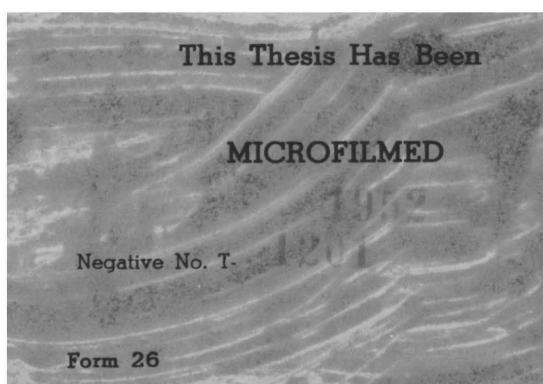
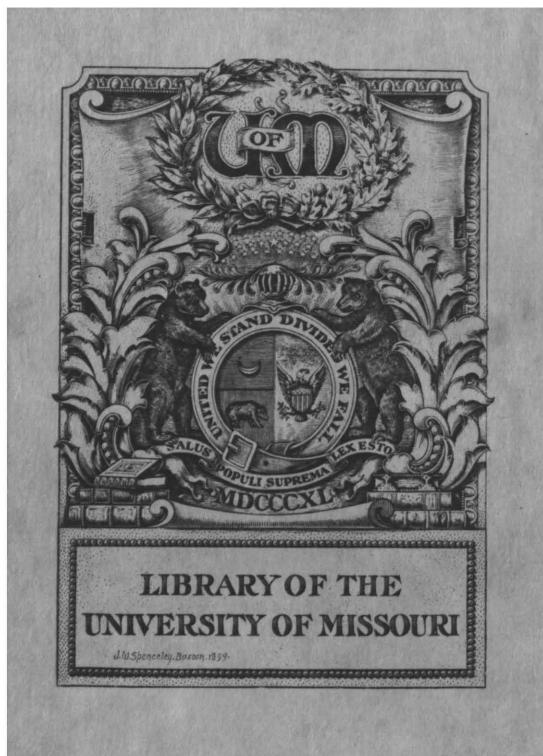




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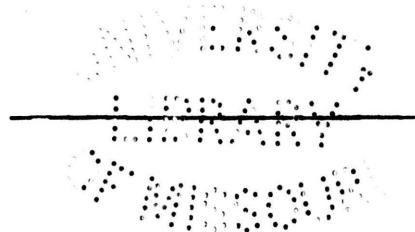


THE TEACHING OF PHYSICS IN
"

THE HIGH SCHOOL

by

ANDREW THOMPSON TILDEN POWELL, B.S., A.B.₂



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PREFACE

In the Summer of 1910, I outlined a practical course in the subject of physics for the high school under the supervision of Dr. J. L. Meriam, who suggested that I collect a body of physical facts without reference to a text-book, and arrange them in a sequence interesting to a high school class. I did so, and was surprised to find so much material. Accordingly, I resolved to make the material the basis of this thesis and to teach the course as outlined. At the same time, I began the study of guiding psychological principles under Dr. W.H. Pyle, with a view to working out a clear idea as to the controlling motives in physics study, and the method of acquiring physical knowledge. I dwelt principally upon the relation of habit and instinct to physics learning, and upon the processes of induction and deduction.

To Dr. Meriam and to Dr. Pyle, who conjointly assisted me in working out this course, I am deeply indebted. And it also gives me pleasure to acknowledge the many helpful suggestions of Dr. O.M. Stewart, Professor of Physics of the University of Missouri, and of Dr. H.M. Reese of the same department.

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INTRODUCTION

There is much unrest as to physics instruction in the high schools, as evidenced by the many and varied discussions of methods of teaching that subject. No phase of the question has been overlooked, laboratory methods, time spent in physics, year offered, amount given, use of text, method of approach, etc. There is pretty general agreement as to one point, that high school physics has depreciated in interest. Dr. Woodhull states that the decline of physics study in the high schools of this country is the most pronounced of anything ¹ in the curriculum. He attributes the fact to the advent of mathematical instead of descriptive physics. However that may be, physics study has become less popular - despite the fact that much time, ability, and costly apparatus have been used to foster the subject in the high schools.

First, there is the laboratory controversy. There are those who consider the laboratory the salvation of the course. These laboratory enthusiasts expend their energies in quarreling over the respective merits of quantitative and qualitative experiments. Some believe that no physical principle or law can be writ large in a pupil's soul until it has passed through the labyrinth of a quantitative experiment. The other group contend that much exact measurement kills the spirit of investigation. They believe in the qualitative, and point in glowing terms to

¹ John F. Woodhull, Decline of Physics,
Educational Review (E.R.), vol. 31, pp. 236-247.

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the popular lectures and qualitative experiments of the early masters. Evidently a proper use of the laboratory is an important question, but the extended discussion has not made physics study in the high school what it should be. Laboratory is not vital.

Again, descriptive and mathematical physics occupy the time of another group of educators. The apostles of the former contend for a course consisting of a series of interesting descriptions of objects, principles, and illustrative experiments, together with the hero-ology of physics, etc. Their opponents contend for the mathematics and mathematical exactness. A textbook by one of the latter is a statement of laws, a mathematical proof of each, and a great deal of stuff not suitable for a high school student. Such a text is filled with formulae and units. This question also is important, but its discussion has not settled the problem of increasing the interest in physics study.

There are those who believe in practical physics, who accept the statement that education should prepare for immediate living. They say that the boy should learn the physics of shop, factory, and commerce; the girl the physics of store, community, and household. Their opponents laud theoretical physics, and scoff at so-called practical physics; their object is to instill the scientific attitude, and to impart a group of physical facts arranged in logical order, and usually designated the textbook.

Quantitative and qualitative experiments, theoretical and practical physics, mathematical and descriptive physics, all have their place in the course. The course herein presented aims to

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secure proper balance between these different phases of physics study, but motive will be considered of highest importance. Therefore, proper knowledge and appreciation of this age of machinery and invention, interest in the physical progress of civilization, and theoretical knowledge for the interpretation of the physical environment have an important place in our course.

The work outlined in the course should secure those results. We accept G. Stanley Hall's statement that high school physics from some points of view seems pretty well along in the stages of educational decadence.¹ We attribute as the cause the prevalent methods, and consider as the most common error the failure to study the environment.

When the outline course herein presented was planned, the following views were kept in mind: The laboratory is useful, and some quantitative work is necessary to give care and exactness and to show how necessary such work has been in the development of scientific knowledge; a large part of the work should be qualitative, but the laboratory is only a part of the physics course and may become too formal; theoretical physics is desirable, but should develop out of the practical and be a growth, not acceptance an unappreciative of scientific facts; mathematics has its place in physics, but is too conspicuous in high school physics; some formulae are needed in a high school course, but they should be developed and as few used as possible; a textbook should be logical, but should be used only as a reference; there is danger of

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G. Stanley Hall, Adolescence (1904) vol. 2, p. 154.

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depending too much even on the laboratory; life is the best laboratory, and nature is the best textbook.

Two things at least are to be considered: the nature of the matter imparted, and the nature of the being to whom it is imparted. Consequently the outline now to be presented takes into account the instinctive and acquired tendencies of the adolescent student, both in matter presented and in method of presentation. In seeking material for this course, I have kept in mind the vital question, Where do the interests of the pupils lie in the acquiring of physical knowledge? What is the order of presentation? First, I spent several weeks in making a list of objects in Rolla that would furnish material for physics study. I then arranged this material under the different instincts that would make each object most interesting for physics study, and added to the list much material from business, commerce, manufacturing, and developed industries. This outline follows, abbreviated very much because the same facts are included in the course as finally outlined and taught in Rolla High School. I insert this only to show the method of procedure.

INSTINCTIVE INTEREST IN PHYSICS

outline

I. Self-preservation. Methods of cooking, blasting and heating. Stoves, furnaces, safety-lamp, refrigerator, shape of boilers to avoid explosions, wire cages to shield from electric shocks, lightning rods, etc.

