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Lab #1: Kinematics

Background: Isaac Newton compared movements with displacement, velocity, acceleration, and force. Isaac Newton described movement as kinematics. The British physicist provided multiple equations now in high school and college classrooms. Today, we describe acceleration from gravity by a linear equation.

Goal: The acceleration from gravity derived from an average, and actual vs expected error.

Null Hypothesis: Equations from Newton never predict an exact solution about displacement.

Alternative Hypothesis: Equations from Newton predict an exact solution about displacement.

Learning Outcomes:

1. Problems evaluating frame of reference, displacement, velocity, and acceleration.
2. A relationship described between friction, air resistance, and other forces.
3. Experimental data tabulated from multiple measurements with one variable.
4. A line graphed of force as a function of angle.
5. Percent errors validating acceleration from gravity.

Equation #1: Velocity:

$$\vec{v}_{avg} = \frac{\Delta\vec{d}}{\Delta\vec{t}} = \frac{d_f - d_0}{t_f - t_0}$$

Equation #2: Acceleration:

$$\vec{a}_{avg} = \frac{\Delta\vec{v}}{\Delta\vec{t}} = \frac{v_f - v_0}{t_f - t_0}$$

Equation #3: Newton's First Law:

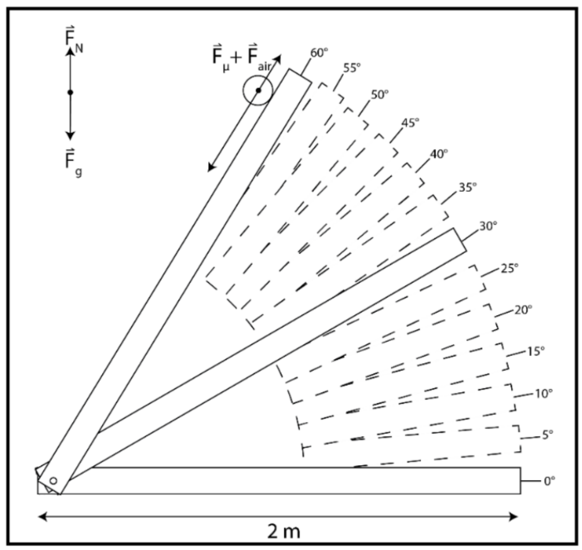
$$\vec{F}_g = m\vec{a}_g$$

Equation #4: Air Resistance:

$$\vec{F}_{air} = \frac{1}{2}\rho AC\vec{v}$$

Equation #5: Kinetic Friction:

$$\vec{F}_\mu = \mu m a_g$$



Equation #6: Force as a function of angle:

$$\vec{F} = ma = \vec{F}_g - \vec{F}_{air} - \vec{F}_\mu = m\vec{a}_g - \frac{1}{2}\rho AC\vec{v} - \mu m a_g = (1-\mu)m\vec{a}_g - \frac{1}{2}\rho AC\vec{v} = \text{"}mx + b\text{"}$$

Equation #7: Standard Deviation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}|x_i - \bar{x}|^2}{N}}$$

Equation #8: Percent Error:

$$Percent\ error\ (\%) = \frac{|Measurable\ value - Actual\ value|}{|Actual\ value|} * 100\%$$

Evaluation:

Note: Please practice answers on paper before submission.

1. What are displacement, velocity, and acceleration?
2. What is a graph from experimental data about velocity?
3. What is a graph from experimental data about acceleration?
4. Why is percent error important?
5. Newton was or was not correct about the equations?

Lab #2: Motion Graphing

<u>Background</u>: Free body diagrams apply to diagrams about movement by Newton's laws. Engineers sketch the system before the experiment via determination of total force. Gravity is a force in sketches, along the x-, y-, and z-axis, in addition to, friction, tension, or normal forces. Although, angles are difficult to new students, especially with cosine and sine. Today, students draw a free body diagram about a cart on a ramp.

Goal: The acceleration from gravity with derived error of the actual vs. expected physics.

Null Hypothesis: The velocity of the cart is not dependent on time throughout the experiment.

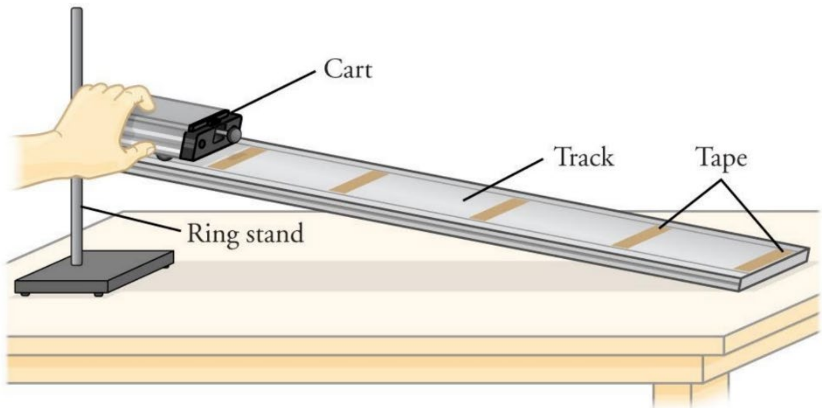
Alternative Hypothesis: The velocity of the cart is dependent on time throughout the experiment.

Learning Outcomes:

1. Problems involving frame of reference, displacement, velocity, and acceleration.
2. Experimental data tabulating a record with one changing variable.
3. A line of the tabulated data as a function of angle, then standard deviation.
4. Percent error to historically recorded values and constants

Equation #1: Velocity:

$$\vec{v}_{avg} = \frac{\Delta\vec{d}}{\Delta t} = \frac{d_f - d_0}{t_f - t_0}$$



Equation #2: Acceleration:

$$\vec{a}_{avg} = \frac{\Delta\vec{v}}{\Delta t} = \frac{v_f - v_0}{t_f - t_0}$$

Equation #3: Newton's First Law:

$$\vec{F}_g = m\vec{a}_g$$

Equation #7: Standard Deviation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}|a_i - \bar{a}|^2}{N}}$$

Equation #8: Percent Error:

$$Percent\ Error\ (\%) = \frac{|Measured\ value - Actual\ value|}{|Actual\ value|} * 100\%$$

Tabular Data:

Measurement [Full-Distance]	Time (sec)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Measurement [Half-Distance]	**Time (sec)**

1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Evaluation:

Note: Please practice answers on paper before submission.

1. What are differences between displacement, velocity, and acceleration?
2. What is the free body diagram above? A label of gravity, and normal are requisite.
3. Why is half-distance and full-distance in the experiment?
4. What is the acceleration?
5. What is the force from movement?

Lab #3: Repetitive Motion

Background: Automotive and robotic assembly is repetitive. Since the first vehicle by Henry Ford to Charlie Chaplin's initial films, motion is a childhood favorite. Prior in time, mechanical dolls repetitively wrote articles by Pierre Jaquet-Droz. Also, vintage watches from Swiss-manufacturing repetitively determined time. Today, in home devices generate simple motions, including printers and dishwashers. For class, we generate basic repetitive motion.

Goal: Discrete m

ovements measured by a series of photogates and a graph about a transient object.

Null Hypothesis: The independent and dependent variables in then graph below have no relationship.

Alternative Hypothesis: The independent and dependent variables in the graph have a relationship.

Learning Outcomes:

1. A car on a rail repeating movements back and forth along the rail.
2. A graph about measured position vs. time of repetitive motions done by hand.
3. Velocity from moving the rail car in both positive and negative directions.
4. The plot of acceleration from calculating velocity.

Equation #1: Position:

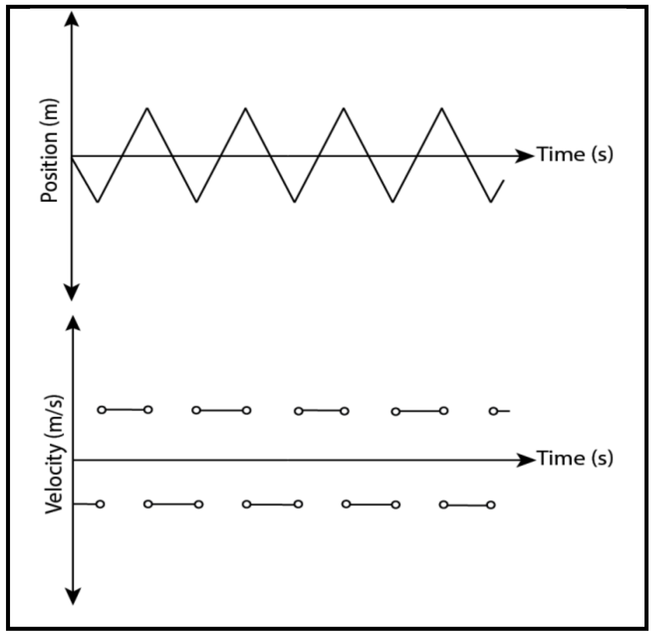
$$\Delta x = x_2 - x_1$$

Equation #2: Velocity:

$$\vec{v} = \left(\frac{x_2 - x_1}{t_2 - t_1}\right)$$

Equation #3: Acceleration

$$\vec{a} = \left(\frac{\vec{v}_2 - \vec{v}_1}{t_2 - t_1}\right)$$



Tabular Data: Photogate 1-2 (cm): _______ Photogate 2-3 (cm): _____ Photogate 3-4 (cm): ______

	Photogate																			
	#1	**#2**	**#3**	**#2**	**#1**	**#2**	**#3**	**#2**	**#1**	**#2**	**#3**	**#2**	**#1**	**#2**	**#3**	**#2**	**#1**	**#2**	**#3**	**#2**
Time (ms)																				

Evaluation:

Note: Please practice answers on paper before submission.

