the stopping voltage does not change with light intensity is tested using the various apertures that change the light intensity by partially blocking the light.

Use the 850 Universal Interface and PASCO Capstone to collect and analyze data.

Both the picoammeter and the power supply for the stopping voltage have sensor ports on the front that connect to the analog sensor ports of the 850 Universal Interface. PASCO Capstone automatically recognizes these instruments and can read the current and the voltage. During the experiment, each time a different filter is applied, the user clicks "Keep in PASCO Capstone and the value of the stopping voltage for that frequency is recorded and automatically graphed vs. frequency.

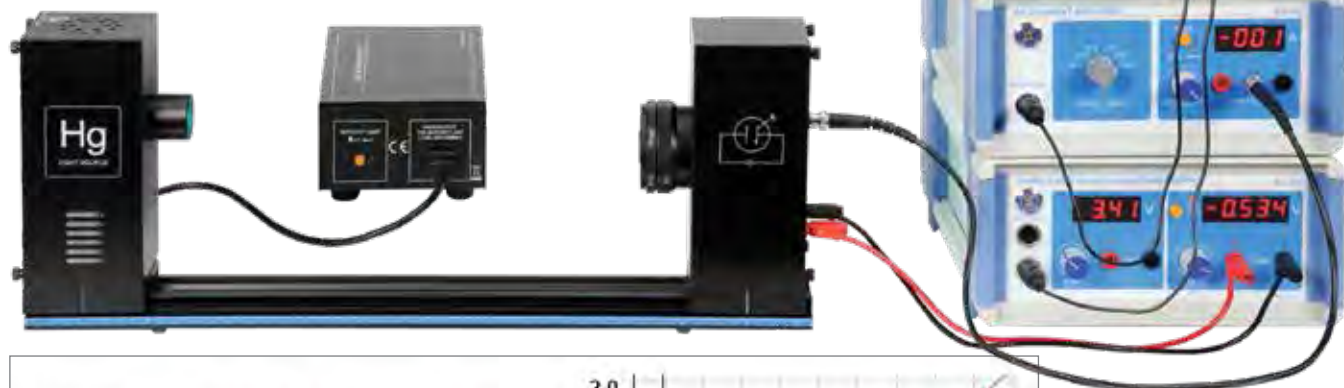
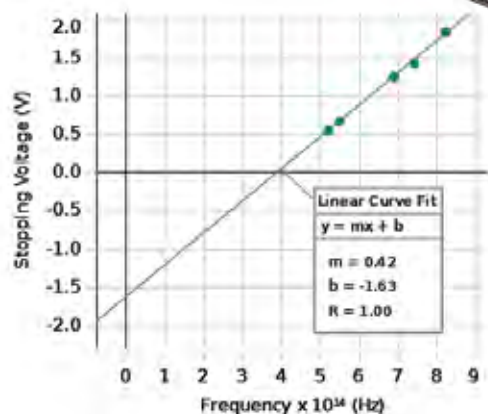


Table 1: Photoelectric Effect with 4 mm Aperture

| | ▲ Run #1 | ■ Run #1 |
|---|---------------------------------|----------------------|
| | Frequency $\times 10^{14}$ (Hz) | Stopping Voltage (V) |
| 1 | 8.214 | 1.835 |
| 2 | 7.408 | 1.428 |
| 3 | 6.879 | 1.248 |
| 4 | 5.490 | 0.671 |
| 5 | 5.196 | 0.551 |



For the typical sample data shown, the graph of Stopping Voltage vs. Frequency gives a slope of 4.2×10^{-15} V-s. This results in a value for Planck's Constant of 6.7×10^{-34} J-s, which is 1.3% above the accepted value. Graph generated using PASCO Capstone software.