II. Parental and Social Instincts. Ventilation, fuels, improved machinery, transportation, ice manufacture, sewer system, music, pumps, heating train, storage, distillation, electric heating,

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electric ironing, musical instruments (actually studied in class), creamery, shops in town, many objects in home and community.

III. Imitation. Mirrors, whistles, echo, sound reflection, moving picture apparatus, etc.

IV. Adaptive. Such things as toys, toy electricity, football, swing, etc.

V. Curiosity. Fly's locomotion, elasticity, bell, door as lever, transformation of heat and energy, conservation of matter and energy, theory of matter, how things are made in general, examining door bells, phones, incandescent lamps, electric bells, etc.

The outline just indicated was valuable to me in directing my attention to material vitally interesting to the student. I afterwards merged this outline into the course presented in Chapter One.



Chapter One

Actual Course Outlined for Rolla High School

Avenues of Approach

1. Home and Environment
2. History of Physics and Development of Industries
3. Laboratory
4. Construction
5. Home Experiment
6. Text-book

Outline by Months

September.- First lesson. "Class, you will need no text-

Chapter One

Outline of Course

books for sometime". We then talked of books, chairs, tables, desks, windows, walls of the school building, etc. Noted like-nesses and differences preparatory to the study of properties of matter.

First Week

1. Home and Community.- Study moving objects, wagon, train, ball, swing, boy, etc., note speed, cause of moving, as wagon by horse, train by engine, etc. Why they stop moving. Teach terms Force, Inertia. Note falling bodies, ax, rain, stones, etc., cause, teach term Gravity. Note terms already in minds of pupils (some never heard of term Gravity). No mention of Newton's Laws. Study of house and school-rooms, properties taught, use of nails, plastering, cohesion and adhesion in bricks and mortar, varnish, paints, etc. Note value of different properties. Study fly's locomotion. Make a study of the sewing machine from actual observation, note pedal, band, wheel and axle, etc. Study principles of coffee mill and cider mill. Study the effect of throwing from trains.

2. Home Experiment. (1) Mirror, stand in front of, note position of image. Get pupil's own conclusion as to reason. (2) Make a pendulum and time the swings, vary length, let pupils discover laws and accept their own expressions of them. (3) Make cylinders of different lengths for equilibrium. (4) Invert a tumbler in water, represents a diving-bell, pupil's conclusion. (5) Invert a tumbler full of water with cardboard under it. Have pupil explain.

3. Exercises. Note the properties of different objects

Outline of Course

listed by the students. Give a list of questions for study, such as: The effect of jumping from a train, or swing, Why? Action of water on a grindstone, why the telephone rings, where scissors cut best, where an echo sounds loudest, note reasons. Note sources of information and experiment for the answers. Hard ones reserved for later work, but suggested to show how problems are solved in physics.

4. History. The diving-bell. Galileo, pulse beats and the pendulum, swinging lamp in the cathedral. Newton and gravity, his early life, kites, water-mills, poor student, and other interesting facts.

5. Visit. Railroad tracks and note space between rails for expansion, high outside rail noted at a curve and the reason, construction of a wagon bridge over track, flanges on car-wheels, the breaks, etc.

Second Week

1. Home and Community.- Study the pump, the barometer, phone, stoves, tea-kettle, cooking (a very interesting lesson on the cook-stove was given), radiation, conduction, convection, parts of stove, flue, damper, etc. were studied from stoves in pupils' homes, and drawings were made. A long list of objects was made, and a list of properties from the text and the pupil's own experience was prepared. Study safety-lamp, saw-mill, transportation. Study own home, paper and adhesion, putty in windows, transparent glass, etc. Note slanting roof, springs, how curtains roll, knob on door, door as a lever. Pupils and teacher frame list of questions, such as, "Why are nails used in building a house?", "What useful end

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does hardness subserve?", illustrate- "Why will a pencil not stand upon end?" , "Why may one fall on jumping from a swing or moving train?", and many others. Hard ones left over, or partially answered.

2. Home Experiments.- (1) Tube and rag on stick illustrates pump. (2) Test different objects about the stove for conduction. (3) Evaporate water, and condense steam. (4) Close spout of tea-kettle and note result, caution against accident. (5) Put wire coil around a rod and heat rod, result. (6) Invert tumbler of water and with silk veil over it. Explain.

3 . Visit.- Streets,note scrap-piles, graders, scrapers, old mowing machine, study levers of different classes on these, note uses of the machines and study nice adjustments, etc.

4. History.- Inventions of Franklin. History of stoves, fire-places and chimneys.

5. Text.- On pumps, equilibrium, friction, properties of matter. Criticise topics and get clear statement of things.

Third Week

1. Study levers- doors, ax, arm, balances, scissors, get a list in stores, shop, home, note uses and advantages of levers. Study the piano-lever, pedal, wires, etc. Study lamp shades; use, wedge as ax, knife, etc. Note use of saw. Note incline plane in town, vibrating bodies as reed, tongue, wings, pendulum, etc. Note sources of light, as sun, lamp, incandescent lamp, fire, "lightning bug", etc. Also sources of heat as fire, friction, etc. Note trunk-lid, egg-beater,

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etc. Study the bicycle- tires, frame, levers, gear, pump, etc.

2. Home Experiments.- (1) Test point and heel of shears. (2) Sing into a piano and get wires to respond for sympathetic vibrations. (3) Balance a uniform stick and find out necessary conditions, put small weight upon one end and balance again, note result. (4) Study hand-car for levers, etc. (5) Make a pair of balances.

3. History. Of railroad development, wooden rails, iron strips, rock roads, flanged iron rails, flanged wheels, illustrations at World's Fair , St.Louis. Engines, Watt, Stephenson, The Rocket, the first railroads in England and the United States, ten miles an hour to the present speed, etc. Feats of railway engineering.

4. Laboratory. Make a simple lever in the laboratory and balance. Practice weighing and measuring for accuracy.

5. Visit. Blacksmith shop, study bellows, levers, making wagon wheels for expansion, etc. All visits written up in note books with accompanying drawings.

6. Text-book. Machines, difficult parts omitted. Text as reference following up outside study.

Fourth Week

1. Note six types of machines in town, note objects that float, images in water, pond banks, water pressure, echo, etc. Study incandescent lamp in the superintendent's office, telephone in office, the school bell why placed in belfry, sound and light as to obstructions, etc. Study centrifugal force from the grindstone. Study light and shadow, note size, variation, intensity of shadow, etc.

Outline of Course

2. Home Experiments.- (1) Cut a hole in the side of a can filled with water, note pressure, compare pond banks. (2) Tube connecting small and large bottle containing water, heat small, water rises in it, explain. (3) Make a fountain with two bottles. (4) Weigh a vessel, fill with water, weigh again. (5) Jet tube over hole in bottom of a tin can, press water, inference.

3. History and Development. Review Newton and Galileo. Study uses and origin of fire. Describe a cold storage plant. Note errors of period about 1600 such as, "Earth sinks below the water because it belongs below it", "Heavy bodies fall faster than lighter bodies" (disproven at Pisa), "A small fish stopped a ship by adhering to it", "Moisture of water is due to its coldness", "Water has no gravity in water". Note Ariago's wonder that several weights increase pressure on a board since only one touches it, etc.

4. Laboratory.- Measure and find the volume of a wooden cube, parallelopiped. Perform simple specific gravity experiment.

5. Visit. Refrigerator at department store. Visit the creamery, note wheel and axle, circular motion, freezing process, making of ice cream, cream tester, etc.

6. Text. Finish machines, leaving out formulae for incline plane, screws and pulleys, for the present. Refer to laws of fluid pressure and read some about specific gravity. Text as reference.

Second Month

1. A hasty review of things learned about force, gravity, inertia, properties of matter, machines, vibrations, pumps, etc.

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Study a swing for action and re-action, grindstone, curved track for curvilinear motion, two horses to a load to illustrate composition and resolution of forces, examples of transformation, transference and conservation of energy, as: heating iron by beating with hammer, striking a punching bag, vibration of reeds, strings, shingles, etc. to produce sound waves, ball struck by bat, chips flying from ax, wheel turned by pedal, fire heating water of engine to move piston which in turn moves the wheels, strike flint to make fire, water wheel, objects moved by levers, falling object creates light, heat, sound. Turning a corner illustrates the effect of centrifugal force.

