# THE DEVELOPMENT OF CERTAIN CONCEPTS OF PHYSICS IN HIGH SCHOOL STUDENTS.

## AN EXPERIMENTAL STUDY.

BY

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# CHAPTER I.

## THE PROBLEM.

*In this study an attempt is made to contribute something to the problem of subject-matter and method in* High School Physics and General Science *from the* point of view of conceptual development.

In recent years much attention has been focussed on the problems of educational measurement with the result that numerous tests have been devised and standardized for the purpose of measuring objectively the products of teaching. A few tests in the field of High School Science have also been constructed. This widespread interest in measurement, however, partially eclipsed the long standing and important questions of method and subject-matter and teachers appeared to be more interested in applying tests of attainment than in the learning process itself.

The standardized science test, however, actually is throwing into relief the very problems which it appeared to be overshadowing. Test results have to be accounted for, and one is soon face to face with the real problems of the class-room and the laboratory. Thus we find recent studies of Webb and Dvorak to determine the suitability of various types of subject-matter and method in General Science and that of Powers into the difficulty of the subject-matter of High School Chemistry. The next step, obviously, is to supplement our standardized achievement tests in Science by diagnostic test units and by methods of remedial instruction. It is not the purpose of this study, however, to develop a scale of diagnostic tests, but rather to conduct preliminary investigations into the problems of subject-matter and method, the results of which may be of use and guidance to future constructors of diagnostic tests and of remedial methods of teaching in the field of High School Science.

From the point of view of psychology, one aim of science teaching should be to provide the pupil with such experiences as would increase his store of concepts, qualitatively as well as quantitatively. Old concepts should be changed and developed into richer and more scientific concepts. New concepts should also be formed. When the child first enters the Physics class he is equipped with a store of concepts all his own; he has his notions of Heat, Gravity and Weight, notions that were built up unreflectively without any consciously directed thinking. These are what Ernst Mach calls the "instinctive" notions, the vague or naive notions which the study of science is supposed to develop into logical or scientific concepts. It is one purpose of this study to find out just what some of these "instinctive" notions are.

The building of concepts is not an end in itself; on the contrary, concepts are merely valuable tools for further investigations, their value being proportional to their significance to the pupil. Thus the formation of the concept Mass by a pupil is not the end but rather a tool of operation in the further study of Mechanics or Dynamics. It will be recalled that this concept was first formed by Sir Isaac Newton as a necessary means of further investigation. Similarly, the concept of Weight as a force may or may not be more useful intrinsically than the notion of Weight as heaviness; in fact the latter notion seems to be adequate for all practical and every-day affairs. But for further scientific investigation, or for the formation of later concepts, a scientific concept of Weight is absolutely necessary and prerequisite.

The study of science should not only enable pupils to form entirely new concepts, that is, concepts with which they have previously been unfamiliar; but it should also enable them to change their naive notions to scientific concepts. With this thesis in mind, the writer attempted to find out whether the study of Physics or General Science does produce a change in pupils' notions.

The method of deciding whether a concept is naive or scientific was in accordance with Dr. Dewey's criterion, viz:— "Our conceptions attain a maximum of individuality and generality (or applicability) in the degree to which they show how things depend one upon another, instead of expressing the qualities that objects possess statically....A scientific definition is founded, not on directly perceived qualities nor on directly useful properties, but on the way in which certain things are causally related to other things, i.e. it denotes a relation." [1]) The "heaviness" notion of weight would, therefore, be classified as naive or vague, whereas the notion that weight is a measure of the attraction between the earth and a mass would be regarded as scientific.

An attempt will also be made to trace certain very prevalent naive or erroneous notions to their geneses and to discover why some concepts do not become scientific in spite of formal science teaching. This will be done by detailed study of existing notions of pre-science students, by examination of individual pupils or by observation and examination of pupils under controlled conditions of teaching. This study is divided into two parts. Part I is concerned with the collection of data on existing concepts whereas Part II gives the results of causal investigations into the conditions found in Part I of the study.

The field of Physics is so wide and so much is attempted in the High School course, that it would be a tremendous task to treat all subject-matter in the proposed way, that is, to classify data qualitatively as well as quantitatively. In the majority of the newer types of examinations and tests responses are scored as either right or wrong and little attempt is made to analyse the wrong responses qualitatively. This method of treating results, however, is essential to this study. For this reason it was thought that a detailed analysis of a representative sampling of subject-matter would throw more light on problems of science teaching than a general survey of the whole field of Physics.

(1) Dewey "How we think", p.134.

## CHAPTER II.

## SURVEY OF OTHER STUDIES.

Studies on concepts held by children and especially by High School pupils are scarce and the writer has been able to trace only a few relating to the sciences. There is plenty of literature and much discussion on concepts, their nature and formation, from the viewpoints of both the formal logicians and the psychologists. Interesting as these may be, it is beyond the domain of this study to treat concepts from these points of view.

During the child study movement great importance was attached to and much work done on the types of concepts held by children. G. Stanley Hall [1]) carried on investigations to discover children's ideas of Fire, Clouds, Weather etc. To quote from his findings, "Thus it appears that children as early as five years do understand that there is some connection between weather and thermometer. Their first impressions are that the thermometer controls the weather......From eight years on the notion that weather affects the thermometer is prevalent, but the child does not know how." In the case of Heat, he found that most of the young children he examined thought of it as Fire, a notion evidently built up through experiences with fire. Investigations of this kind were also made in Europe, by Olsen [2]) in Denmark and by Hartmann in Germany [3]).

Another study is that of Chambers [4]). His method consisted of selecting certain words and of asking school

(1) Hall, G. S. Content of children's minds on entering school.
(2) Olsen J. "Children's ideas" Paidologist Vol. 2 1900.
(3) Hartman J. "Die analyse der kindlichen gedanken kreises".
(4) Chambers J. "How words get meaning" Ped. Sem. 1904.

the new concepts must be built are of infinitely greater qualitative variety and wider quantitative range than even the most scattered results of a term's instruction."

Webb's other study relates to the subject matter of General Science [1]. In an attempt to determine the difficulty of the various sciences composing General Science, certain "learning tests" were used. The child was allowed 2 minutes to study a piece of subject matter after which 4 minutes were allowed to answer certain questions to test assimilation of and power to apply the subject matter studied. This method has its advantages when used to make a preliminary survey of a whole field or type of subject matter, but it is not well suited to test in detail a specific piece of subject matter from one science such as Physics.

This study of Webb and that of Powers [2] into the subject matter of High School Chemistry are examples of the diagnostic methods to which all the High School sciences will have to be subjected.

Dvorak's "Study of Achievement and subject matter in General Science" [3] is a study of the General Science curriculum. A set of 300 questions was given to pupils who had and had not studied General Science in the 8th and 9th grades, also to pupils of the higher grades. By an analysis and statistical treatment of the results of the test questions, he obtains a standardized General Science test. He finds that many pupils are familiar with much of the material of General Science before taking the course and concludes...."the fact makes it desirable, if not imperative, to classify pupils....on the basis of their previous knowledge of the subject." Dvorak calls his final scales "Diagnostic Tests....which will serve to place pupils into sections homogeneous as to the point at which their General Science course should begin and *as to what*

(1) Webb H. A. "General Science Instruction in the Grades". Geo. Peabody Contrib. to Educ.

(2) Powers S. R. "Diagnosis in H.S. Chemistry".

(3) Dvorak A. "Study of achievement and subject matter in General Science" (Unpublished).

*it should include.*" The tests probably will be able to differentiate quantitatively among entering students, but the writer fails to see how it will be known what the courses should include. The items which compose the test cannot be used separately. Thus in item 46, for example, 29.4% of 8th grade non-General Science girls and only 18.6% of 9th grade General Science girls knew that Heat travels through a vacuum by radiation. In other words about 30% of students who have never studied General Science are apparently familiar with a fact which they could hardly have learned from everyday experience, while only about 19%, after a year in the General Science course, know the same fact.

Other items in the test give similar results. Evidently the results of single items in a test of this type (multiple choice) have little meaning, but only the results of all the items together. Dvorak's test therefore does not throw any light on specific subject matter, and in the mind of the writer, is no more diagnostic than similar kinds of tests, although it may be excellent as a means of measuring "ability in General Science", "range of information", "achievement" or what not.

## CHAPTER III.

### GENERAL METHOD OF PROCEDURE.

In order to trace development of significance of a concept it was decided to make a collection of the concepts held by pupils before and after studying General Science or Physics and then to compare these concepts qualitatively as well as quantitatively.

In the large majority of High Schools Physics is either an 11th or 12th grade subject and General Science a 9th grade subject. The small 10th grade Physics group used in this study was drawn from two schools only; no other schools could be located where Physics was offered in this grade. Biology too is a very popular 9th grade subject just as Chemistry is an elective 11th or 12th grade course. Rarely does a student go through High School without electing one of these sciences — General Science, Biology, Physics or Chemistry. It was therefore difficult to get "pure" control groups, i.e. groups of pupils who had not had either General Science or Physics and impossible to find pupils who had not studied any science.

The control groups used in this study, however, were pupils who had not studied General Science or Physics, although they had had Biology or Chemistry in most cases. This, however, is no disadvantage since, after all, students who enter a Physics class normally would also have had one or more of these subjects. In addition 8th grade, and in some cases 6th and 7th grade pupils were also used. The groups involved in this study then are:— Grades 6 to 12 non-Physics, non-General Science; 9th grade General Science; 10th, 11th and 12th grade Physics. The non-science groups, for convenience, will be referred to as the minus groups (— 9, — 11 etc.) while the General Science or Physics groups will be known as the plus groups (+9, +11 etc.)

In a study of this kind it was not only necessary to know whether a certain Physics class had studied "Heat", but also whether they had had a particular topic in Heat, for example, Specific Heat. Such information was obtained from the teacher in charge by means of a questionnaire which was included in and returned with each set of test questions. A +12th group, therefore, means that the students had studied Physics and, in particular, the subject matter in question. The results of Physics students, who had not studied the necessary subject matter, were disregarded for that particular concept.

## METHODS OF OBTAINING DATA.

All data in this study were obtained from pupils' written responses to the common form of questioning, for example, "Tell how Dew gets on the grass"; or from short essays written by pupils, for example, "White an essay on Heat. First tell what you think Heat is and then tell other things you know about it".

In view of the advances that have recently been made in the matter of examinations, such methods as were employed may appear obsolete. They were chosen, however, after many weeks of trial and ultimate discard of the true-false, multiple choice and completion types of examination, and not as the path of least resistance. Why then were these newer types of examinations not used?

*Firstly*: Because of the nature of the problem, it was not sufficient to know that a certain answer was right or wrong. For example, it was not sufficient to know what per cent. of pupils had vague or incomplete notions of Specific Heat or Condensation, but also just what these notions were.

*Secondly*: Chance plays too great a part in some of the newer types of examinations when a few items are involved. For example, were the writer to use item 46 of Dvorak's scale in order to discover children's notions of heat transference, there would be the probability of more —8th graders than +9th graders having a notion of radiation. By taking many such items together, on the other hand, to reduce pure chance, a test could, of course, be constructed and scored. Here again the score would be of little use for this study; to "score" a pupil's concept of a Rainbow or Acceleration conveys little.

*Thirdly*: Tests like the "Completion," apart from depending too much on Intelligence, control the response too much. This may prevent non-science pupils from responding, and this could certainly not be interpreted as "no concept," especially in such cases as Boiling, Weight etc., of which most children have some notions.

*Fourthly*: The newer types of examinations were designed as scientific instruments of measurement. Primarily, the purpose of this study was not to derive an instrument for measuring with scientific accuracy concepts of children, if such could be done; but to discover just what these concepts are and how they develop qualitatively. Knowledge of these is prerequisite to their measurement.

To get a child to respond to a question, it was absolutely necessary to exert as little control over the response as possible. For this and the reasons previously given the writer used the ordinary form of written question and answer. In addition it was necessary in certain cases to resort to oral questioning of individual pupils in order to account for certain concepts held.

In every case, each question or set of questions, was first tried out on a small group of non-science and science students in order to correct any ambiguity or indefiniteness of meaning and also to obtain an estimate of the approximate time taken. Although the speed factor did not enter into this study, nevertheless it was necessary to know approximately how long the pupils of the various grades would take.

## METHOD OF RECORDING DATA.

Every set of questions returned was read through by the writer and the response to every question was classified and recorded. The percentage of pupils of each grade giving a particular response was then calculated. This laborious method was employed throughout this study. The concept Weight may be used as an illustration. All responses that "Weight is the heaviness of a thing" were grouped; all responses that "Weight is the number of pounds in a thing" were grouped; scattered responses such as Weight is pressure, amount etc. which did not occur to a great extent, were grouped as miscellaneous. The percentage not making a response was also calculated.

## METHODS OF OBTAINING GROUPS.

Through the co-operation of Dr. Reynolds of the Bureau of Educational Service of Teachers College, the writer was supplied with the names and addresses of Teachers College Alumni who were superintendents or principals of schools. Letters explaining the purpose of the study and asking for co-operation by giving the "tests" in their schools were sent to about 110 alumni as well as to a number of Physics teachers who were members of the Central Association of Science and Mathematics Teachers. [1])

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| | |
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## CHAPTER IV.

## PRELIMINARY SURVEY.

In the preliminary survey single direct questions were used to obtain pupils' notions of Energy, Evaporation, Condensation, Dew and Rainbow formation, Acceleration and Specific Heat. Thus, the pupil was simply asked to "Tell how Dew gets on the grass". In this way data were gathered concerning a multitude of concepts, of which only a sampling can be given here.

This chapter contains a sample of the battery of questions used in the preliminary survey together with an analysis of results. The responses to questions are first classified in Tables 1 to 9 and then discussed.

### *Preliminary Test Battery.*

Fill in all blanks before taking the test.

Name.................... School..................

Age: Years.... months.... Boy or Girl.... Grade....

Are you studying Physics at present?........

In the following list underline the subjects you have studied and write after each the grade you were in then.

General Science ( ) Biology ( ) Chemistry ( ) Physics ( )

*Directions*: This is a short science test. Even if you have never studied science, try your best with every question. Read each question over carefully and then write your answer in the space just below it.

1. The acceleration of an automobile is greater than that of a street car. Tell what "Acceleration" means.
2. What do you mean by saying that a thing has energy?
   Has wind any energy?....Why?
   Has coal any energy?....Why?
3. There is more evaporation on some days than on others. Tell what you think "Evaporation" means.
4. The condensation of vapor is a common occurrence. Tell what you think "Condensation" means.

5. The specific heat of glass is .2. Tell what this means.
6. Tell in your own way how Dew gets on the grass.
7. Tell how a Rainbow gets into the sky.

---

It was previously ascertained by experimentation that nearly all the pupils of the grades in question could finish in less than 30 minutes. The majority of schools offered a 40 minute class period for the test. The instruction to the pupils were that they should hand in the test when they had answered all the questions they could. The few papers that were not handed in before the end of the 40 minute period were collected.

The responses to the various questions are classified in the tables that follow, the type of response given appearing on the left and opposite it the per cent. of pupils in each grade giving that type of response. The number of pupils in each grade, the median age for the grade and the type of grade-population (Science or Non-Science) are also indicated at the head of each table.

## Table 1.

(Percentage of responses to questions) :—

The acceleration of an automobile is greater than that of a street car. Tell what Acceleration means:—

| Grade .. .. .. .. .. .. | 6—8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Number .. .. .. .. .. .. | 100 | 105 | 114 | 100 | 142 | 150 | 231 |
| Med. Age .. .. .. 6— | 12.1 | | | | | | |
| 7— | 12.11 | | | | | | |
| 8— | 14.0 | 14.11 | 17.0 | 17.10 | 15.0 | 16.9 | 17.7 |
| 1. Rate of change of speed .. .. .. .. | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 32.7 | 35.1 |
| 2. Picking up of speed | 0.0 | 2.9 | 2.6 | 3.0 | 7.7 | 6.0 | 5.4 |
| 3. Speed (or) rate of speed .. .. .. .. | 36.0 | 38.0 | 42.1 | 41.0 | 43.0 | 32.0 | 33.6 |
| 4. Power, strength, force | 27.0 | 21.9 | 14.1 | 11.0 | 20.4 | 4.7 | 2.3 |
| 5. *Miscellaneous .. .. | 7.0 | 9.5 | 14.1 | 11.0 | 7.0 | 17.4 | 19.1 |
| 6. No response .. .. | 30.0 | 27.7 | 27.1 | 34.0 | 21.1 | 7.3 | 4.6 |

**Miscellaneous.*

Grade.

—(6-8) .... It can go better. It is part of the car. It has less power but more speed. It means its movements. It can turn in a shorter distance. It means that its speed can change.

—(9th) .... It can travel. The distance it goes. It means its movement (or) motion. The change in its motion (2%). The part you put your foot on. Its engine is greater.

—(11-12) ... Its momentum. Moderation. It means maintaining speed. Its motion. Its relative motion. Refers to part of the car. It can develop more horse-power. Its efficiency.

+(9th) .... Its momentum. Power to coast. Can cover a greater distance. Acceleration has to do with its power. Its getaway is greater. Can run faster with less power. Change in speed.

+(11, 12) .. The change in speed (14 %, 18 %). The way the speed changes. It has more power to stop. The rate. The rate of change.

## Table 2.

(Percentage of responses to questions) :—
What do you mean by saying that a thing has ENERGY?

| Grade | —6—8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Number | 100 | 105 | 114 | 100 | 142 | 150 | 131 |
| 1. It has ability or capacity to do work. Power to do things or work | 5.0 | 14.3 | 26.4 | 29.0 | 31.7 | 71.3 | 78.6 |
| 2. It does something It can do something | 7.0 | 5.8 | 13.2 | 7.0 | 9.2 | 2.7 | 3.1 |
| 3. It has power; force or strength | 36.0 | 31.4 | 21.0 | 25.0 | 28.3 | 4.7 | 2.3 |
| 4. It has life, vigor | 16.0 | 9.5 | 3.5 | 4.0 | 3.5 | 0.0 | 0.0 |
| 5. It can move by itself | 6.0 | 3.8 | 1.7 | 3.0 | 1.4 | 0.0 | 0.0 |
| 6. *Miscellaneous | 9.0 | 8.6 | 12.3 | 17.0 | 14.1 | 12.0 | 11.4 |
| 7. No response | 21.0 | 26.6 | 21.9 | 15.0 | 11.3 | 9.3 | 4.6 |

**Miscellaneous.*

Grade.

—6, 8, 9.. Heat. Materials to make it work. It is healthy. It has ambition. It gives off much heat (light). It has ability. It is quick. Very willing to work. It is not lazy. It has "pep". Full of action. It can do a lot.

—11, —12.. It can move. Heat. Ambition. Heat and power in it. It gives off heat and light. It is energetic. It can lift. Power to lift a force. It has work in it. It is physical. (?) It is more happy to work. It does much work. Its power is unlimited. It is never still. It can make starch.

+9th...... It can do things without aid from machines. It has movement. It has heat. Its force lifts. Force which moves it around. It means it has stored energy. Its horse-power. Its speed is very great. It does too much work.

+11, +12.. Heat, power to burn. It has working material like force. Has a way of working. It has same latent force. It has stored or potential energy. It has horsepower. The foot pounds it has. Its ability or capacity. It is moving. It can accomplish things.

## Table 3.

(Percentage of responses to questions) :—

Has wind any *Energy? Explain.*

| Grade | 6—8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Number | 100 | 105 | 114 | 100 | 142 | 150 | 131 |
| Yes | 70.0 | 72.3 | 76.3 | 73.0 | 80.9 | 94.0 | 96.2 |
| No | 17.0 | 18.1 | 14.1 | 13.0 | 10.6 | 2.0 | 1.5 |
| No choice | 13.0 | 8.6 | 9.6 | 14.0 | 8.5 | 4.0 | 2.3 |
| REASONS: | | | | | | | |
| 1. YES. Becasue it can run (turn) windmills,, blow trees, cause destruction etc. It causes motion | 21.0 | 40.9 | 38.4 | 36.0 | 43.0 | 61.3 | 64.9 |
| 2. It can be used to do work. It can be harnassed | 1.0 | 0.0 | 3.5 | 1.0 | 9.9 | 19.3 | 24.4 |
| 3. It moves. It is always moving | 17.0 | 9.5 | 12.3 | 15.0 | 10.6 | 2.0 | 1.5 |
| 4. *Miscellaneous | 8.0 | 9.5 | 9.6 | 10.0 | 11.3 | 6.7 | 1.5 |
| 5. NO. Only living things have energy | 14.0 | 7.6 | 7.1 | 7.0 | 2.8 | 0.0 | 0.0 |
| 6. You cannot get heat or light from wind | 0.0 | 0.0 | 0.8 | 2.0 | 1.4 | 0.0 | 1.5 |
| 7. *Miscellaneous | 1.0 | 3.8 | 1.7 | 1.0 | 1.4 | 0.0 | 0.0 |
| 8. No reason given | 38.0 | 28.7 | 26.6 | 28.0 | 19.7 | 10.7 | 6.1 |

## Table 4.

(Percentage frequency of responses to questions) :—

Has Coal any *Energy*? Explain.

| Grade | 6—8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Number | 100 | 105 | 114 | 100 | 142 | 150 | 131 |
| Yes | 67.0 | 71.5 | 67.6 | 65.0 | 81.7 | 94.7 | 96.2 |
| No | 24.0 | 19.0 | 19.2 | 15.0 | 11.3 | 2.0 | 2.3 |
| No choice | 9.0 | 9.5 | 13.2 | 20.0 | 7.0 | 3.3 | 1.5 |
| REASONS: | | | | | | | |
| 1. YES. It gives heat which is energy (or) It gives heat which makes steam which drives machines (or) does work | 22.0 | 46.7 | 45.6 | 48.0 | 56.3 | 65.3 | 61.8 |
| 2. It has energy stored up in it (or) it has potential energy | 1.0 | 0.0 | 2.6 | 4.0 | 16.2 | 27.3 | 33.6 |
| 3. It burns | 31.0 | 18.1 | 11.4 | 8.0 | 6.3 | 2.0 | 0.0 |
| 4. *Miscellaneous | 1.0 | 3.8 | 2.6 | 3.0 | 1.4 | 0.0 | 0.0 |
| 5. NO. It cannot move things like wind | 4.0 | 2.9 | 5.3 | 3.0 | 2.1 | 0.0 | 0.0 |
| 6. It does no work | 0.0 | 0.0 | 0.0 | 0.0 | 1.4 | 1.3 | 0.8 |
| 7. Only living things have energy | 16.0 | 6.7 | 6.2 | 8.0 | 2.8 | 0.0 | 0.0 |
| 8. Miscellaneous | 0.0 | 2.9 | 1.7 | 1.0 | 0.7 | 0.0 | 0.8 |
| 9. No reason | 25.0 | 18.9 | 24.6 | 25.0 | 12.8 | 4.0 | 3.0 |

## Table 5.

(Percentage frequency of responses to questions) :—
There is more evaporation on some days than on others.
Tell what evaporation means.

| Grade .. .. .. .. .. | 6—8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Number .. .. .. .. | 100 | 105 | 114 | 100 | 142 | 150 | 131 |
| 1. Liquid changing to gas or vapor. Water changing to vapor or steam .. | 9.0 | 18.1 | 35.1 | 38.0 | 40.1 | 80.0 | 84.0 |
| 2. Drying up of water | 33.0 | 19.0 | 14.1 | 16.0 | 17.6 | 5.3 | 3.1 |
| 3. Drawing up of water by the sun .. .. | 28.0 | 33.3 | 24.6 | 19.0 | 14.1 | 4.7 | 4.6 |
| moisture taken up by the sun .. | 28.0 | 33.3 | 24.6 | 19.0 | 14.1 | 4.7 | 4.6 |
| 4. *Miscellaneous .. | 21.0 | 17.2 | 14.1 | 16.0 | 21.8 | 6.0 | 5.2 |
| 5. No reponse .. .. | 9.0 | 12.4 | 12.1 | 11.0 | 6.3 | 4.0 | 3.1 |

**Miscellaneous.*

Grade.

(—6, —9) . . Gas goes off into the air. Drawing up of moisture. Going forth of water. Heat dries moisture in air. Taking up moisture by air. Water gives off moisture. Rays of sun take up moisture. Process of vaporizing. Heat takes water out of a substance.
izing. Heat takes water out of a substance.
air. Process of becoming steam.

(—11, —12) When water evaporates. Changing of moisture from vapor to air. Moisture in air condenses. The going out of a flame or fire. Steam escaping. When water changes to air. When vapor dries up. When hot air comes in contact with something cold then it evaporates. Absorption of water by sun. Sweat. Boiling. Oxygen and air going off. When a thing disappears. When vapor in air changes to water. When hot air evaporates.

(+9).... The carrying of water to the clouds by the sun where it is stored. Sweat. To melt. What makes things disappear in the air. Amount of moisture combining with the air. Evaporation means to evaporate a thing. Water turning into air. Water or moisture on a 'winder' and by absorption it evaporates. Amount of water absorbed by air. A kind of vapor, moisture in air sucks vapor up.

(+11, +12)..Vapor changing into air. Absorption. Drying up of anything by light. Disappearing of a substance. The velocity of the molecules become so great that they jump off int^ the air. Condensation. Vibration of air.

## Table 6.

(Percentage frequency of responses to questions) :—
The condensation of vapor is a common thing.
Tell what condensation means.

| Grade | 6—8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Number | 100 | 105 | 114 | 100 | 142 | 150 | 131 |
| 1. Changing of vapor to liquid or steam to water (or) gas to liquid | 4.0 | 15.2 | 38.4 | 34.0 | 41.5 | 78.0 | 85.5 |
| 2. To condense water, to water, to vapor | 16.0 | 7.6 | 3.5 | 5.0 | 5.6 | 0.0 | 0.8 |
| 3. Changing of liquid to vapor, (or) water to vapor, steam, (or) evaporation | 31.0 | 18.1 | 14.1 | 16.0 | 16.2 | 4.7 | 3.0 |
| 4. *Miscellaneous | 13.0 | 33.3 | 21.0 | 19.0 | 18.3 | 12.0 | 6.1 |
| 5. No answer | 36.0 | 25.8 | 23.0 | 26.0 | 18.3 | 5.3 | 4.6 |

**Miscellaneous.*

Grade.

(—6, —8)..Heaviness. Water turning into air. Rising of vapor. Vapor. Making volume smaller. Mixing of vapors. Escaping of vapor. The force of steam. Clouds of vapor.

(—9).... Humidity. Mixing of gases. Changing of vapor to air. Compressing. Evaporation of steam. Coming together of vapor. Evaporation of vapor to air. Forming of clouds in air. (8.8%)

(—11, —12) Superheated water vapor. Changing of vapor into air. Coming down of vapor. The falling of moisture. Moisture collecting in the clouds. Thickening of vapors. The humidity. Changing of moisture from vapor to air. The forming of fog. The disappearing of vapor. The compressing of a vapor is condensation.

(+9).... Changing of air to water. Water changed to heat. Mixing of vapor. Storing of vapor. Drying of vapor. Evaporation of vapor. Liquid in form of vapor changed to solid. Vapor turned to cold. Storing in clouds. Changing of vapor in form. Cloud breaking into air. Vapor in another form. Vapor changed to air. Collecting of drops of moisture.

(+11, +12) Vapor changing to air. Collecting of vapor. Vapor changing into another form. Gathering of moisture to form clouds. (Majority of miscellaneaus responses of this type). Collecting of drops of water. The decreasing of volume by compression.

## Table 7.

(Percentage frequency of responses to questions) :—
The Specific Heat of Glass is .2. Tell what this means.

| Grade .. .. .. .. .. | —6—8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Number .. .. .. .. | 100 | 105 | 114 | 100 | 142 | 150 | 131 |
| 1. .2 calories needed to heat 1 gram glass 1°C .. .. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 29.3 | 27.5 |
| 2. Glass required only .2 as much heat as water to heat it | 0.0 | 0.8 | 0.0 | 1.0 | 0.7 | 20.0 | 12.2 |
| 3. .2 calories required to raise the temperature of glass 1°C .. .. .. .. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.3 | 9.9 |
| 4. Glass heats up more easily than water | 0.0 | 0.8 | 2.6 | 3.0 | 1.4 | 1.3 | 0.8 |
| 5. Its heat it .2, (or) It is .2 hot (or) its temperature is .2 | 14.0 | 12.4 | 9.6 | 16.0 | 14.1 | 2.7 | 2.3 |
| 6. Amount of heat to *melt* it (or) the temperature at which it *melts* (or) amount of heat it can stand before melting .. | 9.0 | 6.7 | 13.2 | 8.0 | 13.4 | 5.3 | 4.6 |
| 7. Heat it will stand before cracking .. | 7.0 | 3.8 | 2.6 | 3.0 | 2.4 | .7 | 0.0 |
| 8. *Miscellaneous .. | 12.0 | 8.6 | 13.2 | 11.0 | 24.6 | 27.3 | 26.7 |
| 9. No answer .. .. | 58.0 | 66.9 | 58.8 | 58.0 | 44.4 | 16.0 | 16.0 |

**Miscellaneous.*

Grade.

(—6, —8) .. The heat it throws. A special kind of heat. Temperature while it is being manufactured. So hot you can't stand it. .2 grams. It is .2 of 100. Heat at which glass is boiled.

(—9, —12) .. It is so much hotter than a certain substance. Heat at time of reading. There can be no more heat in it. The moderate amount of heat is .2. The percent. of heat in it. The heat can get no greater than .2. It evaporates its artifical heat. The tempering point. The glass stays cool. Glass has to be heated up to 98 (100-2). The required heat is .2, 200 degrees of heat. How hot it really is and not how hot it feels. Glass will dissolve at .2. 2 units. Temperature is 2.2 of a calorie.

(+9th) .. .2 of a 100 warmth. Highest temperature of glass. Temperature of the heat given from the glass. It is a poor conductor of heat. Intensity of glass heat. Not a whole degree, only .2. Heat in glass above heat in air. Warm or cold according to atmosphere. .2 of the boiling point. It can stand .2 of the boiling point. It is .2 Fahrenheit. Specify it by heat .2.

