USING DEMONSTRATIONS IN TEACHING
HIGH SCHOOL PHYSICS

A Thesis
Presented in Partial Fulfillment of the Requirements
for the Degree Master of Arts

By

WILLIAM ROBERT RILEY, B.A., B.S. in Educ.
The Ohio State University
1952

Approved by:

[Signature]
Adviser
ACKNOWLEDGMENTS

Many persons from time to time have offered valuable constructive suggestions which have aided the author in writing this thesis. To all of them the author wishes to express his grateful appreciation. Special indebtedness and appreciation for valuable assistance is due to Dr. G. P. Cahoon, Professor of Education, The Ohio State University.

To Dean Emeritus Alpheus Smith the author is pleased to extend his thanks for assistance in preparing the historical review.

To Mary, my wife, there is due appreciation for her encouragement and assistance.

To Lillyan Smith my gratitude for her kindness in typing the thesis.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>II</td>
<td>Historical Review</td>
<td>11</td>
</tr>
<tr>
<td>III</td>
<td>Important Uses of Demonstrations in Teaching High School Physics</td>
<td>22</td>
</tr>
<tr>
<td>IV</td>
<td>Hints and Techniques for Good Demonstrations</td>
<td>31</td>
</tr>
<tr>
<td>V</td>
<td>Suggested Demonstrations in Heat</td>
<td>50</td>
</tr>
<tr>
<td>VI</td>
<td>Suggested Demonstrations at Low Temperatures</td>
<td>69</td>
</tr>
<tr>
<td>VII</td>
<td>Suggested Demonstrations in Light</td>
<td>82</td>
</tr>
<tr>
<td>VIII</td>
<td>Summary and Recommendations</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>Bibliography</td>
<td>97</td>
</tr>
</tbody>
</table>
Chapter I

INTRODUCTION

One purpose for using a lecture demonstration\textsuperscript{1} in science teaching is that the observers will obtain a better understanding of the principles involved than can be gained advantageously by other means. If obtaining an understanding of principles were the main goal in teaching high school physics, then a good teacher would need only to make a list of all the important principles which the students should understand as the course progresses, develop the equipment with which to demonstrate the principles, and then perform the demonstrations in the best manner known to him.

Reports\textsuperscript{2} have shown that the demonstration method is not the most effective means of teaching for all

\begin{itemize}
\item[1.] The word demonstration is an English derivative of the Latin word \textit{demonstrare} which means to show or to point out. Most educational writers and writers of theses suggest that demonstrations involve the use of apparatus or materials and are usually performed by an individual before a group.
\end{itemize}
objectives, nor is the laboratory method in itself the best or most effective means of teaching the science of physics. Some combination of these and other methods is possibly better than either used alone.

Demonstrations may be used at times in teaching the scientific method, in previewing a unit of work, in explaining a principle or applications of a principle, and other specific objectives. It is well to note that the demonstration has a place in the teaching of a science and can best serve its function when the demonstrator fully understands the purpose of a given demonstration, the principle(s) to be shown, the equipment to be used, and what is for him the best manner of performing the demonstration.

The Need for Good Demonstrations

In the past few decades there has been a rapid expansion in scientific knowledge and in practical applications of that expanded knowledge. In spite of these expansions the percentage of secondary school pupils enrolled in science courses has continued to decline. The percentage enrollment in physics has declined along with that in certain other areas of science even though tremendous contributions have been made by this science toward the advancement of human knowledge and welfare.
This is a serious problem which has not yet been met satisfactorily.

It is possible that there are many underlying causes for this decline. Outstanding among these may be: (1) The teacher may not know enough physics to teach it so well as to continue to attract his percentage of students into the course. (2) The teacher may know physics but may not have the proper demonstration manners to retain a lively interest on the part of the students. Both of these causes are related to the use or misuse of demonstration equipment which results from insufficient knowledge of physics or of workable teaching methods. The former might be cared for by study (either formal or informal); the latter can also be remedied by study, specifically of methods and procedures of teaching an enlivened course.

Many demonstration experiments are suggested in collections and throughout the professional literature available to the secondary school science teacher, but explicit teaching procedures with accompanying suggested projects, questions and exercises for use in teaching physics are not to be found in abundance. Some teachers have been fortunate enough to learn how to use demonstrations effectively from the example set for them by their high school and college instructors. Others have
had no good example set for them and have painstakingly developed their own procedures and methods of use around ideas acquired from reading periodicals and studying reference books on the subject. There are many teachers who use demonstrations infrequently because they lack either the time or the inclination to do the spade work necessary to make the use of demonstrations seem worthwhile to them.

Statement of the Purpose

The purpose of this study, therefore, is threefold: (1) To determine possible uses of the demonstration in teaching high school physics; (2) To suggest ways in which demonstration procedures and methods could be made more effective; and (3) To present several specific demonstrations giving explicit teaching procedures and proposing sample projects, questions, and exercises to accompany the demonstrations.

Procedure

In order to fulfill the purpose the following steps have been taken:

(1) A survey of literature related to demonstrations was made. There have been published in the past 15 years several books dealing wholly or in part with the use of demonstrations in science teaching
and articles related to this topic have appeared frequently in professional periodicals. Several theses concerned with demonstrations are to be found in the libraries of The Ohio State University. (There is a bibliography of pertinent writings at the end of this thesis.)

(2) A brief historical review of the use of demonstrations in teaching science has been developed. It was thought that a study of the history of the use of demonstrations would be helpful in determining what present uses there are for demonstrations; but no such history seems available in any single book. One stimulating part of the preliminary work has been the studying of various biographical memoirs, science teaching methods books, and old apparatus supply catalogs for the purpose of reviewing the growth of the use of demonstrations.

(3) A number of ways of using demonstrations in high school physics teaching have been set forth. Emphasis has been placed on using demonstrations for stimulating thinking, teaching scientific method, relating principles to experiences of daily life and for many other objectives.

(4) Hints and techniques for good demonstrations have been presented. Introduced in this section have
been some specific aids in planning a demonstration program, general preparation techniques, and presentation tips. A list of check points is given to help the teacher reduce demonstration failure and time spent in preparation.

(5) Sample demonstrations have been prepared. Demonstrations which are easily adapted to student performance and post-demonstration performance suggestions for the teacher including lists of questions, possible student projects and related experiments have been included in Chapter V. Ideas related to some extra-classroom uses of demonstrations have been presented in Chapter VI and teacher-performed classroom demonstrations have been described in Chapter VII.

Limitations

An abundance of material has been published on the general topic of demonstrations. In this thesis the emphasis is upon demonstrations suitable for teachers of students at the secondary school level, particularly of the eleventh or twelfth grade students of physics. To include all available physics demonstrations would be undesirable. However, an effort has been made to select from reference books, from current literature and
from the demonstrations presented in the basic physics courses at The Ohio State University a few demonstrations that are not so conventional in high school programs yet which are related to the problems of this thesis and which seem appropriate for use in high school. There has been no attempt to present sample demonstrations in all areas of physics. Demonstrations in the areas of light and heat have not received attention in recent theses at The Ohio State University, so the sample demonstrations in this writing will be limited to those two areas. Low temperature demonstrations have now become economically possible for nearly all schools in all parts of this country because of the low cost and ease of obtaining liquid nitrogen; Chapter VI will be devoted to demonstrations at low temperature.

Previous Studies

One reference book on demonstrations in physics has been authored by Sutton\(^3\). It contains an excellent collection of experiments for demonstrations but does not elaborate specific uses for the demonstration in science teaching. The introductory chapter of the book by Sut-

tion and of those by Adlam and Arthur could be read to advantage by all demonstrators.

Theses by Bahler, Bowman, Morgan, and Rinear have been examined. Their reports are closely related to the problem set forth in this thesis. Bahler suggested and illustrated specific uses of the demonstration in modern junior and senior high school science teaching. One use that he proposed, which is related to this problem, is "to disturb some of the less interested students to the extent that they develop an active curiosity about some phase of science." Bowman discusses the projection-type of demonstration as a specific technique in the use of demonstrations. Morgan was concerned with


the general role of demonstrations in the teaching for scientific thinking. Rinear discussed the matter of constructing and using large apparatus in performing demonstrations, the use of such equipment affording all students an equal opportunity to view the proceedings of a given experiment.

Mertz\textsuperscript{10} presented a thesis which is an admirable example of a teacher using low cost, readily available material for many purposes, including demonstration. His use of the automobile in teaching physics would seem to be one approach to holding the interest of students enrolled in the course -- whether hot rod fans or merely members of the high school student drivers' class.

Science teaching methods textbooks are of value in pointing out good general demonstration techniques and practices. One might profitably look at several books on science teaching: \textit{Modern Science Teaching}\textsuperscript{11} and \textit{Methods and Materials for Teaching General and Physical Sciences}\textsuperscript{12} are two which offer valuable suggestions re-

\begin{itemize}
\item \textsuperscript{10} Forest W. Mertz, "Using the Automobile in the Teaching of Physics." Unpublished master's thesis, The Ohio State University, 1948.
\item \textsuperscript{11} Elwood D. Heiss, Ellsworth S. Obourn and Charles W. Hoffman, \textit{Modern Science Teaching}.
\item \textsuperscript{12} John S. Richardson and G. P. Cahoon, \textit{Methods and Materials for Teaching General and Physical Sciences}.
\end{itemize}
lated to the general problem of the use of demonstrations in science teaching.

Organization

The thesis has been organized under the following headings:

Introduction
Historical Review
Important Uses of Demonstrations in Teaching
High School Physics
Hints and Techniques
Suggested Demonstrations in Heat
Suggested Demonstrations in Low Temperature
Suggested Demonstrations in Light
Summary and Recommendations
Chapter II

HISTORICAL REVIEW

A sense of historical continuity is quite as essential to the advancement of science as to the growth of a nation. The man of science who has no memory for its past is not likely to be greatly concerned about its future.

Henry Crew

The use of demonstration equipment in the formal teaching of science to large numbers of students is relatively recent and its history, though not clearly defined, roughly parallels the history of mass education. It lies almost entirely in the past two centuries.

Early Cultures

The early cultures had considerable acquaintance with single physical topics -- the Babylonians, Egyptians, and Greeks were interested especially in the mathematical aspects of mechanics. Pure thinking was the vogue among the educators and the educated few. For the most part they viewed with contempt ideas derived from experimental research. These pure thinkers disparaged the "desecration" of their exalted science of mathematics by those who would apply it to matters of actual experience. But they were not always successful, for
some ingenious person of ancient times must have formed a demonstration device with which a layman could be taught some of the fundamentals of arithmetic, since the abacus is just such a device. One might say that the ancients used demonstration equipment in teaching the next generation in the real-fish grabbing school of science although we would here class that as non-formal education.