2. Experiments. (1) Swing a half-gallon bucket of water over the head to show centrifugal and centripetal forces. (2) Drop water on a hot stove or spit on a hot iron, note spheroidal shape. (3) Board on a table covered by many sheets of paper, hit projecting part with the fist, inference. (4) Tie a small stone to a stick a foot long, and mark the depth to which it sinks in water, try it in kerosene, try other liquids, improve the plan if possible. (5) Stopper in a bottle full of water, push plunger in the hole and note rise of the stopper. (6) Make a spiral and note weight on it, with it construct a crude spring balance. (7) Move a marble on the carpet, and on glass, etc. Note trains on a slick track, persons stopping while running. (8) Measure time up and down for thrown ball.

3. History.- Famous clocks, water clock, hydraulic organ, Hero's Fountain, Otto von Guericke 1602-1686, the air pump, Magdeburg Hemispheres and test with horses before Ferdinand III. Clock, bird,

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grapes, etc. in vacuum. King Hieron's crown, first tin hydrometer to test drinking water. Galileo, review testing pendulum by the pulse, falling bodies, invention of the thermometer, first to use telescope for astronomical purposes, died 1642 the year before Newton's birth. Pascal and the barometer.

4. Visits.- Line's wagon shop, study gas engine, belts, wheels, joiner and other machines. Study the physical principles involved. Note perfection of the machinery and suggest improvements.

5. Laboratory. Work on pulleys, levers, wheel and axle, incline plane, pendulum.

6. Text. Newton's Laws, Resolution and Composition of forces, falling bodies and weight, curvilinear motion, laws of pendulum, illustrations of centrifugal force, work and energy, laws of machines, uniform and accelerated motion.

Third Month

1.(a) Study the barometer and its relation to the pump, study soap bubbles, shape of vessels as buckets, etc. Review pumps (actual pumps inspected, a four valve pump brought to the laboratory). Review specific gravity, water pressure, etc. Summarize course thus far. Study of sewer system and water system, use of water tower, how water is secured to fight fires, value of pressure in such cases, principle of city fountain, study balloons and different types of pumps from actual examples.

(b) Study the school heating plant, section drawing of the plant required, position of the furnace, radiators, pipes, pump-valves,

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etc. being indicated. Drawing made of furnace, fire-box, grate, etc. Note sections of furnace, trace steam through the pipes and radiators, note how water returns, study ventilation of the building, etc. Note construction and expansion of the rails on track, space between rails, stove lid, draught in stove, why flues extend above the house, arrangement of dampers, box, etc. Note use of foot-rests, how lifters are made, polished and unpolished surfaces, etc. Note making of wagon tires, draught at windows, bulb of incandescent lamp, etc. Study green house, refrigerator, objects that melt rapidly, evaporation, drying of clothes, ether, alcohol, dew, rain. Study the methods of cooking for principles of heat transference, etc. Study Papin's Digester.

2. Home Experiments.- (1) Place hands in cold water and hot water, then both in medium, inference. (2) Make a simple thermometer and note the serviceability of different substances. (3) Heat objects for conduction. (4) Boil two liquids at same time and note boiling points. (5) Boil water in two vessels, one covered, the other uncovered. Note capillary phenomena in bottles, blotting paper, tree, ground. (7) Put grease or oil on water, result. (8) Put egg in different liquids. (9) Balance two bottles on a meter stick by means of riders, suck the air out of one bottle and note the loss of balance. (10) Melt several substances and note the melting points.

3. Laboratory. Mechanics and Heat.

4. History and Development- Thermometer, methods and history of cooking, history of fire and methods of making, old method still

Outline of Course

used in the East. Fire departments of cities, hot house, storage, ice manufacture. History of navigation. Note development of pumps. Study different systems of heating, central heating plant, etc. Note hot water, hot air, steam, etc. Advantages of each, etc. Note economy of central plant. Study ancient methods of cooking, fire places, chimneys, etc. Note submarine boats. Study the development of aerial navigation.

5. Visits.- Fountain, study operation. Visit water tower and note its use, principle of operation, etc. Visit New Ward school plant. Study the heating system, note radiation, asbestos covers for the pipes, basement radiators, valves, trace water back to the furnace, study the boiler in all parts, etc. Compare this with the High School heating plant.

6. Text. Fluids and Heat nearly completed, some difficult passages omitted. Many problems outside the book, a great many from the text, density, barometer and other problems. Study the thermometer, expansion and applications, simple fusion, boiling and transmission of heat especially.

Fourth Month

1. (a) Heat.- Take temperature of objects in room, outdoors, melting ice and snow. Note use of cellars, fur of animals, two walls of building, Winter and Summer clothing, study bellows again. Take up the subject of schoolroom ventilation, note the principle of gravitation in ventilation, etc. Study types of boilers, as

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fire-tube,etc . Note systems as direct and indirect. Note siphon in the High School heating plant.

(b) Sound.- Study th piano and note laws of strings. Note the waves on the water,vibrating bodies as tuning fork,board, tongue,reed,noise of insects,sources of sounds,roaring of fire, voice,instruments,whistle,reeds,bells,anvils,door slammed, gun, etc. Note sound of ax seen at distamce, same for sound of gun and sight of the smoke. Note suitability of halls for music and speaking,echo and other acoustic facts,empty and full rooms, sound with and against the wind,resonance in piano,chest,box, also in telephone wire attached to the house. Study scale on the piano,intervals,cord,flats,sharps,etc. How a wind originates, sound through walls,around corners,etc.

(c) Review some in heat,etc. Note Galileo's air thermometer 1600,Rey's water thermometer,1632. This thermometer contained air. Fixed points at first that of ice and that of heat of deer and cows,note other facts.

2. Home Experiments.- (1) Heat a poker and place in water or in ice. (2) Place a small amount of ice in water,then a large amount,conclusion. (3) Boil fresh and salt water,note result, what do you conclude? (4) Make an acoustic telephone of two tin cans and a string. (5) Test sound for different length and size strings.

3. History.- Ancient musical instruments,history of the telephone, graphophone,famous bells. Development of musical instruments. Heat as a civilizing agent.

4. Laboratory. Heat and Sound.

Outline of Course

5. Visit.- School of Mines furnaces. Note automatic regulation, pumps, and various appliances. Two hours spent on visit. Visit and study Rolla Department store heating plant, and compare. Visit a church hot air plant, note pipes, registers, inlet for air, furnace, etc.

6. Text.- Still used very largely as reference. Finish heat and sound. Some topics as absolute scale, Law of Boyles and Charles combined treated slightly. Also such as numerical relation between heat and work. Simple Harmonic Motion, composition of two Simple Harmonic Motions, Graphic methods of studying sound and Manometric Flames, etc. Problems in heat and sound.

Fifth Month

1. Review whole work, and let it be largely deductive. Name some machines in which the Torricellian Vacuum is illustrated. Give many kinds of deductive work. Use more problems in review. Note Newton's Laws, six kinds of machines, law of levers and wheel and axle, two laws of incline plane, principle of screw, pulleys, law of machines, accelerated and uniform motion, composition and resolution of forces, equilibrium, pendulum, fluid pressure, methods of finding specific gravity, barometer, siphon, pumps. Hard passages omitted before are now gotten, but still much outside work.

2. Home Experiment.- (1) Railroad track, two parties at distance, hit track with hammer and signal at same instant, the other party records time for sound to travel through the rail. (2) Make sound as by firing a gun, the second party record time for sound to travel through the air. (3) Speak through pipes and

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tubes. (4) Find the velocity of sound in air by reflection.
(5) Make a whistle, drop pebbles in the water and note waves, study a telephone bell, experiment on hearing through the walls.

3. History and Development.- Dredging, sea sounding, etc. Life of Helmholtz. Describe the pipe organ. Study musical instruments again. Note compensating pendulum. Count Rumford, soldier, statesman, philanthropist, and physicist.