(+11, +12) Physics. Weight of glass compared to equal volume of water is .2. Mass divided by volume is .2. A ratio of 2 compared to same volume of water. Glass capable of generating .2 as much heat as other substances. Glass is .2 of the heat of boiling of barometer. It is .2 on barometer.

Heating process is .2. Ratio of mixture of a substance and heat required to change it. No. of BTU required to heat is. Specific Heat is density 2 grams per cu. cm. heavier than an equal volume of water. Gives off 2°C of heat when cooling 1°C. It is .2 in relation to air. Average heat is .2. No. of calories given off by glass. Amount of heat retained. Weight in air divided by weight in water. Glass expands .2 for every increase of 1°C. .2 as much as water. .2 hotter temperature before and after heating. Number of calories to raise 1 gram of glass without change of temperature. .2 as much for glass as for water. Number of calories to give up the .2 of heat it has. .2 the specific heat of water. .2 calories to heat it. .2 for 1 gram 1C.

## Table 8.

(Percentage frequency of responses to questions) :—
How does DEW get on the grass?

| Grade .. .. .. .. .. .. | 6—8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Number .. .. .. .. .. | 100 | 105 | 114 | 100 | 172 | 165 | 140 |
| 1. It falls from the clouds at night (or) early morning .. .. .. .. .. | 28.0 | 19.0 | 16.7 | 17.0 | 15.9 | 6.1 | 4.3 |
| 2. Moisture or mist falls on grass at night .. .. .. .. .. | 9.0 | 9.5 | 7.1 | 6.0 | 13.5 | 12.1 | 11.4 |
| 3. Clouds descend on to grass wetting them | 3.0 | 5.8 | 4.4 | 2.0 | 1.8 | 0.0 | 0.0 |
| 4. Moisture is so heavy that it stays near the ground and it drops .. .. .. | 0.0 | 2.9 | 1.7 | 1.0 | 3.5 | 1.2 | 1.4 |
| 5. Dampness or moisture in air gets on grass at night | 8.0 | 11.4 | 8.8 | 9.0 | 7.1 | 1.2 | 1.4 |
| 6. Dampness or moisture *coming out* of ground at night | 11.0 | 9.5 | 4.2 | 7.0 | 2.4 | 3.6 | 2.8 |
| 7. Moisture in the air is cooled and goes to the grass .. .. | 0.0 | 2.9 | 12.3 | 10.0 | 4.1 | 1.2 | 0.0 |
| 8. After sunset grass cools below temperature of air and condenses moisture in air on it .. | 0.0 | .9 | 4.4 | 6.0 | 14.7 | 29.7 | 31.4 |
| 9. Same as above except "grass is warmer than air." | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.4 | 2.8 |
| 10. Dew is formed by the condensation of moisture or vapor | 0.0 | .9 | 1.7 | 3.0 | 11.8 | 18.8 | 16.4 |
| 11. Miscellaneous .. | 23.0 | 19.0 | 17.6 | 16.0 | 13.5 | 10.3 | 16.7 |
| 12. No answer .. .. | 18.0 | 18.1 | 21.1 | 23.0 | 11.8 | 13.3 | 12.1 |

**Miscellaneous.*

Grade.

(—6—8) It gets on the grass in the early morning before sunrise. It comes up a mist or fog. It is the moisture which the sun drew up. Before sunrise it is very cold so dew gets on the grass. Because in the morning the air is very damp. It is damper on the grass than indoors. The wind brings it. By evaporation. (A large number described dew without explaining how it got on the grass.)

(—9) . . . . During the daytime the sun evaporates the water, but the sun has to be there to hold the vapor, so when it sets, the vapor changes to water. Oxygen in air at night is refreshed by pure oxygen in morning causing a moisture which spreads among the flowers. Carbon dioxide and water are given off by the grass at night. When the sun rises in the morning the vapor in the air condenses. During the night the vapor from the clouds and the chill of night meet. By the heat of the air. The air is full of water in the early morning. Moisture in the air connecting with vapor. Transpiration of trees causing dew to fall on the grass. Sun condenses the water in the ground to dew in the early morning. It comes from mist, if there is no mist there will be no dew.

(—11, —12) Hot air of the day coming in contact with the cold air of night. A low cloud rests there and melts like. The cool air collects moisture at night. Dew is nothing but fog. Particles of dust gather moisture until it is heavy and gets on the grass. Gets to the grass by means of vapor. Every day after

(*Table* 8—Continued.)

sunset moisture from air settles on the ground. When the air condenses. Heat of ground coming to a chilly air. Contracting of heat and cold. Coolness of the night extracting moisture from earth. At night plants give off lots of water vapor. When a heavy fog rolls over the grass it leaves moisture behind it. It would get on everything but it is damper outside. The sun holds the moisture in the air, so when the sun is not there the moisture will drop out.

**(+9th)**.. Gets to the ground by air travelling. Moisture colects on dust particles, then settles. It gets on the grass because it can't get anywhere else. Objects on earth attract dew. By evaporation after a fog. When it gets cooler (colder) and cooler until it seems as if there was going to be a frost. It refreshes the grass until it becomes moist. When the air gets its dewpoint. Because the air is saturated. By the depositing of moisture. Because grass is colder than air at night.

(+11, +12) When sun's heat goes moisture from air appears. Warm air striking cold air falls as dew. Quick change of warm and cold air coming together. Forms when air is at a certain temperature. Hot air at the surface uniting with cool air above. Moisture of air in contact with moisture of earth. The cold grass causes the air to become saturated. Because of the temperature of the atmosphere. Gravitity draws it to the ground. Because it is at the dewpoint.

## Table 9.

(Percentage frequency of responses to questions) :—
Tell how a RAINBOW gets into the sky.

| Grade | 6—8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Number | 100 | 105 | 114 | 100 | 170 | 165 | 140 |
| 1. A solar spectrum caused by dispersion of sunlight by raindrops | 0.0 | 0.0 | .8 | 0.0 | 7.1 | 13.8 | 20.0 |
| 2. Refraction of sunlight in raindrops | 0.0 | 0.0 | 0.0 | 3.0 | 18.8 | 26.1 | 22.1 |
| 3. Sunlight is broken up into colors by drops | 0.0 | 2.9 | 2.6 | 4.0 | 19.4 | 9.1 | 10.0 |
| 4. Refraction and dispersion of light by drops | 0.0 | 0.0 | 0.0 | 1.0 | .6 | 8.5 | 9.3 |
| 5. Refraction, dispersion and total internal reflection of light by raindrops | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.1 |
| 6. Reflection of sunlight on air, mist, vapor | 14.0 | 16.2 | 24.6 | 28.0 | 23.5 | 16.4 | 13.6 |
| 7. The sun shines on the rain giving the colors | 39.0 | 35.2 | 16.7 | 11.0 | 3.5 | 3.0 | 2.1 |
| 8. *Miscellaneous | 21.0 | 19.0 | 24.6 | 24.0 | 14.7 | 9.1 | 12.1 |
| 9. No attempt | 26.0 | 26.7 | 30.7 | 29.0 | 12.4 | 9.1 | 8.6 |

**Miscellaneous.*

Grade.

(—6, —8) .. A coloring in the sky. Sun shines on rivers and rainbow goes up into sky. All the color of the sky joined together. Reflection of water draws the colors together. The sun shines on a cloud. The clouds still has some dew and they are filling and the sun comes out and that is a rainbow. Gets into the sky by the rain. A

(*Table* 9.—Continued.)

colored ribbon. A sort of reflection of clouds. The rays of sun on clouds. Moisture that when light and heat of sun shines on it is turned into many colors. The sparkling of raindrops. When sun's rays and water and air mix. A lot of complementary colors. The striking of moisture in the air. Sun shining through vapor like a prism. Reflection of sun on the clouds (2). Reflection of sun back into the sky from the earth. Reflection of the sun into water and back into the sky. Water made up of colors. Dew which the sun makes. Appears when the sun is hot. Reflection of different colors. Sun's rays shine on the water and cause color in the evaporation. An illusion caused by the sun shining on mist. Rays of the sun shining on rising vapor. Sun shines on clouds that have been wet by rain. Light produced by electricity and the sun. Electricity draws the raindrops into the sky after a thunderstorm. Sun reflects colors from rain mixed with particles of carbon from smoke. Rain falling in front of colors of sun. No one knows because it has no substance. Sun's rays blending into mist.

**(—9)**.... Dampness shone upon. Sun throws light over clouds which give the appearance of colors. Sort of kollidscope (??). The slanting rays of the sun cause rain to change colors. Reflection on wet vapor. Sun's rays forming a spectral band. Dew gathers in the sky after rain. Sun makes the colors. Caused by wetness over the sun. Moisture throws the slanting rays of sun on sky. Reflection of sun against

(*Table* 9.—Continued).

the sky. The sun casting rays. Sun crosses the rain. Sun is so bright after rain that it forms a rainbow. It always is there, only after rain the sun's rays strike something and bring out certain colors. It is a reflection of one half of the earth. A vapor of dust. It is caused by the sun and the colors of the clouds.

(—11).... Formed by clashing or rain and sun. Sun striking different objects in the sky. A mirage, it does not 'get up into the sky'. Work of the sun on the water. Reflection of sun in rivers, lakes etc., and the colors reflect back into the sky. Vapor evaporates when sun shines on rain, as vapors rise on wet clouds or on anything that is wet. Sun reflects on objects and we see them in the sky. (2) Caused by the sun coming in contact with spectral raindrops. A reflection from the earth.

(—12).... Formed by dust particles in the air. Formed the same way as when light shines on glass. Drops of water absorb all colors and then send them to the eye. Formed only when sun shines on those drops that have prism shapes. Reflection of sun in direct line. Reflection of lightning from raindrops. Meeting of moisture and rays of sun. Formed by different vapors in the sky. A kind of ray in the sky causes it. Reflection of the sun back to the sky. Reflection of sun on moist clouds. Sun makes the colors by a peculiar process. It is nothing but the reflection of colors against the sky. Colors of sunlight become visible against the sky. Colors of sunlight become visible only when sun is in the East or West after rain.

(*Table* 9.—Continued).

(+9).... When the sun hits these drops (rain) they sort of run into one another and we see a rainbow. It is sunlight reflecting on dew drops. Sun shining on rain and particles of dirt and this reflects back to the eye. Sun casting rays on sky while rain falls. Sun shining on vapor from the earth. Reflection from sun from clouds. Reflection of light from moist air. Sunlight in contact with damp air. Dispersing of raindrops in clouds. Reflection of part of sunlight in sky.

(+11, +12) Lıght shining through clouds. Occurs only when sunlight is sifted through rain. Falling water acts as a great mirror the upper surface of the sun is reflected; the rainbow is the upper portion of the sun and the colors are given off. Collecting of rays of light in moisture in the air. Series of rays of light due to rain becomming mixed with rays by rain. Deviation of sunlight. Caused by multiple reflection in drops. It comes after a rain beginning with red real strong and ending with violet very weak. Reflection of sun on clouds. Dispertion and diffraction causes different colors. Refracted according to wave lengths. Sun shines on a bank of clouds. Caused by the dispertion and colors in all directions. Reflecting back and forth of sunlight in raindrops..

(*) Some classified as miscellaneous are correct.

## ANALYSIS OF RESULTS.

ACCELERATION (Table 1). Acceleration is thought of as the "rate of change in speed" by about a third of Physics students, by only one General Science pupil and by no pupil who has not studied science. The vague "picking up of speed" notion is held by a few non-science and science students. The rest of the responses are largely erroneous. The notion of acceleration as "speed" is the outstanding erroneous notion in all groups, and, although it is found to a lesser extent in the Physics groups, it still occurs to an extent which is very significant.

Of the miscellaneous responses, those of the non-science students are erroneous, whereas the majority of "Physics" responses are vague rather than erroneous—14 % and 18 % of the two Physics groups think of accelleration simply as change in speed. This notion certainly is not scientific, for the important element of time or rate is not involved.

Were the question of meaning only involved, "pick up of speed" would probably be taken as correct; but, as a scientific concept, it is too vague for further use in the study of Mechanics. It is practically equivalent to the "change in speed" notion, the latter not being so crude.

On this basis response No. 1 in Table I would represent the extent to which the concept Acceleration is scientific in each grade; response No. 2, together with "change in speed", would be classified as vague, and the rest as erroneous. The extent to which these scientific, vague and erroneous notions occur in each of the 9th and 12th gades, for example, is shown by the following per cents:

| Grades | —9 | +9 | —12 | +12 |
|---|---|---|---|---|
| Scientific | 0 | 0.8 | 0 | 35.2 |
| Vague | 7.7 | 9.2 | 3.0 | 24.6 |
| Erroneous | 64.6 | 70.4 | 63.0 | 36.2 |

The conclusions, as far as this question shows, are (1) The concept acceleration does become scientific in the Physics grades in about a third of the students examined. (2) The majority of non-science and General Science students examined have erroneous notions of acceleration, the most common being "speed" and "power". (3) The most common erroneous notion of the non-science and General Science groups viz. "speed" is also most prevalent in the Physics groups. (4) Whatever differences exist between the —9 and +9 grades are statistically insignificant, whereas the reverse is the case with the — 12 and + 12 grades.

ENERGY (Tables 2, 3 & 4).

Energy is thought of as capacity, ability or power to do work or to do things by a significant percent of even non-science pupils and in the two Physics groups by over 70% of pupils. Taking the responses to this question only into consideration, there can be no doubt of the efficacy of Physics and to a lesser extent of General Science

The next two questions are easy examples of Kinetic and Potential energy respectively. If in Table 3 reasons 1, 2 & 3, and in Table 4 reasons 1 & 2 be taken as adequate, then in each grade the percents would be:—

| Grades | -6—8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Wind has energy | 70 | 72 | 76 | 73 | 81 | 94 | 96 |
| Reasons 1, 2, 3, | 39 | 50 | 54 | 52 | 64 | 83 | 91 |
| Coal has energy | 67 | 71 | 68 | 65 | 82 | 95 | 96 |
| Reasons 1 & 2 | 23 | 47 | 48 | 52 | 73 | 93 | 95 |

Taking into account only those responses accompanied by an adequate reason, the science again excel the corresponding non-science groups, although a very significant number of the latter have reasonably scientific notions of energy.

A common erroneous notion in the — 8th grade is that only living things have energy; the frequency of this notion however, decreases through the grades and disappears altogether in the two Physics groups. The vague notions of energy as "force, strength, vigor," which abound in the non-science and General Science groups, are very uncommon in the Physics groups.

The results of these three questions lead the writer to conclude that pre-science students have naïve notions of energy and that these are well suited as a foundation on which to build scientific concepts. These notions are predominantly vague rather than erroneous, as in the case of Acceleration; the notion that only living things have energy being about the only common erroneous notion. The study of General Science and Physics certainly shows its effects; the concept being scientific to the large majority of Physics and to the majority of General Science students. Not only do a significantly larger per cent associate energy with "capacity for work," but Kinetic Energy, and more particularly Potential Energy, are more significant to these students.

EVAPORATION (Table 5).

A survey of the table will show that most children are familiar with evaporation; those who do not give scientific responses give vague and naive ones, but erroneous notions are not so common.

The majority of non-science students think of evaporation as the "drying up of water", "the drawing up of water by the sun, or sun's rays" or "taking up of water by the air." Such notions are evidently products of everyday experience and are excellent examples of naïve concepts. Sun and water are the two strongest assocations with evaporation.

The effect of General Science and Physics is seen by comparing the frequency of such notions in the —9, —11 & —12th grades with that in the corresponding science grades. In the Physics grades the majority hold that evaporation is a change of state from liquid to vapor, whereas in the corresponding non-science grades less than 40% have that notion. In the two 9th grades the percents are 40 and 19 respectively. The "drawing of water by the sun" may also be taken as a partly erroneous notion. In the —6—8th grades a large number of pupils stated that "You can see the sun's rays drawing the water up from the sea" or "You can see the water going up into the sky or to the sun." Subsequent individual examination of pupils by the writer disclosed the fact the majority of students giving this type of response think of the sun as having a certain attractive force or power for drawing the water up into the clouds, sky or air. Such notions of evaporation are too vague for further study and resemble notions of "suction" for air pressure or "pick up" for acceleration.

Outright erroneous notions are not so common; vague ones are abundant. In all groups, including the Physics, the notion of "vapor or water changing to air" occurs. Literally, the notion is wrong; it may, however, be a case of bad expression when the pupil merely had in mind "water changing and going into the air." This and similar notions, however, are here taken as erroneous.

*Conclusion*: (1) Students before studying General Science and Physics have very naïve notions of evaporation, their concepts are, in the majority, vague rather than erroneous.

(2) The study of General Science and Physics shows its effects; the vague notions persist, they are held by over 30% of General Science and about 11% of Physics students, but the extent to which they occur in the corresponding non-science groups is significantly higher.

## CONDENSATION (Table 6).

The results on Condensation differ from those on evaporation in this respect, that erroneous notions are more common. Everyday experiences of condensation are not as common as with evaporation, where the child sees " water drying up " and " water being drawn up by the sun's rays." The formation of fog, mist, rain and dew, of course, are very common phenomena, but are evidently not associated with condensation.

The outstanding misconception is that condensation is equivalent to evaporation, the changing of water to steam or vapor or simply the changing of a liquid to a vapor. Almost as many +9th as — 9th grade pupils have this notion, whereas in the Physics groups it is found in only about 4% of cases. Many notions involve some aspect of cloud formation; thus 9% of General Science students stated that condensation was the forming of clouds in the air. Such notions certainly are not wrong, nevertheless they are vague and are so classified.

*Conclusion*: The extent to which the concept becomes scientific is about the same as in the case of evaporation. The majority of pre-science pupils have erroneous notions, whereas in the case of evaporation the majority of notions were vague. Confusion of condensation with evaporation is the most common misconception in the pre-science and General Science groups.

## SPECIFIC HEAT (Table 7).

The concept Specific Heat differs from the others discussed in this chapter in that it is a very technical one. Experiences are not met with in everyday life that offer the pupil occasion to form this concept, or rather when the experiences are offered, the " specific heat " element in the total situation may not be abstracted. Thus many children probably are familiar with the fact that the water in a lake after sunset is warm relative to the ground, but may be ignorant about specific heat. The concept was examined, however, for this very reason.

From the results it appears that the percent of non-science students who hold a notion, even a vague notion, is negligible. The General Science pupils, for that matter, can be grouped with the non-science students. If we take, in Table 7, responses 1 & 2 as scientific; 3, 4 and certain miscellaneous ones as vague and the remainder as wrong, then the table in condensed form would be:

| Grade | —8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Scientific | 0 | 0.8 | 0 | 1.0 | 0.8 | 40.0 | 39.2 |
| Vague | 0 | 0.8 | 2.6 | 3.0 | 1.7 | 14.9 | 16.0 |

From this it would appear:

(1) That the concept Specific Heat is not scientific in pre-science groups. Even vague notions do not occur to any significant extent.

(2) The study of Physics clearly shows its effect—the concept being scientific to about 40% of pupils.

DEW FORMATION (Table 8).

The response occuring most often in the non-science groups is that dew falls from the clouds at night. This misconception persists right through to the 12th Physics grade. The surprising thing is that about 16% of General Science students hold this notion. The second response in Table 8 is an anomoly—the percentage of Gen. Science students giving it being greater than that of the non-science. Whether it be an erroneous or only a vague notion, its frequency increases after the study of science.

Response No. 6 is an erroneous one found in all grades; 11% of — 6 — 8th graders think that dew comes out of the ground. If we assume that No. 8 represents a scientific concept; No. 5, 7, 9, 11 and certain miscellaneous ones to be vague and No. 1, 2, 3, 4 and 6 to be erroneous notions, then, together with the miscellaneous responses, the percentage of pupils having each type of notion will be as follows:—

| Grade | —6—8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Scientific | 0 | 1 | 4 | 6 | 15 | 31 | 32 |
| Vague | 23 | 25 | 30 | 29 | 31 | 28 | 29 |
| Erroneous | 59 | 56 | 45 | 42 | 42 | 27 | 27 |

The judgment of the writer, of course, is involved in deciding whether a response is vague or erroneous. The various miscellaneous responses were so classified, however, without knowledge of the grade or type (non-science, General Science or Physics) of students making the responses.

Whatever error in judgment was made, therefore, holds for all grades and types of students. If it is held, for example, that such a response as "Dew is formed by the condensation of moisture or vapor" is correct and represents a scientific notion, which the writer has classed as vague, then those percentages must be added to the "scientific" and substracted from the "vague" notions.

*Conclusions*: (1) Non-science students, on the whole, have no scientific notion of dew formation. Their notions are mostly erroneous; that dew falls from clouds or comes out of the ground—these two notions are held by as many as 39 % of —6—8th graders and by 24% of —12th graders.

(2) Although 15% of General Science students have a scientific notion of dew formation, 42% still hold wrong notions—16% still think that dew falls from clouds.

(3) About 31 % and 32 % of + 11th and + 12th grade Physics pupils have scientific notions of dew formation. The number of erroneous notions is less than in the General Science group and the corresponding

non-science grades, except for the notion that "Dew is moisture or mist that falls on the grass at night."

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## RAINBOW (Table 9).

A glance at the table will show two corners in which the percents are concentrated. The first five types of responses are given largely by General Science and Physics students; the last four, including miscellaneous and no response, are given mostly by non-science students.

The majority of non-science pupils are familiar with the fact that the rainbow is caused by some interaction of sunlight and rain, but do not know what the process is. Not a single pupil of grades —6—8 seems to be able to explain the colors; these pupils are either content to state that the sun shines or reflects on the rain or raindrops or offer erroneous explanations.

A large number of science students are content to say that the rainbow is caused by the Refraction of sunlight in the raindrops. Although dispersion or the breaking up of white light into colors is caused by refraction, mere refraction of light it itself will not always give rise to colors. This notion will therefore be regarded as a vague one.

The range of miscellaneous responses is large, these are all extremely vague and erroneous. In many cases no attempt is made to account for the phenomenon, it is simply described or mention is made of the necessary factors as rain, sun, mist etc. There is no erroneous notion among the miscellaneous ones that occurs or persists to a significant extent and which could, therefore, be classified separately. They are important, however, in that they show the wide range of notions children have of so common a phenomenon as the Rainbow.

If, in Table 9, notions Nos. 1, 3, 4 & 5 are taken to be scientific, then the following percents would show the extent to which the notions of rainbow are scientific in the various grades:—

| Grade | —6—8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Scientific | 0.0 | 2.9 | 3.4 | 5.0 | 27.1 | 36.4 | 41.4 |

If we consider Response No. 2 in table 9 as scientific (i.e. refraction of light), then the percentage would be:

0.0 2.9 3.4 8.0 45.9 62.5 63.5

*Conclusions*:

(1) The majority of non-science students have extremely vague and erroneous notions of a Rainbow. There is no particular type of erroneous notion occuring and persisting to a significant extent, the majority of notions being remotely vague.

(2) The study of General Science and Physics shows its effect, although concepts of rainbow are not scientific in the majority of students. Most of these students have changed their old notions, but some of the new notions are too vague to be considered as scientific, for example the notions that the rainbow is caused by the refraction or the reflection of sunlight in raindrops.

## CHAPTER V.

## CONCEPTS OF HEAT.

The concept next examined was that of Heat. In the General Science or Physics course offered in schools one branch studied is Heat, and it is the practice in most schools to teach the subject of Heat after Mechanics in the Physics course. There seems to be no set procedure in General Science; the subject of Heat, however, is introduced fairly early in the course.

By applying a range of information test to General Science pupils or a standardised Physics test (such as Camps) to Physics students after completing the course, it is possible to find out how many facts about Heat a student has accumulated, how many problems he can solve or how he stands in relation to General Science or Physics students in general. One aspect such a test does not measure, however, is whether the student, through his formal study of Heat, has changed his old notion regarding the nature of Heat or just what is his present notion.

A student may know about thermometers, calorimeters, the boiling and freezing points, specific heat etc., and yet have a vague or erroneous notion of Heat itself. If a concept of Heat consists merely of the sum-total of all the separate facts a pupil has learned, then ordinary tests would give a fair estimate of the significance of his notion of Heat.

A concept of Heat, however, does not consist merely of a number of disconnected facts. Facts may be important intrinsically and they certainly are essential for the changing of old and the building up of new concepts; but their acquisition, especially in the form of a mass of disconnected facts, does not necessarily ensure a changed and scientific concept of Heat. Thus a knowledge of the "Mechanical Equivalent of Heat" is acquired by most Physics students; it may, however, merely be one of a number of isolated facts or it may be the means of changing a student's notions of Heat from a "material substance" to "a form of energy."

Secondly, even if it were possible to rely on the findings of a standardized test for the General Science and Physics groups to test the concept Heat, the non-science groups could not very well take the same test, for scores of zero on such a test would have no meaning.

To get a definition of so abstract a term as Heat from a student who has not studied Physics, or, for that matter, even from an adult, is a difficult matter. Originally a direct question of the type used in the preliminary survey of the last chapter was tried: "What is Heat?" Of the 52 students in the writer's General Science and non-science classes not even one-half attempted to answer the question. The non-science students, most of whom failed to respond, gave as reason that they could not be expected to "know a definition" of Heat, never having studied science; or that they could not "make up" a definition. Next the writer tried a free association test more or less on the lines suggested by Professor Thorndike, that is, students were asked to write down the first ten words they thought of when seeing the presented word; Heat, Light, Sound or Electricity. The associations formed were interesting, but threw little light on the students' concepts.

Finally an attempt was made to obtain these free associations by letting the pupils write ordinary essays, that is, to write as many things as they knew about Heat etc. Every student handed in an essay, and over 70% made an attempt in the essay to explain what they thought Heat was. Fifteen minutes were allowed for writing the essay, but it was found that after six minutes the majority did not have anything more to say.

It is surprising that this method brought forth more responses than the direct question "What is Heat?". Firstly, however, it was given through the English department as an ordinary essay, and non-science students seemed to have more confidence in themselves. Every student had something to write about Heat as he would about any other subject given. Secondly, some of those who felt that they could not tell what Heat was in the beginning of the essay, did so unconsciously while "telling other things" they knew about Heat. In short, the essay is nothing but a type of free association test on Heat, but, unlike the ordinary form of free association test, it is more intelligibly connected.

This "test" was then mimeographed and sent to various schools to be distributed, wherever possible, through the English Departments. With every set of "tests" was included a sheet of directions to the teacher in charge or to the principal, also a statement relating to the purpose of the essays. The time allowed was 8 minutes.

The large majority of essays were written during the months February to May. It was not possible to have all the essays from the Science Groups written at the same time as the subject of Heat is not treated at the same time in all schools. With the exception of one set of General Science essays, which was not used, all "science" essays were written after the subject matter Heat had been studied. The "test" follows:

Name.................. School....................

Age: Years.... months.... Boy or Girl.... Grade....

Are you now studying Physics?.... General Science?....

*Underline* the subjects you have studied *before*:—

Physics General Science Biology Chemistry

*READ THIS.* You are going to write a short essay for which you will be allowed 8 minutes. Start writing on this side and continue writing on reverse side of paper. The essay is on HEAT. You may start your essay by telling just what you think Heat is, and then tell other things you know about Heat.

"What I think HEAT is, and other things I know about Heat."

## METHOD OF RECORDING DATA.

As in the case of the preliminary survey, no attempt was made to "score" the essays as a whole. A grade of C— or 40% or a T score would have little meaning besides being irrelevant to the immediate purpose of this study. Every one of the 840 essays was carefully read and the contents were analysed and recorded under the following classifications:

(1) What the pupil thinks Heat is.

(2) The sources of Heat mentioned.

(3) The effects and uses of Heat mentioned.

(4) Any other statements made.

In the tables that follow are given the per cent. of pupils of each group making a certain type of response. Tables 10 to 16 give the type responses under classification (1) above, Tables 17 to 19 those under classification (2), (3) and (4) above. Thus Table 10 is to be read as follows:— Of the 120 pupils in Grades 5, 6 and 7 who had no formal General Science or Physics, 26.6% have the notion that Heat is "Hot air," "Warm air" or "Heated air".

## Table 10.

Nature of Heat.

***Grades*: 5, 6 & 7.** *Class*: No science. *Number*: 120

| *Percentages* | *Types of responses.* |
|---|---|
| 26.6 | Hot air, warm air, heated air |
| 17.5 | Warmth, Hotness |
| 13.3 | What keeps us warm (or hot) |
| 7.5 | Fire |
| 5.0 | Rays of the sun |
| 4.2 | Power of the sun |
| 3.3 | A vapor in the air |
| 3.3 | Force from a fire (or stove) |
| * | *Power of heating air |
| | Warmth in the air |
| | Force that makes things hot |
| | Warmed air with oxygen burned out |
| | Substance coming from a fire |
| | The strong light of the sun |
| | Something in the air |
| | Temperature in the air |
| | Steam in the air |
| | Hot rays blown by the wind |
| | A power |

*Where no percentage is given, it is less than 1%.

## Table 11.

Nature of Heat.

*Grade* 8. *Class*: No science. *Number*: 84.

| *Percentages* | *Types of responses* |
|---|---|
| 20.5 | Hot air, warm air, air that has been warmed. |
| 15.5 | Warmth |
| 14.3 | Warmth of the sun |
| 6.0 | The sun's rays |
| 3.6 | Moisture in the air |
| 3.6 | What causes temperature to rise and fall |
| 3.6 | Steam, Hot steam |
| 8.3 | What keeps us warm, (hot) |
| 2.4 | A temperature that is warm |
| 2.4 | What can be seen and felt but not heard |
| 2.4 | Opposite of cold |
| | What can be felt but not seen |
| | Amount of warmth thrown off by a hot thing |
| | Something warm |
| | A substance in the air |
| | A power measured by temperature |
| | Rays thrown by any burning thing |
| | Power from fire |
| | Power used to thwart cold |
| | Property of waves of matter that makes a body warm |
| | Warmth is measured by temperature |
| | A form of dry moisture which evaporates until it becomes warm |
| | Force of materials and minerals put together form heat. |

## Table 12.

Nature of Heat.

