A SERIES OF LECTURE DEMONSTRATIONS IN COLLEGE PHYSICS

A Thesis

Presented in partial fulfillment of the requirements for the

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Department of Physics

of the

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by

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NOTE

Inasmuch as the nature of this manuscript does not lend itself, in form, to the directions specified by the Graduate School, it has been found expedient to depart from the exact form prescribed. This departure has been approved by the major professor.

"For we are borne to quest and seeke after trueth; to possesse it belongs to a greater power."

Florio's Montaigne

Bk. III, Chap. 8

Of the Art of Conversing

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PREFACE

In these days, when of the writing of theses there is no end, it appears important to me that good reason should be advanced for writing another. The program which I have pursued and which is presented here as a "thesis" has for a long time been in my mind. The situation which presented itself this year provided a most favorable opportunity to carry out the project. In the first place, I had charge of lecture-demonstrations for two men in the department. This in itself would not ordinarily be much of a job. But when it becomes necessary to spend some hours in gathering together the several pieces which constitute a demonstration of one single principle, the task becomes no small one. (I refer here to such details as finding a glass tube of the right bore, bending it, and fitting it to a stopper.) The reasonableness of the undertaking, therefore, became more evident to me as time advanced. It seemed to me that considerable advantage would be found in having a collection of lecture demonstrations placed away in such a manner as to be immediately available for the classroom. Thus in the first instance was my program governed by actual need.

The second impelling force was, that as a teacher I am constantly urged by the ambition to make my teaching more effective. From my brief experience I am convinced that no better instrument exists than good demonstrations. Fortunately, the teaching of Physics is, by the very nature of the subject, particularly adapted to classroom demonstration.

That there is no substitute for experimental observation needs no debate. Laboratory courses at best satisfy this only cursorily. Of the countless experiments which contribute to an understanding of physical phenomena not more than two score are actually performed in the laboratory. As teachers I believe it is our duty to share as completely as we can the wealth of interest and instruction which lies hidden in experimentation, and one of the efficient instruments for this is the lecture demonstration. It is fairly obvious that there is no more potent means of maintaining interest, of making principles vivid and alive, and of stimulating discussion and decision than lecture demonstrations. As Professor Harvey B. Lemon at Chicago says, "The demonstration lecture has long been the most useful device in science teaching."

Inasmuch as the body of this thesis is concerned with what to demonstrate, it is feasible at this point to say something about demonstrations. The fundamental purpose of a demonstration is, obviously, to demonstrate. It would appear at first unnecessary to remark this, but too often the principle to be conveyed becomes veiled in mysticism. Particularly is this true of those experiments which require elaborate set-ups. Simplicity should be achieved above all things. By elaborate displays the student is very likely impressed but not always instructed, and the more puzzling and intricate the experimental arrangement the less understood is the principle. It is my conviction that the student must see clearly the actual working arrangement of an experiment before he can properly grasp the physical principle involved. In some instances, of course, it is legitimate for the instructor to behave as a "magician", but the final gesture should be to clarify and expose, not to mystify and conceal!

This last leads immediately to the next consideration, namely, that demonstrations are for the student. Very often the instructor's own personal enjoyment determines the merits of a particular demonstration, and the value of the experiment in terms of what the student sees and understands is quite negligible. It is imperative that the student see and hear everything from whatever position he occupies, and every experiment should be examined critically with this in mind. It is not uncommon for instructors to show demonstrations which are practically invisible to most of the class.

Concerning the methods of demonstrating, it is obvious that each instructor behaves in his own peculiar manner and applies his own methods to his own situation. There are perhaps as many "methods" of demonstrating as there are demonstrators. However, a few items stand out prominently important and I present them without lengthy discourse.

The first concerns the lecture table. It is important that this present an orderly, systematic arrangement. Nothing can be more distracting and confusing than to have the instructor flitting from one end of the table to the other. If I were to isolate the one most important aspect of lecture demonstrations, I believe it would be orderliness. An orderly lecture table conveys above all else the quality of orderly thinking which should be impressed on all students.

Next to this in importance is the notion of "timing", as it is called on the stage. It is obvious that if an experiment is to become an integral part of the immediate lesson there is but one appropriate time at which to perform it. If shown too soon the student is unprepared; if delayed, its effectiveness is also lost. Too much attention cannot be given this aspect of a demonstration.

The problem of whether to show a few well-selected experiments or to run quickly through a great number has two answers. In general it is perhaps more profitable to show a few with care and deliberation, although an occasional "show" has remarkable stimulating effects.

The manner of presentation is of vital importance, and this is governed to a large degree by the expertness of manipulation and the agility of the teacher. Above all must he be <u>alive and enthusiastic</u>. If, with these, is coupled a clear and forceful language, the most commonplace demonstration cannot fail to excite enthusiasm.

It is of considerable consequence sometimes, from the point of view of human considerations, to enlist or ask for student assistance in the performance of an experiment. There is always an occasional student who has a burning desire to participate and his enthusiasm should not be chilled. It is, of course, advisable that explicit orders be made to the effect that apparatus must not be handled <u>before</u> the demonstration. (The author has found it fruitful to make several standing rules regarding this at the beginning of the year.) After the class period the demonstration pieces should be made available to those students who wish to perform and observe the experiment by themselves. This, it is well known, is rarely, if ever, done. It is obvious, of course, that such habits should not apply to expensive and intricate pieces. That it is not done at all is again a commentary on the system to which we as teachers must yield. Repeatedly is the teacher constrained to rush the apparatus back to the cupboard where it is hidden until another year.

In many demonstrations it is instructive to ask the class to decide for themselves how Nature will behave. This invariably excites an interest which might otherwise be only passive. It affords, too, an opportunity for the student to proceed, by logic alone, from cause to effect.

It is important, in the author's mind, to hold before the class at all times the practical significance of the physical phenomena demonstrated. With nearly every experiment goes the query, "what use can we make of it?", and it is by explicitly pointing this out that the student can see the relation of theoretical principle to everyday workable fact.

Not infrequently one can make the demonstration quantitative by which it then becomes an interesting analytical problem. This should not, however, be done too often for the students will soon come to associate demonstration with problem working and their interest will rapidly wane.

Of particular interest to the author is the history which envelopes every elementary demonstration. More, very much more, should be made of this. It is indeed profitable that the teacher say more about the men who built the science and their humble methods that yielded great discoveries. How really fascinating it is to repeat, under humble conditions, the experiments of Galileo, Faraday, Oersted, Ampere, and others. And the lecture demonstration provides excellent occasion to relive these momentous events.

Finally, there is the matter of a demonstration failing at the crucial moment. This, it is said, happens in the best of families! One should, of course, make as certain as possible that everything is in working order before the demonstration is shown. If pitfalls do then arise excellent use can still be made of them.

It is, of course, vanity to hope that this thesis <u>will not</u> follow the course usually taken by theses, to wit: library files and dust! But it is hoped, nevertheless. The very nature of the paper permits a nearly endless addition and modification and the student who aspires to teaching Physics could not more wisely invest his time. For myself I can say as has many times been said, 'If any shall learn from reading this paper half as much as its writer has learned from writing it, no further justification will be needed.' I may say, too, as Andrade says in that noble dedication to Rutherford, "I fear that it will avail me little to plead the Largeness of my design as an Excuse for an imperfect execution of its Particulars."

J. S. Miller

The University

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As indicated earlier, the author has had this project in mind for some time. Not before, however, has opportunity presented itself for carrying it through. The author is particularly indebted to Dr. G. W. Hammar for permission to depart from the routine research program for a graduate degree. It is practically impossible to acknowledge individually every source of information and even further impossible to thank directly those who have repeatedly given counsel and assistance. The author has, at one time or another, consulted a goodly number of texts in Physics, and it is not unlikely that readers will recognize the pen of more able writers. It is not uncommon for ideas to crop up as one's own when in fact they belong to others. The author is, of course, especially grateful to the members of the Physics Department at the University of Idaho for their untiring willingness to help. A very personal feeling of indebtedness is extended to Dr. Hammar for so nobly tolerating the author's incessant requests. Special thanks are due Mr. Leonard Helland, Department Mechanician, for putting at the writer's disposal his shop, his tools, and his skill. To Mrs. Mildred Kerr, of the Library Staff, the author conveys his sincerest thanks for her unfailing efforts to meet his wants. Finally, to all those upon whom the writer has at some time thrust his enthusiasm, warm thanks for their patience.

J. S. M.

INTRODUCTION

The demonstration experiments which are presented in the following pages are arranged in no rigid or stereotyped order. It is obvious that the sequence of topics studied in the classroom varies with the textbook and the teacher, and this alone precludes any formal order. The experiments are, however, grouped according to the usual main divisions of a course in College Physics, namely, Mechanics, Heat, Electricity and Magnetism, Sound, and Light. Where further division was convenient and helpful, it was introduced. For example, in the main division of Mechanics a series of demonstrations appears which is more properly labeled Mechanics of Liquids.

Each of the demonstrations has a title which conveys the content or nature of the experiment. In general, a list of the necessary apparatus is given, followed by a brief statement of procedure. In some cases, departure from this form was deemed advisable for reasons of simplicity and clarity. An occasional demonstration is cited which requires only a showing or display of the apparatus, e.g., Types of Magnets. These are included as reminders of what the department has in the way of demonstration pieces.

In passing it may be said that every one of the experiments described has been worked out in the laboratory and then shown in the classroom. Where practicable, the set-ups were left intact and placed in closed cupboards, properly labeled, where they are immediately available for use. This has already shown itself to be a considerable time-saving device. In addition, the whole array has been typed out on filing cards, a set of which is in the Office of the Department.