1. What are the independent and dependent variables in the experiment?
2. A description about certainty in the experiment between time and position.
3. What is velocity?

4. Acceleration relates to velocity and position, why?
5. A graph of time vs. position, time vs. velocity, and time vs. acceleration.

Lab #4: Acceleration

Background: The construction, design, and purpose of machines is mechanical engineering. The field touches on virtually every motion, along with safety by failure, functionality, aesthetics, and durability. The failure process entails investigative preservation, visual inspection, electrical testing, reliability per use, and failure mechanism. For today's lab, students inhibit an approach of upward motion through mathematical calculation.

Goal: A prediction about mass and angle from trials stalling an upward motion.

Null Hypothesis: The independent and dependent variables in the graph below have no relationship.

Alternative Hypothesis: The independent and dependent variables in the graph below have a relationship.

Learning Outcomes:

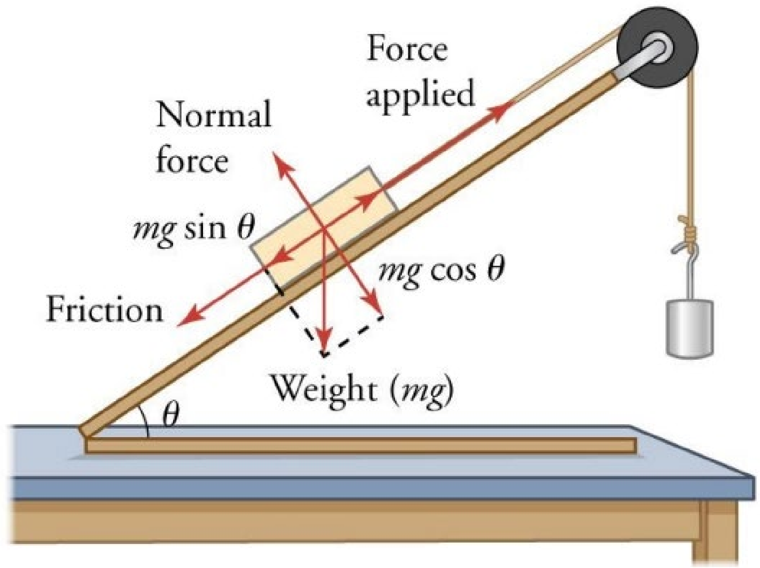
1. An incline angle before measuring linear motion on a ramp.
2. Communicate with others, what is the maximum limit of motion.
3. For three attempts, the maximum mass to an exact stall.

Equation #1: Angles:

$$\cos\boldsymbol{\theta} = \frac{adjacent}{hypotenuse}$$

$$\sin\boldsymbol{\theta} = \frac{opposite}{hypotenuse}$$

$$\tan\boldsymbol{\theta} = \frac{opposite}{adjacent}$$



Equation #2: Newton's 2nd Law:

$$\vec{F} = m\vec{a} = m\left(\frac{\vec{v}_2 - \vec{v}_1}{t_2 - t_1}\right)$$

Tabular Data: Ramp Length (cm): ________ Angle (°): _________ Mass of Cart (g): __________

Experiment	Mass (g)	Length of Travel (m)	Time of Travel (s)
Trial #1			
Trial #2			
Trial #3			

Evaluation:

Note: Please practice answers on paper before submission.

1. What are the independent and dependent variables in the experiment?
2. A description about certainty in the experiment between mass and length of travel.
3. What is velocity in the experiment above?
4. Why are trigonometric equations important to an incline or ramp?
5. Were the trials accurate predictors to stall?

Lab #5: Newton's Third Law of Motion

Background: Newton's third law relates equal forces of opposite direction. For the third law, balloons pronounce an upward rocket thrust. The equal and opposite corollary in a balloon is inertia. A balloon of ideal pressure and dimension simulates conditions of Newton's third law with little drag and friction. For this morning's lab, students produce different pressure systems to substantiate Newton's law.

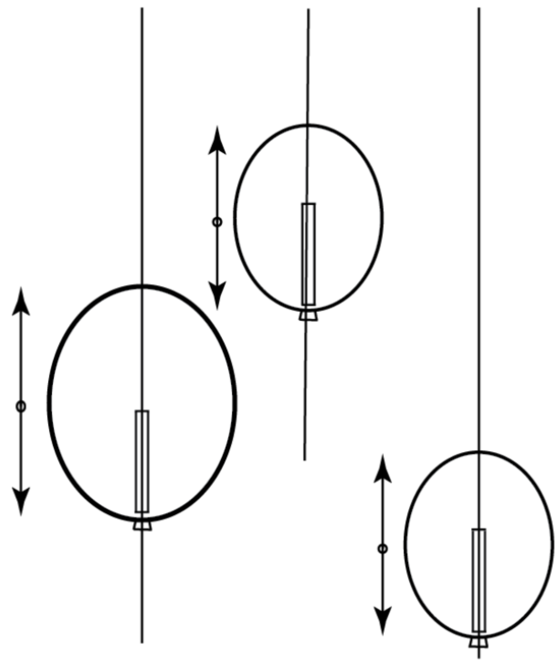
Goal: Prior to lab, the pressure and distance of a balloon modelled on a string from mathematics.

Null Hypothesis: The independent and dependent variables in the graph below have no relationship.

Alternative Hypothesis: The independent and dependent variables in the graph below have a relationship.

Learning Outcomes:

1. A balloon-straw system predicts internal pressure
2. The Ideal Gas Law for intermediate prediction of internal balloon pressure
3. Average distance traveled by a ballon in an experiment
4. Compare and contrast predicted vs. actual pressure in a written argument



Equation #1 – Pressure: $P = \frac{Force}{Area}$

Equation #2 – Ideal Gas Law: $PV = nRT$

Equation #3 - Force: $F = ma = m\frac{\Delta v}{\Delta t}$

Equation #4 - Average: $\overline{x} = \frac{\sum_{i=1}^{n} x_i}{n}$

Tabular Setup:

Total Mass (g): ______________________

Experiment	Radius (m)	Predicted Pressure (atm)	Distance (m)	Travel Time (s)	Actual Pressure (atm)
Trial #1					
Trial #2					
Trial #3					
Trial #4					
Trial #5					
Predicted Average (atm):			Actual Average (atm)		
Standard Error (atm):			Standard Error (atm):		

Evaluation:

Note: Please practice answers on paper before submission.

1. What are the independent and dependent variables in the experiment?
2. The Ideal Gas Law had what purpose?
3. Five total trials were in the experiment. How many trials are necessary in a 95% confidence level? How does confidence level prove a hypothesis?
4. What were clues about the actual pressure?
5. Standard errors are not in the equations. Where is the standard error equation? Please, a citation.

Lab #6: Forces 1-D

Background: Gravity is a fundamental force of the natural universe. The effect upon mass is determinable to the accuracy and precision of the clock measurement. By a vertical ring stand, students delve into free fall, plotting data, calculating accuracy, along with determining precision of their methods.

Goal: Statistically determine the gravitational acceleration constant and experimental error.

Null Hypothesis: Position and time variables have no relationship in the experiment.

Alternative Hypothesis: Position and time variables have a relationship in the experiment.

Learning Outcomes:

1. At Earth's Sea level, gravitational acceleration, a constant using photogates.
2. A simple displacement, velocity, acceleration, and force plot from the data.
3. The accuracy and precision of measured constants with many experimental trials.

Equation #1: y-component:

$$y = y_0 - v_x t - \frac{1}{2} g t^2$$

Equation #2: Standard Deviation:

$$\sqrt{\frac{\sum_{i=1}^{N}(x_i - \overline{x}_i)^2}{N}}$$

Equation #3: Percent Error:

$$Percent\ Error = \frac{|Measured - Actual|}{Actual} * 100\%$$

Tabular Data: **Height (cm): ___________ Mass (g): ___________**

Measurement	Time (s)	Velocity (m/s)	Acceleration (m/s^2)	Force (N)
Photogate #1				
Photogate #2				
Photogate #3				
Photogate #4				
Photogate #5				

Evaluation:

Note: Please practice answers on paper before submission.

1. What are the independent and dependent variables in the experiment?
2. What was purpose of Equation #1?
3. Five total trials were in the experiment. What was the average time, velocity, acceleration, and force? A calculation individually or total average is applicable?
4. What was percent error?