*Grade* 9. *Class*: No G.S. or Physics. *Number* **95**

| *Percentages* | *Types of responses* |
|---|---|
| 20.0 | Hot air |
| 18.9 | Warmth |
| 13.7 | Warmth of the sun |
| 9.5 | Temperature of a thing |
| 5.3 | The sun's rays |
| 4.2 | A kind of steam |
| 3.2 | Warm moisture in the air |
| 3.2 | What comes from a fire or hot thing |
| 3.2 | What keeps us warm |
| 3.2 | Kind of power originally from the sun |
| 2.1 | That which keeps things alive |
| 2.1 | Opposite of cold |
| | The combustion of chemicals |
| | Warm substance that comes from vapors of coal |
| | Condition of the atmosphere |
| | A result of chemical action |
| | Breaking up of different substances which make heat |
| | Warmth from the body |
| | A very warm temperature |
| | A chemical change when there is combination of different gasses. |
| | Power from sun or fire |
| | Energy from sun or fire |
| | A substance which cannot be seen but only felt |

## Table 13.

Nature of Heat.

*Grade* 11. *Class*: No G.S. or Physics. *Number* 108

| *Percentages* | *Types of responses* |
|---|---|
| 22.2 | Warmth |
| 14.8 | Hot air, warm air, air that has been heated |
| 9.2 | A result of fire |
| 6.5 | Temperature |
| 5.6 | A kind of vapor |
| 4.6 | Compressed fire |
| 4.6 | A thing that can only be felt. An abstract thing |
| 1.9 | Power in the air which raises temperature |
| 1.9 | A form of energy |
| | A condition of the air |
| | Vapor which gives off waves |
| | The temperature needed to keep the body warm |
| | A substance (or) an invisible substance |
| | A rising temperature |
| | A phenomena of combustion |
| | A warm moisture |
| | What we get from the rays of the sun |
| | Opposite of cold |
| | A force that makes things hot or cold |
| | A force coming from the sun |
| | A result of oxidation |

## Table 14.

Nature of Heat.

*Grade* 12. *Class*: No G.S. or Physics. *Number* 90

| *Percentages* | *Types of responses* |
|---|---|
| 15.6 | Warmth |
| 13.3 | Hot air, warm air |
| 8.9 | Temperature |
| 4.4 | Result of oxidation |
| 3.3 | A vapor, Vapor in the air |
| 3.3 | A kind of energy |
| 2.2 | Rise in temperature |
| 2.2 | Opposite of cold |
| 2.2 | Result of chemical combination |
| 2.2 | A substance that can be felt but not seen |
| | A force that changes things. Fire, Unit of energy |
| | Effect of pressure. An invisible temperature |
| | A power causing things to expand |
| | A warm moisture. The process of keeping warm. |
| | One of the forces of the air. A variable temperature, having its limits in combustion |
| | What is caused by friction. Atmospheric property caused by the sun's rays. |
| | Temperature above the average. |
| | That which is connected with flame. |

## Table 15.

Nature of Heat.

*Grade* 9. *Class*: General Science. *Number*: 128.

| *Percentages* | *Type of response.* |
|---|---|
| 14.1 | Hot air |
| 2.3 | Hot moisture or vapor |
| 2.3 | A gas. A kind of gas |
| .8 | A gas thrown off by coal |
| 7.0 | A process of oxidation |
| 1.6 | A substance given off during oxidation |
| .8 | A result of chemical action |
| 5.5 | A motion, or vibration, of molecules of a body |
| .8 | The spreading of molecules |
| | Molecules in the air being moved further apart by fire |
| | That which starts molecules vibrating when applied |
| | Molecules vibrate faster when heated |
| | The bumping of molecules so fast that they give heat |
| | Motion of molecules in the air |
| 10.9 | Warmth, Hotness |
| 6.2 | Temperature, High temperature |
| 5.5 | What comes from a burning substance |
| 1.6 | An invisible substance that can only |
| 1.6 | Opposite of cold |
| 1.6 | A force of Nature |
| .8 | A substance |

*TABLE* 15.—*Continued.*

| *Percentage.* | *Type of response.* |
|---|---|
| | A substance produced by fire |
| | The rising of the temperature |
| | An invisible fluid |
| | Something thrown off by a burning thing |
| | Rays from a hot object |
| | Heat is an atmospheric pressure |
| | Something like atmosphere |
| | Warm waves that travel in the atmosphere |
| | That which is stored in atoms |
| 10.9 | A form of energy, Energy from the sun |

## Table 16.

Nature of Heat.

*Grades*: 11 & 12. *Class*: Physics. *Numbers*: 115 & 100.

| *Percentages* 11. | 12. | *Types of responses* |
|---|---|---|
| 22.4 | 22.0 | A form of energy |
| 1.7 | 3.0 | Potential or stored up energy |
| 0.0 | 2.0 | Radiant energy given by the sun |
| .9 | 1.0 | Energy formed by oxidation |
| 0.0 | 1.0 | Energy turned from work to warmth |
| .9 | 0.0 | An effect produced by energy |
| 2.6 | 2.0 | Form of molecular energy |
| 1.7 | 1.0 | Energy which causes molecules to move faster |
| 0.0 | 1.0 | Mechanical or electrical energy |
| 1.7 | 2.0 | Energy |
| .9 | 0.0 | Converted energy |
| 0.0 | 2.0 | Passing of energy from one object to another |
| .9 | 0.0 | A source of energy |
| 0.0 | 1.0 | A great amount of energy |
| 2.6 | 0.0 | An element produced by energy |
| 0.0 | 1.0 | A form of energy that has for its purposes to melt or heat |
| .9 | 9.9 | Kinetic energy |
| .9 | 0.0 | Form of energy that cannot be converted |
| 0.0 | 2.0 | Amount of energy to raise a liquid from 1°C to 2°C |
| 0.0 | 1.0 | Amount of energy to raise temp. from 0°C to 2°C |
| 1.7 | 0.0 | Form of energy which can be felt and from which other forms can be derived |
| 0.0 | 1.0 | Form of energy that performs work |
| 0.0 | 1.0 | Energy used to do some mechanical advantage |

*TABLE* 16.—*Continued.*

| *Percentage.* | | *Type of response.* |
|---|---|---|
| 2.6 | 2.0 | Friction between molecules. They rub against each other which causes friction causing heat |
| 1.7 | 2.0 | Molecules more active when body is hot, less active |
| 1.7 | 3.0 | Heat is caused by motion of molecules |
| .9 | 0.0 | Heat caused by the mingling of molecules of one body with those of another |
| 0.0 | 1.0 | Heat is warm molecules imparted from the sun or a fire |
| 1.7 | 0.0 | A property resulting from constant rushing together of molecules; faster they rush, greater the heat |
| 3.5 | 4.0 | Form of molecular energy; greater velocity of molecules the greater heat in the body |
| .9 | 0.0 | Molecular form of energy caused by molecules that move freely |
| .9 | 0.0 | An increase in temp. of the molecules of the air |
| 0.0 | 1.0 | That form of energy that causes the molecules do move further apart |
| .9 | 0.0 | Any change in the molecules of a thing causes heat |
| 0.0 | 1.0 | Heat is a number of rays of molecules which have a tendency to impart to other molecules their speed |
| .9 | 1.0 | Heat is air in which molecules move faster than usual |
| .9 | 0.0 | A direct result of exciting and liberation of molecules |
| 0.0 | 1.0 | Warmed up air particles or molecules |
| 4.3 | 4.0 | Hot air. Air that has been heated |
| 2.6 | 2.0 | Warmth |
| 1.7 | 1.0 | Warmth given off by something oxidizing |

*TABLE 16.—Continued.*

| *Percentages.* | | *Type of response.* |
|---|---|---|
| 0.0 | 1.0 | Vaporized air |
| .9 | 0.0 | A gas obtained from friction |
| .9 | 0.0 | Vapor given off when two metals are rubbed |
| 0.0 | 1.0 | A weightless fluid which makes a body warm when it enters |
| 1.7 | 0.0 | Warmth given by the sun |
| 0.0 | 1.0 | A result of combustion |
| .9 | 0.0 | Temperature or really the opposite; the degree to which bodies change their state of temp. |
| 0.0 | 1.0 | When work is done part becomes wasted which is heat |
| 0.0 | 1.0 | That condition that takes the place of coldness |
| .9 | 0.0 | An invisible matter |
| .9 | 0.0 | A factor producing work |
| .9 | 0.0 | Reaction between substances in contact with each other |
| .9 | 0.0 | A property of a substance |
| 0.0 | 1.0 | A series of waves produced by fire or electricity |
| 0.0 | 1.0 | A force that can be seen and felt |
| 0.0 | 1.0 | Giving off of calories to produce warmth |
| 1.7 | 2.0 | A result of oxidation |
| .9 | 0.0 | One of the class of phenomena |
| .9 | 1.0 | The friction between two bodies |
| .9 | 1.0 | Something that cannot be seen or heard but felt |
| .9 | 1.0 | The number of calories in a thing |
| .9 | 0.0 | Temperature with weight taken into account |
| 0.0 | 1.0 | The combustion of molecules with the aid of oxygen |

# Table 17.

## Sources of Heat.

| Grade | —5—7 | —8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|
| Average age: | | | | | | | | |
| 5: | 11.1 | | | | | | | |
| 6: | 11.1 | 13—9 | 14--10 | 16—9 | 17--10 | 14—9 | 19—9 | 17—9 |
| 7: | 12.8 | | | | | | | |
| Number | 120 | 84 | 95 | 108 | 90 | 128 | 115 | 100 |
| The sun | 44.1 | 45.2 | 40.0 | 44.4 | 43.3 | 44.5 | 36.6 | 38.0 |
| Sun's rays | 6.7 | 0.0 | 4.2 | 3.7 | 12.2 | 3.5 | 1.7 | 0.0 |
| Fire | 40.0 | 20.5 | 20.0 | 22.0 | 12.2 | 10.6 | 3.5 | 5.0 |
| Fuels (Coal etc.) | 48.4 | 53.6 | 35.8 | 31.5 | 30.0 | 31.2 | 20.8 | 17.0 |
| Stoves | 11.7 | 6.0 | 3.2 | 3.7 | 0.0 | 1.6 | 0.0 | 0.0 |
| Electricity | 10.0 | 20.2 | 12.6 | 13.0 | 10.0 | 14.8 | 19.2 | 21.0 |
| Oxidation and Chemical action | 0 | 3.6 | 9.5 | 9.3 | 6.7 | 13.3 | 24.4 | 20.0 |
| Friction | 3.3 | 6.0 | 9.5 | 9.3 | 12.2 | 20.2 | 33.9 | 39.0 |
| Body Heat | 8.3 | 17.9 | 26.3 | 31.5 | 15.6 | 16.4 | 12.2 | 9.0 |
| Sunlight | 6.7 | 0.0 | 4.2 | 2.8 | 4.4 | 0.8 | 0.0 | 0.0 |
| Compression | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.3 | 0.9 | 0.0 |
| Earth's Heat | 1.7 | 0.0 | 0.0 | 0.0 | 2.2 | 1.6 | 0.0 | 0.0 |

*Miscellaneous sources not given above*:—

(5—7) Warm winds, atmosphere, explosion, by lighting a thing. Matches. The moon.

( —8) Generated by comets and falling stars. Generated by particles of dust. By magnifying glasses. Warm water in the ocean. By taking different gases.

( —9th) By plants, Smoke, Volcanoes, Steam, Hot air.

(—11,—12) By energy, The moon and stars, Volcanoes, Moisture in the air.

(+9th) Spontaneous combustion. From light, steam, from a body raised to kindling point, Equator .

(Physics) From melting ice, Matches, Radiation, Volcanoes, Steam, Convection, Magnetism.

# Table 18.

Effects and Uses of Heat.

| Grade .. .. | —5—7 | —8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|
| Number .. .. | 120 | 84 | 95 | 108 | 90 | 128 | 115 | 100 |
| *Effects of Heat* | | | | | | | | |
| Expansion .. | | 2.4 | 2.1 | | 4.4 | 14.8 | 19.2 | 23.0 |
| Change of state e.g. melting, boiling .. .. | 13.3 | 19.1 | 20.0 | 18.5 | 14.4 | 18.0 | 22.5 | 21.0 |
| Chemical changes | | | | 1.8 | | 1.6 | 1.7 | 0.0 |
| Make things grow | 8.3 | 6.0 | 12.6 | 9.2 | 8.9 | 3.9 | 3.5 | 4.0 |
| Kills germs | 1.7 | | 3.2 | | 2.2 | | | |
| Causes fire .. | | | | | 2.2 | 8.2 | 1.7 | |
| *Uses of Heat* | | | | | | | | |
| Heats the house | 48.4 | 33.3 | 36.3 | 44.4 | 42.2 | 39.4 | 20.9 | 26.0 |
| Cooks food .. | 62.5 | 51.2 | 55.8 | 35.2 | 34.4 | 41.8 | 24.3 | 18.0 |
| Used for running ships, factories etc. | 16.7 | 20.2 | 15.8 | 13.0 | 15.6 | 26.5 | 33.0 | 36.0 |

*Miscellaneous effects and uses*:—

(Non—G.S.—Physics) Makes you sweat, Makes people sick, Causes the seasons, Keeps the blood circulating. Destroys grains. Causes rain. Burns a person, Infuences the living of people. Causes rocks to disintegrate.

(General Science) Heat makes copper faster than other metals (??) Heat causes winter and summer. Helps respiration. Keeps blood circulating.

(Physics) Affects the climate. Causes convection currents. Has power of absorption. Power of making molecules in a liquid expand.

## Table 19.

—Miscellaneous statements made in essays —

| | |
|---|---|
| (5—7) | Without heat we would freeze to death. Heat is essential for all life (10%). It is hot in summer (10). Hot air rises (6.7). Heat rises (5.0). It is hottest at the equator (3.3). Heat is measured by momenetors. Warm air is lighter than foul air. Heat is very strong, Fire throws out warm air. |
| (—8) | Without heat we would die (20.2). Heat rises (6). It is warmer in summer (13.0). It is warmer at the equator because it is nearer the sun (2.4). Heat is always in the Southern Hemisphere but not always in the Northern. Heat is measured in degrees. If heat is placed upon a picture and a person, the picture appears to move. The sun warms the air and the air turns to heat. If the sun is in the Western Hemisphere. In summer the air holds heat and so does water and gradually gives it out. You could see the smoke of the steam but could see nothing of heat. |
| (—9) | Heat is essential for all life (30.5). Hot air lighter than cold air (2.1). Heat rises (2.1). Food we eat turns to heat. Heat expands. Heat can be changed to vapor. Mars is an example of a world without heat. Plants need heat (or) seeds need heat to germinate (10.5). It is warmer in summer because the earth etc., etc. (7.4). You can feel the heat beating against you from a fire. If all the heat is taken from water it freezes. |

(—11,—12) Heat is essential for all life (33.9). Heat rises (3.3) Hot air rises (5.1) Measured by a thermometer (5.9) SEASONS. Heat of summer, equator heat etc. There are two kinds of heat, natural and artificial (3.3) Heat waves can be seen in the air. Heat accompanies light. Fresh air heats more quickly than stale air. Heat has great speed. Heat is the part of a flame that burns. There is an enormous amount of heat stored in the center of the earth. There are two common kinds of heat—hot air and steam; steam is the best. Heat is measured in calories. If it were not for the heat of the sun, the whole earth might be like the North Pole.

(General Science). Heat essential for all life (21.2). Hot air rises (5.1). Heat rises (1.6). Travels by conduction, convection, and radiation (14.1). Measured in degrees by thermometer (7.0). Measured in calories (3.5). Heat has great speed (2.3). There is heat of fusion and heat of vaporization (1.6). Very hot down in earth (2.3). SEASONS—summer, etc. (10.6). No fire, no heat. Not much heat on cold day because the sun is not so hot. Heat burns. The sun is always near the equator. You can see the heat on a very hot day. Heat reflects like light. It is heat that makes it hot.

(Physics.) Essential for all life (37.2%). Heat flows. Heat rises in the air (2.7). Hot air rises (3.2). *Transferred by conduction, convection and radiation (27.9). Heat is measured by Sunlight passing through glass does not heat glass. (calories)

When light rays from sun go through a transparent substance (air) and strike an opaque object (earth) they change into heat.

Measured by thermometers in degrees (3.3). Intense heat will start a fire. Heat travels fastest through solids and slowest through gases. The nearness of the earth to the sun makes heat greater. Sun heat is real but gas heat is artificial. We cannot see heat although vapor of heat can be seen. Heat can be reflected. Heat travels in curved lines as can be seen in a field on a hot summer day. There is heat of fusion and vaporization (3.7). There is a definite relation between heat and work done. Sun heats the earth by radiation (2.3).

(*Examples given in many cases.)

## ANALYSIS OF RESULTS.

Ordinarily it is expected that with mental growth there will be development in the significance of a concept such as Heat; this holds true to a certain extent in this case. Stanley Hall has suggested that to very young children Heat and Fire are synonomous, that is, to them heat is fire and fire heat.

In Grades 5, 6, 7, 8 & 9 more than 30% of pupils think of heat as "warmth," "warmth of the sun" or "warmth of a fire", and this " warmth " notion persists even to the —12th grade to the extent of 15.6%. In these grades heat is not fire itself, but some property of a fire or the sun, and, although these pupils are merely using another term for heat, it is clear that their notions are on a slightly higher level than those of children just entering school.

An unexpected outcome is the prevalence of one particular erroneous notion, namely that of heat as " hot air " or " hot gas". In grades 5, 6 and 7 26.6% have this idea; even in the —12th grade is it found to the extent of 13.6%. It may be contended that this is just one of the many erroneous notions children have. On the contrary, it is not one that occurs in one grade to a negligible extent and not at all in another; it is found in all the non-science and in the General Science grades, only in the Physics groups does it occur to an insignificant extent.

The essays do not show just why these notions are held, only in a few cases do pupils enlarge on this " hot air" notion. Thus statements of the following types were found:— "Heat rises to the ceiling of a room," " You can see the heat or hot air on a hot summer day," " If heat is placed between a picture and you, the picture appears to move," " Heat is air that is used to warm our houses, in our house the kind of heat we use is hot air". In a later chapter more data will be given to account for this notion.

The other notions of the non-science groups are extremely vague. The types of notions held by Physics students are very different from those of both the non-science and General Science groups. A glance at Table 16 shows that over 40% associate Heat with some form of energy, while about 16% associate it with molecular activity. That these notions themeslves are not all correct and that some are gross misconceptions is true; but the fact remains that the majority of Physics students form with heat associations of a more scientific type. Heat is no longer regarded as fire, warmth from a fire or hot air, but as a kind of energy or a mode of motion. About 20% give the same types of responses as the non-science pupils.

Is the difference between the non-science and Physics groups after all so significant? According to Dr. Dewey " popular definitions select certain fairly obvious traits as keys to classification, scientific definitions select conditions of causation, production and generation as their characteristic material. The traits used by popular definition do not help us to understand why an object has its common meanings and qualities; they simply state the fact that it does have them. Causal and genetic definitions fix upon the way an object is constructed as the key to its being a certain kind of object and thereby. Explain why it has its class or common traits.... scientific definition is founded not on directly useful properties, but on the way in which certain things are causally related to other things; that is, it denotes a relation." The majority of non-science and General Science students give popular definitions of Heat, whereas the majority of Physics students give causal and genetic definitions. Based on the above criterion, then, the differences certainly are significant.

To say that Physics students have scientific or logical concepts of heat is not really the case, for many of these are erroneous and vague. To say that the majority of these students are changing their concepts from a popular or naive to a logical or scientific form is nearer the truth. The transition begins in the General Science stage, the majority of pupils not being affected, however; in the Physics groups, on the other hand, the majority are affected, this reconstructive process having taken place in about 60% of cases.

The purpose of giving this essay type of question was to obtain students' notions of Heat. Many other statements were made, however, and these are classified in Tables 17, 18 and 19. Table 17 gives the percent of each group mentioning a particular source of Heat. The sun is mentioned by the largest number in each group. Heat calls to mind "fire" in 40% of the cases in grades 5 to 7 but only in 3.5 % of cases in the 11th Physics group. On the other hand, the percents for "friction" are just in the reverse order. These percents do not show the number acquainted with the particular source of heat, but only the number who mentioned it in the essay. Probably 100% of —8th graders have knowledge of heat and friction.

Table 18 gives the extent to which certain effects and uses of heat were mentioned. These may or may not mean much, as those students who had studied the subject would naturally be better acquainted with the various effects of heat such as expansion, change of state etc. The cooking of foods and the heating of houses were the two uses given by most pupils. Reading across Table 18, however, it will be noticed that the number of Physics students giving these two uses is much less than the number giving them in other groups, whereas the reverse is the case for the third use, namely as power to run machinery, ships etc.

As stated before, the purpose of the essay was primarily to obtain the pupil's notion of Heat and not to test his range of information. The latter could probably have been done much more successfully by direct questioning to that effect. There seems to be, however, some relation between these miscellaneous statements and the general notions of Heat. For example, in grades 5, 6 and 7 the sources of heat mentioned most frequently are sun, fire, stoves and fuels; while the concepts of heat that preponderate are "warmth (from fire, sun etc.)" and "hot air". In the Physics groups the sources given most often are sun, friction, chemical action and electricity and the notions of the majority involve energy or molecular activity . Again, in enumerating the uses of heat, the majority of Physics students give the operation of factories, locomotives, ships and engines of various kinds; the majority of 5—7th graders think of the more obvious uses in cooking and the heating of houses. The conclusions from these results are:

(1) The concepts of the non-science pupils are generally vague. Heat is defined (a) by simple substitution of another word e.g. warmth, (b) as an obvious property of fire, a burning thing or the sun.

(2) The erroneous notion "hot air" appears in all groups of non--science and General Science pupils to a relatively large extent.

(3) The study of General Science does produce a change in concepts of Heat, but the new notions are of a scientific form in less than 20% of cases. The erroneous notion of heat as "hot air", a gas or a substance is still found in about 25% of cases.

(4) The formal study of Heat in Physics produces a marked change in the concepts held. The majority of students hold notions which are ëither scientific or in the process of reconstruction. The notion of energy or molecular motion has displaced the "material substance" notion in the majority of cases.

(5) Although about 16% of Physics students associate Heat with molecular motion, their notions are extremely vague.

(6) There is no appreciable difference between the 11th and 12th Physics grades concerning the types of concepts held or the extent to which they are held.

## CHAPTER VI.

## CONCEPTS OF LIGHT.

Essays were also written on Light in the manner of and under similar conditions as those of Heat of the previous chapter. The majority of students who wrote the essay on heat also wrote one on Light.. The instructions to students were similar to those described in chapter V with the exception that the word "Light" was substituted for the word "Heat".

As before, every one of the 835 essays was read by the writer and the contents recorded and classified under the following headings:—

(1) What the pupil thinks Light is.

(2) Statements concerning the method of light propagation.

(3) Any other statement made.

The results are given in Tables 20 to 28 and are to be interpreted in a manner similar to those of chapter V.

## Table 20.

Nature of Light.

*Grades*: 5, 6 & 7. *Class*: No science. *Number*: 92.

| *Percentages* | *Type of response.* |
|---|---|
| 26.1 | Light is what makes us see (or) what we see by |
| 9.8 | The rays of the sun |
| 8.9 | Brightness (or) brightness of a thing |
| 6.5 | What comes from the sun (or) fire |
| 4.3 | Something to light places at night |
| 4.3 | Power to see (in the dark) |
| 3.2 | The opposite of darkness |
| 2.2 | Substance made by electric (or) gas |
| 2.2 | Something you see when in the dark |
| * | Bright rays |
| | Substance which brightens a thing |
| | A mass of white clouds |
| | Light is when it gets dark |
| | Light is electric |
| | A glow from the sky |
| | Light is when the sun revolves around the earth |
| | A movement of the air |
| | The sunset part of the world |
| | Air becoming bright |
| | A force of gravity |
| | Light is the sun shining on half the earth |

* Where no percentage is indicated it is less than 1%.

## Table 22.

Nature of Light.

*Grade*: 9th *Class*: No science. *Number*: 96.

| *Percentages* | *Type of response.* |
|---|---|
| 21.9 | Light is what enables us to see, (or) substance that makes us see |
| 12.4 | Rays of the sun |
| 8.4 | Sun's reflection (or) reflected sunlight |
| 6.2 | A power from the sun |
| 5.2 | Brightness (or) brightness from sun |
| 4.2 | Opposite of dark |
| 3.1 | A kind of energy (or) energy that makes plants grow |
| 2.1 | A substance present during daytime |
| 2.1 | Reflection of a fire or burning thing |
| -- | Illumination (or) illuminating force |
| | A kind of electricity |
| | A substance like air |
| | A condition when sun shines on the earth |
| | A force in the air |
| | A kind of ways that is visible |
| | A beam or ray thrown off by a fire or bulb |
| | A result of sunshine |
| | An element |
| | A thing which, if there were none we would be blind |
| | That which makes day |
| | A power that can only be seen |

Nature of Light.

Table 23.

*Grade*: 11th. *Class*: No science. *Number*: 112.

| *Percentages* | *Type of response.* |
|---|---|
| 16.1 | Light is what enables us to see (or) substance that makes us see |
| 11.6 | Sun's reflection (or) reflected sunlight |
| 8.9 | Rays from the sun (or) beams of light |
| 5.4 | Result of combustion (or) oxidation |
| 4.5 | Brightness of a thing |
| 4.5 | Energy (or) energy necessary for plant growth |
| 3.6 | An illumination |
| 5.4 | Opposite of dark |
| 2.7 | Power which brightens the world |
| | A force from the sky |
| | Result of the sun's presence |
| | The object of seeing something not hidden |
| | Light is a stimuli |
| | Light is when we see |
| | A form of seeing things |
| | Power sun has directing rays to earth |
| | A quality associated with fire |
| | Power to distinguish objects |
| | A necessary thing when in darkness |
| | Force travelling on invisible waves |
| | What a difference between day and night |
| | Invisible waves in the air |
| | Something like electricity |
| | Nobody knows what light is |
| | Light, according to Einstein is a dimension |
| | Something that can be seen but not felt |
| | Something like heat |

## Table 24.

Nature of Light.

*Grade*: 12th. *Class*: No science. *Number*: 115.

| *Percentages* | *Type of response.* |
|---|---|
| 19.2 | Reflection of sun on earth, sun's reflection |
| 10.4 | What enables us to see (or) substance etc. |
| 5.2 | Form of energy from sun (that makes plants grow) |
| 5.2 | Result of combustion, burning, oxidation |
| 4.3 | Opposite of darkness |
| 4.3 | Absence of darkness |
| 4.3 | What comes from the sun |
| 2.6 | Result of sun's rays striking the earth |
| 2.6 | Rays of force from the sun |
| 2.6 | A property of electricity |
| 2.6 | A substance which fills all space and which effects the eyes |
| 1.7 | What makes things visible |
| | Another form of heat |
| | Product of a flame |
| | Condition produced by sun's position |
| | A power to distinguish between night and day |
| | A sensation |
| | What makes plants grow |
| | What gives a thing color |
| | An invisible power in the air |
| | A substance that strikes the eye causing light |
| | Brightness of a thing |
| | A thing that has to do with ether |

Table 25.

Nature of Light.

| *Grade*: 9th. | *Class*: General Science. *Number*: 111. |
|---|---|
| *Percentages* | *Type of response.* |
| 14.4 | Reflection of sun on earth (or) sun's reflection |
| 13.5 | What enables us to see; substance enabling etc. |
| 6.3 | Rays from a bright thing |
| 4.5 | Result of heating to incandesence; result of oxidation or burning |
| 3.6 | Beams coming from the sun (or) sun's rays |
| 3.6 | Opposite of dark |
| 3.6 | Brightness; brightness of sky or a thing |
| 3.6 | A form of energy; form of energy like heat |
| 3.6 | Energy from the sun |
| 1.8 | Power to see |
| 1.8 | Power used to illuminate |
| | Vibration of electrons in the ether |
| | Motion of molecules in ether |
| | Vibration of ether in the air |
| | Vibration of molecules |
| | Vibration of molecules to form incandesence |
| | Something composed of small molecules of energy |
| | Light is ether |

(Table 25.—Continued).

Waves of different color
Something that sends out waves to our eyes
A luminous substance we see with
The shine an object gives
Lightness of the sky
Light is the sun
That which distinguishes between night and day
A way of seeing in the dark
A substance having a great speed
That which drives dark away
An invisible substance in the air

## Table 26.

Nature of Light.

