

Introductory Physics Laboratory

Abstracts of Experiments

Experiments in New Gold Lab Manual

1. Measurement

Students are introduced to basic measurement techniques such as length measurement with a meter stick and vernier caliper, mass measurement with a triple-beam balance and time with a stopwatch. They obtain the volumes of various size cylinders from measurements of the cylinders' lengths and diameters. After measuring the masses of the cylinders, they calculate the densities of the metals and compare them to the expected values. They also determine the density from all their data by plotting mass vs. volume of the three or four cylinders they measure and finding the slope. Students also measure the time it takes a freely falling ball to hit the ground. Errors, which are relevant to the equipment and measurement methods and their propagation, are determined.

2. Vector Addition

Forces on an object at rest are studied. Weights are suspended from several strings and via pulleys, and the string forces are determined using spring scales. Directions are measured with a protractor. The vector nature of the forces and vector addition is explored. Students add forces (two or three). Both the graphical and the trigonometric method are used for additions. During the experiment students should get a better understanding of Newton's first law of motion.

3. Free Fall

Students measure the successive positions of a freely falling weight attached to a paper tape onto which a timer makes a mark every 25 msec. From these data, they determine the speed as a function of time, as well as the acceleration (gravity) of the motion. By repeating the experiment with different weights, the independence of the acceleration of a falling object from its mass is investigated. For small masses the paper tape provides a significant drag.

4. Two-Dimensional Motion

Tracing the path of a puck moving on a frictionless inclined plane, students determine the x and y components of its successive positions at constant time intervals. From these data puck velocities are obtained. From the velocity data, the accelerations in the vertical and horizontal directions are determined. The independence of the two components of the motion is investigated.

5. Newton's Second Law

Students measure the acceleration of two masses connected to each other by a string that runs over a pulley. One mass moves on a frictionless horizontal table. The other one is freely suspended from the string. Both masses can be varied. Therefore the dependence of the acceleration on force or mass can be studied.

6. Friction

The friction of wood on wood is studied. In the first part, a wooden block on a horizontal wooden surface is connected via a string and pulley to a freely suspended plastic cup, to which small weights can be added. Both static and dynamic friction is studied, and the coefficients of friction determined. In the second part of the experiment similar studies are made on inclined planes. Error determination is an important part of this experiment.

7. Uniform Circular Motion

Students measure the average speed of an object in uniform circular motion. They separately measure the centripetal force, which produces this motion. The apparatus consists of a rotating gallow from which a plumb bob is suspended. A horizontal spring attached to the plumb bob provides the centripetal force. Student measure the period of rotation required to stretch the spring a given distance. Then they determine the static force that stretches the spring by an equal length. After repeating this experiment with various springs, they plot angular velocity vs. centripetal force to verify that the centripetal force increases as v^2 .

8. Work and Energy on the Air Table

An air table with a spark timer is used in this experiment. By tracing with spark marks the path of a frictionless puck on a tilted air table, students measure puck velocities during the motion at fixed time intervals. From this they get kinetic energy as function of position. They also measure the coordinate of each mark along the tilt direction of the table. That and the tilt angle provides the potential energy. From these data they can obtain the gravitational acceleration. Next, velocities of a puck that is moving on frictionless level surface under the influence of a hanging mass, are measured. By plotting V^2 against position, the acceleration of the motion is estimated and compared to the theoretical predictions. This experiment is similar to Exp. 5, except here the important quantities used are energies.

9. Conservation of Momentum in Collisions

Conservation of momentum is investigated in this experiment. Tracing the path of two pucks that collide with each other on the frictionless air table, students measure the momentum of each puck before and after the collision. By comparing the total momentum and the total kinetic energy of two pucks before and after the collision the conservation laws under the elastic case are investigated. Next inelastic collisions are studied. Attaching Velcro to the pucks makes them stick together in a collision. Momentum and energy conservation under these conditions are studied. Also by tracing the center of mass of the two pucks, the motion of the center of mass of a two-body system is studied.