5. Three plots prepared with position (m) vs. time (s), velocity (m) vs. time (s), and acceleration (m) vs. time(s).

Lab #7: Projectile Motion

Background: Documentation of projectiles existed from before the 12th century. The arcs of high-tensile bow and arrow represent a historic point in African and Eurasian history. Projectile motion led researchers to space, and beyond. For lab, students predict location and distance.

Goal: An equation about arcs from time, position, and velocity by using Newton's laws.

Null Hypothesis: The position and time variables have no dependent relationship.

Alternative Hypothesis: The position and time variables have a dependent relationship.

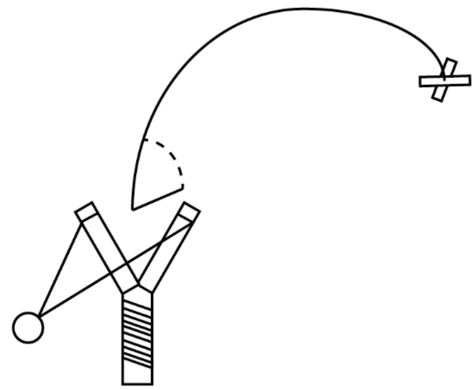
Learning Outcomes:

1. Two equations having separable and dependent time components.

2. A position predicted by an angle via a model from Newton.
3. The actual distance compared to a target already on the floor before experiment.

Equation #1 - Position:

$$x = vt + x_0$$



Equation #2 - Velocity:

$$v = at + v_0$$

Equation #3 - Acceleration:

$$a_g = 9.8\, m/s^2$$

Derivation:

Tabular Data: Angle (°): ______________ Force (N): _______________________

Experiment	Predicted x-Position (m)	Predicted y-Position (m)	Actual x-Position (m)	Actual y-Position (m)
Trial #1				
Trial #2				
Trial #3				
Trial #4				
Trial #5				
Average				

Evaluation:

Note: Please practice answers on paper before submission.

1. What are the independent and dependent variables in the experiment?
2. What was the purpose of Equation #1, #2, and #3?
3. A paragraph written about the derivation, experiment, and trials.
4. Which variable, x or y is dependent on gravity?
5. How close was the target to prediction?

Lab #8: Forces 2-D

Background: Forces have separable components. Within the Cartesian coordinate system, individuals practice the F_x, F_y, and F_z forces on a free body diagram. An example is an incline with 2-dimensional forces in both x-and-y directions from gravitational acceleration up the slope. Today, we apply Newton's 2^{nd} Law to determine the free body diagram and individual components.

Goal: An object traveling by gravity up an incline, across a pulley, and down a ledge.

Null Hypothesis: The force in the x-direction never depends on the force in the y-direction.

Alternative Hypothesis: The force in the x-direction depends on force in the y-direction.

Learning Outcomes:

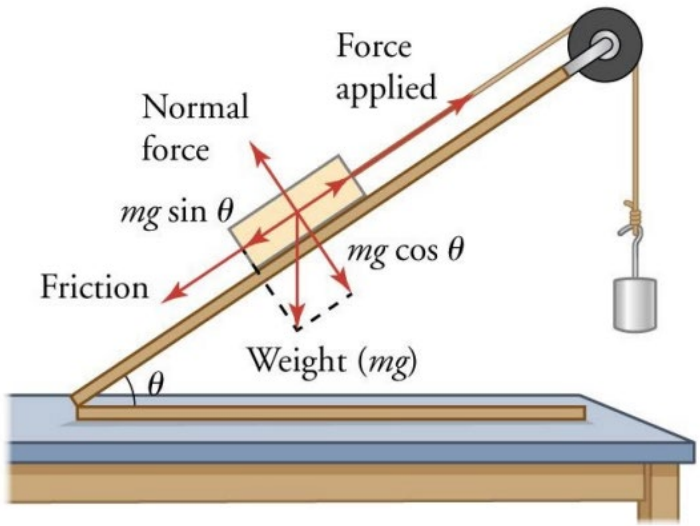
1. A free body diagram of a mass balanced on an incline by a block.
2. The forces to movement (F_x, F_y) after mass releases.
3. Newton's 2nd Law demonstrating where forces equate.

Equation #1: Angles:

$$\cos\theta = \frac{adjacent}{hypotenuse}$$

$$\sin\theta = \frac{opposite}{hypotenuse}$$

$$\tan\theta = \frac{opposite}{adjacent}$$



Equation #2: Newton's 2nd Law:

$$\vec{F} = m\vec{a} = m\left(\frac{\vec{v}_2 - \vec{v}_1}{t_2 - t_1}\right)$$

Tabular Data: Length (cm): ____ Angle (°): _____Mass of Cart (g): ___ Mass of Weight (g): ____

Measurement	Time (s)	Velocity (m/s)	Acceleration (m/s²)	$\vec{F}$ (N)	$\vec{F}_x$ (N)	$\vec{F}_y$ (N)
Photogate #1						
Photogate #2						
Photogate #3						
Photogate #4						
Photogate #5						

Evaluation:

Note: Please practice answers on paper before submission.

1. What are the independent and dependent variables in the experiment?
2. What was purpose of Equation #1?
3. What is the free body diagram from the incline?
4. A plot about graphs showing time vs. x-position and time vs. y-position?
5. What is the free body diagram where forces equate?

Lab #9: Pulleys and Tension

Background: A pulley system is historical. The framework transfers force in a circular motion and distributes tension across further connections. The first pulley operation was in 1500 BCE by Mesopotamians for resources. Archimedes used pulleys and Leonardo Da Vinci. For exposure to multi-pulley systems, students measure the force of gravity across three types of vertical hoists.

Goal: Newton's second law applied to force across multiple pulleys.

Null Hypothesis: Displacement is not dependent by mass with a number of pulleys.

Alternative Hypothesis: Displacement is not dependent by mass with a number of pulleys.

Learning Outcomes:

1. A pulley system using single, double, and triple wheels.
2. The distance during free fall by applying a body diagram with tensions.
3. The error extracted from measurements in a one-, two-, three-, or tuple-wheel systems.

Displacement of Pulley System:

Single Pulley System	
Mass A (g)	
Mass B (g)	
Predicted Displacement (m)	
Actual Displacement (m)	
Error (m)	

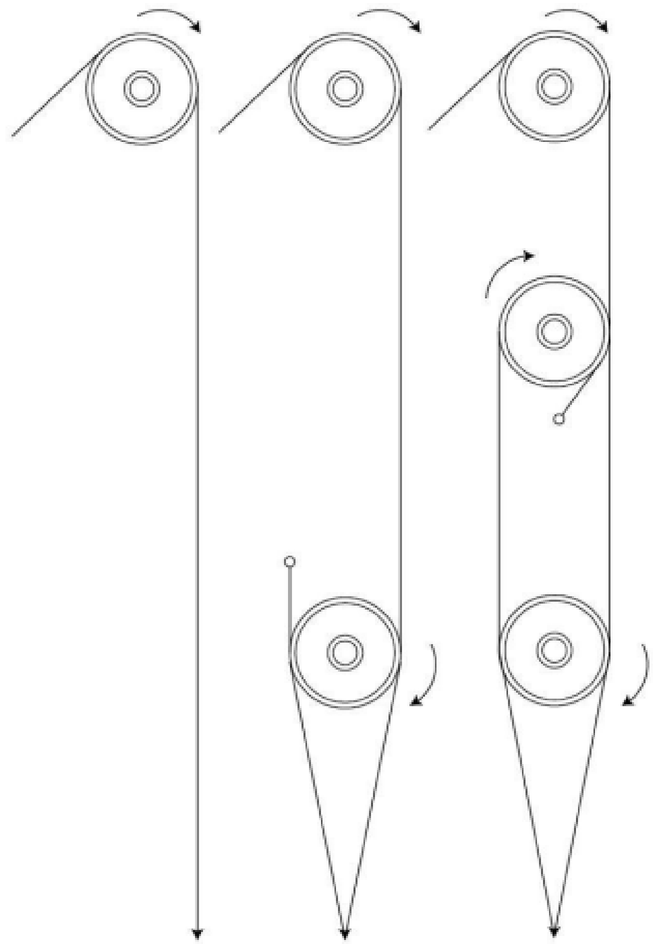
Calculations:

Double Pulley System	
Mass A (g)	
Mass B (g)	
Predicted Displacement (m)	
Actual Displacement (m)	
Error (m)	

Calculations:

Triple Pulley System	
Mass A (g)	
Mass B (g)	
Predicted Displacement (m)	
Actual Displacement (m)	
Error (m)	

Calculations:



Evaluation:

Note: Please practice answers on paper before submission.

1. What are the independent and dependent variables in the experiment?
2. What happens from additional pulleys?
3. What is the free body diagram about each system?
4. Why is a triple pulley system helpful with lift?
5. What is the error in each system?

Lab #10: Periodic Motion – 1D

Background: An occurrence at regular intervals is periodic. When about a circle, the direct motion is recurrent and cyclic. In a single dimension, amplitude distinguishes (co)sinusoidal model by extreme position. While, frequency describes periodic behavior. The solution to the model is unique and about natural motion. A circular ring represents a wave when perpendicular. For lab, students rotate a ring for periodic motion.