Experiment Includes

- Photoelectric Effect Apparatus SE-6614
- DC Current Amplifier SE-6621
- Tunable DC Power Supply SE-6615
- Cables for 850 Interface

Order Information

Photoelectric Effect.....EX-5549A

Required:

550 or 850 Universal Interfacepp. 28-30
PASCO Capstone Software.....pp. 72-75

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Quantum

Hall Effect

EX-5560

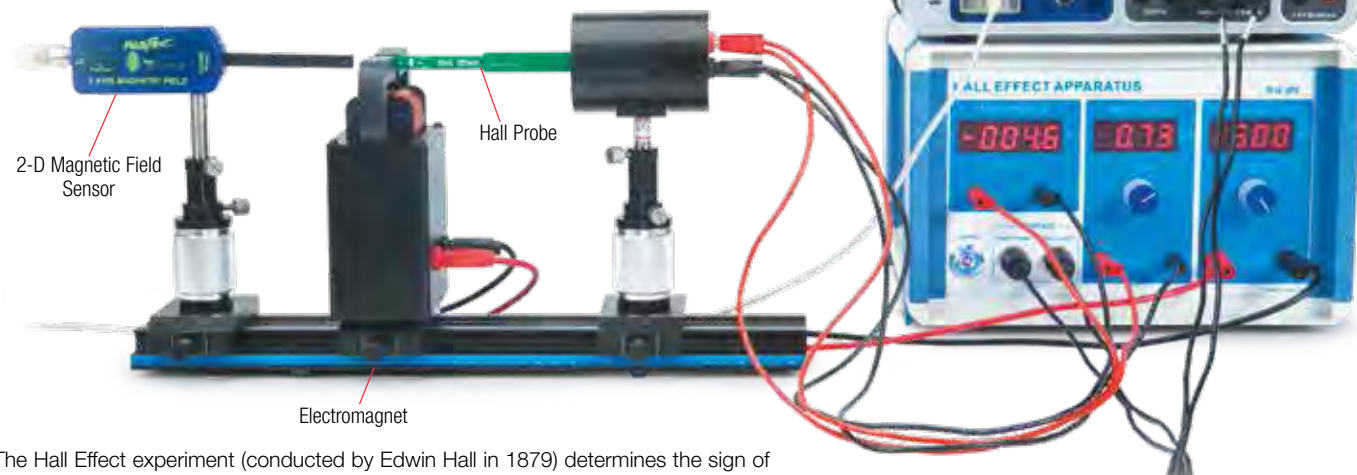
Concepts:

- ▶ Determine sign of charge carriers
- ▶ Vary magnetic field and current

Designed for use with either of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface

550 Universal Interface



The Hall Effect experiment (conducted by Edwin Hall in 1879) determines the sign of the charge carriers in current flow. A current can be thought of as a negative charge moving in one direction (Figure 1) or as a positive charge moving in the opposite direction (Figure 2). To determine which it actually is, the semiconductor is immersed in the magnetic field transverse to the direction of flow of current. The moving charge experiences a $q\vec{v} \times \vec{B}$ force, causing a charge buildup on one side of the semiconductor (creating an electric field), which in turn leads to a qE force. The direction of the electric field will depend on the sign of the charge carriers, and the polarity of the Hall voltage across the semiconductor reveals this sign.

The magnitude of the Hall voltage is dependent on the current, the charge carrier density, and the magnitude of the magnetic field. In modern day electronics, the Hall Effect is used to measure the magnitude and direction of magnetic fields.

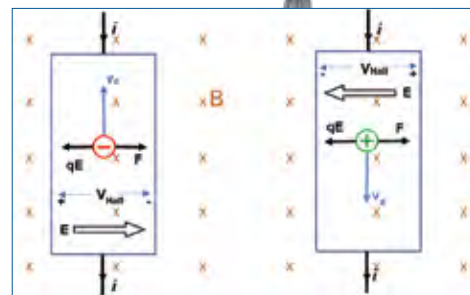
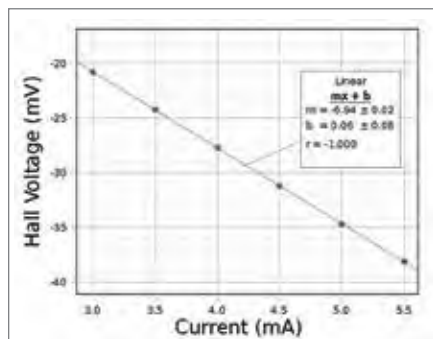


Figure 1

Figure 2



Using the 550 Universal Interface to record data, this plot of the Hall Voltage vs. the Current was made in PASCO Capstone software. In this case, the magnetic field was held constant and the current through the semiconductor was varied.