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BY

JULIUS SUMNER MILLER

MECHANICS

Principle of Moments

Apparatus: Meter stick provided with knife-edge clamp and supporting stand; weights provided with loops of thread.

Procedure: Balance the meter stick. On the right arm hang a weight of any magnitude at any position. On the left hang another, not necessarily equal to that on the right, and reëstablish balance. Show algebraically that the sum of the moments is zero. Modify the demonstration by the addition of further weights and show the principle in each case on the blackboard.

Principle of Moments

Apparatus: Platform balance; meter stick and support; weights.

Procedure: Support the meter stick off center and balance it with a single weight. Give to the class the positions of the known weight and the center of gravity of the stick and from this data have them compute the weight of the stick. Check the value by weighing on the platform balance.

Principle of Moments

Apparatus: Drawing board supported on horizontal axis normal to its plane through its center and free to turn in a vertical plane; weights; thread; thumb tacks; meter stick.

Procedure: Hang several weights from thumb tacks stuck into the board at various points. Adjust these for equilibrium. Show that the algebraic sum of the moments of all the forces is equal to zero.

Equilibrium of Forces

Apparatus: Two spring balances; string, weights, hooks or nails some distance apart at the top of the blackboard.

Procedure: Hang the balances from the nails and connect them with a string. To the middle of the string attach hooked weights. Now draw lines under the strings and lay off proportional magnitudes.

The resulting vectors can now be moved parallel to themselves to form a closed triangle or two of them may be used as the sides of a parallelogram the resultant of which (its diagonal) may be checked with the third force, the equilibrant.

This demonstration permits a large number of variations.

Center of Gravity; Leaning Tower

Apparatus: Piece of 2x4 with one end cut obliquely; small pieces to be placed on top.

Procedure: Show that the block is stable when a line through the center of mass falls within the base. Now raise the center of gravity upon which the system becomes unstable.

This may be discussed with reference to the Leaning Tower of Pisa.

Center of Gravity

Apparatus: Irregular sheets of plywood each provided with several small drill-holes around the edges; nail; string; plumb-bob.

Procedure: Suspend a sheet by the nail through one hole and drop the bob from the support. Draw a line on the board to coincide with the vertical. Repeat with another point of support. The point of intersection of the two lines locates the center of gravity. It should now be shown that lines similarly drawn from other points of support will pass through this intersection. If now, a nail be driven through the sheet at this point the sheet can be shown to be in equilibrium in any position in a vertical plane.

Potential Energy

Apparatus: Double cone; diverging double-railed track.

Procedure: The wide end of the track is higher than the vertex. Place the cone symmetrically on the vertex end. It will roll up the incline thus appearing to negate the fundamental principle that the potential energy of a system tends toward a minimum. If the cone is pushed back <u>down</u> the incline it is quite effective to observe that it wants to roll uphill! Obviously, the divergence of the track and its inclination are so related to the shape of the cone that the center of mass of the cone descends as the cone rolls.

Inertia Apparatus; Newton's First Law

Apparatus: Short upright with a concave top mounted on a base which carries also a slender strip of spring-steel; card and ball.

Procedure: Place the card and ball symmetrically atop the upright. Give the card a sudden blow with the spring whereupon its slides from under the ball, which has no time to gain horizontal momentum, but drops into the concave top of the stand.

Inertia; Newton's First Law

Apparatus: Heavy iron ball provided with two screw-eyes; string.

Procedure: Suspend the ball by a light string and attach another string of the same size to the lower hook. A steady pull on the lower string breaks the upper string; a sudden pull breaks the lower string.

Paradox of Forces; Newton's Third Law

Apparatus: Small board with pulley fixed at each end; spring balance; string; 2 - 1000 gram weights.

Procedure: Arrange the spring balance between the pulleys with cords attached to each end and hanging over the pulleys. Suspend a mass of 1000 grams from each end. Ask the class to decide on the balance reading!

Newton's Third Law

Apparatus: Bicycle wheel; rotating platform (e.g. piano stool or swivel chair with back removed).

Procedure: Let a student sit on the platform and hold the wheel above his head with the axis vertical and in line with the axle of the turntable. Let the instructor give the wheel a smart turn. The student then stops the wheel with one hand whereupon he and the turntable start to rotate in the same sense.

Starting with everything at rest the student can himself set the upper wheel into rotation. The torque exerted exercises an opposite torque on the turntable, and it is observed that each wheel acquires the same angular momentum, Iw, but of opposite sense.

Action and Reaction; Newton's Third Law

Apparatus: Hero's steam engine; water; burner.

Procedure: Pivot the cylindrical boiler on a vertical axis. The tubes emerging from the boiler radially have nozzles directed tangentially and in the same sense. When steam is generated in the boiler some of it is forced out through the nozzles. The escaping steam exerts a reaction and the boiler is set into rotation.

Moment of Inertia and Angular Momentum

Apparatus: Rotating stool; two - 1000 gram weights.

Procedure: The instructor (or a student) stands on the stool with arms extended holding one weight in each hand. He is then given an appreciable angular speed which is observed to increase greatly when he lowers his arms. Since angular momentum is conserved, the decrease in moment of inertia is compensated for by greater angular velocity.

Impact Apparatus; Momentum and Energy

The apparatus consists of a horizontal track made of a 6 foot length of angle iron on which rest 10 or 12 pool balls. At one end of the track and inclined to the horizontal is another strip of angle-iron, the inclination of this last variable. Now if <u>one</u> ball is allowed to roll down the incline and impact the system at rest, we find that <u>one</u> ball leaves the system; if <u>two</u>

are rolled, two leave, and so on. The demonstration shows effectively conservation of momentum and energy.

Moment of Inertia; Axes of Rotation

The apparatus consists of a hoop to which is attached at one point on the periphery a universal joint. The hoop is supported from the universal joint by a wire leading to the chuck of a hand-drill held vertically. The system is now rotated and as the speed of rotation is increased the hoop assumes rotation in the horizontal plane, the axis of rotation being that principal axis about which its moment of inertia is a maximum.

The experiment can be demonstrated with a rope or chain which at first hangs limp but upon rotation takes on circular form in a horizontal plane. A stick supported from one end performs in the same manner.

Angular Momentum

Apparatus: Bicycle wheel; rotating stool.

Procedure: Give the wheel a rapid spin while standing on the rotating stool. With the wheel in a vertical plane (passing through the axis of the stool), there is no rotation of the stool. Now turn the spinning wheel into a horizontal plane; the stool now rotates in the opposite sense to the spin of the wheel. If now the wheel is turned through 180°, the stool reverses direction.

Gyroscopic Motion

Apparatus: Gyroscope

Procedure: The important rules of gyroscopic motion such as the relations between directions of spin, torque, and precession, may be demonstrated. The graphical analysis can be shown on the blackboard.

Sliding Friction and Area of Contact

Apparatus: Iron block provided with hook to which a sensitive spring scale may be attached; iron rail.

Procedure: Pull the block across the metal rail using different faces. Show that as long as the speed is constant the reading of the scale is the same regardless of area of contact.

Mass and Rate of Fall

Apparatus: Simultaneous release apparatus which consists of electromagnet and circuit, iron and wooden balls of the same size, the wooden one provided with an iron plug.

Procedure: Arrange the electromagnet on a support projecting over the lecture table. Suspend the balls from the magnet. When the circuit is broken the balls fall together and simultaneously strike the floor. The pole faces may be covered with adhesive tape to insure quick release when the circuit is broken.

Rate of Fall and Horizontal Projection

Apparatus: Device which drops one ball vertically and simultaneously with one projected horizontally.

Procedure: An elementary device which gives satisfactory results consists of a flexible metal strip to which is fixed on one end a wooden block cut out to accomodate 2 balls, the other end being clamped to the table. The free end can be drawn back with a string which is then burned. The forward ball is projected horizontally while the rear one is dropped vertically. Both strike the floor simultaneously.

Experimental Proof of Archimedes' Principle

Apparatus: Bucket and cylinder (commonly called Archimedes' Principle Apparatus); beam balance and weights; distilled water; beaker.

Procedure: Suspend the bucket by its bail from one arm of the balance and attach the cylinder to the bucket by the hook beneath. Counterpoise the two by weights until the beam indicates equilibrium. Now bring up the beaker of water beneath the cylinder until the latter is just submerged. The equilibrium is now destroyed by the buoyant force of the water upon the cylinder. Now pour water slowly into the bucket until the latter is level full, upon which the balance again indicates equilibrium. Obviously the weight of the water in the bucket balances the buoyant force on the submerged cylinder, or, according to Archimedes' statement, the upward force on a solid immersed in a liquid equals the mass of liquid displaced by the solid.

Floating Bodies

Apparatus: Overflow can; platform scale; block of wood; catch bucket; weights.

Procedure: Fill the can to overflowing and balance on the scales. Place the empty catch bucket in position and gently put the block of wood into the can. After the water has stopped overflowing, it will be observed that the scales again balance. This means that the weight of water which overflowed was just equal to the weight of the block. This can be verified by weighing the water displaced by the block and caught in the bucket.

Specific Gravity of a Solid

Apparatus: Beam balance provided with platform over one pan; beaker; distilled water; solid whose specific gravity is to be determined; thread.

Procedure: Suspend the solid from one arm of the balance and note its weight in air. Now bring up from beneath it the beaker of distilled water, which may be rested on the platform. Balance the scales with the body thus submerged. The specific gravity is obtained immediately by dividing the weight of the body by the loss of weight in the water.

The method, if carefully manipulated, can be made to yield fairly accurate results.

Density of Liquids and Solids

Apparatus: Water; mercury; steel ball; lead ball; large open dish.