Goal: A continuous movement about unit circle by oscillating a wire loop.

Null Hypothesis: The motion around a unit circle never represents a wavey motion.

Alternative Hypothesis: The motion around a unit circle represents a wavey motion.

Learning Outcomes:

1. Unit circle exposure by experimental periodic rotation around a circular object.
2. Angular rotation directly depends on wavey motion along a line in different dimensions.
3. A model about error from rotational motion with a metal ring in two-dimensions.

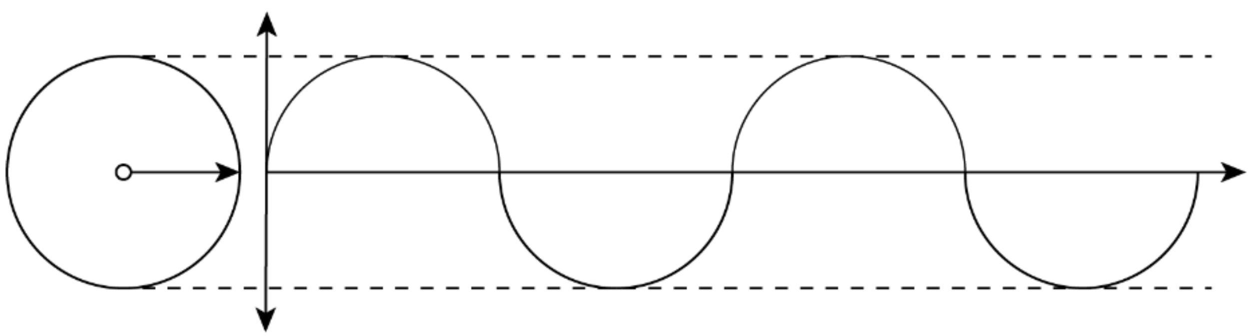
Equation #1 & #2 - Periodic Motion in x-, and y-directions

$$x(t) = A\cos(\omega t + \varphi) \qquad\qquad y(t) = A\sin(\omega t + \varphi)$$

Tabular Data: Rotation time (sec): ___________________

Rotation time	**Unit Circle**				**Periodic Wave**			
_____________sec	Member Values			Average	Member Values			Average
Amplitude (cm)								
Frequency (1/s)								
Period (s)								
Phase (rad)								

Model Position (cm): ___________ Model Position (cm): _____________



Evaluation:

Note: Please practice answers on paper before submission.

1. The metal ring did what?
2. What is amplitude?
3. What is frequency?
4. Why was motion repetitive and periodic?
5. What is phase?
6. What was the error from rotation?

Lab #11: Simple Harmonic Motion

Background: Simple harmonic motion on a pendulum describes oscillatory motions. The sinusoidal behavior from position matches a sine (or cosine) function near equilibrium. With a weight and pivot point, students determine a model of frequency, displacement, and periodic motion.

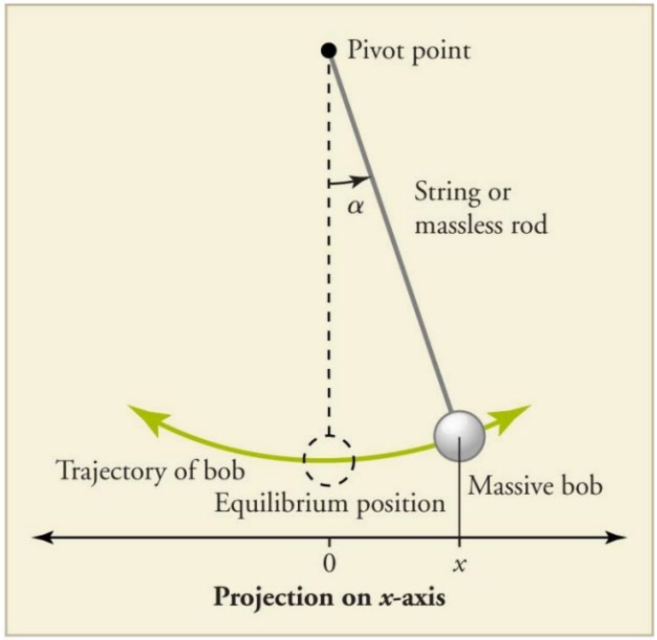
Goal: A simple harmonic oscillator calculation from parameters in a pendulum near minimum.

Null Hypothesis: The angular frequency from a pendulum is never dependent on time.

Alternative Hypothesis: The angular frequency from a pendulum is dependent on time.

Learning Outcomes:

1. A trigonometric model to harmonic motions from a pendulum.
2. Boundary conditions exposed through a sinusoidal function.
3. The frequency, position, and period of a sizeable multi-meter pendulum.



Equation #1: Period:

$$Period\ (s) = T = 2\pi\sqrt{\frac{L}{g}}$$

Equation #2: Angle:

$$\alpha\ (t) = \omega t + \phi$$

Equation #2: Displacement:

$$x = A\sin(\omega t + \phi)$$

Tabular Data: Length of String (cm): __________ Mass of Weight (g): _________

Trials	Time (s)	Displacement (m)	Angle (°)	Period (s)	ω (rad/s)
Trial #1					
Trial #2					
Trial #3					
Trial #4					

Evaluation:

Note: Please practice answers on paper before submission.

1. What was the average period from the pendulum?
2. What is the mathematics from period to angular frequency?
3. A heavier mass has similar or different outcomes?
4. What was the angular frequency?
5. What is a boundary condition?

Lab #12: Momentum

Background: Conservation of momentum symbolizes total object mass at a velocity. The momentum vector is the displacement by an object times mass per duration of travel. In a system without friction, drag, or other forces, momentum conserves during collision. Today's experiment transfers momentum before and after the collision. From photogates, the average and precise measuring about a perfectly elastic collision.

Goal: Quantitatively measure conservation and the total momentum of contact.

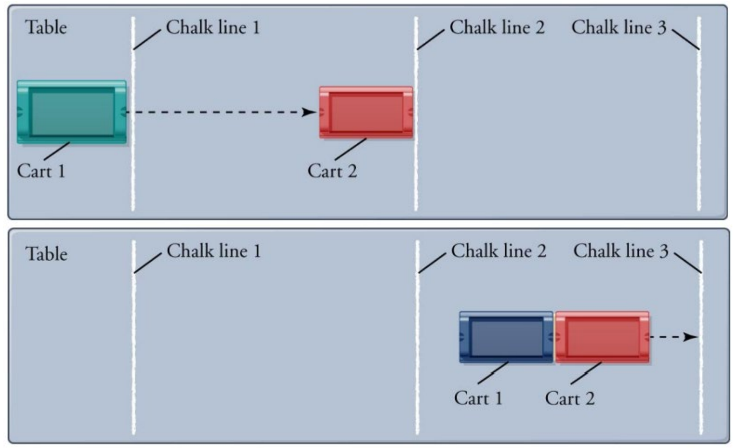
Null Hypothesis: Momentum of a car has no relationship before and after collision.

Alternative Hypothesis: Momentum of a car has a relationship before and after collision.

Learning Outcomes:

1. Collisions between frictionless physics cars at different marked lengths.

2. Quantitatively measure velocity with a series of photogates.
3. Experimental practice measuring the mass of objects.
4. A hypothesis before experiment about predicting the collision parameters.
5. Momentum to kinetic energy for further calculating conservation of energy.



Equation #1: Momentum:

$$p = mv$$

Equation #2: Total Momentum:

$$\left(\sum_{i=1}^{n} m_i v_i\right)_{initial} = \left(\sum_{i=1}^{n} m_i v_i\right)_{final}$$

Equation #3: Kinetic Energy:

$$K.E. = \frac{1}{2} m v^2$$

Tabular Data: Mass Car #1 (g): ___________________ Mass Car #2 (g):___________________

Trial	Initial		Final	
	Velocity #1 (cm/s)	Velocity #2 (cm/s)	Velocity #1 (cm/s)	Velocity #2 (cm/s)
1				
2				
3				
4				
5				
6				
7				
8				
9				

Evaluation:

Note: Please practice answers on paper before submission.

1. What was the average velocity of car #1 before collision?
2. What was the average velocity of car #2 after collision?
3. A paragraph about the momentum transfer.
4. What was the kinetic energy of car #1 before collision?
5. What was the kinetic energy of car #2 after collision?

Lab #13: Potential Energy Storage

Background: Across sciences, potential energy is the difference to ground. Count Rumford's studied thermodynamics, and also formulae about local heat and energy. Primary discoveries by Count Rumford (Benjamin Thompson) were plants correlation to rays from the sun, intensity in wax candles, conduction, convection, hot weights, and instrumentation thereof. Later scientists, Davy, Lavoisier, Mayer, Joule, Kelvin, and Carnot characterized their discoveries of thermo- and electrodynamics. Soon after, potential energy solidified. In the afternoon, students determine potential energies linear relationship.

Goal: A relationship between height and potential energy through a ramp with spherical mass.

Null Hypothesis: Potential energy has no correlation to height on a slope.