Includes

- Hall Probe Unit, n-Semiconductor (GaAs)
- Hall Effect Power Supply
- U-Core Electromagnetic Coil
- Track, Length 40 cm
- Optical Carrier (2)
- 2-D Magnetic Field Sensor (PS-2162)
- Adjustable Post Holder with 9 cm Post (2)
- Banana Cords (6)
- Connecting Cables for 550/850 Interface (2)

PASCO Advantage

The open design of this Hall Effect apparatus makes it possible for students to see the direction of the current and the magnetic field, enabling them to use the sign of the Hall voltage to deduce the sign of the charge carriers.



The directions of the current and the voltage probe are clearly marked on the probe that holds the semiconductor.

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Order Information

Hall Effect..... EX-5560
 Required:
 550 or 850 Universal Interface pp. 28-30
 PASCO Capstone Software..... pp. 72-75

Franck-Hertz

EX-5561

Designed for use with either of the following:

- ▶ 850 Universal Interface
- ▶ 550 Universal Interface

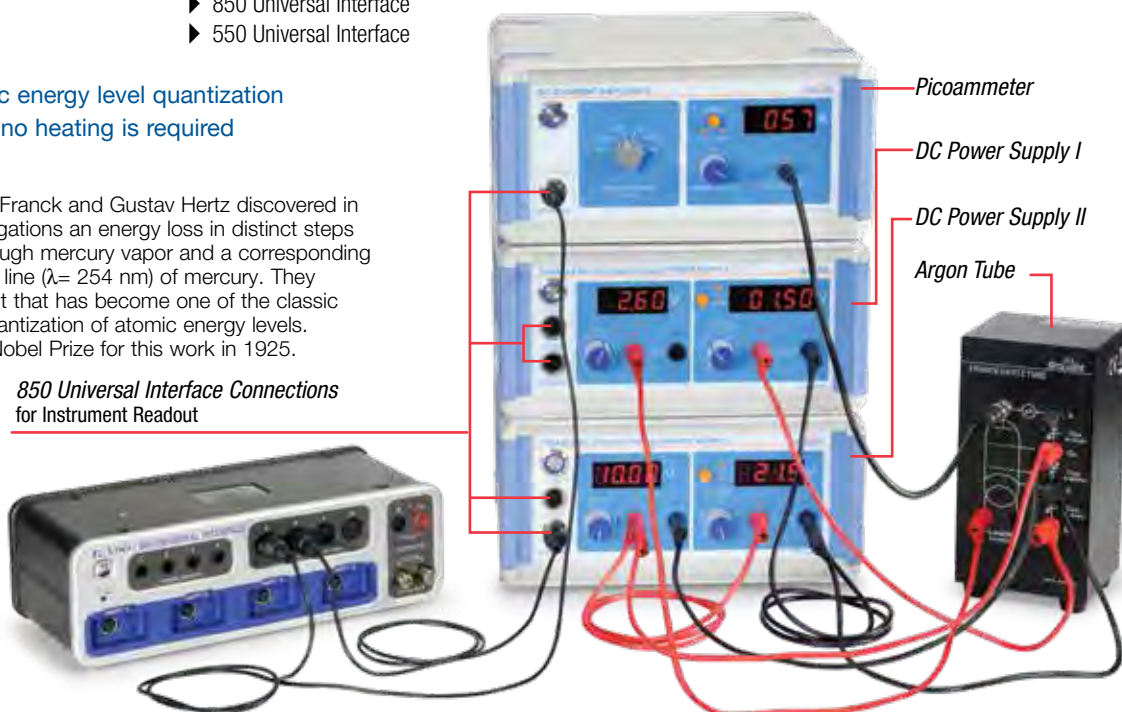
Concepts:

- ▶ Demonstrate atomic energy level quantization
- ▶ Uses argon gas so no heating is required