4. Visits.- Trip around town to note physical principles, illustrations of law of levers, wheel and axle, screw, etc., in shops. Note examples of friction, composition and resolution of forces, principles of work, $W = FS$, centrifugal force, etc. A large list of these was collected, the pupils noting them independently.

5. Text. Closer study of text, but largely as reference. Outside study has prepared for the mastery of more difficult passages. Let all the following be well understood: Atwood machine, moment of force, couple, work and energy, hydraulic press, Archimedes Principle, Boyle's Law, refraction and reflection of sound, and many other passages. Mechanics, Heat and Sound are pretty well mastered according to orthodox standards.

6. Laboratory.- Finish Heat and Sound.

Sixth and Seventh Months

1. Study reflection in mirrors and on the water, in silverware, polished furniture, window panes with opaque object behind them, etc. Note the use of shades for the eyes, value of lashes and eyebrows, etc. Study the change of size of pupil for accommodation, note the principle illustrated by looking through the keyhole,

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study the pinhole camera in the leaves of the tree, the eye, the camera, etc. Note the apparent size of distant objects, combine lens and pinhole camera of the eye, experiment with lens and pinhole camera to note result. Study kinds and uses of spectacles, diseases of the eye, note reflection from the blackboards. Note sources of light as incandescent light, arc light, fire, animals as bugs, etc. Study shadows, size, umbra and penumbra, note two shadows for one object when two sources are used. Study spoons as circular mirrors, note colors in the eyelashes when looking at the sun, note colors of the flowers, buildings, goods, papers, etc., and learn names of colors not known. Teach the primary colors, note spherical aberration in a cup, note colors of sky at different times in the day, note various phenomena.

2. Home Experiment.- (1) Study image of a person in a plane mirror, note inversion of image. (2) Measure a few objects and their shadows, note ratios. (3) Make pinhole camera of cardboard, note relation of size of image to object compared with the distances. Show how objects appear smaller at a distance. Note use of double-convex lens in vision. (4) Take a light or candle and measure for law of pinhole camera. (5) Perform the experiment for concave mirror for locating image, with a spoon.

3. History.- Burning ship by focusing rays according to the myth. Galileo and the telescope, simple one with lenses and organ pipe. Use of spectacles in time of Job (See Book of Job). History of lighting and influence on morals and business of cities.

4. Visit.- Moving picture apparatus for study. Visit electric light plant. Note switch, dynamo, etc.



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5. Laboratory. Light.
6. Text. Follow text about as written.

Eighth and Ninth Months

1. Study carefully the telephone in office and make drawing, also the incandescent lamp, resistance, etc. Bells, batteries, receiver, transmitter, etc. were carefully observed. Note telephone and telegraph wires, insulators, etc. Study lightning rods and essentials, study the cut-offs on phones, etc. Study toys such as dark lanterns lighted by electricity, note tiny battery, etc. Find objects with which to produce electricity, as mole skin, rubber of fountain pen, hair and comb, etc. Study electric eel, and other animals with electric charges; cages for protection from electric charges, etc. Note various methods of producing electricity, as induction, friction, percussion, evaporation, tearing, crystallization, etc.

2. History and Development.- Franklin's kite, etc. Gilbert's work. Note modern uses of electricity as power, as in shops, factories, lighting of houses, street railways, etc. Note its production at Niagara Falls, etc. Explain traction system, the power house, car connections, rails, etc. Study electric irons, electric cooking, etc. Study the laying of cables, and explain in a simple way the working of the wireless telegraph. Have boys bring in an induction coil, sounder, etc. Make use of all those things. Study Volta's life and the Voltaic Cell. Study the electrophorus, electroscope, condenser, note origin of term volt, etc. Study the life of Edison, his education, his work as telegraph operator, and his achieve-

Outline of Course

ments in electricity.

3. Visits.- Visit School of Mines dynamos, note operation. Visit depot for study of transmitters, sounder, batteries, relay, signals, etc. Visit telephone office and note operation on the switch board, etc.

4. Note varied uses of electricity, its value in electro-plating, mining, blasting, shot-firing, lighting of mines, etc. Note use of magnetism, the compass, etc. Note transition from age of steam to age of electricity.

4. Laboratory.- Magnetism and Electricity.

5. Text. Magnetism and Electricity completed. Use as much as possible as a reference.

Tests

1. Musical instruments. What physical facts are illustrated in the violin? Answers:

Law of tension in tightening with peg and in placing the fingers on the tuning board". "Law of mass in tones of different strings". "The larger the string, the lower the tone". Another said, "The larger the string, the less frequent the vibrations". "The finger board illustrates the law of length". "The violin has a sounding board". "The smooth bow removes friction". "The bridge gives an example of equilibrium". "The greater the thump, the greater the sound". "The peg is a lever". Only one student quoted the laws of mass, length and tension.

2. The clarinet. The same question was asked. "Adhesion where parts are joined together". "Air vibrations in reeds". "Bell-shaped mouth is a resonator". "Felt over holes to prevent so much vibration". "The keys are levers". "Laws of organ pipes by opening and closing the holes". One student spoke of over-tones. Several quoted the laws of open and closed pipes.

The instruments were before the class, and they examined them. This test was given after sound had been completed, and was sprung suddenly. No help was given in the answers. Pupils displayed much interest in the different parts of the instruments. After the test, many other things were explained about the instruments.

3. There are three kinds of equilibrium. Explain and tell what you have learned about this fact.

"We learn it by experience". "Stand flat-footed, that is stable, stand on tiptoe, that is unstable. A sphere has neutral

Tests

equilibrium". "If there were no stable equilibrium, we would be falling all the time". "Unstable equilibrium enables one to throw a ball". "If it were not for balls having neutral equilibrium, houses would be moving all the time".

These are curious statements, some of them. But they show that pupils are willing to think.

4. In a lever, $W/P = P.A./W.A.$ How do you know this is true?

"I have seen levers working and noticed that the farther the power from the fulcrum, the less it took to lift a load". "By experiment". Several gave references to the text, and several gave proof from geometry.

5. Friction decreases the efficiency of machinery, and wastes energy. What reason have you for believing this statement. "Objects will go farther through the air than through the water". "Objects are easier moved on smooth than on rough surfaces". "A rusty saw doesn't saw as well as a bright one".

6. Give examples of transference and transformation of energy.

(a) Transference. "One pendulum strikes another". "One billiard ball hits another". Various examples like these were given.

(b) Transformation. "Burning coal". "Heating iron by hammering". "Heating water of steam engine to turn wheels". Many examples were given.

7. Examine a house, and state physical principles illustrated in its construction.

"Doors are examples of levers, roof of incline plane;

Tests

pulleys in the window, radiation and conduction in the heating of a house, plaster and paper illustrate adhesion, wedge illustrated by nails or two panels of door fitted together, frame work must be strong to overcome force of gravity on material". These were worked out by one pupil. He gave several pages like this. Only a few of these can be given. "A stairway illustrates a kind of incline plane". This was an excellent study for the class. With these lists at hand, we reviewed principles gone over.

8. Tell how the following are illustrated in everyday life: (a) Vibration. "Human tongue", "Reeds of instruments", "Vibration of vocal cords", "Vibrations of piano wires", "Every sound is caused by vibrations".

(b) Cohesion. "The clinging together of particles of water, oil or paint", "Concrete", "Put water and paint together, they do not mix readily".

(c) Adhesion. "Water clings to rubber, glass, etc.", "Spoon in liquid while cooking". Many examples of these things were given, and of great variety, for instance, water dropping from the house was cited, also the example of an egg in brine.

(d) Buoyancy. "Egg in brine and other liquids", "Dipper in the water", "Person wading in deep water".

(e) Elasticity. "Spring on the door", "Rubber", "Bar of metal bent".

It is impossible to show the variety of statements made in these tests, some of them very curious. One boy gave meat as an illustration of elasticity.

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9. On your visit to Line's shop, note the physical facts and laws taken advantage of in the construction and operation of machinery.