Procedure: Show that the steel and lead balls sink when placed in the water. Their masses and density may be impressed upon the class by dropping them on the floor or playing "catch" with them. Now drop them gently into the dish of mercury. The demonstration, although exceedingly elementary, is very effective. It is also very instructive to allow the students to handle the bottle of mercury for this is an experience which they will long recall.

Specific Gravity of Liquids

A glass tube of about 1 inch bore and 12 inches long, sealed on one end, is mounted upright on a wooden block. The tube is filled with mercury, carbon tetrachloride, water, and kerosene, in this order. At the interfaces float small cylinders of iron, hard rubber, wood and cork.

Specific Gravity of Liquids by Balanced Columns

Apparatus: Two glass tubes 50-60 cm. long arranged vertically and fixed to a common junction; 2 beakers; distilled water; liquids whose densities are to be determined; meter sticks.

Procedure: Set up the tubes fixed to the meter sticks and with their lower ends dipping into the two vessels, one containing water, the other one of the liquids whose specific gravity is to be determined. When some of the air in the tubes is sucked out, the liquids rise to relative heights which yield immediately the specific gravity.

Hooke's Law

Apparatus: Heavy spiral spring rigidly fixed to a calibrated support; weight pan; slotted weights.

Procedure: Arrange spring and support vertically and show that the extension of the spring is proportional to the load. If the value of the spring permits the elastic limit can be exceeded and the consequences made evident to the class.

Young's Modulus

Apparatus: Young's Modulus apparatus provided with chucks to support the wire to be tested; optical lever; pan and weights; directed light source; vertical scale.

Procedure: Arrange the system so that light reflected from the optical lever falls upon the scale set up vertically at a suitable distance. Take the zero reading with sufficient load to take up any slack. Take scale readings as successive weights are added. Remove the weights and observe whether the reading returns to the proper zero.

Simple Harmonic Motion

Apparatus: Coil spring mounted on a stand and provided with a hook for variable loading; weights.

Procedure: The more simple aspects of simple harmonic motion may first be shown. The measured period of the loaded spring may then be compared with the period calculated for the spring constant and the applied mass.

Simple Harmonic Motion; Projection of Uniform Circular Motion

A circular disc, to the periphery of which is attached a rod at right angles, is mounted on the rotator. The disc is rotated in either the horizontal or vertical plane and the motion shadow projected by means of a diverging light source properly placed. If attention is restricted to the shadow (which can be done by shielding the disc from the audience) the motion of the shadow is observed to be simple harmonic.

The Motion of a Simple Pendulum is Sinusoidal

A hollow right-circular cone made of metal with a small hole at the vertex is supported by bifilar suspension from opposite ends of a diameter. The cone is filled with fine sand and set swinging. If, now, a horizontal board is drawn with constant velocity beneath the pendulum, and at right angles to the plane of swing, the flowing sand describes a sine curve.

Period of a Simple Pendulum

Three pendulum bobs are hung on bifilar suspension from the same horizontal support, the vertical distance being in the ratio 1 : 4 : 9. By means of a stop watch the time for any number of oscillations can be clocked and these will be found to be in the ratio 1 : 2 : 3. It is amusing to check the periods by swinging two simultaneously and counting outloud the oscillations.

Transference of Energy; Resonance

A horizontal meter stick, narrow edge up, is clamped at one end to the table top. Two simple pendulum bobs are hung by strings of the same length from the free end of this non-rigid support. (15 or 20 cm. apart.) If one of the balls is now set into oscillation the other will be set into vibration by the small disturbances propagated through the support. The first bob will come to rest and the energy transfer is repeated.

Centrifugal Force

Apparatus: Metal hoop mounted on an axis, the top of the hoop free to slide. (Cenco's Centrifugal Hoop)

Procedure: Rotate the hoop by drawing rapidly on the cord coiled about the axis. The poles are observed to be flattened and the equator bulges. Reference should be made to the effect of the earth's rotation.

Centrifugal Force

The apparatus consists of a disc with a grooved circumference in which rests a light chain. About a half-inch "play" is allowed. The disc is mounted on a rotator and spun at high speed in a vertical plane. The chain is then tripped off the disc whereupon it rolls away like a hoop, centrifugal force on the links imposing a rigidity on the whole structure.

Centrifugal Force

A paper (or light cardboard) disc of about 6-inch radius is mounted on a rotator and spun at high speed. A rigidity is imposed on the structure by virtue of centrifugal force and the edge of the disc can be shown to cut as does a saw blade.

Elasticity; Torsion

Apparatus: Torsion apparatus; rods to be tested; weights.

Procedure: The apparatus provides means for rigidly fixing the ends of a rod. The graduated wheel at one end has a flat peripheral surface around which passes a steel ribbon carrying a weight-holder. Set up the apparatus with the metal rod to be tested. Add weights to the pan whereupon a twisting force is exerted on the rod and the amount of twist produced can be read off in degrees on the wheel. It can thus be shown that the twist is proportional to the stress.

Compound or Physical Pendulum

Apparatus: The apparatus consists of a stick one meter long supported by a thin nail running through a hook on one end, and thus free to swing as a pendulum; simple pendulum.

Procedure: The length of the equivalent simple pendulum is two thirds the length of the stick and this (bob attached to a string) may be fixed to the other end of the supporting rod. The two pendulums may be swung together and the period for both observed to be the same.

The point on the stick opposite the bob is the center of oscillation and this may be made the point of support without affecting the period. The stick may be swung on an axis one fourth the length from one end and the time of swing shown to be a minimum.

Momentum; Elastic and Inelastic Impact

Apparatus: Tripod and vertical rod provided with adjustable bifilar suspensions and graduated arc; impacting masses.

Procedure: Balance the system so that the balls pass over the scale without wobbling. The impacting mass may be drawn aside by a thread which is then burned so as to release it without imparting to it any accelerations other than that due to gravity. The initial and final positions of the masses together with their weights are then used to check the law of conservation of momentum. Inelastic impact can be demonstrated by attaching a little wax to the mass at rest.

Moment of Inertia; Angular Acceleration

Apparatus: Hollow and solid cylinders; spheres of different sizes and masses; inclined plane.

Procedure: Demonstrate the relations between moment of inertia and angular acceleration by rolling different combinations down the incline. The results of the mathematical treatment of acceleration of rolling bodies can be easily verified.

The Bernouilli Effect

Apparatus: Flat metal disc with hole to which is attached a tube; piece of cardboard; air pressure; pingpong ball; funnel; 2 light balls suspended about 2 inches apart.

Procedure: Connect the tube to the air pressure. Show the force of the air current by playing it on loose papers on the desk. Now bring the disc down normally on the piece of cardboard, which now immediately sticks to the disc.

Blow a strong current of air between the two suspended balls. The blast of air, instead of blowing the balls apart, will actually "suck" them together. The velocity of the air rapidly decreases after leaving the very narrow space between disc and cardboard, thus indicating a diminution of pressure within the constriction.

The air jet inclined at a considerable angle may be made to support one free ball. The pingpong ball can be supported in an inverted funnel through which a jet of air streams downward.

Adhesion

Apparatus: Two well-polished plate-glass discs.

Procedure: The discs, when clean and dry, exhibit an appreciable adhesion for one another. When a drop or two of water is placed between the plates the force, perpendicular to the surface, required to separate them is greatly increased. The plates may, however, be separated laterally with ease.

Diffusion of Gases

Apparatus: Porous cup fitted with stopper and glass tube; beaker of colored water; illuminating gas (or Hydrogen if available); bell jar.

Procedure: Support the porous cup with attached tube in a vertical position with the end of the tube dipping into the beaker of colored water. Invert the bell jar over the porous cup and allow the hydrogen to pass up into it. Bubbles are observed rising from the end of the glass tube. The hydrogen molecules have about 4 times as great velocity as those of air and pass through the porous wall, forcing the air out at the bottom. If the gas source and the bell jar are now removed, the colored water slowly rises in the tube, showing that the gas inside the cup is going out.

Osmosis

A hemispherical metal casting is provided with two washers between which a semi-permeable membrane may be stretched and held by means of screws. Ordinary cellophane serves this purpose.

The hemisphere is filled with a colored concentrated sugar solution and connected to a vertical glass tube. It is then immersed in a vessel of distilled water. The inward diffusion of the water molecules into the sugar solution increases the volume of the solution inside and the liquid rises in the tube.

Note: Inasmuch as some time is necessary for an appreciable rise to take place, it is advisable to start operations at the beginning of the lecture period.

Surface Tension

Apparatus: A right-circular cone made of wire, having three lateral edges, with a fourth wire (projecting from the vertex toward the base) on which is placed a cork float; battery jar.

Procedure: Submerge the float until the ring is under the water, then carefully release it. The ring will push up against the surface of the water because of the buoyancy of the float but it will not rise above the surface. With good surface forces the whole system can be made to oscillate up and down.

The Measurement of Surface Tension

A triangular frame of wire is so suspended from a Joly balance that one side is horizontal. This frame is attached to a slow-motion screw. The extent of stretching the spring by surface forces is then measured. Knowing the spring constant, which is determined by calibrating with known weights, and the length of the film, the magnitude of the surface tension in dynes per centimeter can be at once calculated.

Note: It is very important that the fork be clean. This is best achieved by passing it through a flame.

Fall of Pressure in a Pipe

Apparatus: Metal pipe of .5 cm. bore, closed at one end, with small holes bored at intervals along its length, the open end provided with a rubber tube for connection to gas jet or water tap.

Procedure: When the gas passing through the tube is lighted at the holes, the decrease in the height of the flame shows the fall of pressure. When connected to the water tap, the parabolas described are of decreasing magnitudes.

MECHANICS OF LIQUIDS

Levels of Liquids in Connecting Vessels

Apparatus: Set of glass tubes of different shapes; colored liquid.