*Grade*: 11th and 12th. *Class*: Physics. *Numbers*: 114 & 100.

| *Percentages* | | *Type of response.* |
|---|---|---|
| 11th. | 12th. | |
| 16.7 | 18.0 | A form of energy |
| 9.6 | 12.0 | Energy from the sun, fire or combustion |
| 4.4 | 2.0 | That into which other forms of energy change |
| 1.7 | 2.0 | A form of radiant energy |
| .8 | 0.0 | An invisible energy |
| .8 | 0.0 | A form of heat energy |
| 3.5 | 2.0 | A wave motion in the ether |
| 2.6 | 0.0 | Vibration of molecules in the ether |
| 1.7 | 1.0 | A vibration of molecules in the ether |
| 0.0 | 1.0 | Vibrations of electrons in the ether |
| 1.7 | 2.0 | A transverse wave motion in the ether |
| 0.0 | 1.0 | Vibration of molecule in the air |
| 0.0 | 1.0 | Those vibrations in the ether which affect the eye |
| .8 | 0.0 | Ether waves |
| .8 | 0.0 | Ether molecules vibrating |
| 0.0 | 1.0 | A wave motion in space |
| .8 | 0.0 | Propagation of waves along a path until they reach an object which resists. |
| .8 | 0.0 | Effect of light waves on the eye |
| .8 | 0.0 | Effect of light waves on the eye |
| .8 | 1.0 | Waves of some invisible substance in the air |
| .8 | 2.0 | Invisible waves in space |
| 5.3 | 6.0 | Rays from the sun |
| .8 | 1.0 | Rays projected from some body |
| .8 | 0.0 | Composition of rays having power to overcome darkness |

(*Table* 26.—Continued).

| | | |
|---|---|---|
| 0.0 | 2.0 | Rays that illuminate the earth |
| .8 | 0.0 | Source from which one can perceive objects |
| .8 | 0.0 | Color of space in air |
| 2.6 | 4.0 | What enables us to see (or) substance allowing us to see. |
| .8 | 0.0 | Sensation to the eye |
| .8 | 1.0 | An illumination |
| 1.7 | 2.0 | Light is light |
| 1.7 | 2.0 | Product of light, result of heat (intense heat) |
| 0.0 | 1.0 | Illumination by combustion of sun's surface |
| .8 | 0.0 | An artificial thing |
| 0.0 | 1.0 | Result of rapid oxidation |
| 1.7 | 2.0 | A reflection |
| .8 | 0.0 | Molecules in the air |
| 1.7 | 2.0 | Oposite of dark |
| .8 | 0.0 | Small bodies or corpuscles |
| .8 | 0.0 | A mixture of all colors of rainbow |
| .8 | 0.0 | Something like electricity and having same speed |
| 0.0 | 1.0 | Radiations from a burning substance |
| 0.0 | 1.0 | A force making things visible |
| 1.7 | 1.0 | Something that can be seen but not felt |

## Table 27.

### How Light Travels.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Grade .. .. | —5—7 | —8 | —9 | —11 | —12 | +9 | +11 | +12 |
| Number .. .. | 92 | 95 | 96 | 112 | 115 | 111 | 114 | 100 |
| Medium age: | | | | | | | | |
| 5: .. .. .. | 11.0 | | | | | | | |
| 6: .. .. .. | 11.10 | 13.9 | 14.10 | 16.10 | 17.10 | 14.10 | 16.9 | 17.9 |
| 7: .. .. .. | 12—7 | | | | | | | |
| In straight lines | | | | 8.9 | 3.5 | 18.0 | 33.4 | 31.0 |
| Through ether | | | | | | 5.6 | 17.6 | 19.0 |
| In waves .. .. | | | | 7.2 | 6.1 | 9.9 | 10.5 | 11.0 |
| Through space | | | | 1.7 | 2.6 | 2.7 | 3.5 | 2.0 |
| In rays .. .. | | 1.4 | 3.1 | 8.9 | 8.7 | 6.3 | 4.4 | 3.0 |
| Through the air | 3.2 | 3.2 | 2.1 | 1.7 | 2.6 | 2.7 | 2.6 | 3.0 |
| With the sun | 6.5 | 2.1 | 3.1 | 3.6 | 3.5 | 2.7 | | |
| Round earth or sun | 6.5 | 4.2 | 2.1 | 2.7 | 0.9 | | | |
| Travels by day | 4.3 | 4.2 | 3.1 | 0.9 | | | | |
| Travels in wires | 8.7 | 6.3 | 4.2 | 1.7 | | | | |
| Speed very great | 26.1 | 20.0 | 20.8 | 30.4 | 29.0 | 16.2 | 7.1 | 5.0 |
| Speed 186000 miles per sec. | 0.0 | 2.1 | 1.1 | 3.6 | 2.6 | 27.0 | 45.6 | 48.0 |
| Wrong speed given | 0.0 | 2.1 | 1.1 | 1.7 | 0.9 | 9.0 | 4.4 | 3.0 |
| Takes 8 mins. from sun .. | 0.0 | 0.0 | 0.0 | 2.7 | 3.5 | 3.6 | 0.0 | 0.0 |
| Faster than sound | 0.0 | 1.1 | 2.1 | 7.2 | 6.1 | 2.7 | 3.5 | 2.0 |

# Table 28.

(Miscellaneous statements made in essays.)

| Grade .. ..<br>Number .. .. | —5—7<br>92 | —8<br>95 | —9<br>96 | —11<br>112 | —12<br>115 | +9<br>111 | +11<br>114 | +12<br>100 |
|---|---|---|---|---|---|---|---|---|
| Light comes from the sun; *sun gives light* .. | 30.4 | 35.8 | 49.5 | 46.4 | 46.8 | 49.5 | 28.2 | 31.0 |
| Electric Light | 45.6 | 48.4 | 41.6 | 44.6 | 27.6 | 35.1 | 10.0 | 13.0 |
| Moon and stars give light .. | 12.9 | 12.6 | 11.5 | 26.8 | 13.0 | 15.2 | 5.3 | 3.0 |
| Lamps, oil, candles give light | 28.3 | 10.5 | 14.6 | 33.9 | 16.5 | 23.4 | 4.4 | 2.0 |
| Cause of day and night .. .. | 10.9 | 15.9 | 10.4 | 14.3 | 11.3 | 6.3 | 1.7 | |
| Natural and artificial light .. | 4.3 | 9.5 | 14.6 | 14.3 | 13.9 | 4.5 | | |
| When sun sets it gets dark | 9.8 | 9.5 | 5.2 | 3.6 | 2.6 | 1.8 | | |
| When light here it is dark elsewhere .. .. | 8.7 | 3.2 | 1.1 | 1.7 | 3.5 | 4.5 | | |
| *If no light we could not exist* | 10.9 | 13.7 | 15.6 | 19.6 | 14.8 | 18.0 | 9.6 | 10.0 |
| Edison invented light .. .. .. | 4.3 | 5.3 | | | | | | |
| Light causes plants to grow | 4.3 | 8.4 | 20.8 | 17.9 | 13.9 | 8.1 | 3.5 | 1.0 |
| Light can be reflected .. .. | 2.2 | 3.2 | 2.1 | 5.4 | 7.0 | 21.6 | 16.7 | 15.0 |
| Refraction mentioned | | | | | | 9.0 | 26.4 | 28.0 |
| Absorption ,, | | | | | | 1.8 | 2.6 | 1.0 |
| Dispersion ,, | | | | 1.7 | 6.1 | 7.2 | 14.1 | 18.9 |
| Cause of colour ,, | | | | | | 1.8 | | 1.0 |
| Candle-power ,, | | | | | | 2.7 | 3.5 | 1.0 |

## ANALYSIS OF CONCEPTS OF LIGHT.

In order to compare the types of concepts held by students of the different groups, the tables of results will be condensed by further grouping as follows:

(1) Responses which involve notions of energy.

(2) Responses involving some aspect of "wave motion in the ether", "vibrations in ether" etc.

(3) Responses involving some obvious property of light or that have reference to the sun, fires; or that are otherwise vague.

(4) No response.

The percent of students of each grade giving each of these four classes of response will be as follows:

| Grade | —5—7 | —8 | —9 | —11 | —12 | +9 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|
| Group (1) | 0 | 0 | 3.1 | 4.5 | 6.1 | 7.2 | 34.0 | 34.0 |
| Group (2) | 0 | 0 | 0 | 0.9 | 0.9 | 8.1 | 14.3 | 12.0 |
| Group (3) | 80.5 | 81.2 | 77.2 | 73.4 | 67.6 | 61.2 | 26.0 | 29.0 |
| Group (4) | 19.5 | 18.8 | 19.7 | 21.2 | 27.2 | 23.5 | 25.7 | 25.0 |

Notions of groups 1 and 2 are of a scientific nature while those of group 3 are vague or popular. It then appears that the concepts of the non-science students are predominantly vague and incomplete; light is thought of most often as "What enables us to see" or "The sun's rays or reflections".

In the General Science group 61.2% of the pupils also have vague notions while 15.3% hold notions more or less scientific, whereas in the 12th Physics grade, for example, the popular notions drop to 29% and the scientific concepts appear to the extent of 46%.

Classification of other statements made in the essays appears in Tables 27 and 28. It is interesting to note just what associations were made with Light, and to what extent they occurred in the limited time allowed for the essays. Up to the —8th grade electricity is the most frequent association; in grades —9, —11 and —12 the sun takes first place while in the General Science and Physics groups the speed of light is the predominant association. In general, the associations of non-science pupils are the obvious ones which is not the case in the science groups. Perhaps the one exception is the velocity of light which is mentioned by as many as 26.1% of —5—7th graders. Just why this should be thought of by so many non-science students, when it was not directly asked for, cannot be explained. Use can probably be made of this in the teaching of Light to entering classes.

Regarding the nature of light propagation, non-science pupils make some peculiar statements. Thus "Light travels with the sun", "Light travels with the earth or all over the world" or "Light travels a good deal". Statements of this type are practically absent from the essays of the science students; their ideas are more intelligible and scientific. Thus "Light travels through space", "Light travels through the ether, in waves, in rays or in ether waves" and "Light travels in straight lines". A glance at Table 27 will show the distribution of the different types of statements regarding the propagation of light.

There seems to be a relation between all the miscellaneous statements made and the notions of light. For example, in the case of the —8th grade the various associations made are no more scientific than the expressed notions of light. In this grade the sun and the electric light are the most common associations while the notions of light are mainly "what enables us to see or what we see by" or "Rays, reflection, brightness of the sun". In the Physics groups the main associations are the velocity of light, the fact that it travels in straight lines, that it can be reflected and refracted and that it comes from the

Classification of other statements made in the essays appears in Tables 27 and 28. It is interesting to note just what associations were made with Light, and to what extent they occurred in the limited time allowed for the essays. Up to the —8th grade electricity is the most frequent association; in grades —9, —11 and —12 the sun takes first place while in the General Science and Physics groups the speed of light is the predominant association. In general, the associations of non-science pupils are the obvious ones which is not the case in the science groups. Perhaps the one exception is the velocity of light which is mentioned by as many as 26.1% of —5—7th graders. Just why this should be thought of by so many non-science students, when it was not directly asked for, cannot be explained. Use can probably be made of this in the teaching of Light to entering classes.

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The results of these essays lead the writer to the following conclusions:

(1) Non-science students have popular notions of light; "What enables us to see" and the "Sun's rays, reflection or brightness" being the most common.

(2) Whereas the majority of General Science pupils too have popular notions; about 15% hold concepts which are more or less scientific. Of these 8.1% involve some aspect of the Electromagnetic Theory of Light, but they are either extremely vague or erroneous.

(3) There is a decided difference in concepts of light between the Physics and the corresponding non-Physics groups. 48.3% and 46% of 11th and 12th grade Physics students respectively have notions more or less scientific. 34% in each group think of light as a form of energy; 14.3% and 12%., like in the case of the General Science group, involve some aspect of the Electromagnetic Theory of Light in their notions, but these notions are either incomplete or erroneous.

(4) Although the study of General Science and Physics has produced changes in the notions of the students examined, these changed notions are vague. To think of light as energy from the sun is more scientific than to hold that it is the sun's reflection or rays, and such notions have been considered as scientific in this study; but to think of light as "motion of molecules in ether or air" or as "vibration of molecules" is really too vague to support further beliefs.

## CHAPTER VII.

## THE CONCEPTS GRAVITY, MASS AND WEIGHT.

Thus far two methods have been used in arriving at pupil's notions. Firstly, in the preliminary survey a direct question was asked for every concept concerned. Secondly short essays were written by pupils on Heat and Light. From the results it was possible to classify several notions held by children and to trace any development with the formal study of science.

In these questions and essays there was practically no control of response, with the result that the range of notions was large. It could be questioned, however, whether the responses to one question only represent the notions held by students; for in the case of the General Science and Physics students especially there is always the possibility of merely repeating a mere text-book definition.

In the preliminary survey many concepts, not reported in this study, were examined; gravity, mass and weight happened to be included. At the time of recording the responses to the question "What do you mean by the Mass of a body?" the writer felt that the common response of Physics students, "Mass is the quantity of matter in a body" might not be reliable and that another question to test the significance of the "quantity of matter" notion might well have been added.

Furthermore, the most common response of non-science students to the question "What do you mean by the weight of a thing" happened to be "heaviness". Now there is a possibility that many of these pupils may have been familiar with the relation between weight and gravity, but preferred to define weight as heaviness. In such cases further questioning might throw more light on the actual notions held.

Accordingly it was decided to test in greater detail some of the concepts originally examined. Perhaps the ideal way of going about this problem would be to question each student orally and to follow up a response with another question; to continue this prcoess until sure of the pupil's notion. Prof. James in his "Talks to Teachers" refers to such a form of procedure: "The great difficulty with abstractions is that of knowing just what *meaning* the pupil attaches to the term he uses........ so various forms of words must be insisted on to bring the secret out". Repeated questioning of a pupil certainly does reveal secrets as will be shown in Part 2 of this study.

When hundreds of pupils have to be examined, however, this method is not so practical, and it became necessary to apply such a form of procedure to the ordinary written test. Experimenting on his own classes, the writer constructed written tests on mass, weight and gravity in which one set of questions had to be answered and returned before the next set could be answered; and so on until the series of "tests" had been completed.

When personally administering the sets of questions to small classes and enough time is provided, the method is practical; but when given by teachers to large classes under existing school conditions there is a limit to the number of consecutive sets of questions. Ultimately the number of sets of questions was reduced to three and the time limited to 40 minutes. Following is a set of questions on mass, gravity and weight:—

(*Part* 1.)

Fill in all blanks (name, age, etc.) before answering the questions.

Name .................. School ..................

Age: Years...... months...... Boy or Girl ........

Grade ................ Are you now studying Physics?

................ General Science? ..................

What text-book do you use? ......................

In the following list underline the subjects you have studied before, and write after each the grade you were in then.

General Science (    ) Biology (    ) Chemistry (    ) Physics (    )

*Directions*: Answer each of the following questions in the space just below it. When you have answered all you can, hand in this sheet and you will receive Part 2.

1. Tell in your own words what you mean by the *weight* of a thing.
2. Tell in your own words just what you mean by the Mass of a piece of lead.
3. If a stone is thrown up into the air it will always return to earth. Tell why.

(*Part* 2.)

Name........................

*Directions*: Answer each question in the space just below it. When you have answered all you can, hand in this sheet and you will receive Part 3.

1. Tell just what you would do in order to find the Mass of a stone.

   Why do you think this procedure would give you its Mass?

2. An object is compressed to half its size. What effect has this on its mass?

   *Why?*

3. An object is taken miles away from the earth's surface. What effect has this on the mass of the object?

   *Why?*

   What effect would it have on the Weight of the object?

   *Why?*

4. When iron is heated it expands. If you heat a piece of iron what effect would it have on its Mass?

*Why?*

5. "The weight of an object ought to be slightly greater at the North Pole than at the Equator" Is this true?........
   *Why?*
6. If two objects in New York have equal weights, will their masses be equal?........
   *Why?*

(*Part* 3.)

Name........................

*Directions*: Answer each question in the space just below it.

1 When a stone is thrown up it always returns to earth because of *gravity*. Tell in your own words what you think *gravity* is.
2. Mass is said to be the quantity of matter in a thing. Tell what you think *quantity of matter* means.

These sets of questions in mimeographed form, together with sheets of directions to the teachers concerned, were sent to 22 High Schools; The Physics pupils were drawn from 14 schools; the General Science and non-science pupils from 8 schools. Great difficulty was experienced in having the questions answered by non-science students, for, even after explaining the purpose of the study to the school principals, they seemed to think it futile to give a "Physics Test" to students who had never studied Physics.

As before, speed was not taken into account. Directions to teachers were: (1) that a 40 minute class period was desirable, (2) a student should hand in Part 1 as soon as he had finished it in order to get Part 2 and similarly for Part 3.

The results were treated in the same way as were those of the single questions and essays. Every response was recorded, responses of the same type were classified and the frequency calculated in percents. The tables that follow represent the results of the test questions on *Weight, Mass* and *Gravity.*

## Table 29.

Tell in your own words what you mean by the *weight* of a thing.

| Grade | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Number | 114 | 120 | 115 | 125 | 100 | 172 | 86 | 178 | 192 |
| Medium age | 13-11 | 14.10 | 15.10 | 16.9 | 17-8 | 14.9 | 15.8 | 16.9 | 17.8 |
| Measure of the earth's pull (or) Force of gravity on a body (or) measure of pull of gravity | 2.6 | 2.5 | 2.6 | 2.4 | 9.0 | 12.2 | 23.3 | 56.2 | 59.8 |
| Heaviness (or lightness of a thing: How heavy it is | 42.1 | 46.6 | 41.7 | 48.0 | 47.0 | 44.8 | 6.9 | 5.8 | 3.5 |
| Number of pounds or ozs. or grams in a thing | 23.7 | 20.8 | 17.4 | 15.2 | 18.0 | 13.9 | 16.3 | 6.6 | 4.0 |
| *Miscellaneous | 21.1 | 17.6 | 23.5 | 21.6 | 15.0 | 16.3 | 36.0 | 25.1 | 32.5 |
| No response | 10.5 | 12.5 | 14.8 | 12.8 | 11.0 | 12.8 | 17.5 | 6.3 | 2.2 |

*(8th) What a thing weighs (6.1%) The heft of a thing (7.0%) Everything it contains. What a scale shows. Capacity of a thing. Pressure on which it lies. Measure of heaviness compared to air. Avoidupois measure. The amount of a thing.

*(9—12) (Non-Phy) What a thing weighs (4.1%) The amount of anything (2.2%) What makes it heavy or light (2.2%) The capacity of a thing (2.6 pCt.) How large it is (1.9%) Amount of air pressure on it. A unit of measure. That which a scale shows. The heft of a thing. Weight of material in it. Amount of air displaced. The consistency of a thing. The contents of a thing. Its downward pressure. Resistance it offers when lifted.

*(9th G.S.) What a thing weighs. (4.7) The amount of a thing. (2.3) Density or specific gravity (2.3) Density of the material in it. Weight is mass. Amount

or capacity. What its mass weighs. Number of molecules or atoms in the body. Amount of air pressure on every cubic inch. Amount of volume. What is shown by a scale.

*(10th Physics) What a thing weighs (1.2%) Weight is mass (7.0) Weight is mass plus gravity. That which will pull it down. Resistance offered to gravity. A measure of work. Weight is weight of the mass. Amount of water displaced. Volume of a body. Mass times volume. The pressure of gravity. Weight is the measure of the mass of a thing. The amount of avourpodis (?) a thing has. Weight is the measure of a thing. The difference in speed while falling.

*(11, 12th Physics) Pressure a thing exerts (2.2) Amount of force on body by earth's magnetism. Amount of force required to pull scales down one notch. Anything acted upon by gravity. Force required to support body in neutral position. Density of a thing (1.4%) A measure of mass (2.7). Specific number of units in a substance. Measure of specific gravity in a body. Amount of matter in a body (4.9) A property which requires effort to support a thing. Something that has volume. Resistance required to lift against gravity. mass (5.4%) Weight is volume times density. Mass per unit volume. Specific gravity. Volume of substance Something that requires energy to displace. Weight is measured by gravity pull. In Physics it means pull of gravity but to me it is mass. Amount of air a thing displaces (1.4) Weight is the definition of mass. Mass divided by volume. What it weighs. Degree of weight or amount of weight. The force it exerts. A unit of heaviness.

## Table 30.

Tell in your own words what you mean by the *Mass of* a piece of lead.

| Grade | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Number | 114 | 120 | 115 | 125 | 100 | 172 | 86 | 178 | 192 |
| Quantity of matter in it | 0 | 0 | 0 | 0 | 0 | 1.2 | 13.9 | 24.1 | 23.4 |
| Volume: size; No. of cu. in. or cms. | 4.4 | 12.5 | 15.7 | 20.0 | 20.0 | 26.1 | 44.2 | 28.2 | 25.0 |
| Weight. What it weighs; Heaviness, No. of lbs., ozs. in | 12.3 | 14.2 | 17.4 | 19.2 | 24.0 | 11.6 | 27.9 | 12.8 | 12.5 |
| Weight per unit volume | | | | | | | 4.7 | 6.5 | 3.1 |
| The whole piece of lead. Lead taken as a whole | 14.9 | 11.7 | 11.3 | 8.8 | 9.0 | 8.1 | | | |
| *Miscellaneous | 31.6 | 70.0 | 21.7 | 13.6 | 17.0 | 18.0 | 7.0 | 25.7 | 32.4 |
| No response | 10.5 | 12.5 | 14.8 | 12.8 | 11.0 | 12.8 | 17.5 | 6.3 | 2.2 |

*(8th) Material of which it is made (2.6%) A part of the lead (or) a part of the thing (3.5). Capacity. The greater part of the lead. Amount, width, the heavy part. Shape. The solid part. Hardness. It is made up of many parts. A group of it.

*(9—12th Physics) Substance it is made of (4.1). Heavy or heaviest part of it (6.0) Amount. Density. Solidness, Area, Contents, Shape, Diameter, Surface, Weight of a part. The solid part. Weight with size taken into account. Number of times it is heavier than air. Number of the times heavier than water. Bulk or weight.

*(9th G.S.) Density (9.6%). Density per unit volume (2.0). Thickness. Area, Shape. Amount of water it displaces. Bulk or size. Volume plus weight. Number of molecules of which it is composed. The space it occupies. Hardness. The biggest part of it. Its dimensions.

*(10th Physics) Weight plus gravity. Amount of water displaced. Hardness. No of units in unit volume. Space occupied. Weight in comparison to size. Density. Its molecular contents. Pull of gravity on it. The degree of weight.

*(11th, 12th Physics). Density per unit volume (6.8%). Bulk (2.4%). Amount of earth's pull (5.9). Volume X density (1.9) Amount of water displaced (1.3%) Quantity of matter per unit volume. Weight and space occupied. Amount of molecular contents. Amount of it to weigh 1 ounce or 1 pound. Volume occupied by one unit. That it occupies space. Pull of gravity on its volume. Number of cubic units in it. Entire area. The force that bouys it up equal to its own weight. Amount of degree of matter. Amount of the volume of matter. Weight in grams of matter. Amount of calories in it. Area of its volume. Energy required to lift it. Its weight in a vacuum. I mean the DV (?). Weight with its volume and length taken into account. Thickness. Weight in grams, not pounds. Density divided by weight. Weight with dimensions taken into account. Mass is not volume or weight.

## Table 31.

QUESTION 3.

If a stone is thrown up into the air it will always return to earth. Tell why.

| Grade | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Number | 114 | 120 | 115 | 125 | 100 | 172 | 86 | 178 | 192 |
| Gravity pulls it down. (or) Because of the force of gravity | 63.1 | 69.2 | 72.3 | 73.6 | 75.0 | 81.5 | 83.7 | 93.7 | 94.3 |
| It is heavier than air | 26.3 | 23.3 | 20.8 | 18.4 | 20.0 | 13.3 | 9.3 | 3.6 | 4.1 |
| Miscellaneous | 5.3 | 4.2 | 4.3 | 4.0 | 5.0 | 3.6 | 4.7 | 2.7 | 1.6 |
| No answer | 5.3 | 3.3 | 2.6 | 4.0 | 0.0 | 1.7 | 2.3 | 0.0 | 0,0 |

*(Non-Physics, Non-G.S.) It cannot stay up. The earth is round. Air is light. It is not wide enough to float. What goes up must come down. (2.3%) A stone is heavy. Because of its heaviness. A stone cannot float in air.
*(G.S.) It cannot stay up in the air. Atmosphere presses it down. Because of its density. What goes up must come down. Newton discovered a law by which things fall to the ground.

*(Physics) Earth's magnetism draws it down. Because of its center of gravity. Volume of the stone is denser than air. Its gravity is heavier than that of air. It has force. Atmosphere presses it down. Because of its energy.

## Table 32.

PART 2. QUESTION 1.

Tell just what you would do in order to find the *Mass* of a stone.

| Grade | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Number | 114 | 120 | 115 | 125 | 100 | 172 | 86 | 178 | 192 |
| Weigh it on a balance (or) Find its vol. | 7.0 | 5.0 | 8.3 | 13.6 | 9.0 | 8.1 | 20.9 | 29.8 | 22.5 |
| Find vol. of water displaced | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.5 | 27.9 | 21.3 | 24.7 |
| Find weight of water displaced | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.1 | 13.4 | 6.7 | 11.4 |
| Measure its vol. | 3.5 | 9.2 | 7.8 | 8.0 | 6.0 | 9.3 | 4.6 | 7.9 | 14.1 |
| Weight/vol., Vol./weight, weight x volume | 0.0 | 0.0 | 0.9 | 0.0 | 0.0 | 3.5 | 2.3 | 7.9 | 10.8 |
| * Miscellaneous | 4.4 | 6.7 | 6.1 | 8.8 | 5.0 | 5.2 | 2.5 | 9.0 | 6.5 |
| No answer | 85.1 | 79.1 | 76.9 | 69.6 | 80.0 | 62.3 | 27.9 | 20.0 | 10.0 |

*(Non-G.S. Non-Physics) Measure it. Find its capacity. Measure its width. Measure its diameter. Measure its area. Weigh the part that has mass. Find how many times it is heavier than air. Find how hard it is. Find its contents. Finds its thickness.

*(G.S.) Find its area. Multiply its weight by its area. Find its contents. Finds its density per unit volume. Find its thickness. Add its weight to its volume. Find how many times it is heavier than water.

*(Physics) Subtract its gravity from its weight. Find how many units it contains. Multiply volume by density. Divide density by volume. Multiply area by weight. Measure the 'per unit volume'. Volume divided by density. Find average diameter. Weigh it in vacuum for this would shut off gravity. Product of dimensions. Multiply length by width. Find out how many unit volumes it has.

## Table 33.

PART 2. QUESTION 1b.

Why do you think this procedure would give you its mass?

| Grade | −8 | −9 | −10 | −11 | −12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Number | 114 | 120 | 115 | 125 | 100 | 172 | 86 | 178 | 192 |
| Because weight is mass | 5.3 | 2.5 | 4.5 | 10.4 | 7.0 | 6.4 | 11.6 | 20.2 | 28.1 |
| Because this would give vol. which is mass | 2.6 | 1.7 | 1.7 | 7.2 | 4.0 | 3.5 | 20.9 | 19.1 | 15.6 |
| Because of Archimedes' Principle | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.7 | 13.9 | 3.4 | 6.3 |
| *Miscellaneous | 2.6 | 5.8 | 5.3 | 3.2 | 3.0 | 5.2 | 18.7 | 14.6 | 18.8 |
| No reason | 89.5 | 90.0 | 88.5 | 79.2 | 86.0 | 83.2 | 34.9 | 42.7 | 31.2 |

* (Non-Physics. Non- Gen. Sc.) Because it is the only way to do it. Because mass is width (or) diameter (or) shape (or) area. Because mass is the reverse of weight.

* (G.S.) Because weight with volume taken into account gives mass. This would give the specific gravity and mass. By knowing the thickness the bulk or mass can be figured. By multiplying weight by area the size of the thing is taken into account.

* (Physics). Only way to do it. To find the pull of gravity. Number of grams equals number of cu. cms. Mass equals work/weight. To find number of weight units in it. To find weight per unit in cu. cms. Since density is mass per unit volume mass must be density per unit volume. Only a spring balance measures mass. Because it is difficult to measure its area directly. To find its relation to the earth. Because mass equals weight per unit volume. Mass depends on weight and space occupied. The only way to measure a quantity of matter is to find the space it occupies.

N.B.—(In very many cases the method of finding mass was just repeated preceded by the word "because". For example, "Find its area"—"Because mass is area".)

## Table 34.

PART 2. QUESTION 2a.

An object is compressed to half its size. What effect has this on its mass?

| Grade | −8 | −9 | −10 | −11 | −12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Number | 114 | 120 | 115 | 125 | 100 | 172 | 86 | 178 | 192 |
| No effect | 1.7 | 4.2 | 5.2 | 3.3 | 7.0 | 4.7 | 27.9 | 44.9 | 37.5 |
| Mass is half | 17.6 | 23.3 | 20.8 | 25.6 | 37.0 | 35.5 | 62.8 | 32.6 | 53.1 |
| Mass is doubled | 0.0 | 1.7 | 0.0 | 0.0 | 3.0 | 3.5 | 2.3 | 3.4 | 3.1 |
| No answer | 80.7 | 70.8 | 74.0 | 71.2 | 53.0 | 56.3 | 7.0 | 19.1 | 6.3 |

PART 2. QUESTION 2c.

An object is compressed to half its size. What effect has this on its Mass. Why?

| Grade | −8 | −9 | −10 | −11 | −12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Vol. (size) half, therefore, mass is half | 12.3 | 19.2 | 17.4 | 20.8 | 25.0 | 24.4 | 41.9 | 28.0 | 42.2 |
| Mass or quantity of matter always same (or) mass independent of volume | 0 | 0 | 0 | 0 | 0 | 2.9 | 2.3 | 23.6 | 21.9 |
| *Miscellaneous | 3.5 | 3.3 | 4.3 | 4.8 | 5.0 | 7.0 | 9.3 | 14.6 | 12.5 |
| No reason | 84.2 | 77.5 | 78.3 | 74.4 | 70.0 | 65.7 | 46.5 | 33.8 | 23.4 |

*(Non-Physics, Non-G.S.) Because the substance is still there. It has not been broken up (or separated). Extra pressure means extra weight or mass. It occupies only half the space. It is twice as compact. Its area is less.

## Table 35.

QUESTION 3a.