(1) The lathe.- incline plane found in the screws, pulleys, levers on the controller that regulates power. Planer-pulley on belt wheels. Grindstone- lever in crank handle (a long list was given by this pupil).

(2) Screws, pulleys, wedges, wheel and axle, laws of sound, friction on belts and saws, curvilinear motion on wheels, etc. This also was a long list, and the paper by these two students were typical of them all.

10. What advantage to you does the text afford in the study of physics?

(1) Used as a guide. Suggests experiments. Gives an idea of what to follow.

(2) Gives you the fundamental principles, made by broad men. Text a great help in understanding the experiments and principles.

(3) The textbook simply serves as a guide to the pupils.

(4) Makes the subject clearer. Saves the time of the teacher.

(5) Gives good definitions, and answers to questions.

Some indications are to be gotten from this test. The answers of these five pupils are abbreviated.

11. What in physics have you most enjoyed? Be specific and answer fully. What have you least enjoyed?

(1) I have liked all the subjects except light, which seemed so imaginary and difficult. The other subjects seem to

Tests

be things which you find and see every day. I like mechanics or sound best. Electricity starts out interesting.

(2) So far I like mechanics best, but think I may like electricity best because I have had a good deal to do with it.

(3) I have least enjoyed the study of light, because I never did see anything in tracing rays. I have most enjoyed heat, because I like to note the difference in ice and heat. I think fire is interesting.

(4) I have enjoyed all subjects so far, but think sound was the most interesting because it takes up the velocity of sound, vibrations, pitch and etc. , which are essential in music, and I love music so much.

(5) I have enjoyed light least. I think it was just as thoroughly treated by the teacher as the other subjects, but my mind was not strong enough to grasp the meanings. I like electricity so far. As a child I could bear more current than most another child. This set me to studying electric devices. So I have always been interested in electricity.

(6) I like light least, because I got tired of playing with lenses. (This was a boy) I like electricity because of its queer effects and the variety of experiments.

12. Physical principles in daily life. "Screws for raising a house", "Screws are used to secure boards", "Friction makes the train go", "Ear trumpet for reflection of sound", "Sounding board back of a speaker on a platform" , etc. Long lists were handed in.

My object is to show the attitude of the pupils toward the

Tests

study of physics, as indicated in these tests. These tests do not indicate as well as I had hoped the pupil's pleasure in the study of home environment, etc. But it is clear from them that the pupils like to get out of the textbook and see reasons for things. I insert at the close an interesting statement from a test, in the pupil's own language.

" The part of physics that I dislike most is the study of light. The subject is so dry, and some textbook has to be used to get information on the subject. Observation doesn't do much good in this subject, and textbooks on light are not very interesting. There are many dry rules, but this would not be so bad if we could see that they are true. The part I have enjoyed most, so far, is mechanics; we could get that from observation, and didn't have to depend on the textbook.

Note.- Light was the only subject followed out in the text. And this was done partly as an experiment.

I see in these tests some shrewd answers, and illustration of the fact that pupils enjoy the study of physical principles from objective life around. The tests have served their purpose, if they have shown the relation of the different factors in the course, and the interest of the pupils, which was so clearly manifested in this phase of the work.

Discussion of Plan

Chapter Two

Section I. Description of the course.

This outline makes the home environment the center of the course, everything else supplementary. First, we began with a general survey of the environment, the schoolroom, the street, the home, the shop, objects and machinery everywhere. The objects were examined, and properties of matter noted. Forces, motion, simple principles of light, heat, sound, etc. were noted and studied. Often an object was studied at different times for different principles illustrated by it. Pupils were asked to study various things at home, and to do many home experiments. This attracted their attention more to the things around them, and although some of the experiments were very crude much good was derived from them, in relating laboratory work to the outside world. The value of machinery to the world was kept constantly in mind; and a most valuable part of the course was the consideration of the development of modern machinery and improvements, while the history of physics, the crude beginnings of science, and the ancient ways of doing things made it still more interesting to the pupils.

During the first month a general knowledge of the six classes of machines, and such instruments as the pump, barometer, phone, cook-stove was obtained; such things as convection, conduction, radiation, the properties of matter, vibration, specific gravity, etc. were pretty well learned. The pupils also acquired some ability to construct, to weigh, to measure, to form inference and to make applications. At the close of this period, the pupils

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were permitted to make the formal divisions of physics, mechanics, heat, sound, light, electricity. The first month is outlined more fully as an illustration of the fulness of the outline throughout the whole course.

In the second month, we began the study of mechanics in the same manner, and almost everything was studied objectively. Even the ideas of transference, transformation, and conservation of energy were developed by numerous examples usually noted by the pupils. Such examples were used as: A rock is struck with a sledge, the pavement by a horse's hoof, a board by a hammer; or a rock falls to the ground, car wheels press on the track. The pupils were asked to note the kinds of energy resulting. Things previously observed were^{now} used for a more serious study of mechanics, and a wealth of material was at hand, vehicles, plows, graders, hand-cars, pumps, machinery of various kinds. The approach was inductive as far as possible, and this was followed by deductive applications. The other divisions of physics were treated in the same way, except light, and they were given in the order named: heat, sound, light, electricity.

The text was used almost uniformly as a reference, and practically no dogmatic teaching was indulged in. Some difficult passages were omitted altogether. Little attention was paid to such units as erg and dyne. Much stress was laid upon interpreting the text, so as to avoid mere memorizing without understanding. In the assignment of a lesson, it was pointed out how to attack a difficult passage, and frequently a recitation consisted in interpreting the subject matter of the

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text. The text was used as a means, not an end. Care was taken that laws were developed, not memorized, and the pupil was given opportunity to state them in his own words. In this way, the text was used to get clear statements, and to gather some facts to be gained in no other way. The use of the text saved time, and it was a very great help in deductive reviews. In such reviews, questions were given like this, What machine illustrates Pascal's Principle? Name some machine operated on the principle of the wheel and axle. Such a review gave variety to the work, and impressed the main facts of the course. The main object in using the text was to understand it, and to make it a part of the pupil's experience.

In this course, the laboratory is made to assist nature's laboratory. It is useful to supply the deficiency of phenomena for illustrating physical principles, and to assist the outside experience wherever possible. The use of apparatus in the laboratory was correlated with the use of actual machinery in the outside world, and the laboratory was used largely to answer questions arising in dealing with outside phenomena. We tried to get away from the manual, and to have the pupil form his own conclusions. The pupil had to know what the experiment was for before beginning it. No copying a manual was tolerated. Care was given to the retention of the fundamental facts of an experiment, and to accomplish this frequent reviews were given. The pupil was often required to state the purpose of an experiment to the teacher, and afterwards to state the results. The

Description of the Course

laboratory was enlivened by the constant appeal to the physics of nature round about. The laboratory was placed second to the material forces round about, for the pupil must see the relation of the laboratory to the outside world and feel the need for the experiment to be performed.

General Discussion is

I find that the text ^A less a bore by this method. In fact, it serves the real purpose of a text - to answer questions about the outside world. When a topic was assigned, the pupil saw a need for grasping the facts involved. How useless the cramming of facts not appreciated nor understood. Often too much is taken for granted in high school teaching, the pupil is given too much credit for knowledge. Preparation must be made for the study of any text, and it is especially true of high school physics. For high school students are usually poorly prepared for science work of any kind. There is grade preparation for mathematics, history, literature, languages, but usually little for that branch of knowledge which Spencer mentions as of most worth - science. The grade "nature study" usually gives little of the attitude for high school science work, especially physics.

There should be closer union between grade and high school work. We have tried the plan of giving some elementary physics to Seventh and Eighth grade pupils, and it works admirably. Pupils at that age love machinery, and love to see things "go". They can understand the workings of a force pump, a siphon, levers,

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pinhole camera, pulleys, etc. as well as can high school students, and are easily interested. The work was given in connection with physiology. For instance, when the subject of the eye came up, the students were taught the principle of the pinhole camera and the focus of rays for the double-convex lens, etc. by actual experiment. A course was outlined containing the simpler parts of the outline in Chapter One, and much was done in the limited time allotted to it. I also believe that a course in the study of machinery, simple principles of physics, and laboratory and construction work should be offered to Freshman and Sophomore high school boys. If either, or both, of these plans were followed, more pure physics could be taught in the Senior year.