Procedure: Show that the surfaces of the liquid in the various vessels lie in the same horizontal plane, from which it is concluded that the pressure beneath the surface of a liquid depends simply on the vertical depth beneath the free surface, and not at all on the size or shape of the vessel.

Capillary Rise and Depression

Apparatus: Set of connected capillary tubes; mercury; clean water.

Procedure: Use the set of connected capillary tubes, first with mercury, then with clean water. The mercury will show capillary depression while the water will show a rise inversely proportional to the diameter of the tubes. It is effective to show this simultaneously with the levels of liquids in connecting vessels. (quod vide)

Upward Pressure of Liquids

Apparatus: Large battery jar; glass cylinder (edges smoothly ground) with glass plate large enough to cover one end; string fixed to middle of plate; beaker; colored water.

Procedure: Hold the glass plate against one end of the cylinder by means of the string which is passed through the cylinder. Now lower the closed end of the cylinder into the battery jar of water. As the cylinder is pushed into the water the upward pressure due to the water keeps the plate against the cylinder, and the string may be released. Now pour colored water into the cylinder. The plate stays in place until the levels inside and outside are the same. We conclude that the upward pressure exerted by a liquid at any depth is equal to the downward pressure at the same depth.

Relation Between Depth and Pressure

Apparatus: Liquid pressure gage provided with colored liquid; large battery jar; meter stick.

Procedure: Lower the gage beneath the water surface in intervals of, say, 5 centimeters, and thus show that the pressure is directly proportional to the depth. Turn the gage so that it indicates upward, downward, and lateral pressure and thus show that liquid pressure is equal in all directions. (The density of the liquid may be altered by making a salt solution.)

Transmission of Pressure by a Liquid

Apparatus: Cartesian Diver; cylinder, rubber diaphragm.

Procedure: Such out the air from inside the diver and allow water to enter until weight of diver and water just permits the diver to float submerged. Press on the diaphragm; the pressure is transmitted by the water to the air in the interior of the diver, which is compressed, allowing more water to enter the diver, whereupon it sinks. Upon releasing the pressure the compressed air within the diver expels the excess water and the diver rises.

Note: The demonstration may be first tried with water just slightly warm. In this case it will invariably fail and the reason makes a good class problem.

Pressure in a Siphon

Apparatus: Siphon to which is attached manometer tube; large beaker of water.

Procedure: The manometer may be filled with colored liquid or mercury. Start the siphon by drawing on the longer end. It is immediately observed that the pressure in the upper part is less than atmospheric when the siphon is in operation.

Bernouilli's Principle

Apparatus: Large beaker of colored water; glass tubing about 2 feet long and of 1/2 inch bore; connection to air line.

Procedure: Stand the tube upright in the beaker of water. Direct the air line normally to this and blow a strong current of air across the top of the tube. The liquid will be seen to rise in the tube. With a little adjustment the liquid can be raised to a considerable height.

Pressure Reduced in a Constriction

The apparatus consists of a horizontal tube gradually tapered towards the center so as to provide a constriction. A tube leads off normally at the constriction and is connected to one end of a manometer, the other end of the manometer open to atmospherics pressure. When air is passed through the tube a drop in pressure is registered by the manometer.

Incompressibility of Water

A bottle is filled completely with water which has been boiled. The bottle is then corked tightly. (A screw-top is preferable.) If, now, the bottle containing the water is held by the neck it may be swung like a hammer and made to drive a 20 penny nail into a plank! If the instructor wishes he can then show that the bottle is shattered by performing the experiment with the bottle empty.

ATMOSPHERIC PRESSURE

Proof That Air Exerts Pressure

Apparatus: Open-necked bell-jar provided with rubber diaphragm; air pump.

Procedure: Exhaust the air from beneath the membrane which will then be observed to be more and more depressed until it will finally burst under the pressure of the air above. A small wooden ball placed on the membrane can be observed by the class to disappear as the membrane becomes depressed.

The expansibility of air can be also shown by placing the rubber diaphragm over a beaker which is then placed under a larger bell-jar connected to the air pump. When the pump is set into operation the air inside the beaker will expand with sufficient force to burst the rubber or at least greatly distend it.

Magdeburg Hemispheres

The device is amusing and instructive, and has considerable historic interest. (The original hollow hemispheres were about 22 inches in diameter and required 16 horses, four pairs to each hemisphere, to pull them apart. The originals are now in the Deutsches Museum in Munich.) The dimensions of the hemispheres can be given the class and the pull required to separate them calculated.

Atmospheric Pressure: Porosity

Apparatus: Wooden funnel with solid stem ground to fit open-necked bell-jar; mercury; small beaker; air pump.

Procedure: Pour mercury into the wood funnel which is then fitted tightly over the bell-jar. When the jar is evacuated the mercury passes through the invisible pores of the wood and falls into the beaker placed beneath it. The experiment demonstrates at once the porosity of wood and the significance of atmospheric pressure.

Expansibility of Air

Apparatus: Large bell-jar connected to air pump; 2 bottles connected by U-tube, one nearly filled with colored liquid and tightly stoppered, the other open and empty.

Procedure: Place the bottles beneath the bell-jar and evacuate. As the air is exhausted the liquid from the tightly stoppered bottle passes through the U-tube into the empty bottle. Now let the air in and the operation reverses.

Vapour Pressure: Atmospheric Pressure

Apparatus: Empty tin can, preferably with square corners, and rubber stopper to fit; stand and burner.

Procedure: Put a small amount of water in the can and coil for a few minutes to expel the air. Remove the flame and quickly insert the stopper. As cooling progresses the vapour pressure within the can becomes less and atmospheric pressure soon collapses it. The effect can be hastened by pouring cold water over the can, or, if it is small enough, by immersing it in a vessel of cold water.

Vapour Pressure

Apparatus: Large-neck flask with #10 one-hole stopper to fit tightly; glass tube drawn to a small aperture; small glass vial; ether; warm water, preferably colored; elastic band.

Procedure: Fill the flask about half full with the warm colored water. Fix the vial to the lower end of the glass tube by means of the elastic band and at such a point as to allow it to be half immersed in the water. With this arrangement the ether vapour pressure forces a stream of water up the tube and through the orifice. The action may be hastened by the gentle application of heat to the flask. (Caution).

Vapour Pressure

Apparatus: Glass tube sealed off, about 80-85 cm. long; stand and clamps; meter stick; mercury; funnel; piece of rubber tubing; large evaporating dish; curved pipette; ether.

Procedure: Fill the glass tube with mercury using the funnel and rubber tubing, place the finger over the end, invert, and clamp upright against the meter stick. We now have a Torricelli tube. By means of the pipette introduce a drop or two of ether into the bottom of the tube. The drop rises at once to the top and evaporates in the vacuum which exists above the mercury column. The pressure of the vapour depresses the mercury column. If a flame is passed quickly across the tube near the upper level of the mercury, the vapour pressure will be seen to increase.

The demonstration can be modified by arranging four such tubes side by side, and introducing into one a drop of water, into the second alcohol, and into the third ether, thus yielding a relative measure of vapour pressures. The fourth gives the atmospheric pressure for comparison.

A still further modification is possible by first introducing air into one tube until the mercury column stands at about 50 cm. Then introduce a drop or two of ether. The mercury will not be found to sink instantly to its final level as it did before, but although it will fall rapidly at first it will continue to fall slowly for several hours. At the end of a long interval, say a day, it will show a depression which indicates a vapour pressure of the ether just as great as that existing in the tube that contains no air. We conclude that just as much liquid will evaporate into a space which is already full of air as into a vacuum. The air has no effect except to retard greatly the rate of evaporation.

Kinetic Theory; Brownian Movement

A pyrex tube about 3 cm. in cross-section and 25 cm. long contains a few cc. of mercury on top of which rest several layers of colored glass pellets. The tube is evacuated and sealed off. If now the mercury pool is gently heated in a Bunsen flame the pellets are put into chaotic motion by the vapour rising from the mercury. The behavior of the particles resembles true Brownian motion and in fact, the visible motion is caused by the bombardment from the invisible mercury molecules.

HEAT

Expansion of Solids; Principle of Shrink Fit

Apparatus: The two pieces commonly designated as ball and ring; Bunsen flame.

Procedure: Show that the ball, when heated, will not pass through the ring but will pass through when the ring in heated.

The principle of shrink fit can be demonstrated by placing the heated ring symmetrically on the ball and allowing the ring to cool while in this position.

Differential Expansion

Apparatus: Compound expansion bar; Bunsen flame.

Procedure: Show that the compound bar, which consists of two strips, one of brass, one of iron, when heated edgewise in a flame so that the two metals are heated equally, bends in such a way that the more expansible metal (the brass) is on the outside of the curve. (This principle is incorporated in the compensated balance-wheel.)

Coefficient of Linear Expansion

Apparatus: Linear expansion apparatus and accessories.

Procedure: The apparatus may be set up (after taking the initial length of the rod) with an electric bell connected to the vernier. The initial and final readings are thus easily made and the ringing of the bell makes the demonstration a bit more impressive.

The initial length, the change in length as given by the vernier, and the change in temperature as given by the thermometer constitute sufficient data to calculate the coefficient of expansion for the specimen used.

Heat from Friction

Apparatus: Brass tube, one end of which fits the chuck on a rotator; felt pad, ether, alcohol or water.

Procedure: The tube is mounted in a vertical position and partly filled with ether, alcohol or water, then tightly corked. The felt pad is held snugly about the tube which is then spun and the heat generated by friction raises the temperature of the liquid until its vapour pressure projects the cork explosively.

Conductivity of Heat

One piece of apparatus consists of several rods of different metals extending from a common metal center. To the ends of the rods may be fixed small pellets of wax or match heads may be placed in the indentations. The metal center is heated in a flame.