Alternative Hypothesis: Potential energy has a correlation to height on a slope.

Learning Outcomes:

1. Conservation of energy through potential and kinetic energy transfer.
2. A graph incorporating height vs. potential energy or gravity, mass, and height.
3. In words, how to increase experimental accuracy and precision.

Equation #1: Momentum:

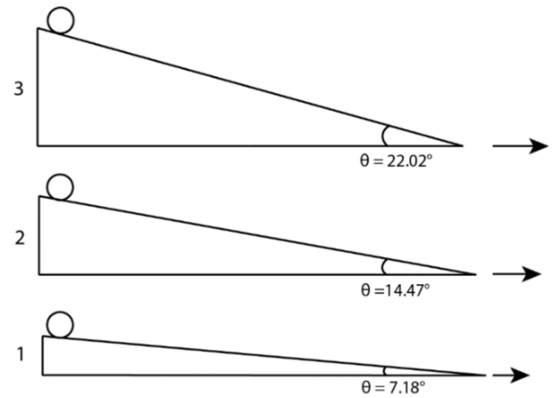
$$K.E. = \frac{1}{2}mv^2$$

Equation #2: Total Momentum:

$$a_g = 9.8\, m/s^2$$

Equation #3: Kinetic Energy:

$$\Delta E = KE + PE \cong 0$$



Tabular Data: Mass Car #1 (g): ___________________ Mass Car #2 (g):_______________

Experiment	Ramp #1		Ramp #2		Ramp #3	
	Distance (m)	Time (sec)	Distance (m)	Time (sec)	Distance (m)	Time (sec)
Mass #1						
Mass #1						
Mass #1						
Kinetic Energy (J)						
Potential Energy (J)						

Evaluation:

Note: Please practice answers on paper before submission.

1. What was the average kinetic energy in each trial?
2. What was the average potential energy in each trial?
3. How close were potential and kinetic energy?
4. What height effected potential energy?
5. A plot about Height (m) vs Potential Energy (J).

Lab #14: Mechanical Waves

Background: A mathematical representation of waves is foundational. Every day students hear terms about 'the speed of sound', 'light', 'p-wave', 's-wave', and 'earthquake!' Traditional calculations found in the medium of travel, but also less complexity. An incident wave reflects into an observable interference. For today's lab, thoughts explore incident phase, frequency, amplitude, and kinetic energy.

Goal: The kinetic energy of a transverse or longitudinal wave produced on a spring.

Null Hypothesis: The kinetic energy never depends on the wave function from the spring.

Alternative Hypothesis: Kinetic energy depends on the wave function from the spring.

Learning Outcomes:

1. Observable waves on spring by oscillating frequency and/or phase of movement.

2. Quantitatively determine the amplitude of a wave with a standard ruler.
3. A multitude of wavelengths across varying frequencies.
4. A functional relationship of simple waves using laboratory information.
5. Separately, kinetic energy calculating a model to the experimental waves.

Equation #1: Wave Equation:

$$y(t) = A\sin(\omega t + \varphi)$$

Equation #2: Velocity of Wave:

$$v = \lambda f$$

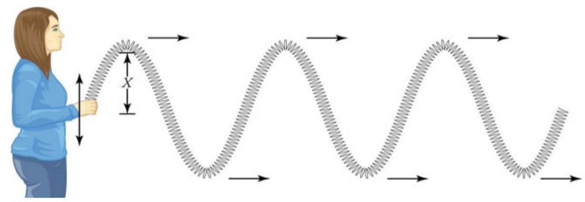
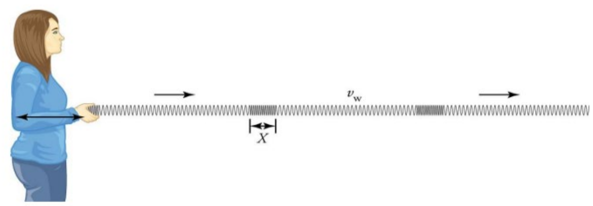


Figure 11.2: A **transverse** wave, showing the amplitude *X* and direction of motion.

Equation #3: Kinetic Energy:

$$K.E. = \frac{1}{2}mv^2$$



Tabular Data:

Experiment	Phase	Frequency (1/s)	Amplitude (cm)	Wavelength (cm)	Function of Wave y(t)	Velocity (cm/s)	Kinetic Energy (J)
Trial #1							
Trial #2							
Trial #3							
Trial #4							
Trial #5							

Evaluation:

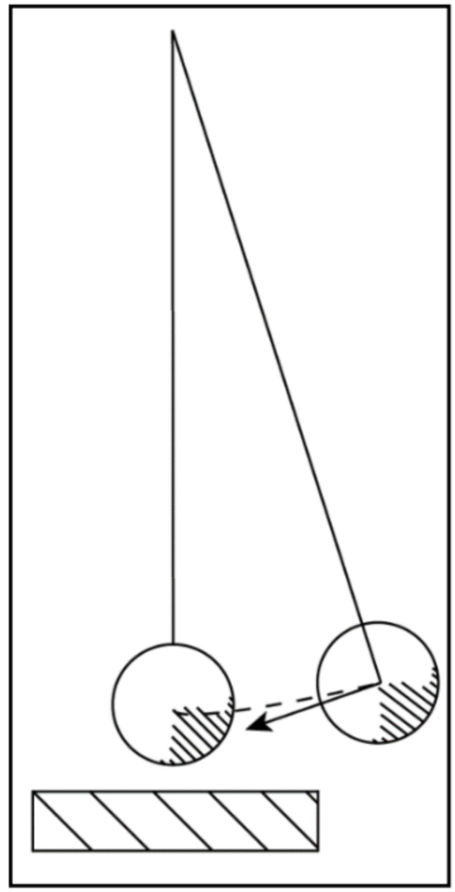
Note: Please practice answers on paper before submission.

1. What is phase?
2. Why is frequency essential to Equation #1?
3. Amplitude contributes to Equation #1? How?
4. What was the wavelength from each trial?
5. Kinetic Energy was similar or dissimilar between each trial?

Lab #15: Pendulum Momentum

Background: In China, Ganzhou, Jiangxi Province is a large pendulum. At 12.8-meters, Harmony Tower commissioned a pendulum in a clock by clockmakers - Smith of Derby. Prior to 2010's design, another pendulum existed for experimentation. With a length of 4,250 feet, two lengths of No. 24 steel piano wire, Professor Fred W. McNair of College of Mines, Michigan utilized Tamarack Mines with weighted bobs Down a shaft labelled No. 5 suspended an experiment about gravitational separation. Science Magazine published results of gravitational separation on Friday, June 20th, 1902. For examination, students' measure momentum from a pendulum.

Goal: Standardize momentum for a single pendulum then collide two pendulums



Null Hypothesis: Angular momentum never depends on time.

Alternative Hypothesis: Angular momentum depends on time.

Learning Outcomes:

1. A standard calibration for (later) measure of angular momentum.
2. Two pendulums as a momentum transfer experiment and observation of inelastic collision.
3. Momentum for single and double pendulum movements.

Equation #1: Angular Velocity:

$$\omega = \frac{v}{r}$$

Equation #2: Angular Momentum:

$$\vec{L} = \mathrm{I}\omega$$

Tabular Data: Mass #1 (kg): __________ Mass #2 (kg): _____________

Pendulum Calibration					
Experiment	Radians (rad)	Time (sec)	Angular Velocity (rad/s)	Moment of Inertia (kg/m^2)	Angular Momentum (kg/m^2s)
Trial #1					
Trial #2					
Trial #3					
Average					

Second Pendulum Collision					
Experiment	Radians (rad)	Time (sec)	Angular Velocity (rad/s)	Moment of Inertia (kg/m^2)	Angular Momentum (kg/m^2s)
Trial #1					
Trial #2					
Trial #3					
Average					

<u>Evaluation:</u>

<u>Note:</u> Please practice answers on paper before submission.

1. What are radians?
2. Calibration had what purpose? Why was a second pendulum important?
3. What is momentum?
4. What is the mathematical relationship between moment of inertia and angular momentum?
5. Two pendulums generated error? What was the average error?

Lab #16: Electrostatics

Background: Electrostatic forces relate to Coulomb's Law. An electron's charge act across distance by both direction and magnitude. The force is proportional through an inverse square law and during laboratory experiment. Two balloons charge by electrostatic electricity and exemplify Coulomb's Law. A coefficient undermines the experiment (Equation #1) as a universal constant. Student's examine charges, a proportional constant, and a reciprocal square in Coulomb's law.

Goal: An experiment testing laws and equations, specifically Coulomb's.

Null Hypothesis: The distance from midline (center) is not proportional to Coulomb's constant.

Alternative Hypothesis: Distance from midline (center) is proportional to Coulomb's constant.

Learning Outcomes:

1. An apparatus using balloons and tangential forces.
2. Experimental values accurately quantifying Coulomb's constant
3. A precise determination by using uncertainty.