Introduction

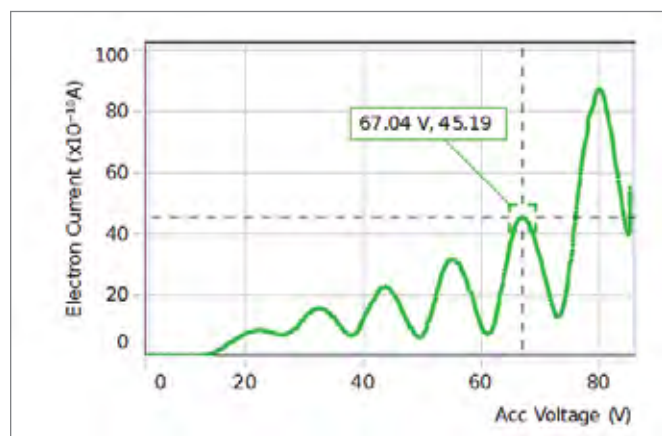
As early as 1914, James Franck and Gustav Hertz discovered in the course of their investigations an energy loss in distinct steps for electrons passing through mercury vapor and a corresponding emission at the ultraviolet line ($\lambda = 254$ nm) of mercury. They performed this experiment that has become one of the classic demonstrations of the quantization of atomic energy levels. They were awarded the Nobel Prize for this work in 1925.

850 Universal Interface Connections for Instrument Readout



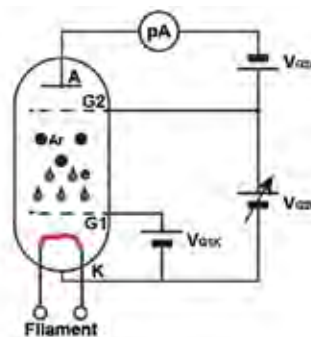
PASCO Advantage

The advantage of using Capstone is that students are able to get many more data points compared to manually taking readings from the digital readouts. The peaks and troughs are easily measured using the coordinate tool.



Includes:

- Franck-Hertz Tube Enclosure with Argon Tube (SE-9650)
- Tunable DC (Constant Voltage) Power Supply I (SE-6615)
- Tunable DC (Constant Voltage) Power Supply II (SE-9644)
- DC Current Amplifier (SE-6621)
- Red and Black Patch Cords
- Interface Cables (2)



This diagram shows the internal structure of the Franck-Hertz tube and the wiring diagram.

How It Works

Electrons are accelerated by applying a known potential between two grids inside the argon tube. When an electron has sufficient kinetic energy to excite one of argon's outer orbital electrons and has an inelastic collision with an argon atom, the electron loses a specific amount of kinetic energy. This loss of electron kinetic energy causes a decrease in the electron current in the argon tube. Within a very short time, the excited argon electron will fall from the excited state back into the ground state level, emitting energy in the form of photons.

As the accelerating voltage is increased, the electrons undergo multiple collisions and the excitation energy of the argon atom can be determined by the differences between the accelerating voltages that cause a decrease in the current. Planck's Constant can be determined.

Order Information

Franck-Hertz..... EX-5561
 Required:
 550 or 850 Universal Interface pp. 28-30
 PASCO Capstone Software..... pp. 72-75

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.