An object is taken miles away from the earth's surface. What effect has this on the Mass of the object? *Why?*

| Grade | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Number | 114 | 120 | 115 | 125 | 100 | 192 | 86 | 178 | 192 |
| 1) No effect | 6.2 | 7.5 | 6.1 | 14.4 | 14.0 | 16.3 | 57.0 | 65.1 | 68.8 |
| 2) Mass gets less | 5.3 | 4.2 | 8.7 | 6.4 | 8.0 | 21.5 | 23.2 | 21.4 | 26.0 |
| 3) Mass gets more | 14.9 | 16.7 | 15.7 | 13.6 | 11.0 | 9.9 | 2.3 | 1.7 | 1.0 |
| 4) No answer | 73.6 | 71.6 | 69.5 | 65.6 | 67.0 | 52.3 | 17.4 | 11.8 | 4.2 |
| REASONS: | | | | | | | | | |
| 1) Gravity does not affect mass | 0.0 | 0.0 | 0.0 | 1.6 | 1.0 | 1.7 | 10.5 | 14.6 | 13.5 |
| Mass always is the same | 0.0 | 1.7 | 0.0 | 0.0 | 1.0 | 3.3 | 24.4 | 24.8 | 21.8 |
| Gravity gets less further from the earth | .8 | 1.7 | 2.6 | 2.4 | 4.0 | 15.8 | 17.4 | 15.6 | 11.5 |
| Gravity more the higher you go | 1.7 | 2.5 | 3.5 | 4.0 | 2.0 | 2.3 | 0.0 | 0.0 | 0.0 |
| Weight involved | 5.3 | 5.8 | 4.3 | 7.2 | 9.0 | 7.0 | 4.7 | 3.4 | 7.3 |
| *Miscellanecus | 4.4 | 3.3 | 5.2 | 4.0 | 5.0 | 4.7 | 4.7 | 2.8 | 5.7 |
| No reason | 87.8 | 85.0 | 84.4 | 80.8 | 78.0 | 65.2 | 38.3 | 38.3 | 40.2 |

**Non-Science*: Because it is farther from the earth. It is cold high up. It does not get any bigger. It is still all there. The whole thing is still there. It is the same size. It will expand.

**Science* (No effect). Because nothing has been added or taken away. It still contains the same quantity of matter. Its size does not change. It is still all there. Density is the same. Air pressure does not change mass. Temperature has nothing to do with mass. Because of gravity. *Gets more*: Air pressure gets less (more). Because of gravity.

## Table 36.

PART 2. QUESTION 3.

An object is taken miles away from the earth's surface. What effect has this on the weight of the object? *Why?*

| Grade | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Number | 114 | 120 | 115 | 125 | 100 | 172 | 86 | 178 | 192 |
| No effect | 12.3 | 9.2 | 10.4 | 12.0 | 11.0 | 9.9 | 9.3 | 6.1 | 3.1 |
| Weight decreases | 10.5 | 11.7 | 20.8 | 28.8 | 24.0 | 46.4 | 62.9 | 79.6 | 82.3 |
| Weight increaes | 2.6 | 6.7 | 7.0 | 5.6 | 3.0 | 22.0 | 20.9 | 10.1 | 4.7 |
| No answer | 74.6 | 72.4 | 61.8 | 53.6 | 62.0 | 21.7 | 7.0 | 5.6 | 9.9 |
| REASONS: | | | | | | | | | |
| Farther from the earth hence gravity not so strong (or) force of gravity less | 1.7 | 5.0 | 4.3 | 6.4 | 6.0 | 16.3 | 37.2 | 53.4 | 57.3 |
| Air pressure is less (or more) | 3.5 | 3.3 | 6.1 | 4.8 | 7.0 | 10.5 | 8.1 | 9.5 | 8.3 |
| Nothing has been added or taken away | 7.1 | 6.7 | 7.0 | 7.2 | 6.0 | 3.5 | 4.7 | 3.4 | 2.6 |
| *Miscellaneous | 4.4 | 4.2 | 6.1 | 7.2 | 9.0 | 12.2 | 14.1 | 10.7 | 12.5 |
| No reason | 83.3 | 81.0 | 76.5 | 74.4 | 72.0 | 57.5 | 35.9 | 23.0 | 19.3 |

*(Non-Science): It is colder the higher you go. (2.6%). Because the higher you go the less (or more) the weight becomes. The weight of a thing is always the same. Position makes no differense to weight. Because it is taken farther from the earth (2.1%).

*(G.S. & Phys.) Weight decreases with height above sea-level (8%). Weight increases with height above sea-level (1.1%). Power of the sun is so great that it would make anything weigh more. Because it is nearer the moon. It will have less energy therefore less weight. It offers less resistance. Weight never changes. Its volume expands therefore it weighs less.

# Table 37.

PART 2. QUESTION 4.

When iron is heated it expands. If you heat a piece of iron, what effect would it have on its mass? *Why?*

| Grade | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Number | 114 | 120 | 115 | 125 | 100 | 172 | 86 | 178 | 192 |
| No effect | 2.6 | 3.3 | 6.1 | 4.0 | 9.0 | 6.4 | 25.6 | 37.1 | 38.0 |
| Mass increases | 19.3 | 25.0 | 20.8 | 24.0 | 35.0 | 37.8 | 55.8 | 43.8 | 48.9 |
| Mass decreases | 0.0 | 0.0 | .9 | 1.6 | 0.0 | 4.1 | 3.5 | 4.5 | 4.2 |
| No answer | 78.1 | 71.7 | 72.2 | 70.4 | 56.0 | 51.7 | 15.1 | 14.6 | 8.9 |
| REASONS: | | | | | | | | | |
| Volume (size) greater; it is bigger (larger) therefore mass more | 9.6 | 13.9 | 11.3 | 15.2 | 21.0 | 24.4 | 37.2 | 36.5 | 37.5 |
| Mass independent of size. Mass or quantity of matter in a body is constant | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.3 | 3.5 | 23.6 | 22.5 |
| *Miscellaneous | 4.4 | 5.8 | 5.2 | 4.8 | 7.0 | 8.1 | 8.1 | 12.8 | 13.1 |
| No answer | 85.0 | 80.3 | 83.5 | 80.0 | 72.0 | 65.2 | 51.2 | 27.1 | 26.9 |

*(Non-Phys. Non-G.S.) Expansion makes its area, capacity, width, surface, diameter or weight more. Heat has been added, therefore it weighs more. Heat makes it lighter. A hot thing does not weigh more than a cold thing. No effect because it will still be iron.

*(Physics & G.S.) Mass greater because area, surface, diameter, amount of displaced water, space occupied, dimensions, will be greater. Volume greater therefore density or mass greater. No effect because mass will still be the same. Displaces more air therefore mass more. Weight per unit volume less. Heat has not weight, so it will weigh the same. Volume less therefore volume times density less. Material of which made is still there.

## Table 38.

PART 2. QUESTION 5.

The weight of an object ought to be slightly greater at the North Pole than at the Equator. Is this true? *Why*?

| Grade | −8 | −9 | −10 | −11 | −12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Number | 114 | 120 | 115 | 125 | 100 | 172 | 86 | 178 | 192 |
| Statement is true | 16.7 | 18.3 | 17.4 | 20.0 | 24.0 | 62.3 | 70.9 | 84.3 | 85.9 |
| Statement is false | 56.4 | 60.0 | 55.6 | 48.0 | 44.0 | 26.1 | 22.1 | 12.4 | 10.0 |
| No answer | 26.9 | 21.7 | 27.0 | 32.0 | 32.0 | 11.6 | 7.0 | 3.3 | 4.1 |
| REASONS: | | | | | | | | | |
| North Pole is nearer the centre of the earth, therefore, pull is less, i.e. weight is less | 0.8 | 2.5 | 2.6 | 4.8 | 6.0 | 23.2 | 39.5 | 57.7 | 54.2 |
| All the substance is still there so weight is same | 12.3 | 13.3 | 17.4 | 12.8 | 14.0 | 13.3 | 17.4 | 9.0 | 6.5 |
| Colder at North Pole | 8.8 | 5.8 | 6.1 | 8.0 | 7.0 | 8.1 | 7.0 | 3.6 | 3.6 |
| *Miscellaneous | 5.3 | 3.3 | 4.3 | 4.0 | 5.0 | 16.3 | 10.5 | 12.8 | 10.0 |
| No reason given | 72.8 | 75.1 | 69.6 | 70.4 | 68.0 | 39.1 | 25.6 | 22.9 | 25.7 |

*(Non-Phys. Non-G.S.) North Pole is no different from other places except that it is colder (2.6). If the same scale is used the weight will be the same everywhere. The weight of a thing is always the same. Climate does not affect weight. There is no reason for its weight to be more at the North Pole. The air is thinner and colder. *(G.S. and Phys.) An object will weigh more at the Equator. (or) The reverse of statement is true. The weight of a thing varies on different parts of the earth's surface (5.4) False because weight is constant. False unless the place it is weighed at the Pole is above (below) sea-level. Because the force is more, so the weight is more. It weighs more because it has more energy. It will weigh more because of the earth's pull (or gravity) (1.-%). The air pressure at the North Pole is different.

## Table 39.

PART 2. QUESTION 6.

If two objects in New York have equal weights will their masses be equal? *Why?*

| Grade | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Number | 114 | 120 | 115 | 125 | 100 | 172 | 86 | 178 | 192 |
| Yes | 6.2 | 10.8 | 8.7 | 9.6 | 9.0 | 12.8 | 25.6 | 25.8 | 24.0 |
| No | 24.6 | 18.3 | 14.8 | 20.0 | 17.0 | 26.0 | 53.5 | 50.5 | 52.0 |
| No answer | 69.2 | 70.9 | 76.5 | 70.4 | 74.0 | 61.2 | 20.9 | 23.7 | 24.0 |
| YES. Because weight proportional to mass (or) mass can be measured by weighing or masses can be compared by their weights | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 2.3 | 3.9 | 3.6 |
| YES. Because mass equals weight (or) is the same as weight | 4.4 | 4.2 | 4.3 | 5.6 | 7.0 | 7.5 | 10.5 | 11.2 | 12.5 |
| NO. Because they may have different sizes (or) one may be larger | 5.3 | 10.0 | 9.6 | 8.0 | 11.0 | 11.6 | 18.7 | 14.6 | 15.1 |
| NO. Because their weights per unit vol. may be different, or Densities may not be the same | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.1 | 3.5 | 15.1 | 13.5 |
| *Miscellaneou | 5.3 | 6.7 | 4.3 | 4.8 | 6.0 | 5.3 | 10.5 | 8.2 | 5.8 |
| No reason | 85.0 | 79.1 | 81.8 | 81.6 | 76.0 | 66.9 | 54.7 | 47.0 | 49.5 |

* *(Non-Science)*

NO. their composition may be different
their areas, shapes, dimensions, contents, materials or widths may not be equal or the same.

YES. because they are the same or equal..
because the whole object is taken when weighed.

**General Science.*

NO. because their dimensions, areas, thicknesses or shapes may not be the same.

They may be made of different materials (or substances).

Their densities per unit volume may be different.

Their specific gravities may be different.

YES. because gravity pulls on both.

because the number of molecules is the same.

**Physics.*

NO. because mass is the quantity of matter.

because their specific gravities may be different.

because mass and weight are unlike even if weights are equal.

because one may have a greater weight per gram of unit.

because mass is the molecular contents of a body.

They may offer different resistances.

Molecules may be more closely packed in one.

One may displace a greater weight of water.

Densities per unit volume may be different.

YES. Mass does not vary in one place.

If the weights of the amount of matter are equal then the quantities of matter are equal.

Mass and weight are equal in the same place.

The earth's pull is the same.

Mass equals weight at sea-level.

Pull of gravity is the same on both volumes.

# Table 40.

PART 3. QUESTION 1.

When a stone is thrown up it is always pulled back to earth by gravity. Tell in your own words what you think *gravity* is.

| Grade | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Number | 114 | 120 | 115 | 125 | 100 | 172 | 86 | 178 | 192 |
| Pull (attraction) of the earth on a body. (or) Mutual attraction between earth and body | 8.0 | 9.2 | 7.0 | 9.6 | 10.0 | 23.9 | 67.5 | 73.0 | 74.0 |
| Something in the centr of the earth that pull all things to it | 10.5 | 10.8 | 15.7 | 13.6 | 17.0 | 20.3 | 5.8 | 3.9 | 4.7 |
| What makes stone fall. What keeps us on earth. What keeps things from falling off the earth | 29.8 | 31.6 | 29.6 | 30.4 | 30.0 | 20.9 | 13.9 | 11.2 | 10.4 |
| *Miscellaneous | 28.0 | 26.7 | 34.8 | 32.0 | 33.0 | 23.2 | 8.1 | 7.9 | 6.7 |
| No answer | 23.7 | 21.7 | 16.5 | 14.4 | 10.0 | 11.7 | 4.7 | 3.9 | 4.2 |

*(—8th) A strong power. Force of the earth. Force of instinct. Electricity. Moving in the air. Magnetism in the earth pulling things down (8.0). The holding of the air of an object. A force like suction that pulls things down. What holds the earth in place. Strength (8.8). An unseen object that holds things to earth. Something in the air that has power (1.7). Gravity is the gravity in the earth.

*(—9, —12) Earth's power of magnetism (6.3%) Air pressure drawing things to earth. What keeps the earth rotating on its exis. A natural law. Something we have on earth. A law which draws objects to earth. A force of power. Gravity means that we cannot hold a thing up—must hold it toward the ground. A law of Science that forces things down. What keeps things standing upright on earth (4.8). An invisible force in the air (1.9). Earth's strength or power. The earth pulling like a magnet (8.2). The Law discovered (in-

vented) by Newton. The Law that states "What goes up must come down." The force in the soil that makes things grow. What makes the roots of the plants grow down. The power that keeps us on earth, otherwise we would fly like birds. The power that causes the tides. The bearing down of objects towards the earth.

*(General Science 9th Grade) Something in the air like a magnet. A kind of magnetism in the earth. That which holds space around the earth. A substance in the earth that attracts. Air pressure that holds everything to earth (1.7). A pressure on all sides. Weight of heavens and earth. Discovered by Newton, he said everything must come to earth such as his experiment with the falling apple. What keeps everything to earth except lighter than air things. A natural law that draws everything to the center of the earth. A force that pulls things towards it. Downward pressure of air on an object. Pressure that attracts everything to it. What makes a ball roll downhill. Work of he substance called gravity. What proves the saying "Everything that goes up must come down." Force of soil that makes things grow. Earth always gravitating the sun, — it means it draws its heat and light. Anything pulling towards the earth.

*(Physics) Earth is a great magnet, the force of gravity is the magnetic pull of this magnet (2.9). Power of earth to attract things. The theory that makes things fall to he ground. What holds us to earth, a sort of pressure. The pulling downward of substances heavier than air. The downward pressure of the air. Something like a magnet in the center of the earth. An invisible force pressing all things down. A force at the center of gravity. The force in all bodies discovered by Newton. All bodies attract or repel each other with a force inversely proportional to the distance between them. The pull by gravity. The center of gravity of two bodies attract each other. An invisible force in the universe that draws all things to itself.

## Table 41.

PART 3. QUESTION 2.

Mass is said to be the quantity of matter in a thing. Tell what you think *quantity of matter* means.

| Grade | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Number | 114 | 120 | 115 | 125 | 100 | 172 | 86 | 178 | 192 |
| *Weight* of the material (or) matter in it | 4.4 | 4.2 | 7.0 | 8.0 | 12.0 | 14.5 | 20.9 | 19.0 | 18.7 |
| *Volume* (size) of the material (or) matter (or) substance | 3.5 | 3.3 | 7.8 | 7.2 | 7.0 | 25.0 | 34.9 | 25.8 | 28.1 |
| That which measures the inertia of the body | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.2 | 5.2 |
| Density (or) weight per unit volume (or) weight with volume taken in | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 3.5 | 6.2 | 5.2 |
| *Miscellaneous | 3.5 | 2.5 | 4.3 | 4.0 | 6.0 | 2.9 | 5.8 | 6.6 | 10.4 |
| No answer | 88.6 | 90.0 | 84.9 | 80.8 | 75.0 | 56.4 | 34.9 | 36.2 | 32.4 |

*(Non--Phys. Non-G.S.) The amount of matter (or) material. How much there is of it. Amount of it that is solid. How much of it is matter.

*(Phys. and G.S.) The amount of material in it. Its bulk. The substance that gives it weight. The matter in it that cannot change in amount. That which makes it hard to move the body.

## *ANALYSIS OF RESULTS.*

The results can best be interpreted by examining first the answers to each question of Part 1 and then the answers to other questions which serve a "checks" to the answers of Part 1. The majority of non-science pupils hold the "heaviness or lightness" and "number of pounds" notions of weight. These naive concepts of weight evidently are built up through experience, and, being useful concepts for all practical purposes, persist even in the Physics groups.

That such concepts are held is only natural; this study, however, attempts to discover whether they change with the formal study of Physics and General Science. Table 29 shows that General Science students hold these notions to an extent almost equal to that of non-science students, and that only with the formal study of Physics do these notions begin to give way to more scientific notions.

On the other hand, the notion of weight as a force, a measure of the force of gravity, is extremely uncommon in the non-science groups notwithstanding the fact that the majority of those pupils are familiar with gravity (Table 31). This affords a good example of what is meant by a concept becoming scientific. The majority of non-science and General Science pupils in defining weight use some obvious or useful property in their definitions; the majority of Physics students, +11th and +12th, have some form of relationship involved in their definitions. According to Profesor Dewey [1]) "A scientific definition is founded, not on directly perceived qualities nor on directly useful properties, but on the way in which certain things are causally related to other things, i.e. it denotes a relation. Our conceptions attain a maximum of definite individuality and of generality (or applicability) in the degree to which they show how things depend one upon another or influence one another

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[1]) Dewey "How we think,' p. 134.

instead of expressing the qualities that objects possess statically."

The miscellaneous responses appended to Table 29 also show marked differences between the groups. The variety of responses increases with the formal study of science. Thus such erroneous notions as density, mass, specific gravity, energy, air pressure and mass per unit volume appear. The appearance of these responses is probably due to the fact that wrong meanings are attached to them. Thus if a pupil has learned to think of density or mass as weight, he is likely to say that weight is density or mass. The non-science groups are at least immune to this type of misconception.

The responses to question 1, however, should be interpreted in conjunction with those of Part 2 as the association of weight and gravity may have been formed by pupils who preferred to give the "heaviness" type of definition. Table 31 gives the extent to which pupils are familiar with gravity. Table 40 shows the common notions pupils have of gravity. From these two tables it will be seen that, although the majority of non-science and the large majority of science students are familiar with gravity, non-science and General Science pupils have naîve notions of the following types:— Gravity is what keeps things on earth; Gravity is something in the earth or in the air. The majority of Physics students think of gravity as an attractive force of the earth for a body or the mutual force of attraction of the earth and a body. These naïve notions of gravity evidently are formed during the elementary school period mostly in the geography classes, where, by comparing gravity to a magnet attracting iron, many pupils are led to think of gravity as a magnet, or like a magnet, in the earth.

To facilitate interpretation relevant responses from Tables 29, 31, 36, 38 and 40 will be placed in one table together with the percent of students of each group who gave the response.

| Grade | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| *Table* 31. Stone returns because *gravity* pulls it | 63 | 69 | 72 | 74 | 75 | 82 | 84 | 94 | 94 |
| *Table* 40. Gravity is an attractive force between earth and body; mutual *attraction* | 8 | 9 | 7 | 10 | 10 | 24 | 68 | 73 | 74 |
| *Table* 29. Weight is a measure of the forse of gravity | 3 | 3 | 3 | 2 | 9 | 12 | 23 | 56 | 58 |
| *Table* 36. Weight less because gravity is less | 2 | 5 | 4 | 6 | 6 | 16 | 37 | 53 | 57 |
| *Table* 38. Weight more because N. Pole nearer the centre of earth etc., etc. | 1 | 3 | 3 | 5 | 6 | 23 | 40 | 58 | 54 |

The results from any group may now be interpreted from this table as follows:— "Of 11th Grade Physics students at least 94% seem familiar with gravity while 73% give a scientific definition of it. 56% associate gravity with weight in defining weight. In two questions where knowledge of the relation between weight and gravity is necessary, 53% and 58% give correct answers. It seems reasonable to suppose that about 56% have scientific notions of weight". Similar interpretions may be made for the other groups.

The results of the questions on the concept Mass tell a very different story. Scientific notions do not appear at all among the non-science groups, even vague notions are absent and erroneous ones are common. Perhaps this is to be expected as the concept is a very difficult one to form even in later years when Physics is studied. Unlike weight, there is no opportunity in everyday life to build up even a naïve concept. When masses are compared on a scale or balance, we talk of weighing; when the word mass is used in literature, it is usually preceded by the adjective huge or large, and we talk of a mass of people when we mean a large number or crowd, hence the wide variety of notions.

A glance at Table 30 shows that the notions occuring most often are "size or volume", "weight' and "the thing taken as a whole". Taken by themselves these misconceptions may not be so significant; but an examination of the table will show that in the science groups two of these misconceptions are more prevalent; the formal study of Physics does not seem to change these notions.

"Mass is the quantity of matter in a body" (the definition given in every Physics text) is naturally given as a definition of mass by 13.9%, 24.1% and 23.4 % of 10th, 11th and 12th grade Physics pupils respectively, but not given by a single non-science student. Whether this definition is understood by those giving it, and whether others really think of mass as weight or volume, will be seen from the following analysis, where the 'check' questions are taken in conjunction with Quest. 2 of Part 1.

| Grade | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| *Quest. 2. Pt. 1.* | | | | | | | | | |
| Mass—volume | 4 | 12 | 16 | 20 | 20 | 26 | 44 | 28 | 25 |
| *Quest. 1. Pt. 2.* | | | | | | | | | |
| To find mass find volume | 3 | 9 | 8 | 8 | 6 | 16 | 33 | 29 | 39 |
| *Quest. 2. Pt. 2.* | | | | | | | | | |
| Mass is half | 18 | 23 | 21 | 26 | 37 | 36 | 63 | 34 | 53 |
| Because vol. is half mass is half | 12 | 19 | 17 | 21 | 25 | 12 | 42 | 28 | 42 |
| *Quest. 4. Pt. 2.* | | | | | | | | | |
| Mass more | 19 | 25 | 21 | 24 | 35 | 38 | 56 | 44 | 49 |
| Because vol. is more | 10 | 14 | 11 | 15 | 21 | 24 | 37 | 37 | 38 |
| *Quest. 2. Pt. 3.* | | | | | | | | | |
| Quantity of matter means volume | 4 | 3 | 8 | 7 | 7 | 25 | 35 | 26 | 28 |

The last column shows that of 12th graders at least 25% and at most 53% associated mass with volume in some way or other, 42% gave a definite reason which involved volume, the remaining 11 % either giving no reason or a reason involving something other than volume. Taking into account, therefore, in questions 2 and 3 of Part 2 only those answers accompanied by a 'volume' reason, it is found that the average percentage of 12th grade Physics students associating mass with volume is about 36%. The average percentage for all groups associationg mass with volume would be approximately:—

| Grade | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| Percent | 7 | 14 | 13 | 16 | 18 | 23 | 39 | 33 | 36 |

It may be argued that this increase in the frequency of an erroneous notion is only apparent since the majority of non-science students do not respond to the questions. This is probably true. There is no way to force non-science pupils to respond; were it possible, then responses would probably be very unreliable. Where the subject matter is known they respond well, as in the case of Quest. 3 Part 1. The fact remains, however, that of the total number of Physics students who answered the question, a certain number associated mass with volume or size, and the percentages given above for the Physics students hold good irrespective of what the non-science students did. For this and other reasons given in a later chapter, the writer feels that in the case of non-science pupils, single questions of the kind used in the preliminary survey give a fairly good estimate of the notions held by these pupils.

The notion of mass as weight can be analysed in the same way. The numbers in the following table represent the percent of pupils of each group who associated mass with weight in the check questions as well as in the definition of mass.

| Grade .. .. .. .. .. .. | —8 | —9 | —10 | —11 | —12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|---|---|
| *Quest.* 2. *Pt.* 1. Mass is the weight of a body etc. .. .. .. .. .. | 12 | 14 | 17 | 19 | 24 | 12 | 28 | 13 | 13 |
| *Quest.* 1. *Pt.* 2. Weigh it because weight is mass .. .. .. .. .. .. | 5 | 3 | 5 | 10 | 7 | 6 | 12 | 20 | 28 |
| *Quest.* 2. *Pt.* 3. Mass or quantity of matter is weight .. .. .. | 4 | 4 | 7 | 8 | 12 | 14 | 21 | 19 | 19 |
| *Quest.* 3*a*. *Pt.* 2. Reasons in which mass is thought of as equiv. to weight .. .. .. .. .. .. .. | 8 | 10 | 10 | 14 | 15 | 25 | 27 | 22 | 19 |

Taking the results for the four questions together for the Physics groups, the average percents of the "weight" notion of mass are: 10th—22%, 11th—18 % and 12th—20%. The results of Question 2, Part 3 for the non-science group, even for the General Science group, can really not be considered in this way as not a single non-science pupil defined mass as the quantity of matter in a body, and only 1.2% of General Science pupils gave that definition. In fact, the majority of these pupils did not respond at all to questions 1 and 3 of Part 2 and to question 2 of Part 3. Again the results of Question 2 of Part 1, the definition of mass, for these groups would probably be just as significant if taken by themselves. It is interesting to note, however, that non-science students when left to themselves with the definition " Mass is the quantity of matter in a thing" get the "volume" and "weight" ideas to a greater extent than any others.

The results of Question 2 Part 3 show that Physics students do not understand the meaning of "quantity of matter ". About one-third of their number did not even attempt to answer the question, and among these there were probably many who remembered the text-book definition and warning " Mass is not weight....

not volume" and thought the easiest way out of the difficulty was not to answer at all!

What relation does the student form between weight and mass? The results previously referred to tend to show that more than one-third of Physics students think that weight and mass are one and the same thing, that mass is just another word for weight. Table 34 gives results of a question involving this relation directly. Less than 4% of Physics students mention the proportionality of weight and mass, the majority of responses again involving the idea of equality of mass with weight, volume or density. The majority of non-science pupils give no reasons.

The impression left is that there is a great confusion in the minds of pupils regarding mass. Such a state of affairs is to be expected in those grades where Mechanics has not been studied. The writer feels that the pupils are not wholly to blame for the number of vague and erroneous notions of mass. All the answers to Question 2 Part 1 from a certain High School Physics group were of the following type: Mass is the quantity of matter in a body. Mass is not weight or volume. Yet about 60 % of these same students thought that the mass of a piece of iron on expanding would increase!

The text-books seem satisfied to warn students against erroneous notions of mass by stating "mass is *not* weight etc., but quantity of matter" without making an attempt to clarify "quantity of matter". The result is that the student is just as much in the dark as he was when he entered the class except for the fact that he has been warned what "mass is not". Moreover he has hardly been in the Physics class for two weeks when he meets the term mass involved in the common definition of Density viz: Density is the mass per unit volume. Is it any wonder that 15% of 11th and 12th graders define man as the "Density per unit volume," "density" or something pertaining to density?

More will be said about the concepts Mass and Weight in Part 2 of this study where results of experimental teaching will be given. As far as the answers to the foregoing questions are concerned, the conclusions are as follows:—

(1) The majority of non-science students are familiar with gravity, but their notions are mostly naïve.

(2) The large majority of General Science and Physics students are familiar with gravity. The majority of Physics students have scientific notions, but the notions of the General Science pupils are vague in the majority of cases.

(3) The concept "weight" becomes scientific through the study of Physics in about 56% of 11th and 12th grade cases and in 33 % of 10th grade cases.

(4) Non-science students have naive notions of weight, the "heaviness" and "number of pounds" notions predominating.

(5) The majority of General Science students have vague and popular concepts of weight, but in about 17 % of cases has the notion become scientific.

(6) The majority of all students examined, non-science as well as science, have erroneous notions of mass.

(7) The formal study of General Science or Physics does not appear to change these erroneous notions, on the contrary, they are found to a larger extent in the Science groups.

(8) The most common notions of mass are weight and volume. Density also appears to a significant extent in the science groups.

(9) The meaning of "quantity of matter" is not understood by the Physics students of this study.

(10) There is no significant difference between the 11th and 12th Physics grades regarding the types of concepts or the extent to which they occur; but there is a significant difference between these wo groups on the one hand and the 10th Physics grade on the other.

## CHAPTER VIII.

## CONCEPTS OF EBULLITION.

It was stated in Chapter 1 that it mattered little for the purposes of this study just what concepts were to examined. In the selection of a concept from the subject of Heat, Boiling or Ebullition was chosen for the following reasons:—

There can be little doubt that every child has some time or other seen water boil or has even had occasion to boil water himself, and that he has his own ideas about the process in consequence of such experiences. During the course in General Science or Physics he learns many more facts about boiling which may lead him to reconstruct his old concept. Since boiling is an example of a phenomenon not new to the child when he enters the science class, it is admirably suited to a study in conceptual development. Boiling forms a part of the subject matter of both the General Science and Physics courses in practically every school, whereas many other concepts of Heat are treated only in the High School Physics course.

The general method of procedure of arriving at the pupil's notions was similar to that described in the case of weight, mass and gravity. A set of questions consisting of three parts was drawn up, tried out and then distributed to Physics students in 10 schools and to General Science and non-science students in 8 schools.

The method of recording and classifying results was similar to that used throughout this study. A sample of the three sets of questions together with a questionaire sent to the science teachers is given below.

(Part 1.)

Fill in all blanks (name, age etc.) before answering the questions.

Name.................... School..................
Age: Years.... months .... Boy or Girl.... Grade....
Are you *now* studying Physics?.... General Science?....
What text-book do you use?.............

In the following list underline the subjects you have studied before, and write after each the grade you were in then.

General Science ( ) Biology ( ) Chemistry ( ) Physics ( )

*DIRECTIONS*: Answer each of the following questions in the space below it. When you have answered all you can, hand in this sheet and you will receive Part 2.

1. What do you mean by the Boiling Point of a liquid?
2. While water is boiling big bubbles rise to the surface of the water. What is in these bubbles?
3. While alcohol is boiling big bubbles rise to the surface of the alcohol. What is in these bubbles?
4. At what temperature Centigrade does water usually boil?
5. At what temperature Fahrenheit does water usually boil?