10. Inclined Plane Determination of Gravity

This experiment is about one dimensional motion on an inclined plane. It introduces the student to the Ultrasonic Measurement System which uses a computer to collect position and time data of a glider moving up and down a linear air track. The students will tilt the track at some angle and take data of a glider that is released near the top of the track and bounces off the end of the track (several times). The computer plots position vs. time, velocity vs. time, and acceleration vs. time. The students use a fit to a constant, a linear fit, and a quadratic fit to determine the acceleration. The students then use each acceleration to find the acceleration due to gravity. The students are then asked to find the acceleration of the glider for several different angles. This allows the students to cancel any error due to the track not being level. Again they are asked to find the acceleration due to gravity. As always, the students are asked to compare their results with the theoretical predictions.

11. Work and Energy on the Air Track

An air track with a computer is used in this experiment. By analyzing the data collected with the computer of the glider on a tilted air track, students measure the glider's velocities during the motion at fixed time intervals. From this, they get kinetic energy as function of position. They measure the tilt angle which provides the potential energy. From these data they can obtain the gravitational acceleration. Next, velocities of the glider that is moving on frictionless level track under the influence of a hanging mass, are measured. By plotting V^2 against position, the acceleration of the motion is estimated and compared to the theoretical predictions. This experiment is similar to Exp. 10, except here the important quantities used are energies.

12. Forces and Torques in Equilibrium

The static equilibrium conditions on a weighted meter stick are investigated. First, by balancing a weighted meter stick on one's finger, the center of mass is determined. Next, students mount one end of the meter stick on a pivot so that the stick can swing freely in a vertical plane. The other end is then supported by a string attached to a spring scale in different ways such that the meter stick and the support string make different angles with the horizontal. They measure components of forces and of torques acting on the meter stick, calculate the sum of torques and compare to the expected values. Finally, after adding an unknown force to the balanced meter stick, the students estimate the torque caused by this unknown force from the equilibrium condition and compare it to the directly calculated value and verify the equilibrium condition.

Experiments in New Red Lab Manual

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14. Maxwell's Wheel

Maxwell's wheel consists of a vertical aluminum disk mounted on a horizontal axle, suspended on two threads from above. When the disk is rotated, the threads wind themselves on the axle, somewhat similar to a yo-yo, and the disk rises. Once at the top the threads begin to unwind, and the disk falls. Students first measure the dimensions of the wheel plus axle and calculate the moment of inertia. Next they measure falling distances and falling times of the wheel, and determine the downward acceleration. From the motion, they obtain a moment of inertia and compare it to the value calculated in the first part of the experiment. Brass knobs are attached to the Maxwell's wheel to change the moment of inertia in the last investigation.

14. Pressure and Flow in Fluids

After the definition of pressure and Pascal's Law are explained, students are required to measure the densities of water and glycerin in three different ways. First the densities are determined by measuring the volume and the masses of liquids directly; next by measuring the pressure in a liquid using a manometer, and finally by measuring the buoyancy force of an object in a liquid. By measuring the fluid resistance, the dependence on pressure of the water flow rate through a capillary is studied. The dependence of flow on capillary diameter is also investigated.

16. Simple Harmonic Motion of a Spring-Mass System

In this experiment, the simple harmonic motion of a vertically vibrating coil spring is studied. In a static measurement, applying the relation $mg=kx$, students determine the spring constant. Then student measure the periods of vibrating motions for different masses and plot the period squares against masses. The force constant is determined from the plot and compared to the previously measured value. This experiment is similar to the previous one. It's typical of the oscillating spring problem usually discussed in the lectures.

17. Simple Pendulum

Students measure the periods of a simple pendulum for several different lengths of string and make a plot of period squared against length. Then they determine the gravitational acceleration from their plot. By repeating the experiment with different mass, they investigate the independence of period on the mass.