Equation #1: Coulomb's constant:

$$k_e = 8.998 \, x \, 10^9 \; N \cdot m^2/C^2$$

Equation #2: Electron charge:

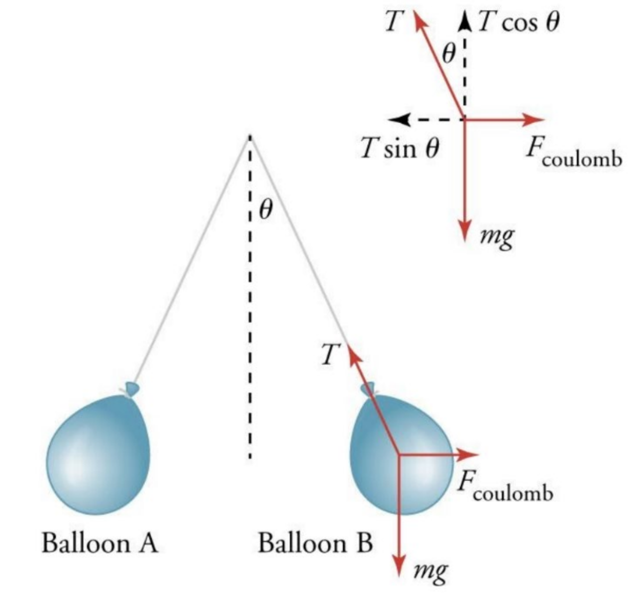
$$q = 1.602 \, x \, 10^{-19} \; C$$

Equation #3: Coulomb's Law:

$$\vec{F} = k_e \frac{q_1 q_2}{r^2}$$

Equation #4: Force of Coulomb:

$$\vec{F} = m\vec{g} \tan\theta$$



Tabular Data: Mass Balloon A (g): __________ Mass Balloon B (g): ___________

Experiment	Distance from Center (cm)	Measured Coulomb Constant ($N*m^2/C^2$)
Trial #1		
Trial #2		
Trial #3		
Trial #4		
Trial #5		
Trial #6		
Trial #7		
Trial #8		
Trial #9		

Average Coulomb Constant ($N*m^2/C^2$): ____

Uncertainty of Measurement (%): ____

Evaluation:

Note: Please practice answers on paper before submission.

1. What is a tangent function?
2. What is a relationship between Equations #1 and #2?
3. Any human errors arise from the experiment?
4. What were experimental values about Coulomb's constant?

5. How justifiable is error from actual Coulomb's constant?

Lab #17: Ohm's Law

Background: Ohm's Law describes a direct relationship between voltage, current, and resistance. Voltage (V) is potential difference from an energy source in an electric circuit. While current (C) is the flow of electrons in a conductive wire. Current flow is directly proportional to voltage by a coefficient, resistance (R). The linear relationship in the experiment was evidence to conductance. Students, today prepare a standard curve from a voltmeter across a circuit.

Goal: A standard curve (linear relationship) graphed between voltage and current.

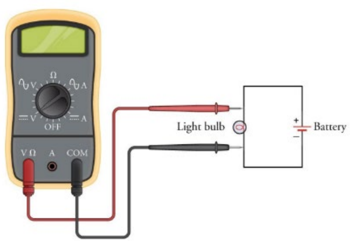
<u>Null Hypothesis:</u> Voltage is independent to current in electrical circuits.

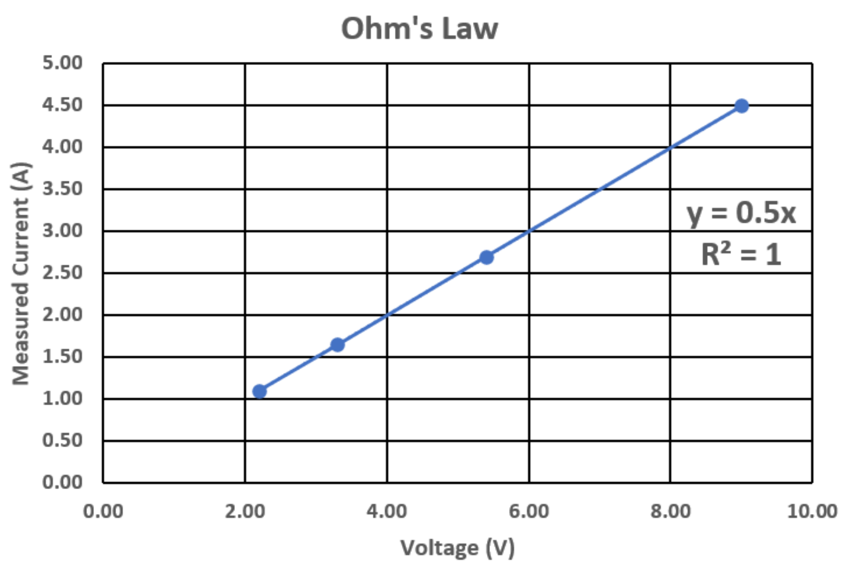
<u>Alternative Hypothesis:</u> Voltage is dependent to current in electrical circuits.

<u>Learning Outcomes:</u>

1. An electric circuit's current by using a voltmeter (ammeter).
2. A lightbulb contains resistance across positive and negative terminals.
3. A linear curve collected at specific voltages onto a plot and graph.

<u>Equation #1: Ohm's Law:</u> $V = IR$





<u>Tabular Data:</u> Instrument Model: ______________________________

Experiment	Voltage (V)	Current (A)
Circuit #1		
Circuit #2		
Circuit #3		
Circuit #4		
Circuit #5		

<u>Evaluation:</u>

<u>Note:</u> Please practice answers on paper before submission.

1. A 5-7 sentence paragraph about voltage, current, and resistance.
2. What changed between each experiment?
3. Voltage and current have units, any specific reason?
4. Voltage (V) versus Current (I) plot.

5. What was the light bulb's resistance?

Lab #18: Resistor Circuits

Background: Circuits are conductive paths to positive and negative charges. Series circuits contain resistance across a single path, while parallel circuits resistance across multiple paths. Despite nearly infinite combinations, the simplest circuit involve wires, resistors, and batteries. A voltmeter or ammeter measure circuit voltage and amperage, respectively. A demonstration about Kirchhoff's law is the plan in the lab below.

Goal: Students examining series and parallel circuits through ammeter values.

Null Hypothesis: Current is not directly proportional to resistance in series and parallel circuits.

Alternative Hypothesis: Current is directly proportional to resistance in series and parallel circuits.

Learning Outcomes:

1. Ammeter or voltmeter usage for circuit information.
2. Multiple circuits engineered as series and parallel circuits in a rigid test.
3. Kirchhoff's law from collected electrical values as proof to the law.

Equation #1: Kirchhoff's Law for Currents:

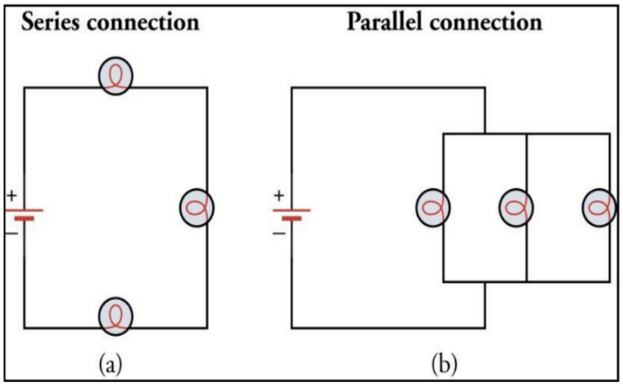
$$\sum_{i=1}^{n} I_i = I_1 + I_2 + I_3 + \cdots + I_n = 0$$

Equation #2: Kirchhoff's Law for Voltage:

$$\sum_{i=1}^{n} V_i = V_1 + V_2 + V_3 + \cdots + V_n = 0$$

Equation #3: Kirchhoff's Law for Resistance:

$$\sum_{i=1}^{n} \frac{1}{R_i} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n} = 0$$



Experimental Data:

Series Circuit:

Parallel Circuit:

Evaluation:

Note: Please practice answers on paper before submission.

1. What are series and parallel circuits?
2. Gustav Kirchhoff made laws for series and parallel circuits. Why?
3. How many circuits are necessary as proof to Kirchhoff's law?

4. What changed between each experiment?

5. What is error from the experiment above?

Lab #19: Torque

Background: Torque is an extension from kinematics. A tangential force upon a perpendicular axis is directly proportional to force-distance i.e., torque. A force applies across a length in a circular motion, as torque. The alternative perspective is angular momentum (L) and the relation to moment of inertia (I). By acceleration from gravity, the demonstration involves incremental mass onto a wrench and bolt.

Goal: Torque for a fastened bolt or nut and angular momentum from the same system.

Null Hypothesis: Torque is not dependent on mass in a linear equation.

Alternative Hypothesis: Torque is dependent on mass in a linear equation.