The influence of these ancients, particularly of the Greeks, hobbled science education from the time of Christ until the Renaissance. The black magic of the alchemists seems to have been an unfortunate but necessary state through which the evolution of man's notions of matter and fundamentals was forced to pass.

Beginnings of Science

Science did not become recognized as an international and cooperative enterprise until the seventeenth century. Galileo, Newton, and Leibnitz were instrumental in developing a foundation for modern science. The first

4. Eric T. Bell, Men of Mathematics.
great scientific societies were founded in that century, and the publications of these new associations were invaluable in informing scientists of work completed or in progress and in calling attention to new problems.

A deliberate effort to define scientific method developed. Francis Bacon and Descartes were pioneers in this field. Bacon by his literary power did much to build interest in discovery and to call attention to the practical value of scientific knowledge. Bacon demanded experiment and new discoveries; Descartes called for conclusive proofs which he sought by rational and mathematical methods.

New instruments were developed to aid observation and measurement; the barometer, air pump, and thermometer are instruments of this period. Mathematical inventions broadened the intellectual horizons; logarithms, the calculus, and decimal fractions are products of the thinking of this period.

**Early Lecture Demonstrations**

All this is important in the history of demonstrations because it was in this period, that of the birth of the Royal Society of London, that demonstrations came into relatively frequent use. Demonstrations aided in illus-
trating the lectures given by members of that learned group. Many of the demonstrations were of experimental work which was in progress or only recently completed. It was as though a university research supervisor of today were giving an illustrated lecture to the learned men of the field with his research equipment present and operating.

Faraday's Contribution

in 1813, the young Faraday, shortly after having taken employment at the Royal Institution of London, set forth in a letter to a friend the requisites of a good lecture. His is one of the earliest available recorded accounts related to the consistent use of demonstration equipment in developing an understanding by a viewer-listener of some fundamental principle or concept; his comments on the use of demonstrations are of no less importance today than when written.

"I need not point out to the active mind of my friend the astonishing disproportion, or rather difference, in the perceptive powers of the eye and the ear, and the facility and the clearness with which the first of these organs conveys ideas to the mind -- ideas which, being thus gained, are held far more retentively and firmly in the memory than when introduced by the ear. 'Tis true the ear here labours under a disadvantage, which is that the lecturer may not always be qualified to state a fact with
the utmost precision and clearness that language
allows him and that the ear can understand, and
thus the complete action of the organ, or rather
of its assigned portion of the sensorium is not
called forth; but this evidently points out to
us the necessity of aiding it by using the eye
also as a medium for the attainment of knowledge,
and strikingly shows the necessity of apparatus.

Apparatus therefore is an essential part of every lecture in which it can be introduced....

Changes in the Classical Curriculum

The use of demonstration equipment at the time of Faraday (approximately 150 years ago) was limited to the purpose of getting fundamentals across to learned adults interested in the problems of the science. But from such adult education methods has developed our secondary school science demonstration. However, before we had science demonstrations in schools, the sciences themselves had to come into the curriculum to stand beside the reading, writing and 'rithmetic. Though usually taught solely from books in the early stages, they (the sciences) had nevertheless become a part of the curriculum. Then, once a part of the curriculum the problem of improving the science offered became a problem of improving the methods of teaching it.

Collections of minerals and instruments began to appear in the schoolroom. It is difficult to pinpoint

any specific date at which collections appeared generally in science classrooms although one might venture a guess at this occurring in the first half of the nineteenth century in America. 6

The use of demonstrations is assumed to have varied from school to school and from teacher to teacher. Facts related to this may be gleaned from the biographies of some of the important teacher-scientists of the past century. 7

As the high schools became the American secondary education outlet, evolving from the academies and grammar schools, the changes in the subject offerings brought about changes in teaching methods. The teaching of physics or natural philosophy in the early high school consisted of the reading and regurgitation of facts. Somehow, somewhere, it must have been decided that pupils could grasp

6. Based on various writings. See especially Magie, A Source Book in Physics, p. 513, concerning Joseph Henry's work on self inductance. Henry used demonstrations in teaching science at Albany Academy, Albany, New York, ca. 1830. Academies such as that at Albany were essentially the American secondary schools from 1770-1870; soon after the Civil War the high school became dominant.

7. E.g. See Biographical Memoirs, Vol. XVI - The Memoirs of the National Academy of Science, pp. 331-351, concerning the teaching of Thomas C. Mendenhall. In 1870 while teaching in the Public Schools of Columbus, Ohio, he had students help him to build and repair equipment which could be used for demonstration purposes.
concepts more firmly if related demonstrations were performed as the concepts were discussed. Eventually men of vision convinced a few high school teachers that demonstrations were worthwhile and that, if these were supplemented by pupil-performed experiments related to the concept to be studied, the pupils might come to feel at ease with the physical world about them. This probably was the 1880-1900 picture.

Growth of the Apparatus Industry

The apparatus needed for demonstrations was not at first available from American manufacturers. The history of the rise of American supply houses is in a sense related to the use of and demand for good scientific apparatus for use in demonstrations and in the student laboratory. Early demonstration equipment was purchased from sources in England, France, and Germany, the main sources being Hilger of London, Duboscq of Paris, and E. Leybold Nachfolger of Cologne. As the use of demonstrations increased and as the student laboratory became a reality, the demand for apparatus increased to the point where it became worthwhile for Americans interested in effective science teaching to form companies which could supply good materials for just that purpose. William H. Welch in 1880, Edward Bausch in 1875 and L. H. Knott in 1880
founded equipment houses. At the turn of the century, protective tariffs were imposed which hastened the rise of the American apparatus supply houses. Central Scientific Company was established in 1900, the Chicago Apparatus Company in 1908, and many others in following years.

When new principles are discovered and when it is desired to teach students the relationships involved in new discoveries, apparatus must be made available. The increase in the use of demonstration equipment is thus inextricably related to the increase of knowledge of principles and to the growth of the sources of supply of apparatus used in demonstrating the increased knowledge. Fifty years ago there was a scramble to demonstrate much of what was known about x-rays, just as today there is a great interest in devising apparatus and demonstrations for the varied aspects of atomic energy.

The Last Half Century

Books and periodicals concerned with science teaching methods have been published in increasing volume in the past fifty years. The early ones made only a general reference to the demonstration as a teaching technique. Those of the past fifteen years have been more thorough in discussing demonstrations and in some instances entire
books have been devoted to listing experiments which could be used especially for demonstrations. Some of the professional periodicals today discuss unusual aids to demonstrations or good demonstrations in nearly every issue. At least one apparatus supply house now publishes a physics digest which contains articles on demonstrations for use in teaching physics and which is available to all science teachers.

Teacher training institutions have made changes in regard to the demonstration. The older outlook on teacher preparation concerned mainly the subject matter attainment of the teacher trainee. One was prepared to teach if he had a good grasp of subject matter alone. The training program today is a bit modified and provides for the teacher trainee to demonstrate certain abilities in addition to that of subject matter comprehension. In some methods courses future teachers are given an opportunity to develop skills which will aid them later in their demonstration preparation. In others they prepare and present demonstrations to fellow students.

Encouraged by grants-in-aid from industry some professional groups sponsor exhibits which afford students

and teachers alike an opportunity to study demonstration materials. The awarding of scholarships for excellent exhibits is an added incentive in these. This is essentially a student demonstration program for the exhibitor must tell what he has done, explain the theory, and in some cases present apparatus in good working order.

The annual summer meeting of the American Association of Physics Teachers includes a Demonstration Experiment Round Table and gives recognition to high school and college teachers of physics for experimental and non-experimental teaching devices; this is an encouraging step in the right direction.

The summer science teacher workshops of the various universities are also helpful in aiding teachers in their demonstration program and should become annual events.

Summary

Men of early cultures were accustomed to winning followers to their way of thinking by using dogmatic statements.

During the seventeenth century an effort was made to show that conclusions arising from dogmatic premises could lead one astray from the facts of nature. Experimental efforts by men of science of that century helped
mold the foundations of modern science. Men began to win adherents to their theories by supplementing word arguments with demonstrable experimental results.

Demonstrations were introduced gradually into the science programs at the college, secondary, and elementary levels. The acceptance of the demonstration as a teaching device is reflected in the steady growth of the many apparatus supply houses throughout the world and in the changed curricula of teacher training institutions.

In Chapter III the reader will find uses for demonstration in modern high school physics teaching.
Chapter III

IMPORTANT USES OF DEMONSTRATIONS IN TEACHING HIGH SCHOOL PHYSICS

In order to be effective in teaching, the instructor of a given subject must contrive situations in which the students have worthwhile experiences. In many instances the teacher is blazing a path for the students into an unknown forest, where, with clear marking along the main trail, they gain enough confidence to make exploratory side trips.

It is in the trail blazing that the teacher stimulates thinking, lays the foundation for the students' learning about scientific method (what it is and how to use it) and maintains the interest of the students in continuing the trips which they start. The demonstration is one of the tools that the teacher can use to notch this trail -- an instrument through which the classroom experiences of the students can be meaningful.

Stimulating Thinking

Historically the demonstration played an important role in stimulating thinking. Galileo, it is said, made his impression at the Leaning Tower of Pisa not with words alone; his demonstration has proved effec-
tive in stimulating men to think and experiment for themselves instead of accepting the dogmatic words of Aristotle. Young's simple demonstrations on interference eventually confuted Newton's weighty ideas concerning the nature of light. Rumford's demonstration on the boring of cannon stimulated men to think and to experiment, and in a short time, it forced revision of the existing theory of heat. These are but three random examples of the use of demonstrations by men of science in the past to stimulate thinking. The physics teacher today can use demonstrations to stimulate students to think for themselves, to experiment, to draw conclusions, and thus to rid themselves of false concepts.

However, little, if any, of this is automatic; there must be good planning if best results are to be obtained from demonstrations devised for stimulating thinking just as planning is a requisite for attaining other objectives.

Teaching Scientific Method

In the past, successful men of science used the scientific method in their attempts to solve theoretical and experimental problems. The increasingly complex nature of our daily life makes it imperative that more men and women be trained today in the use of this
problem solving method; good demonstrating is one way of teaching scientific method. All students should have an opportunity to observe good manipulative techniques; but also, in the teacher performance of a demonstration there should be presented clearly sometimes the individual steps in the solution of a problem -- the steps which constitute one statement of scientific method.