The physics text has many difficult terms that pupils will merely memorize unless a rational approach is provided. One has but to glance over an ordinary text to note how much there is unfamiliar to the beginning student, erg, dyne, ohm, ampere, volt, refraction, simple harmonic motion, ion, capacity, potential, C.G.S. system, theories, etc. Mere textbook reciting is of little value, what is wanted is that it may become real experience. In this course, more time was spent in getting a clear knowledge of the text than in recalling unknown symbols. The text should be only a help, and is not to be followed slavishly anymore in physics than in another subject. The object of the teacher is to secure intelligent assimilation of physical principles, and the text-book is only a means to that end.

The laboratory was an important step away from the text-

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book, but it is not the vital factor in physics teaching. Too much dependence has been placed upon the laboratory of late years. The world has gone almost laboratory-mad. It is a part of a general movement to concentrate all training within the schoolroom, the school curriculum has been extended, costly apparatus provided, enormous buildings demanded, rugs and parlor furniture generously bestowed upon the public schools. Now these things are of value when properly used. But sending a child from the hovel to a palatial school building may or may not make a good citizen of him. It might make an anarchist. I believe in the imbibing of culture by the common people, and in the influence of better material surroundings to elevate , and believe in the best architecture and furnishings for the public schools. But the American boy must see that humble surroundings are not really a check on great achievement. The danger is that school palaces may make the child despise his humble home, and he thus through discontent become a failure. Discontent that makes one strive is wholesome, but the great to object of education in a republic is dignify common life. It is purity rather than opulence we need. I say that these provisions for the public schools are proper, but care must be exercised that false pride does not result, that the child does not rely too much upon the state. Too often this opulent condition affects the teacher, and too much faith is placed in physical material provided. Laboratories may educate, and they may not. I believe in more home training, and a proper start

General Discussion

in that direction is for the school to see that the pupil is given an opportunity to study the home environment, to give him an interest in home and community.

The laboratory has not done what was expected of it, I fear. It was expected, for instance, that it would make the young student respect manual labor more, the kitchen, the factory, the machine shop. But have large returns been realized in this direction? Many a student will cook in the domestic science department who despises the home kitchen. He will handle the apparatus in the laboratory cheerfully, but disdains to touch the greasy wheels of commerce. Mere contact with things will not enlighten, there must be reaction.

There needs to be closer union between home and school. Why have everything taught in the school? Textbooks have become too formal, and that is true of laboratories. Laboratories may shut the pupil in from real life. After all, why have such enormous laboratories, when the world is full of material. Let us have laboratories, but let us have life and reality.¹ The laboratory becomes formal the moment it is shut in from the real world. There is little difference between a laboratory worm and a "book-worm". The "book-worm" reads a book, sets down the data in a mental note-book, closes the book and forgets what he read. The laboratory worm follows a manual, sets down the data (often forged or imagined), puts away the apparatus, and stores his note-book in the garret. The laboratory should be made subsidiary to real things, and as a means of interest-

¹ Dewey, School and Society, p. 24 On study of outside world.

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ing in things about. The laboratory has served a good purpose in making the transition back to real life. It still has its use in making the approach to the outside world easy, but let the contact with that world be vital. It is the reality, and not the toys in the laboratory. Laboratories are necessary, but it has been surprising to me how many laws and facts in physics can be taught with nature's laboratory, and I recommend the simple course herein laid down to those small schools who have been pining for larger laboratories.

We have followed out the idea of studying the real world from every standpoint, and have made the course not only a study of the phenomena of physics, but a study of the historical significance and civilizing tendencies of the science of physics. At this age the youth is impelled to work for the world, and as a part of the world. Idealistic imitation and hero worship are strong. The pupil now admires the heroic, self-sacrificing, and nowhere do we find better material than the "Heros of Science". Pupils love to read about inventors, and I found that Edison, Franklin, and others of that type were very attractive to them. The suffering and persecution of such men as Galileo for science also interested them very much.¹ The biography in connection with the study of difficult phases, as Newton's Laws, etc. is very important. This human interest gives the pupil much more interest in those less immediate topics of physics, and he has a desire to know where we got the facts called physics.

¹ Hall, Adolescence, vol. II, p. 155.

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One of the most interesting parts of the course was the development phase. Knowledge of improved machinery, how transportation has developed, the improvement of civilizing agencies as fire, light, electric appliances, broadens the views of the pupil, makes him a part of the world, and gives him a zest for the study of principles which make these things possible. In all this study, there is illustration of the laws of physics, and it makes the applications in the text-book vitally interesting. Such work is only another phase of the study of life, and it interests the pupil in invention, laws, theories, and inspires him to do and to be.

But the vital part of the course is the study of the immediate phenomena of the natural world. I have stated that there should be closer relation between home and school training, and that the school could further this by studying the problems that concern home life. No child should be trained out of his environment, but in it and for it, the environment improved if possible. It is nonsense to teach a child physics when he knows neither nor cares about its abstract facts. Scientists cannot be made of all pupils, and even if that were possible, text-books never made scientists. It takes contact with reality. There has been too much memorizing principles, laws and facts, and too little real thinking. Now the text is a reasonable thing if properly approached, and the best approach is through the observation and experience of the pupil. I am convinced that more satisfactory work can be done, in the text, by the method here presented

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than by the dogmatic treatment usually adopted. Summarizing, the interesting objects of the environment, the real world, furnish material for physics study. It is about this physical that we wish to learn anyway, and much may be learned first hand. The laboratory is the nearest approach to the real world, and must be employed as a means to pure physics study. But it should not be made formal by isolation from the real world. The text book and written physics is a necessity, but is of value in teaching about the environment and in presenting such facts as can be procured in no other way. It is very rational when approached from the concrete side. The course aims to get away from formal teaching; and it accepts the statement that education is life. The aim is to avoid mere memorizing, and to secure real thinking.

¹ C.R. Mann, A Needed Reform in Science Teaching,
Independent, July-December, 1909.

Also, Edwin Hall, Natural Science Instruction,
E.R. vol. 30, p. 396 et seq.

Discussion of Plan
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SECTION TWO.

I. Since this course is a study of the environment, the natural motives will operate to make the work interesting, and lead the pupil into various fields. Problems are presented, and the text will help solve them, objects create interest and the pupil desires to learn some principle connected with it, the pupil is enthused about the forces operating around him and he desires to know more of the physical laws producing the results. The pupil comes in contact with the objects of his environment, and problems arise. The pupil, depending on himself, sets about for a solution. He studies physics because he has a motive in doing so. He is finally assisted by the teacher, laboratory, and text-book in doing those things which he cannot do for himself, unassisted.

II. In our course, the instinctive tendencies of the pupil have been followed rather than the text-book, for the course is a study of natural and actual phenomena met with in ordinary life. And the youth is prepared for such a course; he is impelled by all the powers of his being to the great world of sense, and fact, and mystery. The accumulated yearnings within him make him strive to be a part of the great world around him. A new world of sense and spirit is opening up to the adolescent. We have stated that the instinct of imitation and hero-worship had been considered in bringing forward the historical phase of the subject, and the same is true of many other instinctive tendencies. He desires fame, fortune, honor. He longs for the good and true. His developing mind sees the world in a new light.

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He would have a hand in the material development of this superior age, and champion the cause of the martyr-scientist. He is a part of a great achievement, and becomes more altruistic. A great desire is born to achieve.

The adolescent feels the need of vocation, of choosing a path in life, desire^s to achieve fame and fortune. This makes more valuable such study as I have outlined. The boy, especially, revels in the study of machinery and invention. I have seen a boy work for hours repairing an electric machine. He feels that this material world must be conquered, and then comes the need of knowing more of its laws. He likes to use the already developed senses of touch, sight, etc. Very few things in the course lacked interest to a boy when he could use his senses. He will study a long time about laws of levers, pulleys, motion, etc. from the real things, and become nauseated at the same amount of study in books. The book becomes interesting only when it helps to solve the problem under consideration. The pupils delight to study the progress of human achievement, methods of lighting, heating, electrical appliances, etc. And in all this study, physics problems were constantly arising.