The other device consists of hollow metal tubes fixed to a hollow axis through which steam is passed. The metal tubes are coated with a special paint and the progress of heat conduction is shown by the change of color which the paint undergoes when heated.

Differential Thermometer

The manometer column responds to the heat of the hand. The device is provided with a platform to hold a Leslie cube, by means of which the relative radiations from various surfaces at the same temperature may be readily shown.

Convection

Apparatus: Convection apparatus and accessories.

Procedure: The apparatus consists of a metal box provided with two glass chimneys. Convection currents may be demonstrated by placing a lighted candle under one of the chimneys and holding a bit of glowing paper (or Touch Paper) at the open end of the other chimney.

Pulse or Palm Glass

Two glass bulbs with connecting tube contain a colored volatile liquid. When one bulb is held in the hand the warmth causes rapid evaporation. The pressure thus produced forces the liquid into the other bulb.

Radiometer

The device is a sensitive detector of radiation. It consists of a light paddle wheel with four very thin vanes blackened on one side and polished on the other, the whole mounted in a partially evacuated bulb. When radiation falls upon the vanes the wheel revolves with the black sides "retreating". The phenomena is explained on the basis that the radiation warms the black sides slightly more than the bright sides, the air molecules rebound more vigorously from the black sides and the wheel revolves because of differential reaction.

Constant-Pressure Air Thermometer

Apparatus: Glass tube (preferably capillary) with bulb blown on one end.

Procedure: Introduce into the tube a globule of mercury. Changes of temperature of the bulb cause the mercury to move because of changes of gas volume at constant pressure.

Expansion of Gases; Galileo's Thermometer

Apparatus: Round-bottom flask provided with tight-fitting stopper and glass tube; beaker of colored water.

Procedure: Hold the flask in an inverted position with the end of the glass tube beneath the level of the water in the beaker. The heat of the hand is sometimes sufficient to cause bubbles of air to be expelled from the flask and to rise through the water. If the heat of a flame is applied bubbles rise rapidly. If after a time the flame is removed and the flask allowed to cool, water rises into the flask. (This experiment is of historical interest inasmuch as the device constitutes Galileo's air thermometer.)

Boiling under Reduced Pressure

Apparatus: Round-bottom 1 liter flask with rubber stopper to fit; stand provided with two ring brackets; large beaker; catch basin.

Procedure: Fill the flask about half full with clean water and boil for 2-3 minutes to expel the air. Remove the flame, and immediately insert the stopper; invert the flask in the ring-bracket provided. The temperature will fall rapidly below the boiling point. Now pour cold water over the flask and observe that the water begins to boil vigorously. The cold water, by condensing the steam, lowers the pressure within the flask and therefore enables the water to boil at a lower temperature. The boiling ceases as soon as enough vapour is formed to restore the pressure. The operation may be repeated many times without reheating the flask.

Caution: Do not use a flat-bottom flask as it is likely to collapse.

Freezing by Evaporation

Apparatus: Air pump and bell-jar; evaporating dish; wire gauze or triangle; watch glass; concentrated sulphuric acid.

Procedure: Set the watch glass containing a little distilled water on the wire gauze which rests on the evaporating dish containing a little sulphuric acid. When the pump is started the dissolved air in the water is first carried away, then as the water evaporates the vapour is absorbed by the acid. Finally, when the pressure is lowered still further, the water begins to boil, and this process requires so much heat that the water freezes. (Absolutely tight connections are necessary for success in this demonstration.)

Freezing by Evaporation; The Cryophorus

The cryophorus is a J-tube provided with a bulb at each end; one of the bulbs is half-filled with water and the system is evacuated and sealed off. With all the water in one bulb the other is immersed in a freezing mixture. Water vapour condenses in the cold bulb and reduces the vapour pressure; the resultant rapid evaporation of the water cools it and it finally freezes.

Expansion of Liquids

Apparatus: Small round-bottom flask provided with stopper and glass tube; colored liquid; pan of ice; burner.

Procedure: Place the flask in the ice and observe the position of the liquid in the tube. Now apply heat gently and observe the rise of the liquid in the tube.

ELECTROSTATICS

Positive and Negative Electricity

Apparatus: 2 rubber rods; 2 glass rods; piece of silk; piece of cat's fur; silk thread; fine wire stirrup; clamp and stand.

Procedure: Rub a rubber rod with the fur and suspend in the stirrup. Bring up in turn another rubber rod rubbed with fur and the glass rod rubbed with silk. In the first case the suspended rubber rod will be repelled; in the second a strong attraction will be exhibited for the charge on the rubber rod. We thus observe a difference in the nature of the electric charges on the glass and rubber. (It need not be remarked that the force actions were exhibited only between the electrical charges possessed by the glass and rubber and not between the rods themselves.)

Repulsion and Attraction

Apparatus: Rubber rod; fur; a well-dried stick about the dimensions of a meter stick; watch glass; string.

Procedure: Suspend the stick so that it hangs horizontally. Rub one end of it with the fur. Approach this end with a rubber rod rubbed with fur. The stick is set into rotation by repulsion. The experiment can be repeated by balancing the stick on the watch glass as a pivot. In this, however, the end of the stick rubbed with the fur will show a dip toward the table top, indicating an induced opposite charge and a resultant attraction.

(The author has performed this by using a well-dried two-by-four.)

Electrostatic Repulsion

Apparatus: Strong directed light source; rubber rod; cat's fur; dry cork filings.

Procedure: Electrify the rod and dip it into the cork dust. A considerable mass attaches itself to the rod due to induced opposite charge and consequent attraction. After a brief interval it will be noticed that some of the particles are ejected from the rod. This is due to the particles being charged by conduction and the consequent repulsion of similar charges. The demonstration can be shadow projected to make the ejections visible to the class.

Electrostatic Induction

Apparatus: Cylindrical conductor with hemispherical ends, mounted on insulating stand, and provided with wire supports, one above each end, from which are hung pith balls so as to just touch the ends of the conductor; charged rod.

rocedure: Approach one end of the conductor with the charged rod. Both pith balls are deflected away from the ends. Charge a third pith ball by contact with the rod, and with this one test each of the two suspended ones. It will be observed that the charges on the ends of the conductor are of opposite sign. The nature of these charges with reference to the charge on the rod can be determined by a proof plane and electroscope.

Electroscopes

An electroscope is a device for detecting the presence of an electrical charge. Arbitrarily, we designate the charge which appears on a rubber rod rubbed with fur as negative, and that on glass rubbed with silk as positive.

(a) The pith ball electroscope: A single pith ball given, say, a positive charge; it will be attracted by a negatively charged body or repelled by one positively charged. It can, therefore, be used to detect the presence and nature of charges.

(b) A charged rod supported in a stirrup and free to swing constitutes an electroscope.

(c) The gold-leaf electroscope: This device needs no explanation. The charge is detected by the motion of two leaves or of one (hanging beside a fixed plate). A shadow projection of the whole electroscope shows clearly the instructor's manipulations and the motion of the leaves.

Electrostatic Induction

Apparatus: Gold leaf electroscope; rubber rod; cat's fur.

Procedure: (a) Preliminary: Slowly bring the electrified rod toward the knob of the electroscope. The leaves will diverge even when the rod is a foot or more from the electroscope. (This indicates that the mere influence which an electrical charge exerts upon a conductor placed in its neighborhood is able to produce electrification in that conductor.)

As soon as the charged rod is removed the leaves collapse. (The electrification is only a temporary phenomenon, due simply to the presence of the charged body in the neighborhood.

(b) Charging the electroscope by induction: Bring the electrified rod near the knob of the electroscope. The leaves at once diverge. (Make a diagram of the electroscope with the negatively charged rod near the knob. By the use of plus and minus signs explain the electrical condition of both the knob and the leaves.) Touch the knob with the finger while the rod is held in place. The leaves will collapse. (Explain by a diagram as before.) Remove the finger and then the rod. The leaves fly apart again. (Explain with a diagram the final electrical condition of both the knob and the leaves.)

Density of Charge

Apparatus: Charged conductor mounted on insulating stand; electroscope; proof plane.

Procedure: Touch one end on the charged body with the proof plane; convey the charge to the electroscope and note the amount of separation of the leaves. Repeat after touching the middle of the conductor. The separation will be found to be much less.

This can be shown well by using an ordinary tin can resting on an insulating stand. The charge density will be greatest at the edges and least on the flat portions.

Electrostatic Screening

Apparatus: Wire netting (window screening) large enough to surround an electroscope.

Procedure: Surround the electroscope with the wire cage, which is then grounded. Bring near to the electroscope (outside the cage) charged rods or any strongly charged bodies. The leaves remain undisturbed. Show the effect when the cage is not grounded. Show also the effect due to flux leakage when the bottom of the cage is removed.

Dissectible Leyden Jar

Apparatus: Leyden jar; static machine; discharging rod.

Procedure: Charge the Leyden jar by holding the outer coating in the hand and putting the knob in contact with one terminal of the machine (say the negative). Electrons pass to the knob and spread to the inner coat of the jar. Here they repel electrons from the outer coat to the earth, thus leaving it positively charged. Now connect the inner and outer coatings with the discharging rod. A strong spark results. Now recharge and place the charged jar on an insulating plate. Touch the knob with the finger. No appreciable charge is noticed. Touch the outer coat; again there is no appreciable discharge.

The experiment shows that one side of the jar along cannot be discharged for practically all the charge is bound by the opposite charge on the other coat. The full discharge can therefore occur only when the inner and outer coats are connected.

The jar may be disassembled after being charged and the electrodes brought into contact. No spark passes. When reassembled the jar is discharged with the discharging rod, indicating that the energy resides in the dielectric.

The Electric Whirl

Apparatus: Two wires crossed at their midpoints and their pointed ends turned at right angles to form a swastika; pivot on which the system can be balanced.