*DIRECTIONS*: Read each of the following statements carefully. If you think a statement is correct then write TRUE after it. If you think it is false, write FALSE after it. Then give your reason for thinking so. DON'T FORGET TO GIVE REASONS.

6. All liquids boil at the same temperature......
   Reason:—
7. A pound of water will boil at a lower temperature than two pounds of water
   Reason:—
8. The longer you heat water, after it has begun to boil, the hotter it becomes.

Reason:—

9. There is no difference between Evaporation and Boiling.
   Reason:—
10. Tepid (luke warm) water can be made to boil without heating it.
   Reason:—
11. Water will boil at a lower temperature than usual in an airship 3 miles high.
   Reason:—

(Part 2) Name ............

*DIRECTIONS*: Answer each question in the space below it. When you have finished, hand in this sheet and you will receive Part 3.

1. Water usually boils at 100 Centigrade. Tell what you would do to make it boil at about 50 Centigrade.
2. Tell what you would do to make water boil at about 130 Centigrade.

(Part 3) Name ............

*DIRECTIONS*: Answer each question in the space below it. When you have finished, hand in this sheet.

1. You can get water to boil at about 50 Cent. if you decrease the air pressure above it sufficiently; or you can get it to boil at about 130 Cent. if you increase the air pressure sufficiently. Tell in detail why a change in air pressure causes a change in the boiling point of water.

## QUESTION BLANK SENT TO SCIENCE TEACHERS.

In order to give a better interpretation to the results will the teacher kindly supply the following information:—

1. Did class study HEAT?................
2. How many weeks ago did class finish HEAT?......
3. Was the topic "Boiling" treated in class?......
4. There are two methods commonly used to demonstrate that the boiling point of water is lowered when air pressure is reduced. Please check method you used. If neither, please check "no demonstration."

   (a) By placing tepid water under the receiver of an airpump and exhausting.

   (b) By boiling water in a flask, putting on stopper while water is boiling, removing flame and cooling by pouring cold water over flask.........

   (c) No demonstration given. ......
5. Please mention any additional demonstrations you gave class on Boiling.
6. Did students perform any individual experiments on Boiling? Which?

Teacher.....................

School....................

# Table 42.

Percentage frequency of responses to question:—
What do you mean by the Boiling Point of liquid?

| Grade | —8 | —9 | —10–12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Number | 100 | 96 | 250 | 120 | 86 | 140 | 125 |
| Medium Age | 13.10 | 14.11 | 15.10<br>16.8<br>17.9 | 14.11 | 15.8 | 16.9 | 17.10 |
| The temperature at which the vapor pressure is equal to or greater than the pressure of the air above it. (or) Vapor tension of liquid is greater than (equal to) air pressure (or) Pressure in air bubbles greater than air pressure | 0.0 | 0.0 | 0.0 | 0.8 | 7.0 | 10.7 | 10.4 |
| The temperature when the pressure of the liquid is equal to (or greater) than the air pressure | 0.0 | 0.0 | 0.0 | 1.7 | 3.5 | 5.7 | 6.4 |
| When its temperature has reached 100°C or 212°F | 2.0 | 4.2 | 10.4 | 14.2 | 12.8 | 7.9 | 9.6 |
| The highest temperature it can have (or) hottest it can become | 23.0 | 25.0 | 24.0 | 10.8 | 10.5 | 7.1 | 8.0 |
| The temperature or point at which it changes from liquid to vapor, (steam) | 17.0 | 20.8 | 25.6 | 40.9 | 27.8 | 20.7 | 19.2 |
| The temperature or point when bubbles rise to the surface | 31.0 | 20.8 | 20.8 | 9.2 | 9.3 | 5.7 | 7.3 |
| *Miscellaneous | 12.0 | 9.4 | 9.6 | 10.7 | 15.1 | 26.4 | 27.2 |
| No answer | 15.0 | 19.8 | 9.6 | 11.7 | 14.0 | 15.8 | 12.0 |

*(Non-Physics, Non-G.S.) When it cooks. When it reached a certain temperature (5.1%). Point of greatest heat without chemical change. Point at which the air in it is changed it steam. When it boils. When it has been heated to 112F or (220,110F) (212C,120C). When it has reached its temperature. The point at which it is changed to air.

*(General Science). When most of the air is evaporated by heat. When it has reached a hot temperature (or) high degree of heat. When it boils. When its temperature is 112F (or 212C) .... (4.2%). The point at which if 900 more heat units were put into it, it will evaporate. The molecules move so fast as to cause bubbling. When it melts. Highest point it can reach without chemical change.

*(Physics). Molecules have expanded so much that they cannot hold their places at bottom of other molecules. Molecules become so active that they fly off in form of vapor. (6.6%) Molecules in violent motion due to air pressure. Molecules in state of intense vibration (2.3%). Point at which it carries off calories. Point at which it gives off 537 calories of heat. Point where it decomposes and oxygen escapes. Temperature at which vapor tension becomes surface tension. When air bubbles come to top because when air is heated it expands (3.7%). The temperature at which it condenses. When it becomes so hot that some is lost in the air. When the atmospheric pressure equals the barometic pressure. When the vapor pressure exerted on the liquid is atmospheric. Point at which the gases boil out (1.1%). Point at which pressure on substance too great for molecules to resist. When the air is evaporated from it. When the water vapor of air is less than vapor of substance. When it reaches a temperature of 212C or 100F etc. (2.3%). When it vaporizes very rapidly giving off oxygen. When the molecules jump off into the air. When the surface tension is equal to the air pressure. Atmospheric. A temperature usually higher than 100C. The temperature at which the pressure

causes bubbles of air to rise. Temperature when liquid escape in form of molecules. The point of ebullition.

## Table 43.

When water is boiling, big bubbles rise to the surface of the water. What is in these bubbles?

| Grade | —8 | —9 | —10,-12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Steam, Water vapor, Vapor | 19.0 | 21.9 | 20.4 | 27.5 | 41.9 | 38.6 | 39.2 |
| Air, (or oxygen) | 34.0 | 39.6 | 36.0 | 26.7 | 41.9 | 53.6 | 51.2 |
| *Miscellaneous | 10.0 | 8.3 | 9.6 | 8.3 | 6.9 | 1.4 | 2.4 |
| No answer | 37.0 | 30.2 | 34.0 | 17.5 | 9.3 | 6.4 | 7.2 |

***(8—12) Non-Physics:** Air heat. Carbon dioxide. Vacuum. Nothing. Heat. Gas. Residue, Hydrogen. Mixture of gases.

*(Physics Groups) Compound masses of hydrogen. Vacuum. Hydrogen (3) Hydrogen and oxygen. Carbon dioxide. Gases.

*(9th General Science) Liquid. Bacteria. Hydrogen. Carbon. Heat. Vacuum. Soap and air. Gases. Carbon dioxide. Fumes. Nothing.

## Table 44.

"While alcohol is boiling big bubbles rise to the surface of the alcohol. What is in these bubbles?"

| Grade | —8 | —9 | —10—12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Alcohol, Vapor, alcohol steam or gas | 2.0 | 4.2 | 8.0 | 10.8 | 30.2 | 31.4 | 30.4 |
| Air (or oxygen) | 11.0 | 29.2 | 21.0 | 22.5 | 27.8 | 42.9 | 41.6 |
| *Miscellaneous | 11.0 | 10.4 | 17.0 | 23.3 | 17.6 | 7.1 | 8.0 |
| No answer | 76.0 | 56.2 | 54.4 | 43.4 | 24.4 | 18.6 | 20.0 |

*(8—12) Non-Physics) Gas or Gases (36%). Carbon dioxide (13). Hydrogen (12). Acid. Heat. Fumes. Alcohol residue. Steam. Vacuum.

*(Physics Groups). Alcohol. Vacuum. Nitrogen. Hydrogen. Steam, Gases. Heat Energy, Carbon Dioxide.

*(9th General Science). Gases. Carbon dioxide. Hydrogen. Water. Alcohol. Heat. Air and gases. Steam. Nothing. Fumes. Liquid.

## Table 45.

"At what temperature Centigrade does water usually boil?"

| Grade | —8 | —9 | —10 —11,-12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| 100°, 100 degrees | 3.0 | 14.5 | 38.5 | 74.2 | 86.0 | 87.1 | 89.6 |
| Incorrect | 42.0 | 20.8 | 17.6 | 10.0 | 4.7 | 7.9 | 7.2 |
| No answer | 55.0 | 64.7 | 43.9 | 15.8 | 9.3 | 5.0 | 3.2 |

## Table 46.

"At what temperature Fahrenheit does water usually boil?"

| Grade | —8 | —9 | —10 —11,-12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| 212°, or 212 degrees | 4.0 | 3.1 | 9.6 | 43.4 | 44.2 | 63.6 | 68.8 |
| Incorrect | 29.0 | 18.8 | 14.4 | 26.6 | 32.6 | 25.7 | 22.4 |
| No answer | 67.0 | 78.1 | 76.0 | 30.0 | 23.2 | 10.7 | 8.8 |

## Table 47.

"All liquids boil at the same temperature". *Why?*

| Grade .. .. .. .. .. .. | —8 | —9 | —10–12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| False .. .. .. .. .. | 49.0 | 54.1 | 64.0 | 83.3 | 84.9 | 91.4 | 89.6 |
| True .. .. .. .. .. .. | 17.0 | 18.8 | 12.8 | 7.5 | 4.7 | 2.8 | 3.2 |
| No choice .. .. .. .. .. | 34.0 | 27.1 | 23.2 | 9.2 | 10.4 | 5.8 | 7.2 |
| *False.* Every liquid has its own B.P. (or) alcohol, gasoline etc. boils at lower temp. than water etc. .. .. | 11.0 | 14.6 | 20.8 | 20.0 | 22.1 | 43.6 | 31.2 |
| *True.* Because the B.P. is 100 degrees (or) 212° .. .. .. .. .. .. .. | 4.0 | 3.1 | 6.8 | 4.2 | 1.2 | 0.7 | 1.6 |
| Miscellaneous .. .. .. .. | 5.0 | 9.4 | 5.6 | 4.2 | 4.7 | 2.1 | 1.6 |
| No - reason .. .. .. .. | 80.0 | 72.9 | 66.8 | 71.6 | 72.0 | 53.6 | 65.6 |

## Table 48.

"A pound of water will boil at a lower temperature than two pounds of water. Right or wrong?"

| Grade | —8 | —9 | —10 —11,-12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Statement right | 45.0 | 20.8 | 31.2 | 14.2 | 8.1 | 10.0 | 10.4 |
| Statement wrong | 43.0 | 41.7 | 60.0 | 85.8 | 87.2 | 88.6 | 88.0 |
| No answer | 12.0 | 37.5 | 8.8 | 0.0 | 4.7 | 1.4 | 1.6 |
| **REASONS:** | | | | | | | |
| Boiling point of a liquid does not depend on amount of liquid. 1 lb. of water will boil at same temperature, but sooner | 18.0 | 21.9 | 48.0 | 74.1 | 82.6 | 81.4 | 84.0 |
| Right, because it does not take so long to boil 1 lb. as 2 lb. | 24.0 | 14.6 | 21.6 | 11.7 | 8.1 | 7.1 | 6.4 |
| Miscellaneous | 9.0 | 10.4 | 7.6 | 3.3 | 2.3 | 2.1 | 2.4 |
| No reason given | 49.0 | 53.1 | 23.8 | 10.9 | 7.0 | 9.4 | 7.2 |

## Table 49.

"The longer you heat the water after it has begun to boil the hotter it becomes."

| Grade .. .. .. .. .. .. | —8 | —9 | —10—12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| False .. .. .. .. .. .. | 19.0 | 22.0 | 32.0 | 50.0 | 59.3 | 83.6 | 81.6 |
| True .. .. .. .. .. .. | 39.0 | 33.3 | 27.2 | 19.2 | 16.3 | 10.7 | 9.6 |
| No choice .. .. .. | 42.0 | 43.8 | 40.8 | 30.8 | 24.4 | 5.7 | 8.8 |
| REASONS: | | | | | | | |
| *False* | | | | | | | |
| 1. Heat changes it to steam but does not change its BP. or BP constant, more heat won't raise it or BP increases with pressure not with longer heating .. .. | 3.0 | 12.5 | 18.0 | 38.4 | 46.5 | 68.6 | 70.9 |
| *False* | | | | | | | |
| 2. The BP is the hottest it can become .. .. .. .. .. | 7.0 | 16.7 | 9.6 | 6.7 | 8.1 | 5.7 | 2.4 |
| *True* | | | | | | | |
| 3. Because the more you heat a thing the hotter it becomes (or) the greater its temp. | 29.0 | 14.6 | 19.2 | 11.7 | 11.6 | 3.6 | 4.8 |
| *Miscellaneous .. .. | 7.0 | 4.2 | 4.8 | 5.8 | 3.5 | 1.4 | 1.7 |
| No reason .. .. .. | 54.0 | 52.0 | 29.4 | 37.4 | 30.3 | 20.7 | 19.9 |

*(—8, —12). No, because the longer it boils the less heat there is. Wrong, the heat always comes the strongest at first(??) Right, if you make a bigger fire it will get hotter. Right, if heated longer it will keep on boiling until all is gone. Wrong, it would blow up if boiled too long. Right, because the more gas escapes the higher the boiling point will be of what is left because there won't be much of it. It does not get hotter but evaporates more quickly.

*(+9th). Right, more heat can get to the water that is left. The longer it boils the higher it rises. The more heat the more temperature it gets. If the flame is kept low the water will have a higher temperature without boiling. Because bubbles of air still continue to rise and burst.

Wrong. The heat is not hot enough. Boiling Point is the minute it begins to boil, not after it has been boiling for some time.

*Physics Groups.

Right. Because of the latent heat. The longer it boils the more heat goes into it, therefore, its Boiling Point would be higher.

Wrong. Only 536 calories are required to boil water. Boiling, or evaporation is a cooling process. The calories increase, not the temperature.

## Table 50.

"There is no difference between evaporation and boiling".

| Grade | —8 | —9 | —10—12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| False | 32.0 | 33.3 | 45.6 | 62.4 | 79.1 | 89.3 | 91.2 |
| True | 48.0 | 29.2 | 21.6 | 18.3 | 9.3 | 9.3 | 7.2 |
| No answer | 20.0 | 37.5 | 32.8 | 19.3 | 11.6 | 1.4 | 1.6 |
| REASONS: 1) Boiling occurs at a definite temp. Evaporation at any temperature. (or) 2) Boiling takes place thruout liquid, evap. only on top. (or) 3) When water boils it is evaporating but when evaporating it is not boiling, etc. | 2.0 | 5.2 | 12.8 | 27.5 | 60.5 | 71.4 | 70.4 |
| No difference because in both cases liquid changes to vapor | 11.0 | 14.6 | 8.4 | 8.3 | 4.7 | 3.6 | 4.8 |
| *Miscellaneous | 38.0 | 27.1 | 35.6 | 23.3 | 16.2 | 10.0 | 7.2 |
| No reason | 49.0 | 53.1 | 43.2 | 40.9 | 18.6 | 15.0 | 17.6 |

*(—8 —12). True. When water evaporates it rises in the air, when it boils the same. If a thing boils long enough it will evaporate. To evaporate water you have to boil it. When water boils it slowly evaporates until nothing is left, so boiling is the same thing. Evaporation is to take something out of something. If a garment is boiled in water it will take out a stain. When water boils it evaporates a little at a time. Evaporation is gas escaping at its will; boiling is gas escaping against its will. Evaporation is a slow process of boiling. Boiling is evaporation at a much higher rate. Boiling water steams and gradually evaporates. Heat distills the water into steam, in either case. In both boiling and evapor-

ation the water disappears. In evaporation water disappears in the air, in boiling it does not but reamains where it is. Evaporation is rising of steam and evaporation is driving off of bacteria and gases out of the water. Evaporation is drawing water to the sun, boiling is heating to a certain heat. Because heat causes evaporation. When water boils part of it evaporates into the air. The longer you boil the less you have, the same for evaporation.

Wrong: When water evaporates nothing is left, when you boil it you just heat it. Evaporation means to go off. Boiling means to go up and down. In evaporating liquid disappears in boiling it evaporates into steam. Boiling is something hot, evaporation means something disappearing. Boiling turns water into steam. Evaporation turns it to vapor. Evaporation changes water to steam. Boiling heats water until it gives off carbon dioxide. When water evaporates it dries up naturally, when it boils it is like dancing water. When things boil they do not always evaporate. Boiling needs heat, evaporation needs no heat. Evaporation means moisture dries up quickly.

(+9th) G.S. True. If you boil it it evaporates slowly. In both cases something disappears. In evaporation it is above a certain temperature, when it boils it is at a certain temperature. Boiling is slow evaporation, otherwise the same as evaporation. Liquid evaporates in both cases. When a liquid evaporates it disappears into the air, when it boils it stops where it is and does not evaporate. When you evaporate water it gets hotter. Same as if you boil it.

Wrong: You first have to boil water before it evaporates. Boiling can be seen, evaporation cannot be seen. Evaporation is caused by air, boiling is caused by heat. When something boils it is hot, when it evaporates it disappears. Evaporation is absorbed by air, boiling is bubbles rising and hot. Evaporation is caused by boiling for a long time. When something evaporates nothing is left, when it is boiled it just heats.

(Physics groups).

Right: Because when a liquid boils it evaporates. Because the more calories you put into it the more is given off. Boiling is just rapid evaporation.

Wrong: Boiling requires heat, evaporation does not. When a liquid boils the steam is visible, when it evaporates it is not.

## Table 51.

"Tepid water can be made to boil without heating it".

| Grade | —8 | —9 | —10–12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Statement true | 14.0 | 13.5 | 20.0 | 50.0 | 55.8 | 72.1 | 70.4 |
| Statement false | 43.0 | 48.9 | 48.0 | 15.7 | 14.0 | 17.1 | 18.4 |
| No answer | 43.0 | 37.6 | 32.0 | 34.3 | 30.2 | 10.8 | 11.2 |
| REASONS: | | | | | | | |
| 1) By decreasing the pressure on it. By decreasing atmospheric press. By putting it in a vacuum | 0.0 | 0.0 | 5.2 | 11.7 | 11.6 | 32.1 | 29.6 |
| 2) By putting it in a flask, closing the flask and pouring cold water over it | 0.0 | 0.0 | 0.0 | 7.5 | 23.2 | 22.1 | 23.2 |
| 3) False, because heat is necessary to boil water | 28.0 | 27.1 | 31.2 | 18.3 | 9.3 | 19.3 | 17.6 |
| 4) *Miscellaneous | 5.0 | 5.2 | 6.8 | 24.2 | 10.5 | 7.1 | 8.8 |
| 5) No reason | 67.0 | 67.7 | 56.8 | 36.7 | 45.4 | 19.4 | 21.0 |

*(—8 to —12). By covering up the vessel. Add chemicals (or medicines). Evaporate it. It cannot be done as heat is necessary to make it hot enough to boil. Reduce temperature of the air. Use liquid air. Put it in the strong sunlight.

*(+9). Put acids or chemicals in it. Put it on the ice. Put it in the sunlight. It can be boiled by evaporation. Go up a high mountain. Heat is necessary for boiling, without heat there can be no boiling.

*(+10, +11, +12). Increase pressure. Apply pressure to the container. Heat the atmosphere. Its specific heat is low and can easily be heated by the sun. Impossible without heat. Apply cold water to the container. By constant stirring. Placing ice in it which gives off enough heat. Place cold wet rag round the bottle with water in it. Go up a high mountain. Go down a mine.

## Table 52.

"Water will boil at a lower temperature than usual in an airship 3 miles high."

| Grade | —8 | —9 | —10—12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| True | 16.0 | 14.6 | 25.6 | 66.7 | 76.8 | 89.3 | 88.0 |
| False | 28.0 | 36.5 | 30.4 | 23.3 | 12.8 | 8.6 | 10.4 |
| No answer | 56.0 | 48.9 | 44.0 | 10.0 | 10.4 | 2.1 | 1.6 |
| REASONS: | | | | | | | |
| Air pressure less high up in air | 0.0 | 0.0 | 3.6 | 38.3 | 55.8 | 80.7 | 78.4 |
| Air pressure is greater up in air | 0.0 | 0.0 | 2.0 | 5.8 | 4.7 | 2.8 | 4.0 |
| Because temperature is lower 3 miles up or it is cooler up there | 13.0 | 10.4 | 13.6 | 15.0 | 8.1 | 2.1 | 1.6 |
| *Miscellaneous | 15.0 | 21.9 | 15.2 | 15.9 | 5.8 | 2.4 | 2.3 |
| No reason | 69.0 | 67.7 | 65.6 | 25.0 | 23.3 | 12.0 | 13.7 |

*Non-Physics: More wind high up. Warmer high up. Speed of airship very great. Water won't boil any quicker in airship. The higher you go up the longer it takes for water to boil. Because it would boil at a higher temperature.

*Physics: Boiling Point increase as you go higher. Boiling Point is higher on top of a mountain, therefore, it must be higher in an airship 3 miles up. Height makes no difference of B.P. of water. Density of air is greater. B.P. is lower. Greater altitude. Air is cooler. Pull of gravity not so great.

## Table 53.

"Water usually boils at 100°C. Tell what you would do to make it boil at about 50°C."

| Grade .. .. .. .. .. | —8 | —9 | —10—12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| 1) Reduce pressure above it (or) 2) Put in receiver and exhaust air .. .. .. | 0.0 | 0.0 | 3.2 | 26.6 | 38.4 | 52.9 | 48.0 |
| Boil in flask, put in stopper. Cool with water | 0.0 | 0.0 | 0.0 | 9.2 | 10.5 | 15.7 | 25.6 |
| *Miscellaneous .. .. .. | 36.0 | 22.9 | 36.8 | 35.0 | 29.1 | 27.1 | 21.6 |
| No answer .. .. .. | 64.0 | 77.1 | 60.0 | 29.2 | 22.0 | 4.3 | 4.8 |

*(—8, —12). Put in closed vessel and do not heat so much. Heat it for half the time or do not heat it so long. Take less water and put on a lower fire. Add chemicals or acids. Put ice in it and then heat. Put it on a very strong flame so that it will heat quickly. Take it to a very cold place and then boil. Take it up a mountain.

*(General Science). Put on more pressure and heat. Add chemicals or acids. Add substance with a lower boiling point for example sugar. Don't let it boil so long. Take more water and less heat. Put it on a low flame. Boil it in an air tight vessel. Take it up a high mountain. Take it below the sea level. Put a wet rag over the flask (or) squeeze water from a sponge over flask.

*(Physics Groups). Increase the atmospheric pressure and heat. It cannot be done as the Boiling Point is constant. If water is put in a closed flask and a wet rag then put over it, it will boil at a lower temperature. Boil and cool. Put it in a flask and attach by tube to a calorimeter.

## Table 54.

"Tell what you would do to make water boil at about 130°C".

| Grade | —8 | —9 | —10—12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Boil it under pressure. Increase pressure on it. Boil it in a closed vessel | 0.0 | 0.0 | 0.8 | 31.6 | 65.1 | 76.4 | 73.6 |
| Put more heat under it. Heat (boil) it longer | 38.0 | 32.3 | 40.0 | 19.2 | 5.8 | 5.7 | 4.8 |
| *Miscellaneous | 11.0 | 13.5 | 11.2 | 27.5 | 20.9 | 5.7 | 8.8 |
| No answer | 51.0 | 54.2 | 48.0 | 21.7 | 8.2 | 12.2 | 12.8 |

*Non-Science: Put in a vessel with no top. Add chemicals. Give gradual heat, take it to the top of a high mountain. Heat longer. Put in ice. Reduce temperature of the air. Heat it underneath and cover the top. Freeze it first. Add chemicals that boil at about 130. (Specifically stated: sugar, alcohol, salt). Boil in a vacuum. It cannot be done as water always boils at the same temperature.

*General Science: Add chemicals (2.4%). Put in a vacuum. Put on ice. Heat very quickly with a very strong flame. Take it to the top of a high mountain (9.2%). Go to a low level (5%). Boil in a deep pan. Add more water. Heat it to about 170° and then let it cool. Take away more heat. Take less water. Make flame higher and add more water.

*Physics: Go up a high mountain. Decrease the pressure (and heat). Heat water several times. Increase pressure in the water. Put in flask and attach by tube to a calorimeter. Apply pressure by using a wet sponge with cold water. Raise pressure by heating it more. Put pieces of glass in the water. It is impossible to boil water at 130°.

## Table 55.

Tell why a change of air pressure causes a change of the boiling point of water.

| Grade .. .. .. .. | —8 | —9 | —10—12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Correct** .. .. .. | 0.0 | 0.0 | 0.0 | 0.0 | 4.7 | 14.3 | 16.8 |
| The bubbles can rise more easily when there is not so much pressure on it. (or) Molecules can jump out of it | 1.0 | 0.0 | 2.6 | 10.8 | 20.9 | 19.3 | 21.6 |
| Because the B.P. of water depends on air pressure, the less, the lower the B.P. and vice versa .. .. .. .. .. | 0.0 | 1.1 | 4.4 | 14.2 | 11.6 | 10.7 | 12.0 |
| It does not take so long to come to the boil | 3.0 | 5.2 | 8.0 | 15.8 | 7.0 | 4.3 | 5.6 |
| *Miscellaneous .. .. | 8.0 | 9.4 | 11.2 | 14.2 | 9.3 | 15.7 | 12.8 |
| No response .. .. | 88.0 | 84.3 | 73.8 | 45.0 | 46.5 | 35.7 | 31.2 |

*(—8—12). It is not so hard to heat it. The fire burns easier. The air won't be too cold then. The steam will be visible sooner. There is less air to boil out. The air escapes easier. Oxidation will be easier. The heat is less.

*(+9). The air is finer. Because the pressure is different. It requires much less heat. Molecules will heat quicker. It would be the same as taking it up a mountain. Because of the pressure. The air escapes more easily.

*(+10). Makes its specific heat greater. It condenses the steam and raises the B.P. Increases the resistance, therefore, higher Boiling Point. Because of the pressure inside the bubbles.

*(+11, +12). Molecules have greater space in which to vibrate with less pressure (3). If pressure is greater it will be warmer. Water will boil quicker. Molecules have greater velocity with increased pressure. Harder

for molecules to become heated. Bubbles of oxygen will form sooner and go off with less pressure. Less heat will be used to make a lower pressure of vapor. Pressure of liquid has not got to be so great to equal that outside. Water vaporizes more easily when pressure is less. Less resistance to steam with less pressure. The bubbles have a better change to form at a low pressure. Pressure of air in bubbles must equal pressure of air outside. Steam not condensed so easily with low pressure therefore, lower Boiling Point. Water molecules on top can fly off easier. Easier for molecules to get heated. Air and water molecules can mingle more easily with less pressure. Air vapor in water can raise to top more easily when pressure is less. With less pressure less resistance is offered. When presure is low the vapor pressure becomes higher.

**(With less air pressure the pressure of the vapor will exceed the air pressure at a lower temperature than with normal air pressure (or) Vapor pressure (tension) will have to be greater to equal air pressure, therefore, vapor will have to be heated to a higher temperature. (or) With a lower air pressure the vapor pressure will be greater than the air pressure sooner.)

## SURVEY OF RESULTS ON BOILING.

Question I of Part I gives every pupil a chance to define Boiling Point in any way he pleases; there is little control over the response. The large majority of non-science and General Science students make use of one or more of the obvious qualities of boiling water in their definitions; these are (a) the rising of bubbles; (b) the giving off of steam; the changing from liquid to steam; (c) the temperature (heat, hotness) when it is boiling.

The Physics students also define in this way but to a lesser extent. About 10 % of +10th and 25 % of +11th and +12th graders associate boiling point with (a) atmospheric pressure, or with (b) molecular theory, although many of these notions are very vague. In the non-science groups such associations are not found at all.

The results given in Tables 47 to 50 show that many non-science students are familiar with facts such as the boiling point of water, the fact that different liquids have different boiling points, and so on. There are, however, some erroneous notions held not only by these students but also by the science students which have to be noted.

(1) Non-science pupils appear to think of "temperature" and "time of boiling" as equivalent. Thus 24% of —8th graders think that a pound of water will boil at a lower temperature than two pounds of water because it does "not take so long" to boil one pound as two pounds. Almost 12% of +9th graders also think so. This notion is found even in the Physics grades, although to a smaller extent. The notion is again found in responses to the question as to how to boil water at 50° or 130°. Here again the most common non-science method is to "heat it for a shorter or longer time". It probably would not be very difficult for science teachers to cope with this misconception if they knew of its prevalence.

(2) That the bubbles in boiling water or alcohol contain air, oxygen, hydrogen and what not is the idea of a suprisingly large number of students, both non-science and science. 54 % of 11th grade Physics students who studied the topic "Boiling" readily say this. It probably is not learned in the Physics class, for about 40% of —9th graders also think so; nevertheless it is retained. Further reference will be made to this in a later chapter.

Differences between the science and non-science grades increase when those questions, in which the relation between boiling point and air pressure is involved, are considered. By placing in one table the correct responses to those questions, (Part I No. 11, Part 2, Nos. 1 and 2) for the various groups and taking an average, it is possible to get an idea of how familiar this relation between boiling point and air pressure is.

| Grade .. .. .. .. | —8 | —9 | —10—12 | +9 | +10 | +11 | +12 |
|---|---|---|---|---|---|---|---|
| Part 1, No. 11 .. .. | 0 | 0 | 3.6 | 38.3 | 55.8 | 80.7 | 78.4 |
| Part 2, No. 1 .. .. | 0 | 0 | 3.2 | 35.8 | 48.9 | 68.6 | 73.6 |
| Part 2, No. 2 .. .. | 0 | 0 | 0.8 | 31.6 | 65.1 | 76.4 | 73.6 |
| Average .. .. .. .. | 0 | 0 | 2.5 | 35.2 | 56.6 | 75.2 | 75.2 |

From the summary just given it appears that with the exception of a few cases in the —10, —11 and —12th grades, non-science students do not know of the relation.