Curiosity is one of the most controlling instincts in the study of physics, securing interest in all kinds of machinery. A girl declared that the best experiment she had performed was setting an electric bell to working, then tearing it to pieces to see how it worked. They like to work with machinery, and always the question arises why does it do this or that. They

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like to see things go, and to know what makes them go. A boy brought an old pump from the wagon shop, and every pupil had the pleasure of seeing how the four valves worked to pump water. They attached the pump to the bucket, and pumped the water out of the bucket. Curiosity makes easy approach. A girl examined a planer, and was most interested to know how many revolutions per second the knives made. Centrifugal force in the grindstone, laws of machines in the shop, principles of reflection as illustrated by the glassy lake, and almost every phase of physics study can be made more vivid by an appeal to this instinctive tendency through a direct study of nature's laws.

The social and parental instincts now increase the value of the study of home life and home appliances. In the study of the cook-stove, the girls especially were very much interested to know how physics concerned cooking. They enjoyed learning that some principle of physics enabled cooking to be done in the oven, that convection kept the potatoes in the bottom of the kettle from burning, that all the processes of cooking were made possible by nature's laws. Example after example could be given, and who will question that, under such stimulus, the principles of physics are very readily learned.

Many instinctive tendencies of the pupils respond to this concrete study of things. And even when an instinct is lost, or covered up and all trace lost, something else takes its place, another instinct, an habitual action, etc. So that a peculiar appeal must be made to them at this period.

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Let the approach be through the natural world. No objections are made to abstract physics, but that comes later. Formulae and units have made the study of physics unpopular with high school students. Certainly the pupils should acquire ability to read from scientific books, but it cannot be done at once, and in parrot-like style. A sensible pupil once said to me, "There are too many definitions and terms to remember in physics".

Books are formal, the laboratory is formal. The logic of science must give way to the order of mental growth and natural interests. Interest must be secured, then usefulness, and last scientific statement and formulae. Hall places popular science first, practical science and applications next, and last pure science. This course has proven to me that the quickest approach to pure science is through the natural, practical and useful. The street, field and factory are the places to study physics, for to know the world about is to destroy prejudice and develop judgment. Along with this comes the home experiments recommended in many German schools. ¹ The laboratory, and finally the text, is consulted for help. The pupil's interest in things, realities, rather than in the representations of things makes this method of approach to physics, it seems to me, the only safe method. I noted that such things as lightning rods, insulation, all appliances for human safety were especially interesting to the students, and it must be partly attributed to the instinct of self-preservation. But enough has been said to show the relation of native tendencies to interest in physics study.

¹ Edwin Hall, "Teaching of Physics and Chemistry in American and Prussian Schools", E.R. vol. 27, p. 145.

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The instinctive tendencies that govern interest have been noted in this course, and as a check individual likes were observed as the course progressed. The fact that the native tendencies overlap, and are interwoven with the acquire powers, should not be overlooked, as it affords varied approach. I have inserted an outline for the study of physical objects made interesting on account of the instinctive tendencies. It has been of great interest to me. The problem seemed to me to find a large amount of interesting material, and then arrange it in a sequence for practical work, and finally rearrange to suit the individual needs of the class. As one can see, this led far from the text and formal physics, but at the same time I feel that no really valuable pure physics has been sacrificed.

III. The wealth of material makes systematic approach easy. Observation comes first. Every person has a desire to see, touch, hear, to widen acquaintance, to extend his powers. Observation should not be random, its use should be to verify, to test, to learn. Especial pains should be taken to avoid hasty inferences from insufficient data and from recurrence in certain order, such as, "Raining and the sun shining, it will rain tomorrow". Physics offers definite scope in this work, and the ample opportunity to study objects made the search for causes easy. Water rises in a tube. Why? Varying conditions in the laboratory to meet the case leads to a solution. Dewey says that observation is for three things:¹ (1) to find out the problem, (2) for furnishing hypotheses, (3) to test the ideas suggested. In following the outline, these problems arose naturally, not as suggested by the

¹Dewey, How We Think, p. 196.

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text-book. Why does this thing happen thus, was asked. And many were the answers, some very crude. But a little help from the teacher or book would finally lead to a correct answer. This is far better than accepting it at once from the text. The texts are now full of means for testing ideas. This is well, but first hand applications from the real world are preferable. The course shows how varied are the means in the community for such work, and it gives the pupil initiative, confidence and strength to do these things for himself. Some one has said that , "Science has originated in a study of the means of perfecting useful devices" ¹, and I think this should be done largely first hand. Again, someone has said that the pupil should not read anything which he could secure first hand. It is largely true. Information should be imparted to help in the solution of problems, or to create new ones, and it should connect with the real experience of the pupil. Certainly, a course in physics that consists of text-book facts is absurd. The first thing, then, was to observe purposively, noting the steps suggested above.

In every problem suggested by observation, there arises the activities of analysis and synthesis. In the first, one chooses from a number of possible causes the real cause of the phenomenon. In the latter, this real cause is given a name, placed in its setting as one of a number of like facts. Analysis assigns the rise of mercury in the barometer to air pressure, and the fact

¹ C.R.Mann, E.R. vol. 38, pp. 150-59

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is attested by experiment. Then by synthesis, we decide that air has pressure because of weight, and this comes in under a still larger fact, objects have weight due to gravity. We now extend the process of synthesis to the cases of siphons, pumps, balloons, etc. To avoid error and meet new conditions, the pupil must work systematically. He should be able to answer such questions as, "Why does the stove have a draught?" , and constantly this process of synthesis goes on, the pulley referred to the lever, pressure on the sides of a vessel referred to weight, etc. It is operative in all mental effort, and this independent study away from books, is in line with the best progress of man. It must accompany book learning. By scientific thought , man has forged ahead to higher achievement. He has taken mere physical force, unusable and harmful sometimes, and transformed it into a usable, manageable power for man's advancements for example fire, rapids, electricity. The pupil should learn to say, "I think".

Charles Kasson Weade puts the matter of method simply,¹ (1) observation of phenomena, (2) induction of principles,etc. from phenomena- an hypothesis, (3) deduction from this guess or principle already established, and the applications such as constructing or studying instruments, (4) experiment to furnish phenomena or test deductions, (5) dogmatic statement or authority. From this, we note three pretty well developed methods, the inductive, the deductive, and the dogmatic. The last of these has no place in

1 Charles Kasson Weade, U.S. Bureau of Education, 1904.

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this course. The other two go hand in hand. The inductive is discovering, the deductive is developing, applying and testing. Care was taken that the pupils had something to work towards. The order was, phenomena, principles, deductions, applications. It was not the amassing of facts so much, but the establishment of principles for deduction and application that was desired. And although not all principles were established, some being accepted on authority, yet the power to think was secured and the truths were made vivid, and interest was maintained throughout.

Throughout the course, principles were generally developed before reaching the book, the book being used for scientific statement and amplification. If the principles were accepted from the book, they were made interesting by objective approach. The applications from the text were little used, and the pupils were expected to make their own applications. Applications in the printing office, laws of sound from musical instruments, etc. are far more interesting, more suitable, and more numerous than those found in the text. The pupil should make his own applications as far as possible.

IV. Acts repeated tend to become automatic, habitual. The pupil has the power to form and to break habits which is an economic provision. Habits are mental as well as physical. There are habits of seeing, observing, measuring, comparing, attending, etc. Phases of physics study will now be pointed out, and the application of the laws of habit formation given.

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First, the habit of observing in natural phenomena and in the laboratory was attended to. The pupil was taught to observe with a view of settling some question and to form an idea as to the answer, then to decide as to the correctness of the conclusion. The purpose was to make the resort to observation and experiment, when a problem is presented, habitual.