Learning Outcomes:

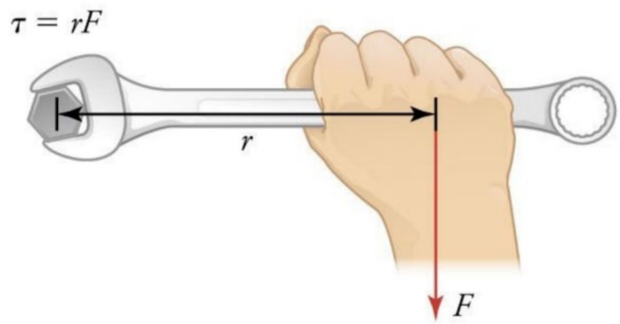
1. An apparatus to quantitatively measure the torque of a bolt.
2. Accurate torque from an arithmetic mean (or average) and multiple samples.
3. Precise torque in the system by multiple experiments using standard deviation.

Equation #1: Torque:

$$\tau = rF$$

Equation #2: Angular Momentum

$$L = I \times \omega$$



Tabular Data:

Tool	Length (cm)	Trial	Total Mass (g)	Force (N)	Torque (N*m)	Average Torque (N*m)
Wrench #1		1				
		2				
		3				
Wrench #2		4				
		5				
		6				
Wrench #3		7				
		8				
		9				

Sum Average Torque (N*m): ___________________

Standard Deviation (N*m): ±__________________

Evaluation:

Note: Please practice answers on paper before submission.

1. What is torque?
2. What is angular momentum?

3. What was the average torque?
4. How precise was the experiment about torque?
5. A paragraph (5-7 sentences) about torques relationship to a hand and wrench.

Lab #20: Angular Momentum

Background: Gyroscope applications model a stationary center of mass. In laboratory settings, gyroscopes rotate about a point with a rigid and symmetrical frame. The generated torque of gyroscope stabilizes or destabilizes the origin i.e., structural center of mass. A formula governs gyroscopes under Cartesian and spherical dimensions. Our experiment has two linear functions; center of mass and a rotation axis in a plane.

Goal: A gyroscopic torque and angular momentum from rotation, angle, and gravity.

Null Hypothesis: Angular momentum has no direct correlation to angular velocity.

Alternative Hypothesis: Angular momentum has a direct correlation to angular velocity.

Learning Outcomes:

1. An object precesses about a rotational point - the 'origin.'
2. Torque from a gyroscope with the radius of rotation, mass, and gravitational force.
3. Angular momentum around a disc from a verifiable experimental setup.

Equation #1: Torque:

$$\tau = rF$$

Equation #2: Angular Momentum

$$\vec{L} = I\vec{\omega} = \vec{r} \times \vec{p} = m\,(\vec{r} \times \vec{v})$$

Equation #3: Moment of Inertia (Disc)

$$I_z = I_x + I_y = \frac{1}{2}MR^2$$

Experimental Data:

Mass of Counterweight (g):_________________

Length of Rope (m):________________________

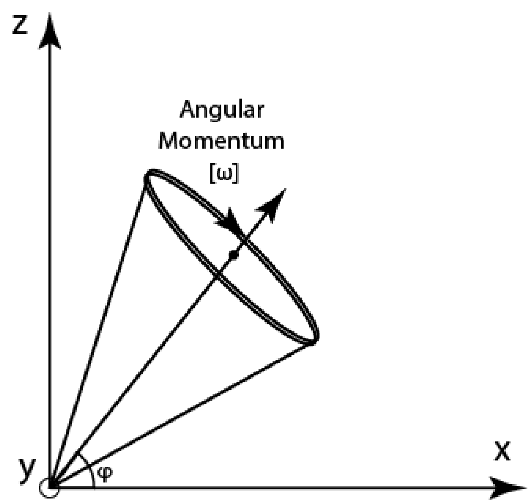
Angular Velocity (rad/s):____________________

Radius of Gyroscope (m): ___________________

Angle of Gyroscope (°):______________________

Torque of Gyroscope (kg m^2):________________

Side



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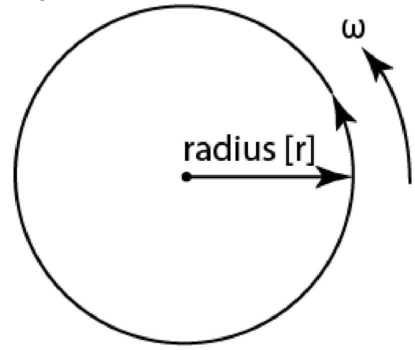


Evaluation:

Note: Please practice answers on paper before submission.

1. What is torque?
2. What is angular velocity?

3. What is a gyroscope?
4. What proves the alternative hypothesis?
5. What data disproves the null hypothesis?

Lab #21: Conservation of Angular Momentum

Background: A system has conserved angular momentum under zero external torque. For a disc orthogonal to gravity, the law of conservation of angular momentum predicts accurate and precise data. To model angular motion, forces balance across a disc at a radial distance. In a proper model, students rotate a flywheel with specific properties, then solve for total angular momentum.

Goal: Masses on a rotational disc quantify the law of conservation of angular momentum.

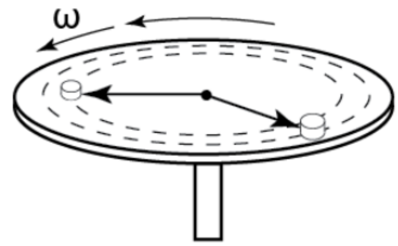
<u>Null Hypothesis:</u> Angular momentum never conserves on a rotational disc.

<u>Alternative Hypothesis:</u> Angular momentum conserves on a rotational disc.

<u>Learning Outcomes:</u>

1. Average trials determining the accuracy of angular conservation.
2. Qualitatively and quantitatively evaluate the standard error of experimental setup

Side



<u>Equation #1: Torque:</u>

$$\tau = rF$$

<u>Equation #2: Angular Momentum</u>

$$\vec{L} = I\vec{\omega} = \vec{r} \times \vec{p} = m\,(\vec{r} \times \vec{v})$$

<u>Equation #3: Moment of Inertia</u>

$$I_z = I_x + I_y = \frac{1}{2}MR^2$$

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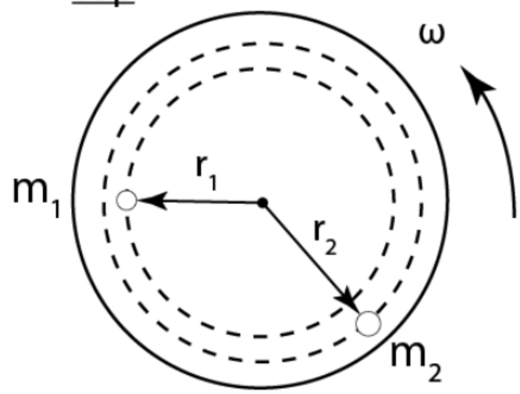

<u>Tabular Data:</u>

Experiment	Trial	Mass (kg)		Radius (m)		Predicted		Actual		
		A	B	A	B	Angular Momentum A (kg rad/s)	Angular Momentum B (kg rad/s)	Angular Velocity (rad/s)	Angular Momentum A (kg m²/s)	Angular Momentum B (kg m²/s)
1	1a									
	1b									
	1c									
								Average		
								Standard Error		
Experiment	Trial	Mass (kg)		Radius (m)		Predicted		Actual		
		A	B	A	B	Angular Momentum A (kg rad/s)	Angular Momentum B (kg rad/s)	Angular Velocity (rad/s)	Angular Momentum A (kg m²/s)	Angular Momentum B (kg m²/s)
2	2a									
	2b									
	2c									

								Average		
								Standard Error		

Experiment	Trial	Mass (kg)		Radius (m)		Predicted		Actual		
		A	B	A	B	Angular Momentum A (kg rad/s)	Angular Momentum B (kg rad/s)	Angular Velocity (rad/s)	Angular Momentum A (kg m^2/s)	Angular Momentum B (kg m^2/s)
3	3a									
	3b									
	3c									
								Average		
								Standard Error		

Model	Experiment	Model
Conservation of Momentum Prediction	**1**	
	2	
	3	
Conservation of Momentum Actual	**1**	
	2	
	3	
Standard Error of Conservation of Momentum		

Evaluation:

Note: Please practice answers on paper before submission.

1. What is moment of inertia?
2. How conservative was angular momentum?
3. What was the standard error?
4. Why ever use a null or alternative hypothesis?
5. What equation modeled conservation of angular momentum from above?