In some manner a problem could be brought before the class, a problematic question, either student or teacher initiated, could arise. The teacher could intentionally guide the class in offering various hypotheses and in proposing ways in which to test a given hypothesis. The devising and setting up of a controlled experiment before the eyes of the students as they prepare checks and balances on the system to be used has possibilities for making clear to them what is being controlled, the nature of the data being obtained, or what can result if their hunch is correct. The actual performance of the demonstration may be considered the testing of the hypothesis. On the basis of the results a proposed hypothesis might then be accepted or rejected. This type of demonstration problem solving technique could be used to point out for the students
the necessity of permitting only one variable in an experiment. With a little practice a teacher, by using proper questions and suggestions, can get students to state the purpose of an experiment, suggest the experimental factor involved, and to plan necessary controls with which to make the results conclusive.

Authors differ in their statements concerned with scientific method. Nearly all seem to agree that there is no one scientific method but that there are scientific methods; however, some writers have proposed that there may be common steps in the many methods. In demonstrations, in project work, and in the laboratory, the teacher may foster the use of some scientific method; there are, of course, other ways of using the demonstration for teaching scientific method than that presented above.

Motivating Students

The alert teacher realizes that many of the inventions of this complex modern civilization may be with us for a while. The reading of a dull, dry text and the regurgitation of statements meaningless to the

1. For more detailed writing on this matter see Richardson and Cahoon, _op. cit._, Chapter 5, pp. 66-82.
student cannot be expected to hold the attention of a normal student whose experiences have been with automobiles, radios, television sets, dial phones, and technicolor movies. The teacher who attempts to "get by" under these conditions by using classical methods of instruction (straight text assignment and recitation) cannot succeed today. While most students are aware of the many marvels of modern life it is likely that none of them know more than a few of the scientific principles and facts of the operation of the marvels; but nearly all may want to learn about them. Taken together these statements mean that every physics teacher has a golden opportunity, for each can, by properly using demonstrations, focus the attention and interests of his students on the scientific principles and the facts of operation of almost any of the devices of modern living to maintain an interest in physics.

**Relating Abstract Ideas to Daily Life**

There is a tendency for people to think of physics and chemistry in the same sense as Latin and calculus -- they assume them to be incomprehensible except to the extraordinary person. Demonstrations using household equipment or using parts of tools of everyday living can be presented to make the principles of physics
concrete and vivid for all students. Even the five-thumbed teacher can with some practice bring the students in his class to an understanding of the physical principles involved in the operation of at least a few modern conveniences. Through properly chosen demonstrations any teacher can show that physics is a part of everyday life and that much of this science can be understood by all students.

Mertz\(^2\) has shown how all the independent systems of the automobile can be used in relating vague physical concepts and law to the experiences of life. Although he wrote mainly of the use of the auto systems in the laboratory, he proposed that they could be used in both teacher demonstrations and pupil-performed demonstrations. By seeing the working of the parts and systems of an automobile and by seeing the relationship of the laws of physics to the parts and to the whole, the student might gain confidence in using an auto wisely and perhaps in addition gain some practical knowledge of physics.

Demonstrations using almost any household device can be contrived so that what is an abstract principle or concept when read in the text becomes concrete and vivid because it has been related to things known.

\(^2\) Forrest W. Mertz, *op. cit.*
The teaching of many principles of physics challenges the conscientious teacher who knows that it is difficult for his students to understand some of these principles. But by the teacher's simple act of relating the principles to some instrument or device with which most students are familiar, the meaning of the principle becomes known.

Other Uses

The four main uses of the demonstration which have been considered include many other uses to which the demonstration may be advantageously put. Perhaps a nearly complete listing of likely specific uses would be one adapted from that by Bahler who suggested that the demonstration can be used:

(1) To aid students to a clearer understanding of a particular idea or concept

(2) To aid in deciding issues

(3) To serve as the starting point for interesting and profitable class discussions

(4) To present some evidence for our present theories, laws, and accepted facts which to the students seem almost plausible

(5) To aid in presenting an effective overview of a unit of study

(6) To aid in guiding student interest into a particular phase of a unit which students otherwise might be a bit reluctant to study

(7) To disturb some of the less interested students to the extent that they develop an active curiosity about some phases of physics

(8) To present experiments which require unusual care or skill in order to achieve worthwhile results

(9) To present experiments which are rather dangerous for pupil performance

(10) To present experiments which involve apparatus which is had in only a limited quantity

(11) To present problematic situations for experiences in the various phases of scientific thinking

(12) To assist in developing within students a confidence in, and respect for, scientific methods

(13) To aid in analyzing and evaluating the quality of a student's thinking.

Richardson and Cahoon have said that the demonstration has proved functional in previewing a unit of

---

4. Richardson and Cahoon, op. cit., p. 16.
work, in providing for particular student needs, in reviewing, in exemplifying certain skills or techniques such as reading vernier calipers, and in evaluating various abilities of the students. One could undoubtedly state other uses for the demonstration; however, the demonstration is not a panacea. It is probable that a demonstration properly planned and properly presented could cure any classroom ill. But that is not what should be remembered; the important idea is that like all other teaching methods, a demonstration is valid only when used as part of an integrated teaching program.
Chapter IV
HINTS AND TECHNIQUES FOR GOOD
DEMONSTRATIONS

The merits of using the demonstration as a device for motivating students have been discussed by various authors. There is no need to elaborate on them here as it is patent that the average student would rather attend a circus or a baseball game than to sit and listen to a teacher or to sit and read a textbook. This is not meant to say that a student will enjoy just any performance of any demonstration more than the reading of a textbook, but a few purposeful, properly planned, and well-executed demonstrations may contribute more to the growth of individual students than all the texts and talks combined.

Acquiring confidence in one's ability to set up an experiment which not only works well and looks good but which also provides a meaningful experience for the pupils is one way to make the routine chores of demonstrations more enjoyable. Toward this end ideas related to the planning, preparing, and presenting of demonstrations will be offered in this
chapter; some though merely expressions of good common sense and consequently obvious to most readers are those points frequently overlooked when a demonstration fails to work physically or fails to produce the desired results with the students. Most demonstrations can be no better than the plans that are made for their success; the matter of planning demonstrations will, therefore, be studied next.

Planning

It is only by an accident that one obtains good results from a demonstration without properly planning for those results. Under the best of conditions one cannot be certain of good results but they are more likely if one plans for them. Under the topic of planning for good demonstrations one might include (1) the general selection of demonstrations to be used, (2) the filing of general and specific information related to the selected demonstrations, and (3) the storing of materials and apparatus.

It is obvious that no single prescription could be written to apply in all teaching situations for nearly every factor involved varies with the existing local conditions. In one school you might find a teacher
holding a doctorate in physics teaching only physics in a well-planned and equipped room which is used exclusively by him. At the other extreme is the teacher with fifteen quarter hours of physics, teaching not only physics but also mathematics, general science and hygiene, supervising two study halls and coaching the basketball team, whose poorly equipped physics classroom is the common science room for the school. There are obviously many situations between those two extremes; however, common sources of ideas concerning demonstrations can be used by all teachers.

Selecting

The selecting of demonstrations and of ideas related to demonstrations for use in a given class depends upon diverse factors such as the available equipment, the training and adaptability of the individual teacher, and the pupils. Whatever the situation, it is to be hoped that there will be available to every physics teacher, in the school library or in his personal library, one or more of the following periodicals in which demonstrations and demonstration aids are suggested directly or indirectly: The American Journal of Physics, School Science and Mathematics, Popular Science, Physics

Ideas for new demonstrations or the revising of old ones are obtained from those sources just mentioned and from exhibits, conventions, and perhaps even professional group meetings. Regardless of the nature of the new demonstration or where it is seen, if you think you are interested in some phase of it for future use you should record enough information about it so that it is available for later reference. This immediately suggests the need for a system of filing such information.

Filing

A new idea file of cards referring to those selected demonstrations or ideas for demonstrations can be a valuable aid in planning for future demonstrations. As a teacher reads of demonstrations which may be of use sometime he should record the title or nature of the demonstration, using a separate card for each demonstration, being certain to include the reference volume and page number where the explanation or suggestion can be found. In the case of exhibits and demonstrations at professional meetings, it is well to record the name and address of the person from whom further information
can be obtained if needed. The cards in this new idea file might best be filed according to that area of physics in which their use would seem most logical.

An active file in which is kept a card for each of those experiments which has been worked out and for which equipment is available would facilitate planning. The cards would be filed according to that area of physics in which they are most likely to be used. Each card would contain the title, a list of the apparatus involved, storage location including cabinet and shelf numbers where applicable, a rough sketch of the arrangement of the apparatus for the demonstration, and brief mention of any particular techniques which will ensure success.

Thus a teacher in planning a given unit of work could select from his files that set of demonstrations which best fits the needs of his particular group of students. (The purpose of a given demonstration may vary with each class of students.) He might also check his new idea file to see whether some suggested demonstrations should be selected and elevated to active duty in the unit at hand; if so, he may have sufficient time to experiment well in advance of the actual use of the demonstration in the classroom.
Storing

There may be several ways in which to store demonstration equipment, one practical method is to file each piece of apparatus as one would file new ideas. Within limits, the equipment and materials are stored in cabinets with specific areas reserved for mechanics, heat, light, electricity, sound, and modern physics. The apparatus is thus stored according to the area in which its use is most likely to be found. The only exceptions to this are bulky pieces of apparatus which cannot be conveniently shelved in their proper areas and things like the optical bench illuminator, used frequently for projecting small demonstrations on a screen, which have uses other than in single area demonstrations. Only a few demonstrations are stored assembled for use; to prepare these few from component parts each time they are used would be most inefficient considering the time involved and the duplicate components available.

Considerable time may be involved in the initial sorting and storing of equipment according to area of use, but it saves untold hours of needless hunting once the job has been done. Every piece of apparatus then belongs on a specific shelf in a specific cabinet. The
important thing to realize is simple, once a piece of apparatus is used it should be returned to its proper storage place, i.e., its proper shelf and cabinet, and it should be ready for use when stored. This means that when one selects a card from the active file and begins to prepare a given demonstration the card shows where the apparatus is (no hunting involved); since each part has been put away ready for use, there is little work to be done in assembling the given demonstration at any time.

It is not necessary to discuss the advantages of such a system of filing and storage. The accumulated preparation time saved in one or two semesters more than repays the time involved in initiating a program such as the one proposed here. Not the least of the attributes of such a system is that there is in the orderliness of filing and storage an overtone of method -- perhaps some scientific method. It augurs not well for a teacher to attempt to instill scientific method if he never presents evidence of method in his daily thinking and acting; his planning for good demonstrations may be tangible evidence of his use of method.
Preparing

Two general situations exist, one in which the demonstrations can be prepared in advance where they are to be used, and the other wherein the apparatus can or must be set up away from the demonstration table to be wheeled or carried into place shortly before it is to be used; there are advantages in both.