The purpose of Part 3 of the test was to determine whether pupils knew just why the boiling point is affected by external pressure. The 'correct' explanation given in Table 55 is really the only one of those advanced that could be accepted as an adequately scientific notion. Such explanations as " The bubbles can rise more easily" or "The molecules can jump off more easily" fail to account for the decreased or increased *temperature* of boiling, and the writer regards them as vague. It would then seem that, although the majority of Physics students are familiar with the relation beween air pressure and boiling point, few can account for it. No General Science student and only about 5% of +10th graders can do this.

Question 10 of Part 1 was originally included in the test for the purpose of determining to what extent students had broken the strong association of boiling with heat, for a scientific notion of boiling need not have this association involved. The results show that non-science students have not severed this relation; to them the idea of "cold boiling water" would probably seem incongruous.

An unexpected notion brought to light by this question was that tepid water can be boiled without further heating by pouring cold water over the container. Physics teachers probably could advance an explanation of this in terms of the common experiment they perform to demonstrate that boiling is lowered under decreased pressure. The questionaire that was returned with the tests showed that of the 10 Physics classes 7 had seen demonstration (b), 1 demonstration (a) and 1 both demonstrations (a) and (b). These demonstrations are explained in the questionaire at the beginning of this chapter. It was not possible, therefore, to compare results of groups that had (a) with those that had (b) as only one small Physics class had had demonstration (a). This erroneous notion will be examined again in Part 2 of this study.

What then do the results of these test questions reveal?

(1) Non-science students have naive notions of Boiling. Their notions involve the common qualities of boiling *water* which are (a) the bubbles rising, (b) the temperature (heat, hotness) of water when boiling, (c) the giving off of steam. Relations of boiling with air pressure have not been formed.

(2) Although non-science students have vague notions of Boiling, an appreciable number are familiar with several facts concerning the process such as the constancy of the boiling point (pressure neglected), boiling point is independent of the mass of liquid, etc.

(3) Non-science students seem to think of "temperature of boiling" and "time of boiling" as equivalent. Another erroneous notion, which is the most common one in both science and non-science groups, is that the bubbles in boiling liquids contain air, oxygen, etc.

(4) At least 35 % of General Science students have formed the "Boiling point-air pressure" relation although no student has a scientific concept of the relation itself.

(5) The majority of Physics students have formed this "Boiling point-air pressure" relation but a small minority have a scientific notion of this relation itself.

(6) Taking into account all the results, there is no significant difference between the 11th and 12th Physics grades. These two groups, however, are superior to the 10th Physics grade whereas the latter is superior to the 9th General Science grade.

(7) No notion, scientific, vague or erroneous, is peculiar to only one non-science or to only one science grade; the only difference being the extent to which it occurs.

(8) Although a concept which involves the relationship between boiling point and air pressure is more scientific than one which uses obvious properties of boiling water, the use of such a concept is limited unless the relation involved is understood. Consequently such concepts of General Science and Physics students, which were taken to be scientific in this study, are not fully developed except in the cases classified as correct in Table 55.

## APPENDIX TO PART I.

### SEX DIFFERENCES.

For the purpose of this study there was no special selection of pupils excepting on the basis of whether science had or had not been studied. Students were drawn from many schools in order to render factors such as intelligence, methods of instruction etc., as constant as possible.

Since many investigations have under [illegible]fferences in achievement between boys and girl, ned with the tests in favor of boys, it probably would have been desirable to have equivalent numbers of boys and girls in the science and control groups. This was not practicable, and the composition of the non-science groups had to be taken as found. The composition of the groups used in this study was as follows:

| | *Non-science* | *Gen. Science.* | *Physics.* |
|---|---|---|---|
| Boys | 59% | 52% | 67% |
| Girls | 41% | 48% | 33% |

Although the groups are not equivalent, differences are not so great as to make, for instance, the General Science students predominantly boys and the corresponding non-science largely girls.

## Table 56.

### SEX DIFFERENCES IN PERCENTAGE FREQUENCY OF RESPONSES TO QUESTION ON ACCELERATION. (See Table 1.)

| Grade | 6—8 | | —9 | | —11 | | —12 | | —9 | | —11 | | —12 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boys | 52 | | 65 | | 62 | | 64 | | 83 | | 103 | | 92 | |
| Girls | 48 | | 40 | | 52 | | 46 | | 59 | | 47 | | 39 | |
| | B | G | B | G | B | G | B | B | B | G | B | G | B | G |
| 1. Rate of change of speed | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 0.0 | 33.9 | 29.8 | 34.8 | 35.9 |
| 2. "Picking up of speed" | 0.0 | 0.0 | 3.1 | 2.5 | 4.8 | 0.0 | 1.9 | 4.3 | 7.2 | 8.5 | 5.3 | 6.4 | 6.5 | 2.6 |
| 3. Speed (or) rate of speed | 36.5 | 35.4 | 43.1 | 30.0 | 45.2 | 38.5 | 42.6 | 39.1 | 45.8 | 39.0 | 31.1 | 34.0 | 32.6 | 35.9 |
| 4. Power, force, strength | 32.7 | 20.8 | 23.1 | 20.0 | 16.1 | 11.5 | 11.1 | 10.9 | 22.9 | 17.0 | 3.9 | 4.3 | 3.3 | 0.0 |
| 5. Miscellaneous | 3.9 | 10.5 | 7.6 | 15.0 | 9.7 | 19.2 | 13.6 | 6.6 | 7.2 | 8.4 | 20.9 | 12.8 | 19.6 | 17.9 |
| 6. No response | 26.9 | 33.3 | 23.1 | 32.5 | 24.2 | 30.8 | 30.8 | 39.1 | 15.7 | 27.1 | 4.9 | 12.7 | 3.2 | 7.7 |

This table giving the results on Acceleration is fairly representative of the remaining tables. Because of the small numbers of boys and girls in each group it is hardly possible to generalize. For the students and concepts treated in this study, however, the following conditions were found to exist:—

(1) No prevalent scientific, vague or erroneous notion was held by pupils of one sex exclusively; a notion that was generally held by boys was also held by girls. The only noticeable difference between the sexes was that a slightly larger percent of boys appeared to hold a particular notion. It may be that this is due largely to (2) below.

(2) The percent of girls not responding to a question was generally greater than the corresponding percent of boys. In the written essays this difference was a minimum. Attempts to explain this would probably have to take into account the question of relative interests of the sexes.

(3) In may instances the smaller percent of girls giving a particular response appears to be due to the larger percent not making a response. Of course the very fact that more girls do not respond, that is, are unable to express their notions, means something. A student must be able to express his concepts as well as to us them.

Two differences that would have an important bearing on the results of this study are, firstly the extent to which any concept has deveolped, and secondly, the types of notions held. It was found, however, that when a concept was scientific to the majority of boys it was so to the majority of girls too; that is, sex differences were not great enough to place boys and girls in two classes on this basis. It was also found that there are no types of notions peculiar to girls only, which means that the composition of the various groups could hardly have affected the notions found.

# PART II.

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Experimental study of the Formation of some of the Concepts treated in Part I.

## CHAPTER IX.

### EXPERIMENTAL TEACHING.

In Part I of this study were given the notions held by children who have and who have not studied General Science or Physics; an estimate of the extent to which any notion occurs having been determined by examination of responses to various questions. These questions were answered by pupils under ordinary school conditions. No real attempt was made, however, to account for the occurence of any particular erroneous notion, or for the small percentage of students who hold particular scientific concepts—the results were just given as representative of existing notions.

It may be claimed, however, that General Science students cannot be expected to hold scientific concepts of Heat and Light as the treatment of these subjects is very elementary as compared to the way the same subjects are studied in the Physics course; it may even be said that certain essential subject matter may not have been treated in the General Sceince course at all. In other words, the question of method and subject matter may be involved.

Although such may be the case, the results of Part 1 are still significant in that they represent the notions children hold under existing conditions of teaching. To answer the question "Does the study of General Science give a child a scientific concept of Light?" we have to take General Science pupils as they are. The same holds in the case of Physics students.

As it is impossible to examine pupils individually regarding the prevalence of any notion or to trace the effect of method on notions that are ultimately formed when dealing with a large number of pupils drawn from various States, it was decided to experiment with small groups and even with individuals under controlled conditions of teaching.

The concept which a pupil develops probably depends on a number of factors of which the teacher and the textbook may only be two; the problem of accounting for the formation of any concepts, therefore, is really a matter of personal observation of pupils during actual instruction in the classroom.

In this part of the study will be given the results of such experimentation regarding some of the concepts treated in Part 1. These are Dew formation, Heat, Light, Mass, Weight, Gravity and Boiling.

The groups used in experimental teaching may be described as follows:

A class of 29 girls in a private school in New York City were to begin the course of Physics in October 1923. The class was composed of 11th and 12th graders and was divided, for teaching purposes, into two groups of 15 and 14 each on the results of the Otis Test—Higher Exam. Form A, in a manner as shown in Table 57. The original group met five periods per week of forty minutes each, but during experimental teaching each group met only three periods per week. No home study was done—all studying being done in the school study hall.

These groups are rather small but nevertheless they have an advantage over ordinary classes, such as the groups to be described later, in that they were formed especially for the teaching experiment, whereas in larger schools groups have to be taken as found and cannot usually be divided to suit the purpose of research because of administrative difficulties. Moreover, for teaching of this nature it was preferable to have small groups for purpose of individual observation. In referring to these groups they will be called "IIX" and "IIY".

In September 1924 the writer was engaged to teach General Science in the New Rochelle High School and was, therefore, in a position to repeat and add to the experimental teaching of 11th and 12th Grade pupils in 1923.

The pupils consisted of boys and girls just entering the 9th Grade of High School after graduating from the 8th Grade of elementary schools.

In teaching these groups, however, the writer had to take them as found and it was not possible to reclassify pupils because of administrative difficulties.

The pupils had all taken the Dearborn Group Intelligence Examination before entering High School; it was, therefore, possible to find out how nearly equivalent the groups were for teaching purposes as far as intelligence is concerned.

Teaching of groups began in September 1924. Each group met six periods of forty minutes each per week, one period being devoted to supervised study. The groups also differ from the two 11th and 12th Grades in that they were not constant throughout the year, although they remained intact for every teaching experiment. In the Winter Session, the two groups were composed of 22 and 26 each; due to a few changes and absences, however, they were ultimately 21 each.

In the Spring Session a change (administrative) was made which partly mixed the groups and partly decreased the number of one. During each teaching experiment, however, the groups were intact.

The data in Tables 58 and 59 represent the assigned number, sex, age in months and Intelligence Quotient of each pupil used during the Winter and Spring Sessions respectively. The number assigned to each pupil will serve as a reference in the results of the teaching experiments on Dew, Heat and Light.

Table 57.

Data on teaching groups IIX and IIY.

*Group* IIX.

| *Pupil* | *Grade* | *Age in months.* | *I.Q.* |
|---|---|---|---|
| 1. | 12 | 207 | 115 |
| 2. | 11 | 195 | 104 |
| 3. | 11 | 190 | 107 |
| 4. | 11 | 187 | 106 |
| 5. | 11 | 205 | 109 |
| 6. | 12 | 209 | 103 |
| 7. | 12 | 216 | 118 |
| 8. | 12 | 223 | 98 |
| 9. | 11 | 200 | 98 |
| 10. | 11 | 188 | 106 |
| 11. | 12 | 208 | 115 |
| 12. | 12 | 217 | 94 |
| 13. | 12 | 206 | 110 |
| 14. | 12 | 217 | 108 |
| 15. | 12 | 216 | 112 |
| Median | | 207 | 107 |
| Range | | 187-223 | 94-118 |

*Group* IIY.

| *Pupil* | *Grade* | *Age in months.* | *I.Q.* |
|---|---|---|---|
| 1. | 12 | 206 | 109 |
| 2. | 12 | 199 | 124 |
| 3. | 12 | 210 | 97 |
| 4. | 12 | 222 | 96 |
| 5. | 12 | 209 | 104 |
| 6. | 12 | 215 | 117 |
| 7. | 11 | 198 | 113 |
| 8. | 12 | 216 | 110 |
| 9. | 12 | 205 | 99 |
| 10. | 11 | 185 | 109 |
| 11. | 12 | 220 | 116 |
| 12. | 12 | 217 | 104 |
| 13. | 11 | 215 | 107 |
| 14. | 11 | 181 | 109 |
| Median | | 209.5 | 109 |
| Range | | 181-222 | 96-124 |

## Table 58.

Data on teaching groups 9X and 9Y (Winter Session).

| *Group* 9X. | | | | *Group* 9Y. | | | |
|---|---|---|---|---|---|---|---|
| *Pupil.* | *Sex* | *Age in months* | *I.Q.* | *Pupil.* | *Sex* | *Age in months* | *I.Q.* |
| 1. | B | 181 | 89 | 1. | G | 168 | 91 |
| 2. | G | 179 | 87 | 2. | G | 185 | 91 |
| 3. | G | 166 | 98 | 3. | G | 177 | 115 |
| 4. | G | 167 | 122 | 4. | G | 189 | 99 |
| 5. | G | 169 | 98 | 5. | G | 197 | 112 |
| 6. | G | 179 | 95 | 6. | G | 211 | 81 |
| 7. | B | 171 | 107 | 7. | G | 213 | 92 |
| 8. | G | 180 | 94 | 8. | G. | 151 | 124 |
| 9. | B | 192 | 91 | 9. | G | 202 | 102 |
| 10. | G | 171 | 120 | 10. | G | 200 | 102 |
| 11. | G | 186 | 96 | 11. | G | 164 | 97 |
| 12. | G | 169 | 93 | 12. | G | 168 | 127 |
| 13. | B | 188 | 95 | 13. | G | 179 | 104 |
| 14. | B | 185 | 93 | 14. | G | 180 | 112 |
| 15. | B | 174 | 113 | 15. | G | 197 | 102 |
| 16. | B | 188 | 90 | 16. | B | 171 | 83 |
| 17. | B | 174 | 113 | 17. | G | 161 | 135 |
| 18. | G. | 178 | 104 | 18. | G | 180 | 104 |
| 19. | G | 210 | 77 | 19. | G | 153 | 120 |
| 20. | B | 180 | 96 | 20. | G | 175 | 108 |
| 21. | G | 166 | 95 | 21. | G | 175 | 84 |
| Median | | 179 | 95 | Median | | 179 | 102 |
| Range | | 166-210 | 77-122 | Range | | 151-213 | 81-135 |

Table 59.

Data on teaching groups 9X and 9Y (Spring Session.)

| *Group* 9X. | | | | *Group* 9Y. | | | |
|---|---|---|---|---|---|---|---|
| *Pupil* | *Sex* | *Age in months* | *I.Q.* | *Pupil* | *Sex* | *Age in months* | *I.Q.* |
| 1. | G | 179 | 87 | 1. | G | 168 | 91 |
| 2. | G | 166 | 98 | 2. | G | 185 | 91 |
| 3. | G | 167 | 122 | 3. | G | 189 | 99 |
| 4. | G | 179 | 95 | 4. | G | 197 | 112 |
| 5. | G | 180 | 94 | 5. | G | 211 | 81 |
| 6. | B | 192 | 91 | 6. | G | 213 | 92 |
| 7. | G | 171 | 120 | 7. | G | 202 | 102 |
| 8. | G | 186 | 96 | 8. | G | 200 | 102 |
| 9. | G | 169 | 93 | 9. | G | 164 | 97 |
| 10. | B | 188 | 95 | 10. | G | 168 | 127 |
| 11. | B | 185 | 93 | 11. | G | 179 | 104 |
| 12. | B | 188 | 90 | 12. | G | 180 | 112 |
| 13. | B | 174 | 113 | 13. | B | 178 | 119 |
| 14. | B | 181 | 99 | 14. | G | 150 | 116 |
| 15. | B | 195 | 98 | 15. | B | 174 | 113 |
| 16. | B | 177 | 115 | 16. | G | 175 | 84 |
| 17. | G | 151 | 124 | | | | |
| 18. | G | 161 | 135 | | | | |
| 19. | G | 153 | 120 | | | | |
| 20. | G | 175 | 108 | | | | |
| Median | | 178 | 98.5 | Median | | 179.5 | 102 |
| Range | | 151-195 | 87-135 | Range | | 150-213 | 81-127 |

No text-book was used in any of the classes, class notes and mimeographed sheets were used throughout. There were many reasons for not having the pupils use a particular text-book, chief amongst which was the nature of the teaching. In the case of Boiling, for instance, most Physics texts give both experiments for boiling water under pressure, or give one experiment in detail while drawing attention to the other. No Physics text presents the subject matter of Mass and Weight in the manner in which it was proposed to be treated in two of the experimental classes.

In the various experimental studies on the efficacy of different teaching methods, the matter of text book may not have been important, but when teaching a specific piece of subject matter, such as Dew formation, or Mass, it must be controlled, and in this case, the writer decided to dispense with text-books.

In each experiment initial testing of pupils was done about a week before teaching began and final testing from two to three weeks after instruction had ceased. Final testing was delayed partly to counteract the effect of recency and to conform, more or less, to conditions of testing in Part 1 of this study, which was done from three to six weeks after the subject had been studied.

The purpose and results of each experiment will be given in the appropriate chapter.

## ADDITIONAL DATA ON MASS, WEIGHT AND GRAVITY.

### THE CONCEPTS MASS, WEIGHT AND GRAVITY.

In the Physics course the one branch known as Mechanics is taught in most cases at the beginning of the course. To a certain extent the subject matter is introduced in psychological sequence in which one concept is prerequisite to the formation of another following. Thus the concept of acceleration follows that of velocity, and the measurement of force and mass assumes a notion of acceleration. Thus, whether the teaching claims to be deductive or inductive, the fact remains that certain concepts cannot be formed scientifically unless others are first formed.

In the General Science course offered in most schools the subject matter of Mechanics is treated somewhat differently. A thorough instruction in Mechanics is not given, but certain portions which are deemed important receive consideration. Secondly, the treatment is elementary, divested of as much mathematics as possible and mostly descriptive. Thus a widely used General Science text presents its Mechanics in the following order:— Matter and Energy; Kinetic and Potential; Transformation and Conservation of Energy; Time; Gravitation......(after 100 pages)......Work and its measurement; Machines.

Under these conditions it cannot be expected that General Science students will have the same concepts as Physics students, because the subject matter that was taught to them was probably presented in a very different way. These factors do not detract from the significance of the results given in Part 1, as those represent existing results.

In order to control method and subject matter it was decided to teach the Senior groups in two different ways, one which the writer thinks is essentially the method of treatment in a General Science course (Method X) and the other the method of most High Schools and Elementary College texts (Method Y). The teaching was repeated in 1924 on the 9th grade pupils. This would mean that the 9th Grade classes were taught the subject matter of Weight, Mass and Gravity as would be most commonly done in both General Science and Physics courses.

Method X (given to Groups IIX and 9X) may be described as follows:—

The concepts Gravity, Weight and Mass were developed in a purely descriptive, non-mathematical way according to some of the most widely used General Science tests. Mass, for example, was taught in conjunction with Weight and treated according to Barber's General Science text. Gravity was described and arrived at inductively instead of from Newton's Law of Universal Gravitation.

*Method Y (given to Groups IIY and 9Y)*, was in accordance with the treatment of Dynamics in most Physics texts and followed the appended plan:

1. *Motion*:
   - a. Velocity—numerical problems.
   - b. Acceleration—numerical problems.
2. *Cause of Motion*:
   - a. Force (gravity special case of force).
   - b. Measurement of force—Weight.
   - c. Newton's first Law of Motion—Inertia, Mass.
   - d. Newton's second Law of Motion—F=ma,
     comparison of forces, masses,
     proportionality of Weight and Mass.
   - e. Newton's third Law of Motion.

3. Newton's Law of Gravitation—$F = \frac{mm'}{r^2}$

The test on Mass, Weight and Gravity described in Chapter VII of this study was given to each of the groups before and after the teaching period, three weeks elapsing after completion of instruction before giving the tests.

The tables following give results of the test before and after instruction. The two columns of per cents under each group represent the results on the test before and after instruction. The data on the groups used can be obtained from Table 57 and 59.

## Table 60.

Percentage frequency of resonses to Questions 1 and 2, Chapter VII, before and after instruction.

| WEIGHT | IIX | | IIY | | 9X | | 9Y | |
|---|---|---|---|---|---|---|---|---|
| | *Before | *After | Bef. | Aft. | Bef. | Aft. | Bef. | Aft. |
| Force of gravity. Earth's pull | 0.0 | 78.6 | 0.0 | 85.7 | 0.0 | 70.0 | 0.0 | 75.0 |
| Heaviness .. .. .. .. .. .. .. | 57.2 | 0.0 | 46.7 | 0.0 | 60.0 | 5.0 | 62.5 | 0.0 |
| No. of pounds in a thing | 21.4 | 7.1 | 26.7 | 7.1 | 25.0 | 10.0 | 18.7 | 6.2 |
| Mass .. .. .. .. .. .. .. | 0.0 | 14.3 | 0.0 | 7.1 | 0.0 | 10.0 | 0.0 | 6.2 |
| Miscellaneous .. .. .. .. | 14.3 | 0.0 | 26.7 | 0.0 | 10.0 | 0.0 | 12.5 | 12.5 |
| No answer .. .. .. .. | 7.1 | 0.0 | 0.0 | 0.0 | 5.0 | 5.0 | 6.2 | 0.0 |
| **MASS** | **IIX** | | **IIY** | | **9X** | | **9Y** | |
| Quantity of matter in a body | 0.0 | 35.7 | 0.0 | 26.7 | 0.0 | 45.0 | 0.0 | 37.5 |
| **Measure of inertia .. .. | 0.0 | 14.3 | 0.0 | 33.3 | 0.0 | 10.0 | 0.0 | 12.5 |
| Volume, Size, Number of cu. units. Amount of it. Quantity of it present .. | 14.3 | 28.6 | 20.0 | 6.7 | 15.0 | 10.0 | 12.5 | 12.5 |
| Weight, Heaviness, Gravity, A measure of weight, Quantity of matter .. .. .. .. | 14.3 | 14.3 | 20.0 | 20.0 | 0.0 | 20.0 | 6.2 | 18.7 |
| The whole piece .. .. .. | 28.6 | 0.0 | 13.3 | 0.0 | 15.0 | 0.0 | 12.5 | 0.0 |
| Density, Density/Volume | 14.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Miscellaneous .. .. .. | 7.1 | 7.1 | 13.3 | 13.3 | 15.0 | 10.0 | 10.0 | 12.5 |
| No response .. .. .. .. | 21.4 | 0.0 | 33.3 | 6.7 | 55.0 | 5.0 | 62.5 | 6.2 |

**Bodies offer a certain resistance to being moved or being stopped when in motion. This depends upon the mass of the body, the greater the mass, the more resistance is offered.

*In future tables (1) will refer to results before instruction and (2) to results after instruction.

## Table 61.

Percentage frequency of responses to Question 3 (Part 1) and Question 1, 2, 3, 4, 5, 6, (Part 2) of Chap VII before and after instruction.

| | IIX. | | 11Y | | 9X | | 9Y | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| *Quest.* 3, *Part* 1. *Gravity* pulls the stone back to earth | 85.7 | 100. | 93.3 | 100. | 81.0 | 95.2 | 76.0 | 100.0 |
| *Quest.* 1, *Part* 2. To find mass we'gh it .. .. .. .. | 7.1 | 35.7 | 13.3 | 66.7 | 5.0 | 30.0 | 12.5 | 50.0 |
| Find its volume .. .. | 7.1 | 14.3 | 13.3 | 13.3 | 10.0 | 15.0 | 12.5 | 12.5 |
| Find water displaced . .. | 14.3 | 7.1 | 0.0 | 6.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Miscellaneous .. .. .. .. | 14.3 | 35.7 | 20.0 | 13.3 | 20.0 | 40.0 | 25.0 | 37.5 |
| REASON :— | | | | | | | | |
| Mass is proportional to weight .. .. .. .. .. .. | 0.0 | 14.3 | 0.0 | 33.3 | 0.0 | 10.0 | 0.0 | 18.7 |
| *Quest.* 2, *Part* 2. Mass ½ when object compressed to ½ | 42.9 | 35.7 | 53.3 | 33.3 | 40.0 | 45.0 | 37.5 | 31.2 |
| Mass same when object compressed to half . .. .. | 7.1 | 35.7 | 0.0 | 60.0 | 5.0 | 15.0 | 0.0 | 31.2 |
| *Quest.* 3, *Part* 2. Mass less miles away from earth .. | 7.1 | 42.9 | 13.3 | 33.3 | 10.0 | 45.0 | 12.5 | 43.7 |
| Mass same miles away from earth .. .. .. .. .. | 14.3 | 42.9 | 20.0 | 53.3 | 15.0 | 35.0 | 18.7 | 37.5 |
| *Quest.* 4, *Part* 2. Iron heated, its mass increases | 35.7 | 28.6 | 40.0 | 26.7 | 45.0 | 45.0 | 43.7 | 31.2 |
| Iron heated, its mass is same | 21.4 | 35.7 | 20.0 | 46.7 | 15.0 | 20.0 | 18.7 | 25.0 |

*TABLE* 61.—*Continued.*

| | IIX | | IIY | | 9X | | 9Y | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| *Quest.* 5, *Part* 2. Bodies in N.Y. have equal weights, masses equal .. .. .. .. | 14.3 | 71.4 | 6.7 | 86.7 | 10.0 | 85.0 | 18.7 | 75.0 |
| *Reason*: Weight proportional to mass .. .. .. .. .. | 0.0 | 28.6 | 0.0 | 40.0 | 0.0 | 15.0 | 0.0 | 25.0 |
| *Quest.* 3, *Part* 2. Weight *less* miles away from earth | 21.4 | 92.9 | 13.3 | 86.7 | 5.0 | 85.0 | 6.2 | 93.7 |
| Weight *more* miles away from earth .. .. .. .. | 14.3 | 7.1 | 26.7 | 6.7 | 15.0 | 15.0 | 12.5 | 0.0 |
| Weight *same* miles away from earth .. .. .. .. .. | 42.9 | 0.0 | 46.7 | 6.7 | 40.0 | 0.0 | 31.2 | 6.2 |
| *Reason*: Pull of gravity less .. .. .. .. .. .. | 7.2 | 71.4 | 0.0 | 86.7 | 5.0 | 70.0 | 0.0 | 81.2 |
| *Quest.* 6, *Part* 2. Weight *greater* at Pole than Equator .. .. .. .. .. .. .. | 7.1 | 85.7 | 13.3 | 86.7 | 10.0 | 80.0 | 12.5 | 81.2 |
| Weight *less* (or same) at Pole than at Equator .. | 35.7 | 14.3 | 26.7 | 13.3 | 35.0 | 20.0 | 25.0 | 12.5 |
| *Reason*: Force, pull of gravity greater .. .. .. .. .. | 7.2 | 71.4 | 0.0 | 50.0 | 0.0 | 65.0 | 0.0 | 68.7 |

## Table 62.

(Question 1, Part 3.)

Definitions of Gravity before and after instruction.

| | IIX | | IIY | | 9X | | 9Y | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| A force of attraction all bodies have for each other. Mutual attraction of earth and another body .. .. .. | 14.3 | 78.6 | 13.3 | 86.7 | 0.0 | 65.0 | 0.0 | 68.7 |
| Something (a substance) in centre of earth .. .. .. | 21.4 | 14.3 | 26.7 | 6.7 | 15.0 | 15.0 | 31.2 | 6.2 |
| What keeps us on earth. What pulls things down, etc. | 35.7 | 0.0 | 26.7 | 6.7 | 45.0 | 10.0 | 37.5 | 6.2 |
| Miscellaneous, e.g. something in the air .. .. | 14.3 | 7.1 | 20.0 | 0.0 | 20.0 | 10.0 | 12.5 | 12.5 |
| No answer .. .. .. .. | 14.3 | 0.0 | 13.3 | 0.0 | 20.0 | 0.0 | 18.7 | 6.2 |

## Table 63.

(Question 2, Part 3.)

Meaning of "Quantity of Matter" before and after instruction.

| | IIX | | IIY | | 9X | | 9Y | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Weight of the material in it .. .. .. .. .. .. .. .. | 7.1 | 21.4 | 0.0 | 13.3 | 5.0 | 20.0 | 6.3 | 18.7 |
| Size, Capacity .. .. .. .. | 14.3 | 14.3 | 6.7 | 6.7 | 5.0 | 10.0 | 12.5 | 6.2 |
| Amount of substance contained .. .. .. .. .. .. .. | 7.1 | 21.4 | 6.7 | 13.3 | 5.0 | 30.0 | 6.2 | 18.7 |
| Material it is made of .. | 0.0 | 14.3 | 0.0 | 6.7 | 5.0 | 10.0 | 0.0 | 12.5 |
| That which measures its inertia or resistance to be moved .. .. .. .. .. .. .. | 0.0 | 14.3 | 0.0 | 33.3 | 0.0 | 10.0 | 0.0 | 18.7 |
| Miscellaneous .. .. .. .. | 14.3 | 7.1 | 13.3 | 13.3 | 10.0 | 5.0 | 6.2 | 12.5 |
| No answer .. .. .. .. .. | 57.2 | 7.1 | 73.3 | 13.3 | 75.0 | 15.0 | 68.7 | 12.5 |

## ANALYSIS OF RESULTS OF TEST.

It will be found that the results of the test given before instruction are very much the same in type as those given in Part I of this study, the percent giving any particular response varies but this is to the expected in groups of the size used. Every student was familiar with gravity but notions of gravity were vague. No student was familiar with the law of universal gravitation, gravity was "something in the air" that had the power to do certain things.