Procedure: Connect the system to one terminal of the electrostatic machine. When the machine is operated the whirl rotates rapidly in a direction opposite to that of the pointed ends. The air close to each point is ionized. Ions of opposite charge are drawn to the points and discharged. The other ions are repelled. The repulsion is mutual and it is these reaction forces which cause the rotation.

Motion of Charged Particles in an Electric Field

Apparatus: Two metal plates arranged horizontally, one about 1 cm. above the other, and well insulated; electrostatic machine; pith balls.

Procedure: Connect the plates to the terminals of the machine. Place the pith balls on the lower plate. When the machine is operated the pith balls take on the charge of the lower plate and are repelled to the upper plate. Here the charge is reversed and they are driven down. The continual motion is amusing and instructive.

(The demonstration is more effective if shadow projected.)

"Electric Wind" - Discharge from a Point

Apparatus: Candle; pointed conductor (stiff pointed wire attached to one terminal of the static machine).

Procedure: Place the burning candle near the pointed end of the conductor which is connected to the positive terminal of the static machine. The flame is strongly repelled. If the negative terminal is used the flame is attracted. The phenomenon is due to the presence of positive ions. (Under favorable conditions the flame can be blown out.) Mention should be made in connection with this experiment of the notion of charge density and curvature.

Mechanics and Electrostatics; Coulomb's Law

Apparatus: Two fairly large aluminized pith balls of equal known mass suspended by silk threads from a common point; rubber rod; fur; meter stick.

Procedure: Charge the balls by contact with the electrified rod; they immediately fly apart. Give to the class the distance between the balls, their masses, and the lengths of the supporting strings, and have them calculate the charge.

The demonstration serves to tie up the notions of mechanics and electrostatics.

The Electrophorous

Apparatus: Electrophorous; fur.

Procedure: Give the plate a negative charge by rubbing with the fur. Place the metal disc (provided with insulating handle) on the plate, whereby it is charged inductively, the lower side positively, the upper negatively. Touch the disc with the finger;

the free negative charge escapes leaving on the disc only bound positive charge. Finally, remove the disc and thus free the positive charge on it which may be removed by touching the plate. This cycle of operations may be repeated indefinitely without again charging the wax.

It should be pointed out that the amount of charge the disc receives by <u>conduction</u> is negligible. The surfaces of the disc and the plate are not perfect planes and consequently come into contact at a few points only.

The demonstration should be accompanied by blackboard diagrammatic representation of charges.

The Ice Pail Experiment

Apparatus: Hollow conductor (tin can) connected to an electroscope; metal ball on a string.

Procedure: Charge the ball and lower into the conductor. The leaves of the electroscope diverge indicating induced charge on the outside of the conductor. (If the charging body is removed without coming in contact with the tin can the leaves collapse, showing that no charge was transferred to the conductor.) Now touch the ball to the bottom of the can. The can and the electroscope retain a permanent charge.

Observations to be made:

(a) The ball may be moved about inside the can without altering the divergence of the leaves.

(b) The ball may touch the inner wall of the can without affecting the charge on the electroscope.

(c) When the ball is removed it is found to be entirely discharged.

(d) If the uncharged ball is again lowered into the can and touched to the bottom it still bears no charge. If touched to the outside of the can it shows a charge.

Parallel Plate Condenser; Dielectric Constant; Capacitance

Apparatus: Two rectangular sheets of metal mounted on insulating bases (tacked to blocks of wood); electroscope; connections; specimens of dielectric; static machine; proof plane.

Procedure: Set the plates upright, facing each other. Connect one to the electroscope (case grounded), and ground the other. Charge the first one; the divergence of the leaves indicates the potential difference between charged plate and ground. Now bring the plates closer together. Observe that the leaves begin to fall together, showing that the potential of the one is diminished by the presence of the other, although the quantity of electricity on the first has remained unchanged.

Now convey additional charge to the first plate with the proof plane. It will be observed that many times the original amount of electricity can be put on the plate before the leaves return to their original divergence. Now introduce between the plates sheets of insulating material and observe the relative effects of dielectrics. (Remove any charge which the test sheets may possess.)

Piezo Electricity

The device consists of a Rochelle-salt crystal mounted between two electrodes, the whole connected with a neon lamp. When the upper end of the unit is struck lightly with a mallet the neon lamp flashes showing that an instantaneous voltage of several hundred volts has been produced by the mechanical blow on the crystal.

Photoelectric Effect

Apparatus: Gold-leaf electroscope; zinc plate which may be attached to the knob; mercury or carbon arc; sandpaper.

Procedure: Sandpaper the zinc surface to remove any film (oxides) and focus the ultraviolet light on the plate. Charge the electroscope positively and observe the rate of leak. Now charge the electroscope negatively and observe the rapid rate of leak due to electrons leaving the plate. The electroscope can be charged by induction with the glass rod rubbed with silk.

Heat Generated by a Spark; Fixation of Nitrogen and the Production of Ozone

The apparatus consists of an exhaustion flask to the sidearm of which is attached an oil manometer. A two-hole stopper is fitted tightly and provided with two electrodes which are energized either by a Ford coil or an electrostatic machine. When a spark is passed the manometer shows immediately an increase in pressure due to heat generated by the spark. If, after running a number of seconds, the sparking is stopped, the manometer returns immediately to its equilibrium position and then more gradually to a lower level on the atmospheric side, indicating a diminution of pressure within the flask.

Before an explanation is given the class should be asked to account for both phenomena. The first will be easily answered but the second will constitute a stumbling block for many. It can then be shown that the following takes place:

$$N_2 + O_2 \longrightarrow 2NO$$

$$2NO + O_2 \longrightarrow 2NO_2$$

Ozone is also formed, which may be represented thus:

$$\text{Energy} + 3O_2 \longrightarrow 2O_3$$

but this, being unstable, breaks down immediately.

The last two equations show the decrease in the number of molecules. The manometer fluctuations can be made more plainly visible by placing behind it a white cardboard with several horizontal rulings.

MAGNETOSTATICS

Types of Magnets

Show the various forms of magnets: Magnetite, (magnetic ore), bar magnets, horseshoe magnets, and other demonstration pieces.

Floating Magnet

The device consists of a pair of cobalt-chrome steel magnets mounted on a block. One magnet is concealed in the wooden form. With like poles adjacent the one magnet is held floating above the other by repulsion.

Magnetization by Contact

Apparatus: Steel knitting needle; bar magnet; large compass needle swinging in a horizontal plane; iron filings.

Procedure: Show first that the needle has no magnetic properties by sticking it into iron filings; then stroke it with the bar magnet. Now show that it possesses magnetism. The nature of the poles may be shown by approaching the large compass needle.

The needle may be notched with a file at 2 or 3 points and then broken. The indicator needle will show that each piece is a complete magnet with opposite poles.

Induced Magnetism

Apparatus: A number of nails or tacks; bar magnet.

Procedure: Support a chain of nails from one end of the magnet and test the polarity of the end of the chain.

Magnetic Induction

Apparatus: Bar of soft iron; strong permanent magnet; tacks or iron filings.

Procedure: Hold the bar of iron collinear with the magnet and a few centimeters from it. The bar becomes magnetic by induction and the tacks will cling to it. When the bar magnet is removed the tacks will fall off. The polarity of the induced poles can be shown with the magnetic needle. (These effects should be compared with those observed in electrostatics.)

Mechanics and Coulomb's Law

Apparatus: Two bar magnets; small weight provided with thread (or rider of known mass); meter stick; pivot.

Procedure: Balance one of the magnets on the pivot; place the other below it and in such a position as to have unlike poles a few centimeters apart. (The other poles should be far enough apart as to neglect their forces.) Now restore balance by means of the rider. In terms of its position and mass and the distance between the poles, the inverse square law can be approximated.

The Earth's Field

Apparatus: Indicator needle; soft-iron bar; hammer.

Procedure: Hold the iron bar parallel to the earth's field and strike it sharply on the end. The polarity of the rod can then be shown.

If a bar of permalloy is available this can be shown to be magnetized by simply holding it parallel to the earth's field. Its polarity will be reversed upon interchanging the position of the ends.

Magnetic Dilemma

Apparatus: Two very similar bars of iron, one magnetized, the other not.

Procedure: How can we discover <u>without any other equipment</u> which bar is the magnet?

Magnetic Screening

Apparatus: Small nail or piece of knitting needle tied to a string; strong magnet; sheets of ferromagnetic and nonferromagnetic materials.

Procedure: Fix the free end of the string to the table and hold the needle in the air with the magnet one or two centimeters above it. Now introduce between magnet and needle the nonferromagnetic materials. No change in the supporting force is observed. When a sheet of iron is introduced the needle falls.

Effect of Temperature on Magnetic Properties

Apparatus: Horse-shoe magnet; piece of knitting needle; Bunsen flame.

Procedure: Suspend the needle from an arm by threads as free as possible from torsion, and place the U-shaped magnet on a stand in such a manner that the suspended needle is held out of its equilibrium position by the attraction. Now apply a small flame between the pole pieces and directly onto the needle. The needle will be observed to fall away from the magnet. With the proper adjustment an arrangement can be found whereby the needle, upon cooling, will suffer sufficient attraction to be pulled back.

Care should be taken not to injure the pole pieces with the flame.

Shunting Magnetic Flux

Apparatus: Small steel ball; strong bar magnet; non-magnetic soft-iron bar.

Procedure: Pick up the steel ball on the end of the bar magnet. Now place against the bar magnet the soft-iron bar and slide the latter toward the ball. The ball drops off indicating that the magnetic flux has been shunted through the bar to the other pole of the magnet.