Glossary:

ABOUT
ABOVE
ACCELERATION
ACCURACY
ACCURATE
ACCURATELY
ACROSS
ACT
ACTUAL
ADDITION
ADJACENT
AESTHETIC
AFRICA
AFTER
AFTERNOON
AIR
ALONG
ALREADY
ALSO
ALTERNATIVE
ALTHOUGH
AMMETER
AMPERAGE
AMPLITUDE
AN
AND
ANGLE
ANOTHER
ANSWER
ANY
APPARATUS
APPLICABLE
APPLICATION
APPLY
APPROACH
ARC
ARE
ARGUMENT
ARISE
ARITHMETIC
AROUND
ARROW
ARTICLE
AS
ASSEMBLY
AT
ATTEMPT
AUTOMOTIVE
AVERAGE
AXIS
BACK
BACKGROUND
BALANCE
BALLON
BASIC
BATTERY
BEFORE
BEHAVIOR
BELOW
BETWEEN
BEYOND
BLOCK
BOB
BODY
BOLT
BOTH
BOUNDARY
BOW
BRITISH
BUT
BY
CALCULATE
CALIBRATE
CANDLE
CAR
CART
CARTESIAN
CENTER
CENTURY
CERTAINTY
CHANGED
CHANGE
CHARACTERIZE
CHARGE
CHILDHOOD
CHINA
CIRCLE
CIRCUIT
CIRCULAR
CITATION
CLASS
CLASSROOM
CLOCK
CLOCKMAKER
CLOSE
CLUE
COEFFICIENT
COLLECT
COLLEGE
COLLIDE
COLLISION
COMBINATION
COMMISSION
COMMUNICATE
COMPARE
COMPLEXITY
COMPONENT
CONDITION
CONDUCTION
CONDUCTIVE
CONFIDENCE
CONNECT
CONSERVE
CONSTANT
CONSTRUCT
CONTACT
CONTAIN
CONTINUOUS
CONTRAST
CONTRIBUTE
CONVECTION
COORDINATE
COROLLARY
CORRECT
CORRELATE
COSINE

COULOMB
COUNT
COUNTERWEIGHT
CURRENT
CURVE
CYCLIC
DATA
DAY
DELVE
DEMONSTRATE
DEPENDENT
DEPEND
DERBY
DERIVE
DESCRIBE
DESCRIPT
DESIGN
DESPITE
DESTABILIZE
DETERMINE
DEVIATION
DEVICE
DIAGRAM
DID
DIFFERENT
DIFFICULT
DIMENSION
DIRECT
DISC
DISCOVERY
DISCRETE
DISHWASHER
DISPLACE
DISPROVE
DISSIMILAR
DISTANCE
DISTINGUISH
DISTRIBUTE
DOCUMENT
DO
DOLL
DONE
DOUBLE
DOWN
DRAG
DRAW
DURABILITY
DURATION
DURING
EACH
EFFECT
ELASTIC
ELECTRIC
ELECTRODYNAMICS
ELECTRON
ELECTROSTATIC
ENERGY
ENGINEER
ENTAIL
EQUAL
EQUATE
EQUATION
EQUILIBRIUM
ERROR
ESPECIALLY
ESSENTIAL
EURASIAN
EVALUATE
EVALUATING
EVALUATION
EVER
EVERY
EVIDENCE
EXACT
EXAMINE
EXAMPLE
EXEMPLIFY
EXIST
EXPECT
EXPERIMENT
EXPERIMENT
EXPLORE
EXPOSE
EXPOSURE
EXTENSION
EXTERNAL
EXTRACT
EXTREME
FAILURE
FASTEN
FAVORITE
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FIELD
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FINAL
FIRST
FIVE
FLOOR
FLOW
FLYWHEEL
FOR
FORCE
FORCE
FORD
FORMULA
FORTH
FOUND
FOUNDATION
FRAME
FRAMEWORK
FREE
FREQUENCY
FRICTION
FRIDAY
FROM
FUNCTION
FUNDAMENTAL
FURTHER
GAS
GENERATE
GOAL
GOVERN
GRAPH
GRAVITY
GROUND
GYROSCOPE
HAD
HALF-DISTANCE
HAND
HAPPEN
HARMONIC
HARMONY

HAS
HAVE
HEAR
HEAT
HEAVIER
HEIGHT
HELPFUL
HIGH
HISTORY
HOIST
HOT
HOW
HUMAN
HYPOTHESIS
IDEAL
IMPORTANT
IN
INCIDENT
INCLINE
INCLUDING
INCORPORATING
INCREASE
INCREMENTAL
INDEPENDENT
INDIVIDUAL
INDIVIDUALLY
INDIVIDUALS
INELASTIC
INERTIA
INFORMATION
INHIBIT
HOME
INITIAL
INSPECTION
INSTRUMENT
INSTRUMENTATION
INTENSITY
INTERFERENCE
INTERMEDIATE
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KINETIC
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LED
LEDGE
LENGTH
LESS
LEVEL
LIFT
LIGHT
LIGHTBULB
LIMIT
LINE
LINEAR
LITTLE
LOCAL
LOCATION
LONGITUDINAL
LOOP
MACHINE
MADE
MAGAZINE
MAGNITUDE
MANY
MARK
MASS
MATCHE
MATHEMATICS
MAXIMUM
MEAN
MEASURE
MECHANICAL
MECHANISM
MEDIUM
MEMBER
MESOPOTAMIANS
METAL
METHOD
MG
MICHIGAN
MIDLINE
MINE
MINIMUM
MODEL
MOMENT
MOMENTUM
MOTION
MOVEMENT
MOVE
MULTI-METER
MULTIPLE
MULTI-PULLEY
MULTITUDE
NATURAL
NEAR
NECESSARY
NEGATIVE
NEVER
NEVER
NEW
NEWTON
NO
NORMAL
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NOW
NULL
NUMBER
NUT
OBJECT
OBSERVE
OCCURR
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ON
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ONTO

OPERATION
OPPOSITE
OR
ORIGIN
ORTHOGONAL
OSCILLATE
OTHER
OUR
OUTCOMES
PAPER
PARAGRAPH
PARALLEL
PARAMETER
PATH
PENDULUM
PER
PERCENT
PERFECT
PERIOD
PERIODIC
PERPENDICULAR
PERSPECTIVE
PHASE
PHOTOGATE
PHYSICIST
PHYSICS
PIANO
PIVOT
PLAN
PLANE
PLANT
PLEASE
PLOT
POINT
POSITION
POSITIVE
POTENTIAL
PRACTICE
PRECESS
PRECISE
PREDICT
PREPARE
PRESERVATION
PRESSURE
PRIMARY
PRINTER
PRIOR
PROBLEM
PROCESS
PRODUCE
PROFESSOR
PROJECTILE
PRONOUNCE
PROOF
PROPER
PROPERTY
PROPORTION
PROVE
PROVIDE
PROVINCE
PUBLISH
PULLEY
PURPOSE
QUALITATIVE
QUANTIFY
QUANTITATIVE
RAD
RADIAL
RADIAN
RADIUS
RAIL
RAMP
RAY
REASON
RECIPROCAL
RECORD
RECURRENT
REFERENCE
REFLECT
REGULAR
RELATE
RELATION
RELATIONSHIP
RELEASE
RELIABILITY
REPEAT
REPETITIVE
REPRESENT
REQUISITE
RESEARCH
RESISTANCE
RESISTOR
RESOURCE
RESPECTIVE
RESULT
RIGID
RING
ROBOTIC
ROCKET
ROPE
ROTATE
ROTATION
RULER
SAFETY
SAME
SAMPLE
SCHOOL
SCIENCE
SCIENTIST
SEA
SECOND
SENTENCE
SEPARATE
SERIES
SETTING
SETUP
SHAFT
SHOW
SIMILAR
SIMPLE
SIMULATE
SINCE
SINE
SINGLE
SINUSOIDAL
SKETCH
SLOPE
SOLID
SOLUTION
SOLVE
SOON
SOURCE

SPACE
SPECIFIC
SPEED
SPHERE
SPRING
SQUARE
STABILIZE
STALL
STAND
STANDARD
STATIONARY
STATISTICS
STEEL
STORAGE
STRING
STRUCTURE
STUDENTS
STUDY
SUBMISSION
SUBSTANTIATE
SUM
SUN
SUSPEND
SYMBOLIZE
SYMMETRICAL
SYSTEM
TABULATE
TAMARACK
TANGENT
TANGENTIAL
TARGET
TENSION
TERMINAL
TERM
TEST
THE
THEIR
THEN
THEREOF
THERMODYNAMICS
THIRD
THIS
THOUGHT
THREE
THROUGH
THROUGHOUT
THRUST
TIME
TO
TODAY
TODAY
TOOL
TORQUE
TOTAL
TOUCH
TOWER
TRADITION
TRANSFER
TRANSIENT
TRANSVERSE
TRAVEL
TRIAL
TRIGONOMETRIC
TRIPLE
TUPLE-WHEEL
TWO
TWO-DIMENSION
TYPE
UNCERTAINTY
UNDER
UNDERMINE
UNIQUE
UNIT
UNIVERSAL
UNIVERSE
UP
UPON
UPWARD
USE
UTILIZE
VALIDATE
VALUE
VARIABLE
VARYING
VECTOR
VEHICLE
VELOCITY
VERIFIABLE
VERSUS
VERTICAL
VIA
VINTAGE
VIRTUALLY
VISUAL
VOLTAGE
VOLTMETER
VS
WAS
WATCH
WAVE
WAVELENGTH
WAVE
WAX
WE
WEIGHT
WERE
WHAT
WHEELS
WHEN
WHERE
WHICH
WHILE
WHY
WIRE
WITH
WITHIN
WITHOUT
WORDS
WRENCH
WRITE
X-AND-Y
X-DIRECTION
X-POSITION
Y-COMPONENT
Y-DIRECTION
Y-DIRECTIONS
Y-POSITION
Z-AXIS