18. Simple Harmonic Motion of a Glider on an Air Track

This is an air track experiment. A glider is connected with two springs to the track. When deflected from its equilibrium it oscillates. The motion of the glider is obtained from ultrasonic measurements collected by a computer. The computer can plot position, velocity, and acceleration vs. time. The students find the period of the wave from the position plot. They are next asked to calculate the displacement of the glider at several times and compare their results with the raw data. Next, the students calculate the angular velocity. Using this calculated value, they find the period and compare it to the measured period. Finally, the students are asked to investigate the phase relationships between the position, velocity, and acceleration plots and also show that the period is independent of the amplitude.

19. Elastic Deformation

Students study the relation between the deflection of an I-beam, supported at two points, and a weight hung from its center. Plastic and aluminum I-beam are used, and their deflections are studied under different load. The equation relating load and deflection is studied, and Young's Modulus determined.

20. Oscillations of a Rigid Rod

The first part is a study of the oscillations of a narrow cylindrical rod pivoting around an axis inserted successively into several small holes drilled into the cylinder along its axis. The oscillations are related to the moment of inertia. The student finds out about the moment of inertia and the parallel axis theorem. In the second part, the rod is suspended from a wire in two configurations, with the rod axis vertical and the rod axis horizontal. The period of the torsion pendulum for several lengths of wires is determined and the relation $T^2 = CL$ is studied, where C depends on I and the properties of the wire.

41. Thermometry and Calorimetry

The students are first asked to calibrate a high sensitivity temperature probe. The students calibrate the probe by plotting the temperature of water vs. voltage of the probe. The temperature of the water is obtained using a red spirit filled thermometer. The students will then make calorimetric measurements of the specific heats of aluminum and copper. Finally the students are asked to determine the latent heat of fusion of water from calorimetric measurements.

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30. Electric Potential and Electric Field

The characteristics of E and V for two different two-dimensional charge configurations are investigated. For parallel Electrodes, students measure the equipotential lines, determine the electric fields and reconstruct the electric field lines near the center of the two electrodes and fringe-fields near the electrode ends. Students repeat the experiment for concentric electrodes and find the radial electric fields for this geometry. The experiment gives a good feel for the relation between E and V , and for graphical representations of E and V .

31. Electrical Measurements with DC (1)

Kirchhoff's rules are studied for simple series and parallel circuits consisting of batteries or a power supply, some light bulbs, some patch cables, and one or two multimeters (DMM). In part of the experiment, the light bulbs are replaced by resistors. The students also learn how to use a meter to measure currents, voltages, and resistances, and the effects of meters on the measurements. They compare measured and calculated values of resistors combined in various configurations.

32. Electrical Measurements with DC (2)

A continuation of Experiment 31. The students first look at the V - I characteristics of two resistors (ohmic). Next, after making measurements of currents in a light bulb (highly non-ohmic) for various voltages, students plot the voltage against the current data. They examine the how resistance of the bulb - changes with currents. Finally, the students will investigate the characteristics of a diode.

33. R–C Circuits

Transient behavior of RC circuits is studied. A circuit consisting of a resistor and capacitor in series is connected to a 6 V power supplies via a switch. As the capacitor is being charged, students measure the change in voltage first across the resistor, then across the capacitor using a DMM and a stopwatch. The RC is large enough so that this works! They determine the time constant in both measurements and compare them to each other and the calculated value. They also explore the exponential behavior of the capacitor voltage by plotting the voltages against the time. As the capacitor is being discharged, the current in the circuit is measured and log of current is plotted as a function of time. The slope of this graph is compared to the time constant found earlier. Finally, the capacitance of two capacitors in series or parallel combination are studied by measuring the new time constant of the circuit.

34. Magnetic Force & Lorentz's Laws

First the repulsion and attraction of two ceramic ring magnets, are studied, as a qualitative indicator of the strength of magnetic forces. The main experiment is a study of Lorentz' law $F= ILB$ by use of a current balance. The dependence of the magnetic force on a length of wire is measured by balancing it against a known gravitational force. All three variables, I, L, and B can be varied in this experiment, and plots of the magnetic force vs. these three variables verify the linearity of the relation. The experiment also determines the magnetic field strength of the horse shoe magnets used.