Assembly

In small classrooms where the apparatus is stored near the lecture table it is generally advantageous to prepare the demonstration where it is to be used. This method involves little lost motion, but it limits preparation time to those hours when the room is not in use. The prepared demonstration in such a situation is one which may interest students from other areas, for this small classroom is to be found where the science room is shared with one or more other subject areas. The attention of the student of English, civics, or history may be held by the demonstration apparatus rather than by the subject matter under discussion. A major advantage in the single preparation method is that the practice run can be made at the place where the demonstration is to be performed, the solid angle subtended by the apparatus can be determined and a
full practice run may reveal missing necessary items and needed "twists of the wrist."

In larger classrooms where the apparatus is stored away from the demonstration table it may be found desirable to prepare equipment on a movable table from which the device will be moved later to the permanent table. The time and effort saved in reducing leg work makes this type of preparation worthwhile where it is possible. In many cases the apparatus can be prepared by the teacher in any free time he may have without distracting students or other teachers and then can be transferred with ease to the main table at a convenient time. A practice run can be made in the preparation room or at the demonstration table. In any case the demonstrator should check to see that what should be seen can be seen from all seats.

**Protection**

In preparing experiments which are to be presented as demonstrations because they are considered too dangerous for students to perform in the laboratory, it would be wise to plan to protect the students. In preparing any demonstration where students might be endangered, plans should be made to minimize the danger. For instance, the ice-bomb experiment to be presented
in Chapter VI should probably be performed in an empty five gallon paint bucket or some similar metal container of approximately five gallons capacity. (A floor wax can might be obtained from the janitor for such a purpose.) Students are thus spared the unhappy experience of having supercooled water freeze on exposed skin surfaces. A conveniently missing fuse may prevent serious injury to an inquisitive student playing with electrical demonstrations; the teacher can carry the missing item in his pocket until it is needed. Some demonstrators follow a strict policy of keeping one hand in a trouser pocket while presenting electrical demonstrations using Wimshurst machines, Leyden jars, condensers, and other electrical devices; they thus reduce the possibility of current flowing through their body. In presenting demonstrations in the area of heat the simple precaution of wearing gloves will minimize the chances of burns; indirectly this provides protection for the students near the demonstration table. If one plans to present a ballistics pendulum demonstration, the safest course may be to carry the projectile in one's pocket until firing time; the unloaded gun will attract no attention if out of sight but readily available to the instructor in a nearby cabinet. In general, if one takes all pos-
sible precautions at the time the demonstration is prepared, injuries to the demonstrator and students can be avoided.

**Distinguishing Marks**

The preparation of equipment for specific uses may call for distinguishing color schemes on parts of apparatus which serve different purposes or on parts to which the teacher may wish to direct the students' attention for some particular reason. Black and dark green paints serve well on unimportant parts, while bright colors such as white and yellow can be used to emphasize some important piece or unit of a given demonstration. Teachers need not always teach in a drab classroom with drab equipment even though that be the situation that exists when some accept new positions. A few pennies' worth of paint and some of the teacher's time can effect some desirable changes.¹

**Practice Run**

One important aspect of the demonstration preparation is the performance of the practice run. A demonstration should never be presented to a group

---

¹ See Mertz, op. cit., for some suggested uses of color in preparing demonstration and laboratory experiments.
without the demonstrator having first tried it to be certain that it works. Regardless of the number of successful presentations in past years, there may be some extra little twist or push or pull needed to ensure a good performance this time. The practice run reveals the present techniques needed and gives the demonstrator a fresh start. Because of the relationship of the practice run to the successful final performance of any demonstration, the importance of making such a run cannot be too strongly emphasized.

Nothing more severely discredits a science teacher in the eyes of his pupils than to have it said that his experiments do not work. What must they think of a teacher who reprimands them for failing in recitation, or being awkward in the laboratory, and who "flunks" himself when they ask him a question or when he tries to show them an experiment?  

Presenting

Preparing the Students

Since demonstrations are presented primarily to benefit the students, the teacher should give some thought to preparing the students to see what they are supposed to see. It is not enough that the teacher manipulate the apparatus well; nor is it

enough that he know why he is performing a particular demonstration. The student must also understand the purpose of each demonstration if he is to have worthwhile experiences. The major crimes of demonstration presentation would disappear from the classroom if the teacher were to seriously consider his role in bringing the students to see the meanings as well as the motions involved in a given demonstration.

Almost any prefacing statement or discussion question from the teacher can serve as a channel through which the purpose can be brought to each student for reflection. There is ordinarily no need for an elaborate forty minute preparatory discussion period followed by only two or three minutes of seeing. It is possible and often desirable to spend a few minutes in discussing the purposes and theories and an equivalent amount of time in a discussion of the apparatus and functioning of the principal parts thereof in order that the meaning(s) of the demonstration may be seen clearly by the students when the demonstration is actually performed. The procedure should be varied enough to keep things interesting. Some of the discussion and explanation may be worked into the period of actual performance; on certain occasions all discussion may come after the performance.
The Act

The demonstrator should be a showman. Unlike the magician who always attempts to hide necessary apparatus and techniques, the teacher usually should make every effort to shed light on principles and apparatus rather than to darken them. Toward this end the demonstration should be prepared from simple equipment and should usually be so arranged as to make visible as much of the working apparatus as the viewer can understand easily. There may, however, be occasions when the objectives of a given demonstration can best be attained if some apparatus or technique is not made conspicuous. For example, in using demonstrations in previewing a unit of work, the teacher might emphasize only the results obtained when some one thing is done rather than give a detailed explanation of the apparatus used and the principles involved as would be given when that demonstration is performed in the unit studied. Normally the demonstration is not performed in complete silence, though even the silent demonstration has been used by teachers of some subjects.\(^3\)

If the teacher mumbles, or races pell-mell through

---

an explanation thinking that because the demonstration seems logical to him it must be logical to the students, or shouts at students because they do not understand or draw logical conclusions, it can be said of him that he has neither those manners of presentation that endear him to his students nor those which are likely to be related to meaningful learning experiences.

Checklist

A checklist of some ideas related to planning, preparing and presenting demonstrations may be of value.

(1) Use simple apparatus.
(2) Build apparatus on a large scale.
(3) Store apparatus according to area of use.
(4) Store apparatus free from dust and moisture.
(5) Arrange apparatus so that all important components are visible to all students.
(6) Clear the demonstration area of all unneeded apparatus and materials.
(7) Know the purpose of presenting each demonstration.
(8) Experiments should stimulate further thought.
(9) A slight dramatic element is sometimes helpful.
(10) An element of the unexpected is sometimes effective.

(11) The speed of action should be suitable.

(12) The demonstration should be a model for the pupils in clearness, vividness, and good form in presentation.

(13) Are all dry cells that are used good?

(14) Are available storage batteries kept charged?

(15) Are alternating and direct current outlets clearly marked?

(16) Are you familiar with the current carrying capacity of the electrical outlets in the classroom and at the lecture table?

(17) Do you check the continuity of all lead wires when an electrical demonstration fails to work properly?

(18) Do you inadvertently use wet or damp hands in handling electrical apparatus?

(19) Color ordinarily clear liquids when the visibility of the level is important. Liquid oxblood shoe polish is a nice dye for carbon tetrachloride. Water-soluble dyes such as fluorescein and aniline may be used in water and in some organic liquids.
(20) Several demonstrations in the area of light which use a slit are easily prepared once the light source is focused on the slit and the slit is focused sharply on a projection screen. For further information on this point see Chapter VII.

(21) Try all demonstrations previous to the presentation.

(22) Read regularly the demonstration suggestions in the professional periodicals.

(23) Do you use student aids in performing demonstrations? Their reading of thermometers and recording of weights will assure the rest of the class that specific results are not predetermined.

(24) Demonstrations related to the earlier experiences of the students usually achieve satisfactory results.

(25) Expensive apparatus is not always necessary. With some ingenuity and often with student help and supplies obtained from junk yards, five and dime stores, or forgotten corners of attics and garages, a teacher can plan and guide the building of inexpensive demonstration apparatus.
Faraday, as a young observer of lecturers and demonstrators, made some sound suggestions which any person desiring to prepare and present successful demonstrations would do well to apply. His words were not those of an idle faultfinder, for he became a most revered lecturer and demonstrator; he pleased not only the members of the Royal Society, but for many years he pleased also the most critical of audiences, those children attending the juvenile lectures of the Royal Institution. The remarks which are the most relevant to this topic are here presented.

Apparatus is an essential part of every lecture into which it can be introduced; but to apparatus should be added, at every convenient opportunity, illustrations that may not perhaps deserve the name of apparatus and of experiments, and yet may be introduced with considerable force and effect in proper places. Diagrams, and tables, too, are necessary, or at least add in an eminent degree to the illustration and perfection of a lecture. When an experimental lecture is to be delivered, and apparatus is to be exhibited, some kind of order should be observed in the arrangement of them on the lecture table. Every particular part illustrative of the lecture should be in view, no one thing should hide another from the audience, nor should anything stand in the way of or obstruct the lecturer. They should be so placed, too, as to produce a kind of uniformity in appearance. No one part should appear naked and another crowded, unless some particular reason exists and makes it necessary to be so. At the same time, the whole should be so arranged as to keep one operation from interfering with another. If the lecture table appears crowded, if the lecturer (hid by his apparatus) is invisible, if
things appear crooked, or aside, or unequal, or if some are out of sight, and this without any particular reason, the lecturer is considered (and with reason, too) as an awkward contriver and a bungler. 4

He says further,

An experimental lecturer should attend very carefully to the choice he may make of experiments for the illustration of his subject. They should be important as they respect the science they are applied to, yet clear, and such as may easily and generally be understood. They should rather approach to simplicity, and explain the established principles of the subject than be elaborate and apply to minute phenomena only... Let your experiments apply to the subject you elucidate, do not introduce those which are not to the point.

Apt experiments ought to be explained by satisfactory theory, or otherwise we merely patch an old coat with new cloth, and the whole(hole) becomes worse. If a satisfactory theory can be given, it ought to be given. If we doubt a received opinion, let us not leave the doubt unnoticed, and affirm our ideas, but state it clearly, and lay down also our objections. If the scientific world is divided in opinion, state both sides of the question, and let each one judge for himself, by noticing the most striking and forcible circumstances on each side. Then and then only, shall we do justice to the subject, please the audience, and satisfy our honour, the honour of a philosopher. 5

4. Bence Jones, loc. cit., A reading of the several letters dealing with this topic might be of interest to all science teachers.