The method of acquiring physical knowledge, the inductive and the deductive methods, should become automatic in operation. To avoid the acceptance of dogmatic statements and to rely upon investigation, is one of the most difficult things to acquire , and one of the greatest benefits of physics study. The text makes dogmatic teaching very tempting. For example, the law of refraction is stated, illustration is given, then the rainbow is analyzed. The pupil may get the process without much conception of its merits. It is logically arranged, and is easier for the teacher to deal with than is the real phenomenon. By deductions, the pupils must be shown the likelihood of making hasty inferences, or "Jumping at conclusions". I see no harm, however, in letting the pupils advance theories of their own, freely. The race was educated that way. It teaches the use of inference, and the pupil is made to see the necessity of tentative views. A most valuable part of the course is the opportunity for real application and deduction. We spent a good deal of time upon induction and deduction, and even noted the formal syllogism. This was to enforce the idea of deduction and make it more effective. As evident progress can be noted in forming this habit as in forming any physical habit.

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In fact, we were careful to see that no formula, law or principle was learned by rote. To teach things not within the reach of pupils is questionable, if not harmful. Let the pupil get the idea from the real world. Let him see that it requires force to change motion, that there are six classes of machines, that there is such a thing as reaction. After the principle has been developed, then of course problems, etc. are given to make the procedure habitual. But the idea must precede. We work back too much from principle to illustration. The pupil should get the process of discovery. Interest and pleasure aid habit, therefore instinct aids in the formation of mental habits. A pupil's love for music may hold his attention on the principles used in the construction of musical instruments.

Formulae, laws and principles must be made matters of habit. These are usually considered abstract, according to Dewey's definition of abstract.¹ But if a natural approach is had, they readily come within the learner's experience. First, decide on the habit to be formed, get the idea clearly in mind.² Note the immediate stimulus and appropriate reaction. It should not be hastened over. Too many such things are attempted in the usual high school course. There is plenty of material with which to develop the formula or law. It is useless to learn formulae by rote, and a pupil should not be expected to quote laws verbatim. He should be able from his own experience finally to know whether

¹ Dewey, How We Think, p. 137.

² Rowe, Habit Formation.

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the statement of it is scientific. Such formulae as $s = vt$ were carefully learned through numerous examples, the pupil so far as possible arriving at the idea from his own experience. Also, $E = Fh$, $Fd = RD$, $W/P = P.A./W.A.$ (for levers) were all learned in the same way. In all cases, the aim was to make the law or formula a part of the pupil's experience, and then it was drilled upon until the response was made habitual.

The habit of inquiring as to the meaning of the text is a good one. It is easy to memorize the text and this must be avoided. We frequently took passages from the text and analyzed them. Such questions were asked as; "What does this mean?", "Do you agree with the text?", "If not, why not?", "Why do you think this is true?". Whatever else the course afforded, it was not parrot learning. The text was used as a reference, and we tried to interpret it in the light of outside experience. A student defined condenser as, "A device which greatly increased the capacity without increasing the potential". But on questioning the pupil, I found that she did not know what capacity nor potential meant, and did not know what a condenser is, what it looks like, nor how one could be made. The pupil must form the habit of connecting the things gleaned from the book with his own experience, of putting meaning into the passages or extracting meaning from them. Habits of grasping expressions facilitate reading, and I do not overlook the fact that this ability should be acquired in the use of the text, although the usual method is not followed to secure that result.

The laws of habit as laid down by James and Rowe were

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carefully followed. Of course as in all work such habits as neatness, care of material, application, etc. were emphasized. And we found the method of approach very conducive to those things. Pupils learned to think for themselves, to investigate, to see the relation of things. New meaning was given to laboratory work. Manipulation of apparatus was not accepted for planning and thinking, and real pride in the course was generated.

The first thing is to decide upon the habit to be formed, then let the pupil have an intimation as to the principle. Then get the idea clearly in mind, and note the immediate stimulus and appropriate reaction. Take the case of the lever. It was decided to develop the formula for levers, and to make it habitual. After seeing a great many levers in the real world work, the pupil reached the conclusion that there was some relation between the arms , and weight and power. He noted that the further the power was placed from the fulcrum, the more the advantage. Other facts were noted. Quite a bit later experiments were performed to see what relation existed, the law then was stated and verified as carefully as possible. I think some quantitative experiments at least should be performed with only a guess as to the result. We now returned to examples of the lever showing the usefulness of the machine through the operation of this law, it enables one to work a road grader with ease, to pry up a tree in the street, or to shovel coal with ease, and so on. Problems were now given in which one term in the proportion was to be found. Time was not considered, this formula was to be learned and we stayed with it until it was thoroughly learned.

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Chapter Three

In the preparation of this course, I was much hampered for time to arrange material. It is so foreign to the textbook method that it would require a long time to work out such a course fully, as regards to fitting in library, laboratory, text, the course proper, etc. We were also hampered for lack of reference works, especially on such subjects as the development of industries and the historical phase. I also had a fear that we would get too far from the beaten paths, and arouse criticism. But the interest awakened repaid for any uneasiness on that score, and I would in the future go far beyond this present course to make physics touch the lives of the students.

I had to work with extreme care at first to get the pupils to take the right attitude. Many seemed to think it was too easy a course, almost that the work was foreign to the school. But was considered later the practical part ^ the best of the course.

There are great possibilities in the course. The year's work has more firmly convinced me that the text-book method is wrong, that physics should be studied from the things that touch our real lives. The text should be used only as a reference. The laboratory should not shut our eyes to life and nature, it should be vitalized by union with the phenomena of nature. I firmly believe in practical physics, the physics of everyday life and industrial development. Some texts, as Mann and Twiss, are improving in that direction. It only remains to make the physics of shop and factory superior to the text-book.

The great object of the course is to secure independent thought, to throw the pupil back on his own resources, to secure

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real reflective thought instead of parrot learning. In such a course, it is possible to secure self-reliance, industry, love for nature, respect for industries, appreciation for civilization, more real physics than by dogmatic teaching, and, best of all, real interest in the subject for its own sake and not for grades.

I would have these avenues for physics study, and in the order and importance named: the immediate surroundings, home experiment, construction, laboratory, reference books and reference text. The course should be inductive as far as possible, with deduction going hand in hand from utensils, nature and machinery. The first thing on the part of the pupils should be thought. Help should be to stimulate, to impress correct views, and to get scientific statements. Units should be learned when needed, laws come out of experience. For example, Pascal's Principle should follow the study of the Hydraulic Press. Facts should speak for themselves, and principles and applications should go together. Observation, reason, imagination, and good intellectual habits should be emphasized.

Physics which the pupils can understand should be taught. Most high school students lack the basic observation and training in scientific thinking that should go with the course as usually taught. It is strange to me that pupils in contact for eight years of elementary school experience with improvements and machinery of all kinds understand so little of the working of those things. A boy will drink water from a well, and never know how he got the water. At eighteen, he enters the physics class and learns from a drawing how the suction pump is operated. For

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this reason, I am strongly in favor of the elementary course spoken of in Chapter Two, and also the course for boys in the first and second year of the high school course. Then in the last year of high school, more pure physics could be appreciated.

The course should be made to suit the needs of girls in the physiqs class, and a little study in that direction would yield good results. The course can be made to suit any need, because it is a study of real things. There is plenty of material in every town, railroad tracks, hand-car, blacksmith shop, machinery, plows, etc. In larger places, there are the industrial plants. The laboratory is only the industry of the city in miniature. Why not at least show the relation of the laboratory to the real world? What the boy wants to see is not a little hand dynamo, but the monster that turns the wheels of a great city plant. A lesson on the real lever, jackscrew, pulley, is better than one on the pygmy in the laboratory. The text book is of use, the laboratory is of use, but this thesis registers an objection to formal text-book and to formal laboratory work. It is a plea for the inculcation of physical principles through a study of practical things. In the study of any science, it is folly to start the pupil where the scientist left off. Given a teacher who knows machinery, and a thorough working plan of this course, and he will be successful in training pupils to think in terms of physics.

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