CURRENT ELECTRICITY

Simple Voltaic (Galvanic) Cell

Apparatus: Strips of Cu and Zn to which are fixed leads of convenient lengths; beaker; distilled water; sulphuric acid; demonstration galvanometer.

Procedure: Show first that no current flows when the metallic strips rest in the distilled water. Now add a little sulphuric acid. The mechanism of the cell should be explained diagrammatically on the board.

Elementary Storage Cell

Apparatus: Two Pb strips with leads; acidulated water; storage battery.

Procedure: Arrange the Pb strips in the electrolyte and show that no current flows. Now send a current through the arrangement by connecting to the storage battery. Explain diagrammatically the phenomena taking place. After the cell has been charged show that the chemical energy stored gives rise to a current. Point out that the two dissimilar plates (one Pb, one PbO_2) constitute a primary galvanic cell. It may be shown too, that the direction of current during charge is opposite to that during discharge.

Conductivity of Solutions

Apparatus: Lamp bulb mounted on wooden support to which are attached 2 electrodes; small beaker; leads; distilled water; sulphuric acid; sodium hydroxide; common salt; sugar; kerosene.

Procedure: Show first that the distilled water does not conduct electricity. Now add a drop or two of sulphuric acid and observe the lighting of the bulb. The brightness of the lamp can be increased by the addition of acid.

Repeat with solutions of sodium hydroxide, common salt, and the others named above.

A discussion of electrolytic dissociation should accompany the demonstration.

Electroplating

Apparatus: Two electrodes, one carbon, the other copper; supports; copper sulphate solutions; leads; battery.

Procedure: The electrode to be plated (carbon) is connected to the negative terminal of the battery. The copper electrode is connected to the positive terminal. After the current has passed through the solution for a few minutes the cathode is coated with metallic copper while the copper terminal is seen to have suffered a loss.

It is now quite effective to exchange terminals and show that the coating is removed.

Heating Effect of Electric Current

Apparatus: Coil mounted in glass tube with terminals and air outlet; rheostats; air-pump.

Procedure: Connect the coil with resistances to the 110-volt line. Attach the air pump. Show the heating effect by adjusting the rheostats. Exhaust the tube and show the more rapid heating of the wire.

Effect of Temperature on Resistance

Apparatus: Small coil of wire so supported that a Bunsen flame may be passed over it; battery; galvanometer.

Procedure: Connect the battery, coil and galvanometer and observe the reading. Now heat the coil with the flame and observe the decrease in galvanometer deflection.

Effect of Temperature on Resistance

An auto-light bulb is operated in series with 6 volts and a coil of iron wire wound on a porcelain insulator. When the wire is heated in a Bunsen flame the lamp goes out due to increased resistance in the wire at high temperature. As the wire cools the wire again glows. The cooling can be hastened by directing a blast of cold air over the wire.

Thermoelectric (Seebeck) Effect

Apparatus: Copper-constantan thermocouple; galvanometer; Bunsen flame.

Procedure: Show the thermal emf which results from heating one junction.

Magnetic Field due to a Current through an Electrolyte

Apparatus: Glass tubing with ends bent at right angles provided with stoppers and leads; sulphuric acid solution; pivoted compass needle; batteries.

Procedure: Support the glass tube horizontally in the earth's meridian and place the compass needle immediately below it. A current sent through the electrolyte gives rise to a magnetic field as shown by the deflection of the compass needle.

ELECTROMAGNETICS

Lifting Magnet

The magnet can be operated on a single dry cell but gives best results with current from a six-volt storage battery. The magnet and armature are provided with rings for support and load.

Force on Core of Solenoid

Apparatus: Solenoid; iron rod; 6-volt battery.

Procedure: Lay the solenoid horizontally on the lecture table and connect to the source. Insert the iron rod in one end. The rod is violently drawn into the coil, as if by suction, and may oscillate several times before coming to rest. This shows that magnetic material tends to move into the part of a magnetic field that is most intense. If the circuit is broken at the instant the rod reaches the center of the solenoid its momentum may be sufficient to project it out at the other end.

Magnetization of Iron Bar in Earth's Field

Apparatus: Soft-iron bar about 1' long and 1" in cross-section wound about the center with approximately 500 turns; lecture galvanometer; hammer or mallet.

Procedure: With the bar in an east-west position and the coil connected to the galvanometer strike the bar and point out that there is no response in the galvanometer. Now orient the bar parallel to the earth's field and show, by blows increasingly harder, increased deflection of the needle, thus showing increased magnetization.

If the bar is now turned back into the east-west position, repeated striking will cause the magnetism to disappear and the galvanometer will show opposite deflection.

Currents Induced by Magnets

Apparatus: Solenoid; galvanometer; strong magnet.

Procedure: Connect the coil to the galvanometer. Quickly thrust into the coil one pole of the magnet and observe the temporary deflection. Raise the magnet and observe the deflection in the opposite direction. Now lower the magnet and hold it down. The galvanometer pointer comes back to zero. Repeat the experiment moving the magnet slowly, and observe that the deflection is less than before. Repeat with the other end of the magnet and show that the deflections are in opposite senses in the two cases.

Note: If the direction of the galvanometer deflection is first established it can be shown that the induced current has such a direction that its magnetic action tends to resist the motion by which it is produced. (Lenz's Law.)

Currents Induced by Currents

Apparatus: Primary and secondary coils; galvanometer; battery; iron, copper and brass rods.

Procedure: Connect the secondary coil to the galvanometer and the primary to the battery. Move the current-bearing coil into and out of the secondary and observe the induced current. The current in the primary can be varied, thus showing the relation between magnetic field and induced current.

Now insert the iron core into the primary. This enhances the magnetic field, increases the flux and thereby the induced current. Show that the brass and copper rods have no effect on the change of flux by inserting each in turn into the coil.

Electromagnetic Induction; Faraday's Experiment

Two coils of wire are wound on an iron ring. One coil (the secondary) is connected to the lecture galvanometer. The other coil (the primary) is connected to a battery (1.5 Volts). When the primary circuit is closed the galvanometer shows a ballistic deflection in one direction and an opposite deflection when the primary circuit is opened. The second deflection will be found to be less than the first due to the large residual flux. The direction of the current in the primary can be changed and the galvanometer thrust shown to be in the other direction.

Oersted's Experiment

Apparatus: Pivoted compass needle; long straight conductor; 2 dry cells.

Procedure: Hold the current-bearing conductor in the magnetic meridian just above a pivoted compass needle, which is itself so placed as to lie in the meridian. The direction and amount of swing can be shown to depend (respectively) on the direction of the current and its strength. The instructor should make clear the rules of direction of magnetic field with respect to current direction.

Induced EMF and Number of Turns

Coils of 300,600, and 900 turns are wound on hollow cylinders mounted upright on a platform, the ends leading to terminals which allow connection to the demonstration galvanometer. When a strong bar magnet is thrust into the coils (with as nearly as possible the same speed in each case), the emf induced is shown to be proportional to the number of turns. Other related phenomena may be shown, e.g.,

1. deflection opposite when pole is withdrawn;
2. relation between direction of galvanometer deflection and pole used;
3. emf not induced when magnet is at rest;
4. two opposite poles thrust simultaneously yield no deflection.

Force on a Conductor in a Magnetic Field

Apparatus: Narrow strip of tinfoil, the ends of which are attached to brass rods one above the other; battery and leads; U-magnet.

Procedure: Pass a current through the foil at the same time holding the magnet so that the foil hangs vertically between the poles. The force on the conductor is immediately obvious. If the direction of the current is reversed the motion of the conductor is reversed accordingly.

The Force Action Between Two Wires Carrying Current

Apparatus: Spiral of light copper wire supported at its upper end, the lower end dipping into a mercury cup; battery.

Procedure: Pass a current through the spiral. Adjacent turns attract one another, the spiral contracts and the lower end is lifted from the mercury thus breaking the circuit. The spiral then falls back and the operation is repeated.

Ampere's Experiment

Apparatus: U-shaped wire supported by wire loops or in mercury cups; battery; bar magnet.

Procedure: Pass current through the wire. Place one pole of the bar magnet just below the wire which then experiences a displacement according to the direction of the current. By increasing the current and the field intensity the force action can be shown to increase.

Ampere's Left-Hand Rule can be demonstrated.

Magneto Electric Generator

The device consists of a rectangular coil mounted between the poles of horseshoe magnets, the coil provided with a crank which permits rapid turning. The whole is mounted on a base with an incandescent lamp which can be lighted by the current generated. Two terminals are also provided, and with the lamp thrown out of circuit these may be led off as desired. (e.g., shocking handles.)

With a neon bulb in the circuit the reversal of the current with every half-revolution may be observed.

The vibrations which the incandescent lamp filament experiences due to proximity of the magnetic field should be pointed out.

SOUND

Characteristics of Simple Vibratory Motion

The apparatus consists of a strip of steel about a meter long and 2 cm. wide one end of which can be clamped in a vise. The free end is provided with a mass, the position of which can be varied. A force applied at the free end sets the rod into vibration. Hooke's Law can thus be shown. The characteristics of vibratory motion, frequency, period, amplitude, displacement, phase, can be shown.

A Sounding Body is in Vibration; Resonance

Apparatus: Two tuning forks of the same frequency mounted on resonance boxes; ivory ball suspended on a thread and just touching the prong of one fork; mallet.

Procedure: Set the tuning forks some distance apart and strike the one with the mallet. The other fork responds by resonance as is shown by the "dancing" of the ivory ball. The sound is clearly audible throughout the room. One fork may be stopped; the other is still heard indicating that sound accompanies the motion. The effect of decreasing the distance between forks should be demonstrated.

Forced Vibrations

Apparatus: Two tuning forks of the same frequency (unmounted).