5. Ibid., p. 78.
Chapter V

SUGGESTED DEMONSTRATIONS IN HEAT

The demonstrations in this chapter are presented as examples of that type which could be performed in the classroom by students alone or with the assistance of the teacher. The uses proposed are not the only satisfactory ones for the demonstrations set forth; these are merely suggestions for one method of presentation.

In a discussion of any of the areas of physics a good teacher will (as will good teachers of other subjects) try to present new material in a manner that puts the students in a habitual attitude of finding points of contact and mutual bearings. For example a teacher in discussing heat and thermal energy might ask his students to note particularly that these two concepts bear to each other the same relation as do work and mechanical energy. (The assumption is made here that mechanics is treated before heat.) This noting of relationships to something learned in an earlier course or in experiences of earlier life is an important part of the effective education of man. Dewey emphasizes this importance in the following

Almost everyone has had occasion to look back upon his school days and wonder what has become of the knowledge he was supposed to have amassed during his years of schooling, and why it is that the technical skills he acquired have to be learned over again in changed form in order to stand him in good stead. Indeed he is lucky who does not find that in order to make progress, in order to go ahead intellectually, he does not have to unlearn much of what he learned in school. These questions cannot be disposed of by saying that the subjects were not actually learned, for they were learned at least sufficiently to enable a pupil to pass examinations in them. One trouble is that the subject matter in question was learned in isolation; it was put, as it were, in a watertight compartment. When the question is asked, then, what has become of it, where has it gone to, the right answer is that it is still there in the special compartment in which it was originally stowed away. If exactly the same conditions recurred as those under which it was acquired, it would also recur and be available. But it was segregated when it was acquired and hence is so disconnected from the rest of experience that it is not available under the conditions of life.  

Although the complex theory of heat may be beyond the present capacity of some of the eleventh and twelfth grade students, there are many fundamental principles of this area of physics related to daily life which can be demonstrated by the teacher and students. In studying heat the teacher can take advantage of the fact that the lives of today's students have been inextricably related to applications of heat theory.

The automobile as a heat engine, the refrigerator, air conditioning units, the bellows-type thermostat such as is used in autos, the bimetallic thermostatic furnace control found in many homes, the application of heat to foods in cooking and canning, the stove as a heat unit, insulation of refrigerators to keep heat out and of ovens to keep heat in and insulation of the home to keep heat out in the summer and in during the winter, the flatiron, teakettles, pressure cookers, the various home heating units such as the steam radiator, hot water radiator and hot air convection type of units, thermometers, Diesel engines and jet engines are some of the devices of daily life which the teacher can utilize in relating principles of heat to the experiences of the students.

Much of the simple apparatus used in demonstrations in this area of physics can be manipulated well by students; in fact, well-performed student demonstrations in this area are more likely than in any other because of the familiarity and contact of the students with matters of a thermal nature. Some demonstrations which they can present are offered here.

**Demonstrations**

**Kinetic Energy and Temperature**
In teaching that heat is a form of energy one may point out that temperature is related to the kinetic energy of the vibrating molecules. A student can easily set up and present the familiar glass beads in mercury demonstration and he or the teacher can start a discussion on the matter of using vibrating molecules to measure temperature. See Cenco apparatus 77725 or Welch 1724.

Expansion

Demonstrations involving the expansion of various gases, liquids and solids are usually presented early in the study of heat to show how the expansion of substances can be used to measure temperatures and temperature changes. A major point to emphasize at this stage of the course is that at least two fixed reference points such as the ice point and steam point are needed in order to set standards of temperatures; these are familiar points of reference for the students. Among the equipment which can be used in demonstrations involving expansion and temperatures is the following:

The simple air thermometer such as Cenco 77305 or Welch 1603.

The linear expansion apparatus such as Cenco 77365 or 77370.
The ball and ring such as Cenco 77450 or Welch 1661.

The compound bar such as Cenco 77455 or Welch 1663.

The thermostat model such as Cenco 77460 or Welch 1275A or 1275B.

The liquid expansion tube such as Cenco 77465 or Welch 1673.

All of these can fit easily into student or teacher performed demonstrations on the subject. The linear expansion apparatus, the compound bar and the thermostat models can be improvised from inexpensive materials if otherwise unavailable; the making and demonstrating of these could constitute special student projects. A discussion relating the physical principles of expansion to the activities and experiences of daily life might include the preparations that engineers make in allowing for expansion of bridges and highway sections, the matter of heating a bottle neck and cooling the stopper in order to remove a tight stopper, the partial vacuum seal which one obtains in modern canning, the thermostatic controls for the furnace and oven and the many types of thermometers in daily use.

Conservation of Energy

The relation of heat energy to other forms of
energy can be shown by demonstration experiments using the Joule-Rowland mechanical method and the resistance-wattmeter electrical method. Students could build the equipment needed from inexpensive materials if no commercial apparatus is available. There are countless examples of the transformation of energy from one form to another and the many types of heat engines provide an opportunity for introducing the mechanical equivalent of heat and the familiar law of conservation of energy related to the demonstrations. Some student might like to gather some background material on the demonstration by reading of the lives of Count Rumford, Joule, Helmholtz, and Mayer.

Change of Phase

Change of phase is usually discussed in this area of physics and a dramatic demonstration using large scale apparatus can be presented to show the great decrease in volume which accompanies the condensing of steam to liquid water. The apparatus commonly used in this demonstration is a one gallon varnish can. Five gallon cylindrical floor wax cans obtainable in the school or in some other community building are large and of such physical form as to give a de-
layed and sudden collapse instead of the gradual and continuous crushing which is characteristic of a rectangular can.

Pour fifteen to twenty cubic centimeters of water into the wax can and light a gas burner placed beneath the can. In a short time steam will issue from the can. Allow the steam to discharge for one or two minutes, thus forcing the air molecules out of the can and replacing them with water vapor molecules. Turn out the flame beneath the can and screw the lid on tightly. A pair of leather palm gloves will prevent burns. With the lid tight and the burner removed, pour three or four hundred cubic centimeters of cold water on the top of the can and then step back. The water vapor in the can then condenses on the underside of the top and drips to the bottom; do not let the dripping sound mislead you to thinking that the good lid which was used is now leaking, for an effort to retighten the lid may cost a hand. The volume change from the vapor state to the liquid state is of the order of 1800 to 1 so that there is a good partial vacuum in the can. The cylindrical can resists the air pressure uniformly until the difference in the pressure of the vapor inside the can and that of
the air outside becomes so great that at some relatively weak spot the can begins to collapse. When it begins, the crushing is almost instantaneous and involves sudden noise and the throwing of the cooling water from the top surface of the can. If it has not crushed after one or two minutes of cooling, a slight tap with a stick on the side of the can will hasten the desired results. Under no circumstances should the demonstrator or any student touch the walls of one of these cans when it fails to perform as one plans; the forces involved are tremendous and accidents should be avoided at all costs.

The demonstration described is a good one for the showing of the principles involved in phase changes, for stimulating interest in further study, and for injecting a dramatic moment into a quiet classroom; it is straightforward and safe if the precautionary measures mentioned are taken.

The post-performance discussion might include changes of phase from liquid to solid state and the resulting expansion or contraction that is involved, sublimation of various substances, the processes of expansion, liquefaction and the heat interchange involved in the operation of a mechanical refrigerator;
one might even lead the students in a discussion of the anomalous behavior of water. In this section of heat the terms latent heat of vaporization and latent heat of fusion might also be introduced.

Heat of Fusion of an Ice Cream Mixture

Many physics teachers perform a sample experiment on heat of fusion or heat of vaporization and then have the class perform a similar experiment in the student laboratory. Some teachers present no demonstration on the subject and have no laboratory experiment which permits the students to participate in actively learning about this phase of heat. The demonstration which follows is presented as a type which can be used for obtaining quantitative results, if desired, or for teaching scientific method. It is an example of a cooperative teacher-student presentation.

The teacher might introduce the demonstration as follows: "This is one point in the physics course at which flavor can be added to physical principles. Let's do an experiment with the following materials: 3 sugar, milk, vanilla, ice, salt, a steel calorimeter, and a wooden calorimeter jacket.

3. A certain amount of cream is desirable, but to simplify the phraseology and the presentation, the liquid is referred to as milk.
"The purpose of the experiment is to determine the latent heat of fusion of a mixture of the first three substances listed. We shall place the mixture in a thin-walled steel calorimeter which conducts heat well; if the mixture is cooled sufficiently, it will reach a temperature at which the liquid will fuse or solidify.

"If we know the weight of the mixture and can determine the approximate number of calories it gives up in solidifying, we can then determine a latent heat of fusion for the mixture."

At this point the problem has been presented. The teacher might now by means of questions and suggestions get students to enumerate experimental factors involved and to plan the controls necessary to make the results reasonably conclusive. It is assumed that such necessary items as the weight of the mixture, the weight of ice melted, the using of a wooden jacket to prevent great gains of heat from the surroundings, and the relation of heat lost by the mixture to the heat gained by the melting ice will be included in the discussion. A table for needed data may be developed on the blackboard. The teacher might suggest stirring of the mixture as a means of cooling it uniformly and point out that when the stirring becomes exceedingly difficult, the mixture will be fused. Without too much delay, proceed with the experiment."
Students can record the experimental data on the blackboard and can supply the man power needed to stir the mixture properly. The teacher might wish to do most of the weighing and mixing of ingredients in order to reduce waste, although there may be some skilled household assistants in the class who could perform these tasks.

When the stirring has become difficult the conclusion can be reached that the mixture has fused. Pour off the water carefully in order to keep salt solution out of the steel calorimeter; from the weight of the water determine roughly the amount of ice melted. From the known heat of fusion of ice, the quantity of ice melted, and the mass of the mixture, the latent heat of fusion of the mixture can be determined. Do this and then proceed to eat the results.

A hand crank freezer of four or six quart capacity can be obtained at most hardware stores, although some neighborhood owner of such a device might be willing to loan it in the interest of science. Crushed ice can usually be obtained where block ice is sold and the crushed form reduces the preparation mess in the classroom as well as in the home. Addition of ice cream salt to the ice in the ratio of one cup to five cups gives a cranking time of about twelve to fifteen minutes.
The quantity of materials used in this demonstration will depend upon the size of the freezer used, the size of the class and the size of the portions one intends to serve. Each teacher may wish to experiment at home to determine the quantity of materials and proportions needed for best results; this is not usually an unhappy bit of research.