35. The Oscilloscope

The oscilloscope is introduced as a laboratory instruments and device for two-dimensional plots. Students will first measure an Ac and DC voltage. Next they measure frequency and period using a function generator. Then they measure the rise time of a square wave created by the function generator. Finally, they investigate the current and voltage in a RC circuit that is connected to an AC generator. They use the dual-trace capability of the scope in displaying input emf and the voltage across the resistor on the scope at the same time. Thus they can measure the phase difference emf and current in the circuit. Then they compare it to the theoretical predictions by calculating the circuit's impedance.

36. Electromagnetic Induction

Faraday's Law of induction is the topic of this experiment. First, the voltage produced in a pickup coil by quickly moving a permanent magnet. Then a voltage is produced by quickly moving a pickup coil away from a permanent magnet is found. Next Faraday's Law is tested in integral form by using a function of the digital oscilloscope. Students are given 2 coils (with an unknown number of turns) and asked to find the number of turns in each coil. In the main part of the experiment, a function generator producing either a sinusoidal or a saw tooth shaped current in a field coil sets up a time varying field. This field induces a voltage in a pickup coil. The field generating current and the voltage of the pickup coil are displayed and measured with a dual trace scope. The dependence of induced emf on the changing magnetic flux is studied.

37. Standing Waves

Standing waves in two different media, a string and an air column, are investigated. In the first experiment, transverse waves are set up in a string, which is fixed at both ends. Near one end is a vibrator that produces the waves. Students measure the wavelength of the standing waves, which are formed when the tension in the string allows the appropriate wave velocity. They calculate the velocity and plot the velocity-squared versus the tension. They verify the relation between the tension and mass per unit length of the string on one hand, and the wavelength of the wave on the other. The students also measure the velocity of sound in air by measuring the wavelength of sound, obtained by listening to a resonance in an air column the length of which can be varied. The sound is produced by a tuning fork held over the air column

27. Diffraction and Interference

The diffraction of laser light from a single slit, a double slit and a diffraction grating are studied. Students observed the single slit pattern and determine the wavelength of the laser. This can be done, if the slit width is known, by measuring the distance of successive maxima from the central maximum on a screen. Students then examine the double slit pattern and see the superposition of the interference pattern due to the two slits and the diffraction pattern due to each individual slit. They measure the distance of adjacent interference minima on the screen to the calculated values. Then they find the angles between maxima from a reflection diffraction grating (really a cut-up CD) and use this information to find the distance d between the circles on the CD. Finally they study the pattern of a transmission diffraction grating to determine its characteristics.

28. Optical Images

In this experiment students study the law of thin lenses, the difference between real and virtual images and mirror images. In the first experiment, students determine the focal length of a thin lens by measuring the distance between the object and the lens and the distance between the lens and the image. They also examine the magnification law by plotting the ratio of the size of the image to the size of the object against the distance ratio. Then students observe a real image and a virtual image by looking at these two images at the object side of the lens and they compare these two images. Finally, they investigate the mirror images with small cylinders and a plane mirror. By tracing the position of an image, they find the law of specular reflection experimentally.

40. Radioactive Decay

The students observe radioactive decay as a random process and measure the half-life of a short-lived isotope. The first investigation calibrates the Geiger tube by collecting data using a computer and plotting on the computer count rate vs. Geiger tube voltage. The students then measure the background radiation using the computer and plot their data using a histogram to find the average background count rate. Next, the students take data from a ^{137}Cs source and histogram it. They observe what percentage of their data lies within one and two standard deviations of the average count rate. Finally, the students use the computer to collect and create a semi-log plot of their data to determine the half-life of $^{137}\text{Ba}^*$ produced in the ^{137}Cs decay.