Procedure: Set one fork into vibration, then press the stem of the fork against the table or blackboard. The intensification is immediately observed. Now set the two forks into vibration simultaneously (with the same force). Press the stem of one against the blackboard and hold it there until the sound is no longer audible. Then press the stem of the other fork against the blackboard and observe that this one still emits a sound. This shows that the rate of energy dissipation was greater for the fork held against the blackboard.

Standing Waves

Apparatus: Rotator (chuck in horizontal position); vibrator; rope; pulley; clamps and uprights; weights and weight hanger.

Procedure: Attach one end of the rope to the vibrator which is operated by the motor-driven rotator; the other end is put over a pulley and weights added as increase in tension is desired. A set-screw in the vibrator permits variation of amplitude and the friction-clutch gives variations in frequency. Nodes and loops can be shown.

Material Medium Necessary for Transmission of Sound

The apparatus consists of a large bottle in which is suspended an electric bell, the bottle provided with a tight-fitting stopper, leads for battery connections and metal tube for air-pump connection. With air in the jar the bell is set ringing; the sound is plainly heard. The pump is then operated. At sufficiently low pressure the sound from the bell becomes quite inaudible. It should be pointed out that, although a material medium is necessary for the transmission of sound, sound is not a transfer of material particles, but rather a transfer of energy by disturbances in the medium.

Doppler Effect

Hold one of the mounted tuning forks (Frequency 2048) in one hand and set it into vibration by striking with the wooden mallet. Now move it rapidly toward and away from the class. The change in pitch is immediately observed.

Resonance; Velocity of Sound in Air

Apparatus: Bell jar of water; hollow glass cylinder; tuning fork.

Procedure: Hold one end of the cylinder in the water. Above the open end hold the vibrating tuning fork. The cylinder may be raised and lowered and a position found where the sound of the fork is reenforced by the sound of the air column and seems loudest. It should be shown that the length of the air column is one-quarter of a wave length. It can further be shown that a closed resonance column may be 3, 5, 7 or any odd number of quarter-wave lengths. With correction for size of tube the speed of sound may be calculated.

Siren Disc; Pitch and Frequency

Apparatus: Siren disc; rotator; air jet attachment; clamp and stand.

Procedure: Mount the disc on the rotator and clamp the air jet attachment just above the disc. The disc may be rotated at uniform or variable speed (by use of friction clutch) and an air blast directed against the holes. The sequence of regular puffs of air issuing from successive holes produces a musical note. The frequency may be increased by increasing the speed of rotation. Interesting effects may be obtained by "playing" the valves on the air jet attachment.

Frequencies of Enclosed Air Columns

A series of flasks are arranged in order of increasing size and an air jet directed across the mouth of each. Each enclosed air column yields its characteristic pitch and the series of flasks yields an interesting sequence of tonal steps.

Toothed Wheel and Card (Savart Wheel)

Mount the toothed wheel on the rotator. Hold the edge of a stiff card against the rim. The pitch can be varied by varying the speed.

Trevelyan Rocker

The apparatus consists of an iron triangular prism to one end of which is attached a handle, and a lead prismatic block. The iron rocker is heated in the flame and then laid on the cool lead support. The rocker oscillates and produces a musical tone. The fluctuations in pitch can be observed as the temperature changes.

The rocking is due to rapid local expansion of the lead under one edge of the rocker thus tipping it so that the other edge makes closer contact. The alternate expansion and contraction thus set up make the rocking continue.

Xylophone

The apparatus consists of eight pieces of wood suspended by cords; the pieces may be struck successively with a wooden mallet, sounding an octave. The strings are attached to each stick at its nodal points. Saw cuts near the middle of the bars provides lowering of the pitch.

The Phenomenon of Beats

Apparatus: Two mounted tuning forks of the same pitch; piece of wax; mallet.

Procedure: Strike the two tuning forks in quick succession and observe the smooth even tone. Now fix a piece of wax to the prong of one of the forks and repeat the experiment. The frequency of this fork is now diminished and the former smooth tone is replaced by a throbbing or pulsating one. This pulsation is called the phenomenon of beats and is due to the alternate interference and reenforcement of the sounds produced by the two forks.

Kundt's Resonance Tube

The apparatus is familiar. Longitudinal vibrations in the rod set up stationary waves in the air column, which is shown by the pattern of the cork dust, indicating nodes and antinodes. The speed of sound in the metal may be computed from the general equation $V = n\lambda$ or $n = \frac{V}{\lambda}$. Since the frequency is the same in both metal and air we have $\frac{V_m}{\lambda_m} = \frac{V_a}{\lambda_a}$.

The distance between two successive nodes is half a wave length. The length of the rod if clamped in the middle is equal to one half the wave length in the metal.

Resonance Column and Siren Disc

The resonance column is a piece of metal pipe mounted horizontally, provided at one end with a stopper. Mounted on the other end is an air jet attachment which provides connection by rubber tubing. The siren disc is rotated in a vertical plane between the end of the metal pipe and the air jet attachment. The speed of rotation may be governed by the friction clutch on the rotator, and resonance obtained for both open and closed pipes.

Sensitive Flame

The apparatus consists of a metal tube fitted at one end with a one-hole cork stopper which slides over a Bunsen burner, the other end of the tube having 2 holes opposite each other and normal to the axis; a glass tube drawn at one end is held in a clamp, horizontally, the drawn tip just within one radial hole in the tube. Both burner and glass tube are attached to the gas line; the burner acts as a pilot light. With proper adjustment of gas pressure a small flame beam which is sensitive to high-pitched sounds will issue from the opposite hole in the tube. The flame responds to the rattle of keys or the clap of hands, and excellently to the Galton whistle.

OPTICS

Optical Disc

A metal disc about 1' in diameter, surface painted white and rim graduated in degrees is mounted on a horizontal axis about which it can turn. A semi-circular shield concentric with the disc has an opening at its center over which a shutter slips having three horizontal slits. These slits are provided with stops. A parallel beam of light is directed at these slits and the paths are visible against the surface of the disc. Mirrors, lenses and prisms may be attached to the disc and the phenomena of refraction, reflection, etc., can be shown.

Optical Tank

The device is a long trough (comparable to a window flower box) with one glass side and one glass end. It may be filled with water to which a little eosine is added. This makes the paths of the light rays easily visible to the class. Reflection, refraction and total internal reflection may be shown.

Interference in Thin Air Films

An air wedge is formed by laying two large pieces of plate glass on top of one another, the wider end being separated by a light string between the plates. When held in front of a sodium flame so that the flame is seen reflected in the glass the interference fringes will be easily observed.

Dispersion by a Prism

A glass prism is held in the beam of a projection lamp. A continuous spectrum is seen on the wall. The demonstration should be accompanied by blackboard explanation.

Single-slit Diffraction

Each student is instructed to hold two adjacent fingers close to, and directly in front of, one eye, and to observe a straight-filament lamp through the narrow aperture between the fingers. Diffraction effects can then be observed.

If photographic plate is available each student may be provided with a small piece on which has been ruled a single line. This provides a better observation of single-slit diffraction.

Diffraction by Double-slit; Young's Experiment

Each student is provided with a piece of photographic plate on which has been ruled a pair of parallel scratches. By observing a straight-filament lamp provided, each may then see the colored interference fringes from double slits.

Note: This experiment is of such fundamental and historical significance that it is decidedly worthwhile to provide it.

Double Refraction

Double refraction is shown most commonly by calcite crystals. Place the crystal over a printed page and allow the students to view the page individually.

The following permits the showing of double refraction to the whole class at once: A small hole of about 2 mm. diameter in a sheet of cardboard or metal is strongly illuminated, and its image projected. When a calcite crystal is held over the hole, two spots of light appear on the screen. As the crystal is rotated, one spot appears to remain fixed while the other moves around it.

Polarization Phenomena

Several of the more important aspects of polarization phenomena may be shown with the equipment provided in a Polaroid Experimental Kit, obtainable from The Polaroid Corporation. In addition, some form of lantern-slide projector is needed. The following experiments constitute the more important ones of those which may be shown:

The Extinction of Light by Crossed Polarizers

The two Polaroid discs are placed in the holder on the projector. As either of the discs is rotated the illumination on the screen (or wall) varies from a maximum to zero. Unpolarized light from the source is plane polarized by the first disc. The light now is comprised of vibrations in one plane, say vertical. If the polarizing axis of the second disc is horizontal, these vertical vibrations are now intercepted. For zero illumination then, the polarizing axes are perpendicular to each other.

Polarization of Light by Double Refraction

A piece of natural calcite or a doubly refracting prism is inserted in the position occupied by the first disc in the previous set-up. An opaque screen with a hole of several millimeters aperture is placed in front of the source. The two overlapping images of the hole are focussed on the wall. The crystal has broken the light into two beams polarized at right angles to each other. If the Polaroid disc is now rotated first one and then the other of the images is extinguished.

Interference of Polarized Light

A crystalline sheet (e.g., cellophane, mica) is inserted between the Polaroids. The highest saturation of color occurs when the axes of the two polarizers are mutually perpendicular. The color of this transmitted light can be varied by changing the thickness of the crystalline sheet (adding another layer), or its orientation, or by changing the orientation of the polarizers.

Strains in Transparent Materials

The samples provided are held between the Polaroids and distorted by either squeezing or stretching. The photoelastic interference phenomena, due to changes in optical properties, are viewed on the screen. The orientation of the sample may be changed whereupon the interference patterns change also. (Attention should be called to the industrial application for the detection of strains and defects in structures and machines.)

Approved:

Major Professor G. W. Hammar Date May 5, 1940

Head of Department G. W. Hammar Date May 5, 1940

Dean of School or College [illegible] Date May 6, 1940

Dean of Graduate School [illegible] Date June 14, 1940