This recipe can be used for making six quarts of ice cream. Dissolve three cups of sugar in a mixture of three quarts of homogenized milk and one quart of approximately ten per cent cream. Add three tablespoons of double strength vanilla. The recipe can be changed to fit other freezers; the can should never be more than two-thirds full of liquid.

Post-performance discussion might include the reason for using salt on the ice, the use of salt on icy sidewalks and highways, the real reason for stirring the ice cream mixture, how this is just a rough determination of heat of fusion, and the matter of using good insulation and good conduction where desired.

An experiment like the one discussed can be an aid to learning; it is in a broad sense a demonstration and may impart the very type of learning Dewey suggested we needed, for it is connected with "an
experience available under the conditions of life."
It may also be that part of a good demonstration
Faraday referred to when he said:

'Tis well when the lecturer has the ready
wit and the presence of mind to turn any casual
circumstance to an illustration of his subject.
Any particular circumstance that has become table
talk for the town, any local advantage or disad-
vantage, any trivial circumstance that may arise
in company, give great force to illustrations
aptly drawn from them, and please the audience
highly, as they conceive they perfectly under-
stand them.4

Sample Questions and Exercises

What of practical value can students learn from
this area of physics? How can the important prin-
ciples of this area of physics be further related to
the daily living of the pupils and how can the stu-
dents be given opportunities to do some reflective
thinking? The following list of questions might serve
as partial answers to those just asked. It might be
desirable to mimeograph such a list and to give copies
to the students to serve as guides for some of the
important ideas of this section of physics. From time
to time discuss pertinent questions in class. Some
of the questions may cause students to attempt ex-
periments from which they can get an answer.

What is the nature of heat?
What are the sources of heat?
How is the mercury thermometer made?
How does one graduate a thermometer?
How is the mercury thermometer limited?

Discuss thermometers for special uses:

Clinical
Maximum
Minimum
Maximum and minimum
Self-registering instruments

Expansion:

How much do solids expand?
Do solids expand in all directions?
What is the effect of unequal heating on such a solid as glass?
Can expansion of solids be made useful?
How do engineers deal with the expansion problem?
What is compound bar?

Uses: metallic thermometer
thermostat
balance wheel
What is elinvar?
How is elinvar used?
Solids and liquids expand on heating, do gases?
What effect does expansion have on density?
What is unusual about the expansion of water?
What is specific heat and how is it determined for a given substance?
How significant to life is the high specific heat of water?
   In relation to the weather?
   In relation to the human body?
What is fusion?
Does the expansion of water upon freezing help us? If so, how?

Vaporization:
What is vaporization?
What effect does each of the following have upon vaporization?
   Nature of the liquid
   Area of exposed surface
   Temperature of liquid and surroundings
   Humidity
   Breeze
What is sublimation?
What is the effect of pressure on the boiling point?
Why is pressure cooking necessary in some areas?
What is distillation?
How distinct is the boiling point of a given liquid?
What is the "heat of vaporization" of a substance?
How can one determine the "heat of vaporization" for a substance such as water?
Why does evaporation produce cooling?

Transfer of heat:
What is conduction?
Do solids conduct heat?
Do liquids conduct heat?
Do gases conduct heat?
In making ice cream, why is the cream usually put into a metal container and the ice in a wooden vessel?
How does clothing keep us warm?
How can insulators be used to conserve fuel?
What is convection?
What is air conditioning?

1. Discuss the importance of humidity.

2. Discuss the importance of the temperature.

3. How are cleanliness and the motion of the air related to good air conditioning practices?

What is radiation?

Would black radiators be desirable for some of the types of heating systems such as hot air, hot water, steam, vapor heat, radiant heat, solar heat?

How is heat energy related to mechanical energy?

How does the steam turbine operate?

How does a gasoline engine work?

Why is it important to cool an engine?

How does the Diesel engine work?

Read in Magie's *A Source Book of Physics* concerning the work of one or more of the following men: Boyle, Charles, Diesel, Joule, Kelvin, Rumford, Watt.

Related Projects

1. Study the anomalous behavior of water, using apparatus such as Cenco 77480 or Welch 1671. Ice and water are placed in a tall vessel and the temperature of the mixture at various levels is recorded every
fifteen minutes for several hours. The student might report to the class on the results of the experiment and draw the parallel between the experiment and actual water conditions for bodies of water.

2. Compare the following heating systems as to economy and efficiency: hot air, hot water, steam heat, vapor heat, radiant heat, solar heat.


4. Study the life of and prepare a report on one or more of the following: Boyle, Charles, Diesel, Joule, Kelvin, Rumford, or Watt.

5. Compare insulating materials used in air conditioning, refrigerators, stoves, and homes.

6. Have some student propose an experiment which members of the class might attempt in order to determine the relative cost of operation of gas type refrigerators and electrical refrigerators.

7. Some student might desire to make a model geyser, which would have at least one use in showing the relationship of pressure on a liquid to the boiling point of the liquid. A study of the natural geysers might be made concurrently.

Some of the demonstrations suggested in this chapter
and those experimental projects proposed are especially suited for student presentation at school open houses and parent-teacher nights.
Chapter VI

SUGGESTED DEMONSTRATIONS

AT LOW TEMPERATURES

Since much of today's atomic research is concerned with the physical properties of matter at low temperature, there is a need for introducing to the general public as well as to our future scientists the behavior of some substances at lower temperatures than those normally encountered in our environment. In the past low temperature demonstrations have been performed from time to time by lecturers who used liquid air to make mercury hammers, to freeze eggs, and to make rubber brittle in order to amuse and amaze the audience. Five or ten years ago when the price of liquid air was prohibitive and when it was impossible to obtain the liquid except in a few large cities, such a lecture was justified.

Now, however, liquid nitrogen, which is safer to handle than liquid air, can be purchased cheaply locally from nearly any supplier of gas compressed in cylinders. Liquid nitrogen can be obtained for less than one dollar per liter; ten liters would suffice for even

1. Stale liquid air may have a high percentage of oxygen because the nitrogen in it has a lower boiling point and would thus vaporize more readily.
large scale demonstrations and would probably leave some to spare. Thus it has become practical for the physics teacher to perform low temperature demonstrations in the classroom or, with the aid of the science club, or physics club and classes, to present low temperature demonstrations to the entire student body at an assembly program. In the latter instance it might be possible to obtain the liquid air with money from the assembly program funds.

In the smaller schools, a performance such as that proposed here (1) need not deplete the physics funds, (2) gives the physics teacher an opportunity to interest those students in future study of physics who might otherwise never consider it, (3) affords an opportunity for interested students and clubs to perform before an audience, and (4) gives the teacher an opportunity to present to the student body which may include small science classes certain important phenomena which might not otherwise be shown to them.

Planning

There are several demonstrations which can be devised from low cost materials for use with liquid nitrogen. The major expense (except for the liquid itself) in preparing for yearly liquid nitrogen demonstrations,
is in purchasing small insulated vessels for holding the liquid which is to be used. The vessels commonly used are called Dewars and are generally double-walled pyrex glass vessels which have been silvered, evacuated, and sealed. Ordinary commercially available thermos bottles will serve the same function — the sole danger in their use being that they are made of soft glass which may break if the liquid nitrogen spatters unevenly on the lip of these vessels, that area where they are thinnest and which may not be well annealed. Liquid can be poured carefully into them directly without touching the lip. Various items such as carrot strips, a small length of rubber hose, a balloon, cellophane, and other articles can be safely dipped into Dewars containing liquid nitrogen so that the low temperature properties of these substances can be studied.

A more practical substitute for Dewars can be readily fashioned from blocks of the snow-white multi-cellular polystyrene foam known as "Styrofoam" which is

2. See Sutton, op. cit., p. 224, for a diagram of a simple method of removing liquid air from a Dewar flask.
produced and marketed by the Dow Chemical Company. 3
Styrofoam has those properties generally considered
to be most essential in a low temperature insulation
material -- among these properties are its excellent
resistance to moisture, low thermal conductivity, low
density of two pounds per cubic foot, and relatively
low cost of approximately $1.00 per cubic foot.

In fashioning serviceable liquid nitrogen con-
tainers from Styrofoam one needs a block of the ma-
terial which can be handworked with the aid of a hack-
saw blade. The walls of the vessel need be no more than
one inch thick. 4 One can build several containers from
one block of the substance by forming successively
smaller cylinders from the block and fitting each cy-
linder with a bottom which is formed of a one inch
layer of Styrofoam. The walls and bottoms can be ce-
mented together with adhesives containing alcohols or

3. Inquiry regarding local purchases and physical
properties of the material may be made by corres-
dponding with the Dow Chemical Company, Plastics
Division, Midland, Michigan.

4. An amazing revelation for the students comes when a
small block of the substance has some liquid nitro-
gen poured into a hole drilled in the block. This
can be passed around the room; the liquid nitrogen
does not evaporate instantly but remains for all to
see and at the same time feel the outer walls of the
container which remain virtually at room temperature.
When one points that the temperature gradient across
the thin walls is of the order of 200 Centigrade de-
grees per inch, the properties of the container seem
even more fascinating.
water; some plastic adhesives work well and water-soluble glue is a good adhesive in forming liquid-tight seals. Four or five containers of capacity from one-half liter up to four or five liters can be fashioned at a total cost of two or three dollars.

These containers are safer to use than the fragile thermos and the heavier Dewar and with little care will last much longer. Not only can the pyrex Dewar and the thermos be broken by sudden temperature changes, they may break when mishandled. Containers made of Styrofoam can be dropped onto the floor or accidentally bumped without damage.

Demonstrations

Among the numerous demonstrations which can be performed at low temperatures are some which involve inexpensive stage props such as fresh eggs, carrot sticks or celery stalks, small rubber balloons, and other materials. One can prepare the class or audience for the demonstrations by discussing the Fahrenheit, Centigrade and Kelvin scales of temperature. A sketch of equivalent readings on three thermometers (one for each of the three scales) for several reference temperatures and some oral suggestions can soon have the audience thinking how cold 0°C Centigrade is. It may be easy then to
lead the audience mentally to the cold temperature which is represented by liquid nitrogen at atmospheric pressure (less than -195.8°C). It may be helpful to suggest that Alaskan winter temperatures of -68°F are like those of the fiery furnace when compared to the temperature at which nitrogen liquefies. The next step might be to point out that some substances which are normally thought of as liquids may solidify if their temperatures are lowered sufficiently.