Quantum

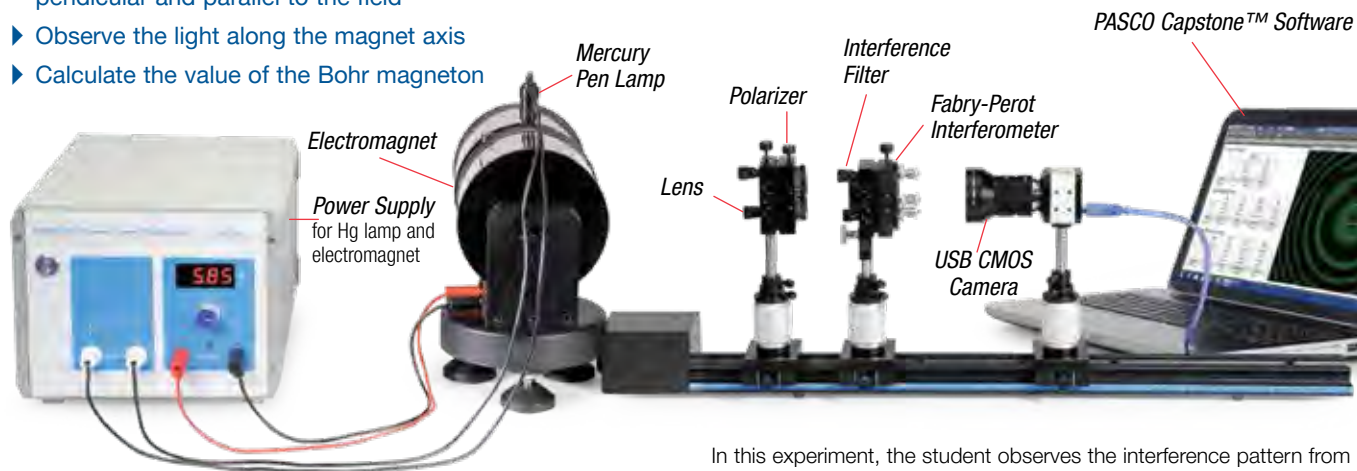
Zeeman Effect

EX-5562

No interface required

Concepts:

- ▶ Measure the Zeeman Effect with polarization perpendicular and parallel to the field
- ▶ Observe the light along the magnet axis
- ▶ Calculate the value of the Bohr magneton



End view through the axis of the magnet

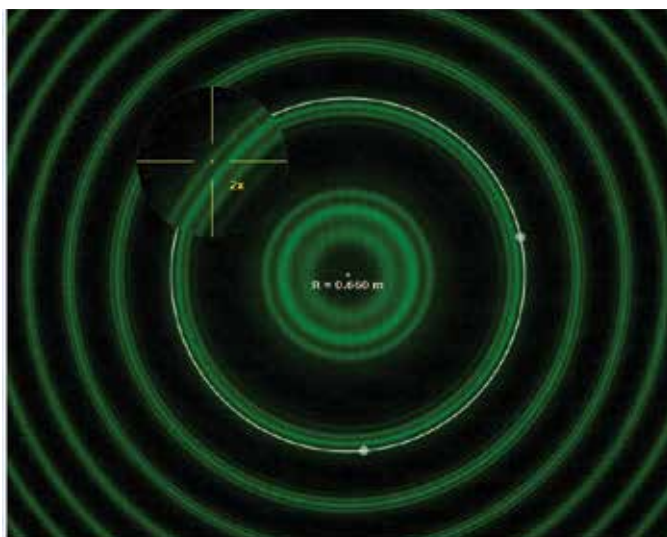


Electromagnet produces about one Tesla.

In this experiment, the student observes the interference pattern from a Fabry-Perot interferometer that results from the 546.1 nm spectral line of a mercury lamp immersed in a uniform magnetic field. The magnetic field is varied from zero to nearly 1 Tesla.

Initially, the light is viewed along an axis perpendicular to the magnetic field axis. A polarizer is used to show the three lines due to light that is polarized parallel to the field axis and to show the six lines that are polarized perpendicular to the field axis. The pattern may also be viewed along the field axis where the light is circularly polarized.

Finally, the pattern that is polarized perpendicular to the field axis is used to calculate the Bohr magneton. All atomic magnetic moments are integral or half-integral multiples of the Bohr magneton.



PASCO Advantage

In PASCO Capstone software, students can use the video magnifier tool to enlarge the region to see the details of the line splitting. Also, the radius tool needs only three points to define the circle, so even rings that are partially out of view can be measured.

Includes

- Electromagnet
- Power Supply
- Optics
- Tesla Meter
- PASCO Capstone Single User License

Order Information

Zeeman Effect EX-5562

Required:

PASCO Capstone Software pp. 72-75

Download This Experiment

The FREE experiment files include instructions in Microsoft Word®, PASCO Capstone workbook files with sample data, and graphics. Download these experiments at www.pasco.com/CapstoneExperiments.