Mercury Hammer

At this stage it is possible to prove one's point by pouring mercury into a match box tray which has been fastened to a small wooden handle by means of a thumbtack. The handle and hammer mold (the tray) have previously been placed in a crystallizing dish so that any spilled mercury can be easily retrieved; the dish rests on a one-half inch thick insulating slab of Styrofoam. Probably not more than 250 ml. of liquid nitrogen will be needed to freeze the mercury and cool the dish; the nitrogen can be poured into the dish and over the mercury from one of the small Styrofoam containers mentioned earlier or it can be transferred from a Dewar, if the proper transfer tube is available. (Do not attempt to pour from a Dewar into another container;
dodging flying glass can be dangerous!)

Now, while the mercury is freezing, insert a short length of lightweight rubber tubing into one of the containers of liquid nitrogen; a piece some sixteen to twenty inches long is large enough. Some liquid air may run up the tube and spurt from the free end when the other end is first immersed in the liquid. The spray may amuse the observers if surprise is feigned. While the rubber freezes, the demonstrator steps to the mercury hammer to see whether it has frozen. It is likely to be solid; if it is, the match box mold can be removed and the hammer put into service. A block of soft wood on the table makes a convenient receptacle for some eight or ten pennyweight nails which can be driven vigorously. (The nails should be broad-headed, not the finishing type, because the mercury hammer may soften!)

Turn then to see how the rubber is behaving at low temperatures. Lay the cold end across the block used above and hit it with the mercury hammer; the frozen tubing shatters. Some pieces can be thrown to members of the audience so that they can see and feel hard rubber in a new form. In a few minutes when the rubber has softened, the attention of the audience can be called to the softening by throwing or sending
via helpers the now soft pieces of the shattered tubing to the audience. It could be pointed out that the demonstrator will pour the hammer back into its bottle, whereupon the mercury hammer is placed in a glass funnel, visible to all, with the stem leading into the bottle from which the liquid mercury was poured originally.

The Chlorine Flask

Liquid nitrogen can be used to liquefy other normally gaseous substances with melting points above that of nitrogen. Chlorine is one such substance and it is an interesting one to work with for several reasons. (1) Chlorine has a distinct color in the gaseous, liquid, and solid states. (2) With liquid nitrogen as a coolant, chlorine gas is readily liquefied (boiling point -34.6°C); and if its containing vessel be immersed for a short while in the liquid nitrogen, the chlorine liquid soon solidifies (melting point -101.6°C). (3) Historically, it is important in the field of liquid gases for it was the gas which Faraday first succeeded in liquefying early in his career at the Royal Institution of London.

Provided one has a sealed flask which contains chlorine gas this demonstration is very simple, for one merely lowers the tip end of the sealed flask into a container of liquid nitrogen and watches as
the greenish gas disappears from the large portion of the flask into the tip. With drawal of the flask tip from the liquid nitrogen reveals a bright yellow crystalline substance clinging to the inner surface of the tip. If one inverts the flask so that the wide base now rests on the table (the upright position), all who are present may be able to watch the oily green liquid run down the walls of the flask and suddenly vaporize. What was momentarily a flask with a yellowish solid occupying a small space soon becomes a flask filled again with gaseous chlorine.

A Method for Storing Natural Gas

Where natural gas is available one should have little trouble in presenting this demonstration. A small distilling flask such as Cenco 27479B is adapted near the base so that lightweight rubber tubing can be fitted to it and so that the gas enters at the bottom through this tubing. The stopper outlet can be heated and drawn to a jet form so that with the gas entering at the bottom a flame can be lighted at the top. The flask then is lowered into a container of liquid nitrogen and the flame dies because the natural gas liquefies and then solidifies.

The tubing is then disconnected at the gas supply
outlet and a clamp placed on the tubing so that the audience can see that no gas now enters the flask. On removing the flask from the liquid nitrogen bath, one hand can be used to warm the flask so that gas will again issue from the jet whereupon a match is touched to the jet and a flame bursts forth. Both hands then can be used to warm the flask and increase the size of the flame.

The possibility of using this method of storing gas during the summer for expected winter shortages may be discussed jokingly. (It is probably not an economical storage method.)

Other Low Temperature Demonstrations

Among other demonstrations which can be presented in the field of low temperature are the following. 1.- A small rubber balloon can be inflated until it is visible to all present. By lowering one end of the balloon into the liquid nitrogen in one of the containers it is possible to liquefy most of the air. The balloon is now about the size and shape of one which has not been inflated. It may be placed on a table or held by an assistant so that all may observe its re-inflation as the liquefied air again becomes a gas.
2. Vegetables (carrots, peppers, radishes) may be frozen in liquid nitrogen and shattered by the blow of the unmelted mercury hammer or the block of wood used earlier with that hammer.

3. One demonstration which is said to work well is that in which a squirming goldfish is removed from a beaker of water and immersed in the liquid nitrogen, frozen stiff, and then returned to the beaker of water. The fish soon revives and swims merrily on.

4. One humorous demonstration is that in which the lecturer "cooks" one or two fresh eggs by lowering them, shells and all, into a container of liquid nitrogen for several minutes. The eggs may be broken after freezing to show that exothermic "cooking" is the converse of the normal endothermic process as a one minute (after removal from the liquid nitrogen) egg is hard boiled and, while a three minute egg might be soft boiled depending upon the original

4. The demonstrator might tell the audience about a medical adaptation of the quick freeze technique which uses compressed carbon dioxide to make possible diagnosis of suspected cancerous material in the histology laboratory while the patient is still on the operating table. Freezing a bit of tissue with a stream of carbon dioxide makes a microscopic study possible within a few minutes while the usual process of hardening tissue so that it can be sliced thin enough for microscopic study takes hours.
"cooking" time, a fifteen minute egg would definitely not be a welcome addition to a lunch pail. The ingenious demonstrator might wish to try his hand at poached eggs à la crystallizing dish.

5. The final demonstration to be discussed is one which makes a nice finale for liquid nitrogen demonstrations. Little apparatus is required. One needs only an ice bomb such as Cenco 77715 or Welch 1670, a small plastic bag or five pound paper sack, and a protective well such as that formed by an empty five gallon paint bucket. In preparation for the demonstration, the bomb is filled with water which has been previously boiled to expel the air and is tightly stoppered with the plug provided. To use the nitrogen most effectively if only a small quantity remains or to hasten the explosion, the loaded bomb may be placed in a vessel of cold water before any of the demonstrations have been presented. It is now placed in the bag within the five gallon well where a piece of Styrofoam on the bottom of the bucket will serve as an insulator.

Since this is the last experiment one may pour as much as a liter or more of liquid nitrogen into the bag containing the bomb. After covering the bucket, one should step back. This bomb will burst with a loud report within a minute after the nitrogen has been ap-
plied. The purpose of the five gallon well is to protect the unwitting observer from the supercooled water which splashes from the bursting bomb. The ice formed in this manner is odd looking and is worthy of comment and of study by the audience. One has enough time to warn the audience, when the liquid air is poured over the bomb, that the engine block of a car may suffer a fate similar to that of the cast iron bomb if it is not protected with antifreeze and there is a sudden cold spell.
Chapter VII

SUGGESTED DEMONSTRATIONS IN LIGHT

Several relatively simple demonstrations are presented here with the belief that they can serve the willing teacher as guides for getting color into the classroom coincidentally with physical principles. The majority of light demonstrations are usually set up so that they can be seen by only one person at a time; it is desirable to have all students see the same phenomena at the same time. The demonstrations described in this chapter are of such a nature that the class members can observe the same phenomena simultaneously.

There is no good reason to believe that students are interested only in the principles of reflection and refraction, just because a book in discussing light presents only mirrors, lenses, and prisms. Demonstrations with mirrors and lenses can be fascinating; but interference demonstrations can be truly colorful as well as fascinating and the teacher may have an opportunity to present intriguing material which is not always offered to high school students. Some teachers may desire to discuss interference phenomena in one
class period. If such is the case, any or all of the demonstrations which follow may be performed within this time. Expansion of the topic into a two or three day unit might be desirable where the students show an interest in studying some of the applications. The possibility of student projects and class field trips should not be overlooked.

The theory related to these demonstrations can be reviewed in almost any first year college physics text and will not be discussed here.

**Preview**

The basic understanding which is necessary in the matter of interference of light is of Huygen's principle. While the light source is being warmed for the single slit diffraction pattern demonstration, the teacher might discuss and sketch ideas related to the Huygen's principle and Young's interference experiment. A comprehension of them will aid in understanding the demonstrations on the single slit, the diffraction grating, and the soap film interference patterns.

**Single Slit Diffraction Pattern**

The intensity of the single slit interference pat-
tern is so low that the pattern cannot be projected satisfactorily. The usual demonstration consists of a two slit setup at the lecture table which can be viewed by the individual students who file by the apparatus singly. Such a procedure can lead to confusion in the classroom, class time may be wasted, and not all students view simultaneously the same phenomenon. There follows one satisfactory setup by which all students in the class are enabled to view together the diffraction pattern of the single slit.

Desirable Apparatus

One monochromatic light source such as Cenco 87300 sodium arc lamp or Welch 3720A flame burner.

One vertical adjustable slit such as Cenco 86140.

Procedure

Start the light early enough before you wish to use it so that it will have reached maximum intensity

1. Perhaps reference to American Journal of Physics, XX No. 5 (May, 1952), p. 309 and p. 311, will be helpful. Articles on those pages deal with a flame source for spectroscopy and a readily available mercury light source for use with a diffraction grating. Each teacher might profit by reading these, especially if he thinks he has no sources available for presenting the demonstrations discussed. Other good references are included in these articles.
when needed. The time required for this depends among other factors on the source you have available. For older arc lamps as much as ten minutes warm-up may be required.

Place the slit as near to the source as can be done conveniently and adjust it to approximately 1/64 inch width. Step back a few feet; by looking between two fingers of either hand held parallel to the slit one can observe the diffraction pattern.

In the usual classroom demonstration, two slits are needed. In the one just described, two are still needed, but one of them is furnished by each and every student who has two fingers with which to form the second slit. A "bow-fingered" student may have slight difficulties but the other hand of such a person may be used to reduce the bow. Each student by varying the width of the crude finger slit can change the separation of the black fringes observed.

Post-performance Discussion

One might describe how refined apparatus can be used to determine accurately the wave length of the light used, emphasizing the smallness of the wave length measurements. One might also discuss the pattern formation of sharp edges, suggesting that the
student try to determine the conditions under which interference patterns can be found around razor blades.

**Diffraction Grating**

With recent advances in ruling engines one can obtain, for a nominal cost (less than $5), a replica of a good grating which can be used to show the continuous spectrum obtained from white light and the dispersion of light from monochromatic sources such as a mercury arc.

**Desirable Apparatus**

- One lathe-type optical bench with carriages.
- One slit.
- One transmission grating replica.
- Two positive lenses of focal lengths approximately eight to twelve inches.
- One portable screen such as is used for a 16 mm projector.
- One white light source.
- One or more monochromatic sources such as an H-4 mercury lamp.

**Procedure**

In the following order arrange one light source, one lens, the slit, the grating holder, and the second
lens on the bench so that the center of each component part lies on a straight line. It may be advantageous not to have the light source on the optical bench but on the table at the proper end of the bench. Recognizing that exact positions will depend on the focal length of the lenses available, the preliminary arrangements are then as follows: (1) Set the slit at from 30 to 50 cm from one end of the bench, (2) adjust the slit width to about 1/8 inch, (3) place the light source at the nearer end of the optical bench and adjust the first lens so as to focus the light onto the slit. This is the first clue to obtaining good results rapidly -- get as much of the light concentrated on the slit as possible.

Now move to the second lens; adjust it so as to obtain a sharp image of the slit on the screen which is placed at the end of the demonstration table and which may be from 3 to 15 feet from the end of the optical bench. With the slit now in focus on the screen, insert the grating into the grating holder which has been placed on the bench between the slit and the second lens. There should now be on the screen one or more orders of the spectrum. Varying the slit width will bring about a variation in the width of the spec-
trum produced. During the practice run, one will probably set the slit at that width which gives a sharp spectrum that can be seen from all seats. Try the various available sources (the white light and one or more monochromatic lights).

The only manipulation in the classroom presentation of the demonstration is (1) the turning on and off of the sources, (2) the placing of them in turn in their proper source position in front of lens #1, and possibly (3) the varying of the grating position between the slit and the objective lens.

Many schools have a standard lantern slide projector which is stored with the rest of the school's projection equipment or which has been lying forgotten in some nook or cranny of a school closet. The objective lens of these projectors are often achromatic and are nice for use as the second lens in the above demonstration. If you use one from a projector, return it to the projector when the demonstration equipment is put away.

If perchance a school has two replica gratings, say a coarse one of approximately 2800 lines per inch and a finer one of some 15,000 lines per inch, the demonstrator may find it instructive to insert each
into the light path between the slit and lens #2 in order that the students might see the advantages of having fine line gratings. Some rough measurements of deviation of a given line of the spectrum and the distance from the grating to the screen will give amazing results on wave lengths which can then be compared to accepted values for the given wave length.

Post-performance Discussion and Possible Projects

The time here could be used to raise questions or discuss applications of diffraction, x-ray diffraction, the diffraction grating, spectrum analysis, use of spectrometers in crime detection work and in industry. The teacher might discuss the precision work involved in making gratings and replicas or might lead the interested student to read for himself applicable articles. (Projects?) Articles on ruling engines are to be found in *Scientific American*, CLXXXVI No. 6 (June, 1952), pp. 45-54, and CLXXXVII No. 1 (July, 1952), pp. 84-87.

Student projects might also stem from their reading

---

2. The Aluminum Company of America uses an applied device which can analyze an alloy within seconds for percentages of as many as twelve elements.
concerning one or more of the following men regarding their contributions to our knowledge of light: Fizeau, Foucault, Fraunhofer, Huygens, Michelson, Newton, Rowland, Wollaston, Wood, Young, and others.

Some students might be interested in setting up a pin hole instead of a slit and a wire gauze (very fine mesh) in place of the diffraction grating in the above mentioned demonstration to note the pattern produced. The helpful clues here are: (1) with lens #1, focus the light onto the pinhole; (2) with lens #2, get a sharp image of the pinhole on the screen; (3) insert the screen where the grating would have been, between the pinhole and lens #2.

Some students might wish to develop a crude ruling engine to make a rough grating on a plastic surface. Others may desire to investigate various light sources for use with interference demonstrations.

Soap Film Interference

Ordinary green liquid soap, which the janitor keeps in his supply closet, is one substance which the physics teacher may have overlooked in his quest for demonstration materials. It gives the teacher an opportunity to present God’s wondrous colors to the students. A piece of baling wire (or some other type of wire in

---

3. See footnote 1.
size 14 or 16) twelve to fourteen inches in length can be formed into a rectangular frame $1\frac{1}{2}$ by 3 inches with the remainder serving as a handle. When this is cleaned by washing any grease from the wire (using soap or any household cleanser), a soap film will cling to the frame after it has been dipped into a beaker filled with the concentrated green soap solution. The soap solution can be returned to the janitor when the demonstration has been performed. (An extra performance for the benefit of the janitor may be rewarding to both the janitor and the teacher. He may not have seen such colors before and will probably appreciate their beauty as do the students; then, too, the cooperation of the janitor is no hindrance to the physics teacher who may need to borrow tools or scout around for scrap lumber from time to time.)

Desirable Apparatus

One transparent air protector.

One wire frame.

One source lamp (incandescent white light).

One plano-convex lens.

One small beaker containing enough soap solution so that the wire frame can be immersed.
Procedure

Set up the apparatus so that the image is to be formed on the screen used in the previous demonstration of the diffraction grating. The transparent air protector can be fashioned from glass, lucite, or any clear plastic; a frame over which cellophane or some other lightweight clear plastic has been fastened will serve equally well; a small empty aquarium might also be useful. The purpose of this device is to retard the drying and consequent breaking of the soap film.

Suspend the wire frame with stretched soap film in the air protector. Direct the white light source onto the soap film at an angle of incidence of approximately 45° with the film. Focus the light beam reflected from the film onto the screen by means of the lens; the best interference pattern is usually observed when the wire frame itself is sharply outlined. Bright shades of many colors will be present. Best results are obtained with the room darkened.

Post-demonstration Suggestions and Possible Projects

A demonstration of Newton's Rings may accompany the above; apparatus is available commercially at reasonable prices for showing Newton's Rings by reflection as well as by transmission of incident
light⁴. A meaningful discussion of the colored oil spots on the highway might follow either the soap film demonstration or the one of Newton's Rings. The mechanically inclined student may be inspired to read about the critical use of Johanssen blocks in the mass production of automobiles and the interference method of checking their accuracy. Some students may wish (projects) to look into the interference pattern of a Boy's cup⁵. Various soap solutions may be studied for their different patterns and staying times⁶.

**Possible Related Studies**

There is a movie on light waves and their uses which might well be shown.

In the over-all discussion of interference of light one might direct the attention of the class to some demonstrations on polarized light. Polaroids are cheaper today than when first developed, and their many uses in daily life may make a study of their properties

---

4. Directions for setting up such a device with equipment found around the laboratory are given on p. 369 of Richardson and Cahoon, *op. cit.*


worthwhile. If it is not planned to present a formal discussion of this phenomena, then related projects could be developed by students as a further step in their study of interference.

Other colorful aspects of light which could be taken up in class discussion, in project work, or in the laboratory are those related to the use of ultraviolet and infrared light by the armed forces and civilian authorities. The sniperscope, invisible inks and fluorescent powders might all be considered as discussion matters and are topics which lend themselves readily to individual and class projects.

Interference and diffraction, soap film studies, polarization, ultraviolet and infrared lighting, and fluorescence all can add to the earlier learnings of reflection and refraction in giving today's students a fuller understanding of the nature of light.
Chapter VIII
SUMMARY AND RECOMMENDATIONS

The purposes of this thesis were (1) to determine possible uses of the demonstrations in teaching high school physics, (2) to suggest ways in which demonstration procedures and methods could be made more effective, and (3) to present several specific demonstrations giving explicit teaching procedures and proposing sample projects, questions, and exercises to accompany the demonstrations.

Important uses of demonstrations in teaching high school physics were determined by studying several books published within the past fifteen years, by studying several recent theses on the use of demonstrations in teaching various science courses in high school and by studying related articles which have appeared in recent magazines and professional periodicals. Some of the uses suggested were: (1) stimulating thinking, (2) teaching scientific method, (3) motivating students, and (4) relating abstract ideas to daily life.

Suggestions were made to aid in planning, in preparing, and in presenting demonstrations. The matters of storing apparatus, assembling demonstration equip-
ment, protecting the students, and the importance of practicing all demonstrations were discussed. In addition a checklist of important related points was included.

Several demonstrations were suggested in the areas of heat and light, and some demonstrations using liquid nitrogen were presented. Those in the area of heat were proposed as likely ones to be presented by the students with some assistance and guidance from the teacher. The low temperature demonstrations were presented as examples of the type of demonstration which could be performed before large groups as well as small classes. The demonstrations in light were suggested as a means for the teacher to get beautiful colors into the physics classroom.

Similar theses might be prepared in the future for such areas of science as chemistry and biology.
BIBLIOGRAPHY


DeMorgan, Augustus  
*Essays on the Life and Works of Newton.*  

Dewey, John  
*Democracy and Education.*  

Dewey, John  
*Experience and Education.*  

Harsanyi, Zsolt  
*The Star Gazer.*  

Heiss, Elwood D., Obourn, Ellsworth S., and Hoffman, Charles W.  
*Modern Science Teaching.*  

Ingalls, Albert  
"Ruling Engines,"  
*Scientific American,* CLXXXVI (June, 1952), 45-54.

Ingalls, Albert  
"The Amateur Scientist,"  
*Scientific American,* CLXXVII (July, 1942), 34-37.

Jones, Dr. Henry Bence  
*Life and Letters of Faraday, Vol. I.*  

Kuehner, A. L.  
"New Tough Films and Bubbles,"  
*Journal of Chemical Education,* XXV (April, 1948), 211.

Larsen, K. D. and Keck W.  
"A Flame Source for Spectroscopy,"  

Magie, W. F.  
*A Source Book in Physics.*  

Mertz, Forrest W.  
"Using the Automobile in the Teaching of Physics."  
<table>
<thead>
<tr>
<th>Author</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morgan, James G.</td>
<td>&quot;The Use of Demonstration in Teaching for Scientific Thinking.&quot;</td>
</tr>
<tr>
<td></td>
<td>Unpublished Master's thesis, The Ohio State University, 1940.</td>
</tr>
<tr>
<td>Rinear, Louis C.</td>
<td>&quot;Large Scale, Home Constructed Equipment for Science Demonstrations.&quot;</td>
</tr>
<tr>
<td></td>
<td>Unpublished Master's thesis, The Ohio State University, 1940.</td>
</tr>
<tr>
<td>Rusk, Rogers D.</td>
<td>How to Teach Physics.</td>
</tr>
<tr>
<td>Sutton, Richard M.</td>
<td>Demonstration Equipment in Physics</td>
</tr>
<tr>
<td>Twiss, George R.</td>
<td>A Textbook in the Principles of Science Teaching.</td>
</tr>
</tbody>
</table>