The results after instruction differ decidedly from those of the corresponding groups in Part I of the study excepting for the concept Mass. Before instruction not one pupil evidently had formed any connection between Gravity and Weight, after instruction 79% and 86% of seniors and 67% and 71% of 9th Graders in defining Weight did so. The "heaviness" and "number of lbs." notions have been abandoned. On the other hand, wrong notions appear which were not held before, viz: the confusion of weight with mass, the confusion being greater in the X than in the Y groups. The "check" question on weight also show differences. From table 61 it will be seen that before instruction the pupils of all groups have the idea that weight is a constant quantity, the few who think that it varies with altitude cannot support their beliefs. After instruction the majority of all groups know that weight varies with distance from the earth and can account for it. This fact coupled with the idea that gravity was not some substance magnetic or otherwise, in the earth, interested the groups more than, perhaps, anything else during the instruction. To think that one would weigh less on the moon than on the earth touched the imagination of the pupils, especially the 9th Graders. In the latter classes, it started a lengthy discussion, and this evidently seemed to impress this relation of weight and distance from the earth firmly in the minds of the pupils.

In all groups, after instruction, Gravity is predominantly an attractive force between bodies. 23.8% of 9X, however, still hold on to notions such as "That which keeps bodies on earth," "something which forces things down" etc.

The two methods of instruction do not seem to affect the students differently as far as Gravitation is concerned. In both methods, Gravitation was treated in a rather isolated way, the only difference really being that Groups 9Y and IIY had the mathematical representation too, viz: $G = \frac{mm^1}{r^2}$

The results of Mass are different. It must be stated at the outset that extreme difficulty was encountered with Group 9Y because they were very weak in arithmetic and had just begun the study of Algebra. They consequently had little or no concepts of equations or proportion. On the other hand, matters were not so easy with the older IIY groups. These students, however, had some notion of symbolic representation, equations and their solutions. Proportion, however, had to be taught along the way as in the Algebra class. Difficulties like these, however, are general. It is just as difficult to get College freshmen to form the $\frac{dv}{dr}$ concept of an instantaneous acceleration in the study of Dynamics when they have just begun, or have not had, the study of Calculus.

In groups 9Y and 11Y all the emphasis was concentrated around Newton's Laws of Motion in an attempt to get pupils to form the Mass concept. At this point too the distiction between weight and mass was drawn and reasons offered why masses can be compared by weighing. Much stress was laid upon the fundamental equation $F = ma$ (or $F = \frac{w}{g} a$). The day following the discussion of hte proportionality of Mass and Weight, 60% and 33.3% of groups 11Y and 9Y, respectively, gave correct written explanation of why mass is proportional to weight. In the final test, however, the corresponding percentages are 33.3 % and 19.0 % for those who state that weighing will give mass because weight is proportional to mass.

At the time of teaching Newton's 2nd Law, the writer thought that the Y groups did not have so much difficulty in distinguishing between Weight and Mass. The equation $W = mg$ was used to show that the two were different quantities. The confusion was noticed, however, in the methods ot attacking numerical problems. The formula $F = ma$ would be used irrespective of the units employed.

Extreme difficulty was encountered in the X groups in distinguishing between Weight and Mass. The fact that Mass and Weight are both measured in pounds, that one talks of a mass of 2 lbs. and a weight of 2 lbs. seemed proof sufficient to the pupils that they are one and the same thing.

What do the results of the test show as far as the concept Mass is concerned?:—

(1) Although Mass was discussed as both "Quantity of Matter" and "Measure of Inertia" the former is more strongly associated than the latter with Mass by all groups, except in the case of the 11Y group where there is equality. The erroneous notions formed in Part I of the study occur here too.

(2) "Quantity of Matter" means anything from weight, volume, amount, up to inertia. 33.3% of the 11Y Groups think of it as the measure of the inertia of a body.

The rest of the results on Mass can be combined as was done in Part I of study. By doing this the average percent of each grade associating mass with volume and weight will be:—

| | IIX | IIY | 9X | 9Y |
|---|---|---|---|---|
| Mass is volume .. .. .. | 27 | 20 | 30 | 29 % |
| Mass is weight .. .. .. | 22 | 12 | 22 | 21 % |

In this estimate the vague notion of "Quantity of Matter" as "Amount of substance contained" was not taken into account as it may mean either weight of volume.

On the whole then, in all groups, more students associate mass with volume than with weight. The differences between the two sets of groups is slight except in the case of the IIX and IIY groups associating mass with weight.

In general the results of the teaching of these groups as far as the questions are concerned, shows:—

(1) The majority of pupils of all grades change their notions of gravity irrespective of method used. The only difference in method was that the Y groups had had Newton's Law of Universal Gravitation, $(F = \frac{mm'}{r^2})$

(2) The majority of pupils of all grades associate weight with gravity after instruction which was not the case before instruction. The two methods show negligible differences in favor of the Y groups.

(3) The concept Mass does not become scientific like Gravity and Weight, although the IIY group shows greater understanding after instruction than the other groups. A third of the pupils of this group think of "quantity of matter" as a measure of inertia. The same erroneous notions occur after instruction as in Part I of the study—Weight and Volume being the two most common.

The responses given to the same question given in Part I are, therefore, very similar to those previously found. The same erroneous notions of mass occur when it is certain that they were not deliberately taught. That the two methods of presenting the subject matter show no great difference between the groups, does not necessarily mean that one is as good as the other. For the express purpose of answering the questions used, differences are not great, but method Y, for example, may have advantages not brought out by these questions.

*Additional data obtained from observations and examination of individual cases.*

Thus far, the results of the test questions given to the experimental groups reveal little more than did those of Part I. Three facts were brought out, however, by the experimental teaching.

(1) When General Science students are given the same subjects matter as Physics students, differences between the groups are not nearly so great as the results of Part I show.

(2) Erroneous notions are formed even though they were not directly taught. In Part I there was no assurance of this.

(3) The concept Mass does not become scientific even when the essential subject matter is presented. In Part I there was no way of knowing just what subject matter had been studied in connection with the concept Mass.

In order to explain the formulation of certain erroneous notions or the inability to form a certain concept, we have to go beyond the mere responses to the test questions, observations in the class room during instruction and examination of individual cases may throw light on this matter.

*Observations.*

Although it is difficult to make observations and record them while at the same time conducting the class, certain phases of the teaching stand out clearly.

*Method X.*

The method of developing "Gravity" in a descriptive way by starting with the child's existing notions, appeared easy as well as interesting to the students. The fact that any two bodies attract each other, that the attraction is mutual, can be used to advantage to counteract the idea of Gravity as a "substance in the earth". It was at this point that old notions of Gravity appear to have been reconstructed. Once this notion of Gravity had been formed, it was relatively easy to develop the notion of weight. Those pupils who still thought of gravity in a vague way gave vague notions of weight.

Difficulties in these X groups started when the concept Mass was introduced. The method was to build up the notion of Inertia first and then to show that Inertia depended on the quantity of matter in a body or the Mass. It was at this point that every pupil associated Mass with either Weight, Size or Inertia itself. In the discussion on the difference between Weight and Mass, which followed, the confusion in the minds of the pupils seemed to increase. The following questions, asked in the 9X Groups during this discussion and recorded by the writer, will give an indication of the strength of preconveived notions:—

"If mass is not weight, why weigh a thing to find its mass?"

"Why is mass measured in pounds, if it is not weight?"

"Isn't it true that the bigger a thing is the more mass it has?"

"Why is there a difference between mass and weight if you find the weight of a thing to get its mass?"

Such confusion was not manifest at any time during the discussion of gravity and weight.

*Method Y.*

Regarding this method of presenting subject matter, the writer feels safe in saying that it is too involved for 9th Grade pupils. In such treatment, a knowledge of equations and their solution, concepts of equations and proportions are prerequisite and 9th Grade pupils are not so equipped. Further, this type of subject matter is not liked by 9th Graders.

Concerning Group IIY, the case was very similar to that of 9Y. Very little interest was shown and coercion had to be employed at times. These students had had the necessary mathematics required for this dynamic treatment of Mass but had little or no concept of an equation. $F = ma$ was not used as a more concise statement of Newton's 2nd Law of Motion but as a "formula". Further, their notions of proportions were vague.

On the test they did better than the corresponding 9th Grade group, but the achievement of the group as a whole, as far as Mass is concerned, is hardly sufficiently satisfactory in relation to other kinds of subject matter, especially since the writer feels that treatment of subject matter was more intense than is usually the case in actual school conditions where so much work has to be crowded into the school year.

*Study of Individual Cases.*

This method consisted of questioning pupils individually and of following up a response with another question, every question and response being recorded. The purpose of this type of examination was to attempt to find out not only what notion the pupil held, but also why he had the notion.

In this way, the writer examined six pupils of each of the IIth Grades, twelve of group 9X and ten of Group 9Y, after teaching and final testing had been completed.

*Case* 1. Girl (3). Age: 15—9. I.Q. 99. (Group Y).

**Q.** When you talk of the mass of a stone, just what do you mean?

**A.** The quantity of matter in it.

**Q.** What do you mean by "Quantity of Matter"?

**A.** The amount of substance in it.

**Q.** Well, supposing you had two stones how would you know which had the more substance in it?

**A.** The bigger one.

Q. Supposing there were two objects lying on this desk, and both were equally big, how would you know which had more substance in it?

A. They would have the same amount if they were the same size.

Q. Their masses then are equal?

A. Yes.

Q. If one were lead and the other iron would their masses be equal?

A. Yes, mass has nothing to do with their weights but with the amount of matter in them, and they both have the same amount of matter.

Q. Did you like this kind of work?

A. No.

Q. Why not?

A. Too much algebra. I don't like algebra.

---

*Case* 2. Girl (6). Age: 17—11. I.Q. 117. Grade 12. (Group IIY).

Q. When you talk of the mass of a body what do you mean?

A. The quantity of matter it contains.

Q. But what do you mean by "Quantity of Matter"?

A. (No answer.)

Q. Well, supposing you had two objects, how would you know which had the greater quantity of matter?

A. Weigh them—the one that weighs more has more inertia.

Q. So you mean "Quantity of Matter" is its weight?

A. No, but the one that has more weight will have more mass.

Q. How do you know this?

A. Because mass is proportional to weight.

Q. Why?

A. I can show it on paper but cannot explain it. (Paper and pencil were provided.)

$$W_1 = m_1 g \qquad W_2 = m_2 g$$

$$\text{Therefore} \quad \frac{W_1}{W_2} = \frac{M_1 g}{M_2 g} = \frac{M_1}{M_2}$$

Q. Why do you cancel "g"?

A. Because g equals 32 in both cases.

Q. But is g always 32?

A. Yes, at the same place on the earth.

Q. So, what now do you mean by "Quantity of Matter"?

A. I can't explain it....I know its not weight but you can find it by weighing.

Q. Did you like this kind of work?

A. No, I don't like the mathematics part of it.

---

*Case* 3. Girl (12). Age: 17—4. I.Q. 115. Grade 12.

(Group IIX).

Q. When you talk of the Mass of a body what do you mean?

A. The quantity of matter it contains.

Q. What do you mean by "Quantity of Matter"?

A. The amount of material in it.

Q. How would you know which of two objects contains more material in it?

A. The larger one would.

Q. So, amount of material or mass is the "volume" of the material?

A. No, mass is not volume.

Q. Well, you said the larger one?

A. I mean the heavier one.

Q. So, you mean mass is weight?

A. No, it is not weight.

G. Well, you said the heavier one?
A. The heavier one will have more mass, but mass is not weight—gravity has nothing to do with mass.
Q. Then what is Mass?
A. I never did understand what it was.
Q. Did you like to learn about Weight, Mass and Gravity?
A. Yes, but it was too difficult.
Q. But I think you understood everything, did you not?
A. No.
Q. But you know what Gravity is and what it does?
A. Yes.
Q. And what weight is?
A. Yes.
Q. And Mass?
A. No, I never did see that.

---

*Case* 4. Boy (16). Age: 14—9. I.Q. 115. Group 9X.

Q. What do you mean by the Mass of a thing?
A. The matter in it.
Q. How would you find out how much matter there is in an object?
A. By moving it.
Q. How would doing that tell you?
A. If it is hard to move, it has a lot of mass or matter.
Q. But supposing you were given a very small object like a dime. How would you find its Mass?
A. I would weigh it.
Q. So mass is the same as weight?
A. No, it is not the same as weight, but it is proportional to weight.
Q. What does that mean?
A. It means that the more mass a thing has, the greater will its weight be.
Q. Did you like the kind of work we had on Weight and Gravity, Mass and Inertia?
A. No.

Q. Why not?
A. Too difficult.
Q. Didn't you understand it?
A. Parts, yes.
Q. What did you not understand?
A. The Mass and Weight.

From the individual questioning of these pupils, it appears:—

(1) The "volume" or "size" notion of mass is due in those pupils mostly to the "quantity of matter" definition of mass. Quantity of matter is taken to mean size or weight or heaviness of the matter or vaguely, amount of matter. The "weight" notion of Mass is due partly to the erroneous notion of "quantity of matter" just referred to and partly to the fact that mass is measured by weighing. It is significant that in Part I of the study and also in the test results of these groups before instruction, when students are left to themselves with the definition "quantity of matter", it is most commonly construed to mean volume or weight.

(2) Pupils of the Y groups, although insistent that mass is not weight or volume, do not know exactly what it is. Pupils of the X groups are even more confused. The three pupils examined who were least confused were Nos. 11 and 13 (Table 57) and No. 13 (Table 59) who had associated mass with inertia.

(3) The majority of 11th and 12th Graders thought the subject matter too difficult and not interesting. Every 9th Grader thought it too difficult, or uninteresting.

The results of the whole experiment lead the writer to the following conclusions:—

(1) Scientific concepts of Gravity and Weight can be formed by both Physics and General Science students

when the subject matter is presented by either of the methods used.

(2) Scientific concepts of Mass cannot be formed by 9th Graders, irrespective of which method of the two is used. Wrong notions appear irrespective of method, although to a higher extent in Method X.

(3) The majority of Physics students instructed do not form a scientific notion of Mass. Method Y shows better results than Method X.

That the concept Mass is a very difficult one to form even in a college course, cannot be doubted. Ernst Mach in his "Science of Mechanics" discusses this concept as follows: "It should be observed that the notion of Mass as quantity of matter is psychologically a very natural conception for Newton, with his peculiar developments ......the concept developed quite instinctively......the formulation of Newton which describes Mass to be the quantity of matter of a body as measured by the product of its volume and density, is unfortunate. As we can define density as the mass per unit volume, the circle is manifest."

Mach seems to think that the notion quantity of matter is a very difficult one to grasp, and shows that it did not occur to great scientists like Galileo and Huygens that weight and mass were different things. Thus on page 216...."We find the expression 'quantity of matter' adapted to explain and elucidate the concept of Mass, since that expression itself is not possessed of the requisite clearness". And on Page 559 Mach declares that ordinarily the concept of mass cannot be built up on the notion of quantity of matter...."to accomplish anything dynamically with the concept of mass, the concept in question must be a dynamical one."

In the opinion of the writer, the place to introduce the concept Mass, if it must be introduced in the High School Physics coursė, is in that part of Mechanics known as Dynamics and not in Statics, and that the term should not be used until absolutely necessary.

# CHAPTER XI.

## ADDITIONAL DATA ON CONCEPTS OF HEAT AND LIGHT.

### CONCEPTS OF HEAT AND LIGHT.

In Part 1 of this study the results of essays written on Heat and Light were given. As the results of the General Science group were very different from those of the Physics groups, it may be necessary to offer an explanation.

In the first place, it may be argued that the General Science students cannot be expected to have scientific notions of Heat and Light compared to the Physics groups since the treatment of these subjects is very elementary in the General Science course. That this is true can readily be ascertained from a survey of General Science courses. Certain parts of the subjects of Heat which may be the means of reconstructing old concepts are not offered. For example, theories of Heat, Heat and Work, the Mechanical equivalent of heat, etc., are not generally taught to General Science pupils. In Light the case is similar with the exception that Physics students do not have so great an advantage. Most Physics texts introduce the subject with a mere statement of the nature of Light; but the subject matter which really concerns the very nature of light—diffraction, interference, polarization, etc., is not taught.

It may also be said that this subject matter and the various theories are too difficult for 9th Graders and foreign to the aims of General Science teaching. The writer was fully aware of conditions when the essays were given. The purpose of the essays, however, was to find out what children thought of Heat and Light and whether a General Science or Physics course changed their old notions and to what extent—all under existing conditions of school teaching.

We may or may not wish to teach 9th Graders theories and difficult subject-matter, but what shall we do to appease the curiosity of these pupils when they want to know what Heat or Light is? In the writer's own classes such questions were not so common at first, but after the writing of the first essays on Heat and Light, the curiosity of the pupils was awakened, and almost everybody wanted information. It was at this point that the writer decided to teach these 9th Graders some additional Physics and to discover whether it would have any affect on their old notions.

The experiment was conducted in the following manner: The two 9th Grade classes, of Table 58, were started off on the regular course in Heat according to the New York State's syllabus for General Science. Before starting, however, each student wrote an essay on "What I think Heat is and other thinks I know about Heat." The two classes were instructed in the same way for six periods per week of forty minutes each, one period being a supervised study period. At the end of the instruction period, each student again wrote an essay. Group 9Y was then given the additional instruction referred to in the syllabus below, while group 9X continued with the regular work, the topics to be taken up with them happened to be "Rusting of Iron," "Corrosion and how to prevent it" and "Water and its composition". Ten days after group 9Y had covered the additional work, all the students were asked to write essays again.

The same procedure was adopted in the teaching of Light, the only difference being that some students left school, while a few changed from one group to another, thus making the number and arrangement slightly different. The composition of the new groups is given in Table 59. The nature of the work done in both Heat and Light is given in detail below. The results of the experiment follow in Tables 64, 65, 66 and 67. Instead of giving the percentage of students making a particular response, the three responses of each student are given side by side. Thus by reading across the tables the change in response can be seen; by reading down the columns, the frequency of any response can be found.

*Syllabus followed in the teaching of HEAT to*

9th Grade pupils.

1. Sources of Heat—sun, friction, combustion, etc.
2. Transference of Heat—conduction, convection, radiation.
3. Applications of (2)—Fireless cooker, clothing, thermos bottle etc., etc.
4. Temperature and thermometers.
5. Effects of Heat—expansion, contraction, etc.
6. Evaporation, boiling, melting, freezing, humidity.
7. Condensation—rain, dew, snow, etc.
8. Quantity of Heat—calorie, specific heat and applications.
9. Heating of the home (project).

*Additional Instruction*:

1. Heat and Work—mechanical, equivalent of heat. Description of Joules experiment.
2. What scientists have thought of Heat. What made them think differently.
3. Molecular theory.

*Syllabus followed in the teaching of LIGHT to 9th* Grade pupils.

1. Sources of light.
2. Total eclipse of the sun (project). Shadows.
3. The velocity of Light.
4. Reflection of light, mirrors.
5. Refraction of light, lenses and illustrations in everyday life.
6. Optical instruments, camera, eye, telescope, etc., etc.
7. Dispersion—spectrum, rainbow.
8. Color.
9. Lighting of rooms (project).

*Additional instruction*:

1. What scientists first thought of light.
2. Why their ideas were discarded.
3. Wave theory—ether, sound waves, electromagnetic and light waves.

## Table 64.

### Notions of Heat before, immediately after, and 15 days after ordinary instruction (Group 9X).

* (The numerals have reference to the pupils in Table 58)

| | | |
|---|---|---|
| 1. Warm temperature | 1. ... ... ... ... ... ... | 1. ... ... ... ... ... ... |
| 2. Hot air from fire | 2. A vapor given off by burning substance | 2. A hot gas |
| 3. Sort of gas made by burning | 3. A gas that is warm | 3. Air that has been warmed |
| 4. Breaking up of substance such as coal, give heat. | 4. A result of combustion | 4. A result or oxidation or burning |
| 5. Result of a chemical change | 5. Number of calories in a thing | 5. Number of calories in a thing |
| 6. Opposite of cold | .6 A high temperature | 6. A temperature |
| 7. Combustion of chemicals | 7. Something given off when two things are rubbed | 7. Friction |
| 8. Air warmed by fire or sun | 8. The calories in a thing | 8. The warmth in calories or degrees |
| 9. ... ... ... ... ... ... | 9. ... ... ... ... ... ... | 9. Hot air |
| 10. Result of a chemical change. | 10. A substance given off by friction | 10. Result of friction, chemical change |
| 11. Warm substance from vapor and fumes of coal | 11. A certain temperature | 11. A rise in temperature |
| 12. A feeling, opposite of cold | 12. Air that has been heated | 12. ... ... ... ... ... ... |
| 13. Power from sun | 13. Difference in temperature | 13. ... ... ... ... ... ... |
| 14. Condition of the air | 14. An unknown force | 14. Something obtained by friction |
| 15. Heat is energy from the sun | 15. A form of energy | 15. One of the forms of energy |
| 16. A natural element | 16. One of the forces from the sun | 16. Warmth of the sun |
| 17. Hot air or steam | 17. A kind of energy or power | 17. Energy changed |
| 18. Hot air or vapor from fire | 18. The No. of calorier to heat a gram of subst. | 18. Specific Heat |
| 19. Warmth | 19. ... ... ... ... ... ... | 19. ... ... ... ... ... ... |
| 20. Form of energy | 20. A kind of energy e.g. friction | 20. Energy |
| 21. Hot air made by coal gas, etc. | 21. The result of friction | 21. What goes with friction |

## Table 65.

Notions of pupils before and after ordinary instruction and 10 days after additional instruction (Group 9Y.)

| | | |
|---|---|---|
| 1. ... ... ... ... ... ... | 1. The calories in a thing | 1. The energy like that stcred in coal |
| 2. Heat is heat | 2. An invisible substance | 2. A fluid that flows from a hot to a cold thing |
| 3. Opposite of cold | 3. A sort of energy from the sun | 3. A form of energy from sun which is changed to what we call heat |
| 4. Warmth of sun | 4. Radiation from a hot thing like the sun | 4. The vibration of molecules of a thing is heat |
| 5. A sort of gas made by burning | 5. A result of friction | 5. Heat is energy caused by friction electricity or oxidation |
| 6. Hot air, a sort of gas | 6. A kind of vapor | 6. Air that has been heated |
| 7. A warm temperature | 7. A high temperature | 7. A form of energy |
| 8. Hot air or steam | 8. ... ... ... ... ... ... | 8. Heat is the changing of energy into another kind, e.g. electricity or heat. |
| 9. ... ... ... ... ... ... | 9. Friction | 9. Molecules moving is heat |
| 10. Warmth given off by a hot thing | 10. Warmth of temperature | 10. Energy from the sun or other powers such as electricity |
| 11. Hot gas or vapor from fire | 11. A high temperature | 11. Molecules in the air that have become heated |
| 12. Something thrown from a fire or the sun | 12. Result of friction | 12. Heat is the moving of little molecules in a thing |
| 13. ... ... ... ... ... ... | 13. Oxidation | 13. A form of energy |
| 14. Warmth | 14. Energy from fire or sun | 14. The faster the molecules in a thing vibrate the hotter it becomes. The vibration of these molecules is heat |
| 15. Hot air or gas | 15. Hot air | 15. A temperature of molecules in the air |

(*Table* 65.—Continued).

| | | |
|---|---|---|
| 16. An invisible substance in the air | 16. A condition following friction | 16. Friction between the tiny molecules of a thing |
| 17. Invisible process made by the sun | 17. Rays from sun | 17. A kind of energy caused by little molecules in a thing moving very fast or something in the air |
| 18. That which keeps us warm | 18. ... ... ... ... ... ... | 18. ... ... ... ... ... ... |
| 19. A high temperature | 19. A difference in temperature between twe thing | 19. A kind of energy of molecules |
| 20. ... ... ... ... ... ... | 20. Warmth like steam or vapor | 20. Moving of molecules give heat |
| 21. Air that has been warmed | 21. Temperature of a thing | 21. Air or gas that has a temperature |

## Table 66.

Notions of Light, before instruction, after instruction, and 17 days after instruction (Group 9X, Table 59.)

| *Before instruction.* | *After instruction.* | 17 *Days aft. instr.* |
|---|---|---|
| 1. A burning mass of rare gases in the sun | 1. Reflection on an object | 1. Reflection of sunlight on an object |
| 2. Rays of the sun | 2. ... ... ... ... ... ... | 2. Rays of the sun |
| 3. Gases burning in the sun | 3. Lots of colors combined | 3. Substance of many colors in the air |
| 4. Reflection of sun's rays | 4. Reflection from an object to eye | 4. Rays traveling to the eye |
| 5. Something a thing can be seen by easily | 5. Reflected rays from the sun | 5. ... ... ... ... ... ... |
| 6. Atmosphere that can be seen thru better than in the dark | 6. Something that can be reflected | 6. Something that reflects to an object |
| 7. Condition when a substance is heated to a high temperature | 7. Rays coming from the sun | 7. Something that comes from an object of intense heat and reflects |
| 8. Reflection of the sun | 8. ... ... ... ... ... ... | 8. Rays from the sun that reflect to the eye |
| 9. Something that makes things bright | 9. Reflected sunlight | 9. Reflection of sun on earth |
| 10. What enables us to see | 10. Colors combined together | 10. ... ... ... ... ... ... |
| 11. Rays from the sun | 11. Brightness reflected from the sun | 11. Reflected rays striking eye |
| 12. Opposite of dark | 12. Rays of the sun | 12. Sunlight striking the earth |
| 13. Brightness of the sun | 13. Something that can be reflected and dispersed | 13. A substance given off by the sun or any burning thing |
| 14. A form of energy | 14. Energy from the sun. Power to see by reflection | 14. Certain rays that reflect to the eye and make things visible |
| 15. Opposite of dark | 15. Reflection of sun | 15. Sun's reflection |
| 16. ... ... ... ... ... ... | 16. Something made up of different colors | 16. A reflection of something bright like the sun |
| 17. The sun's rays | 17. A beam from a bright object | 17. Rays falling on something and reflecting |
| 18. What enables us to see in the dark | 18. Reflection of sun on earth. Something composed of many colors light. | 18. Reflection of sun- |
| 19. A condition of day and night | 19. A reflected ray | 19. Rays from sun reflected to the eye |
| 20. Brightness of the day | 20. Reflection or refraction | 20. (Same as No. 8) |

## Table 67.

**Notions of Light, before instruction, after instruction, and after additional instruction (Group 9Y, Table 59.)**

| *Before instruction.* | *After instruction.* | *After add. instr.* |
|---|---|---|
| 1. Rays from the sun | 1. ... ... ... ... ... ... | 1. Rays in the ether |
| 2. Shadow from the sun | 2. Something that can be broken into colors and refracted | 2. ... ... ... ... ... ... |
| 3. Sun shining on the earth | 3. Something reflected to the eyes | 3. Something from a burning body which is shot out thru the ether and strikes the eye |
| 4. ... ... ... ... ... ... | 4. ... ... ... ... ... ... | 4. Very small ether waves given by sun which travel to us thru air |
| 5. Something that can be reflected by planets and stars | 5. Sun's rays striking the earth | |
| 6. Thing given out by the burning of the sun | 6. Reflection of sun | 6. Small particles from sun to eye and from eye to object which is seen. |
| 7. Rays from the sun | 7. Sun's rays reflect from object to eyes | 7. A substance which travels thru ether in the air |
| 8. Sun's reflection | 8. A color made up of other colors | 8. A color made up of others and traveling in waves |
| 9. Reflected rays of the sun | 9. Reflection from the sun | 9. A substance given off by burning objects |
| 10. A sort of electricity in air which travels with speed of 186,000 miles sec. | 10. Something all around universe which makes you see | 10. Space is filled with ether, very short waves, thought to be electrical travel in this ether and affect our eyes |
| 11. Reflection of the sun | 11. Color composed of all colors of the rainbow | 11. Tiny waves like water waves travel thru the ether |
| 12. ... ... ... ... ... ... | 12. Reflection of sun's rays | 12. Vibrations in the air |
| 13. Reflection of the sun's rays on the earth | 13. Something reflecting from an object to the eye | 13. That which has to do with an invisible substance called ether |

(*Table* 67.—Continued).

| | | |
|---|---|---|
| 14. Reflection of gases burning in the sun | 14. Reflection of sun to eye | 14. Reflected rays from sun that travel thru ether to earth |
| 15. ... ... ... ... ... ... | 15. What enables us to see a reflection | 15. Little bodies shot out by the sun on to an object and then to the eye |
| 16. Light is light | 16. Light is light given off by the sun | 16. ................ |

## ANALYSIS OF RESULTS ON HEAT AND LIGHT.

The responses of both groups 9X and 9Y before instruction are of the same type and generally like those found in Part 1 of the study. Immediately after instruction the responses of both groups are different from what they were previously, with the exception of four students in Group 9X and two in Group 9Y who held on to their old notions among which were four "hot air" notions.

It will be noticed, however, that the majority of students of both groups who change their notions still have vague or erroneous notions. Certain elements of subject matter predominate and are involved in their new responses such as temperature, calories and friction. Only one pupil of the 9X and two of the 9Y group have discarded their old responses in favor of new ones involving some aspect of energy, two of group 9X originally thought of Heat as Energy and retained this notion. The three students who had changed their old notions to new ones involving energy were examined individually in the manner previously described. In two cases Heat was very strongly associated with friction. In response to the question "Why do you think Heat is Energy?" both said that it was produced by friction and that friction was energy. The third case gave as reason "because heat can expand and smash iron bridges."

Thus far, however, the notions of the two groups are very similar in form. After additional instruction to Group 9Y differences are found. Whereas the notions of Group 9X are practically the same as before, only three notions in Group 9Y remain the same, of which two are "hot air" notions. Of these changed notions seven involve "energy", eight some phase of "molecules", two both "energy" and "molecules." Although some of these notions are erroneous or extremely vague, there is no doubt in the mind of the writer that additional instruction of the kind given changes the vague notions of pupils to more complete, it not scientific, concepts.

In order to account for the common erroneous notion of Heat as "hot air" which was found existent in Part 1 of the study as well as in these groups, individual examination was resorted to. For this purpose, essays were written by two 9th Grade Biology classes (not connected with the teaching experiment) and thirteen of the pupils who had given the "hot air", "warm gas" response examined individually. Samples of these questions and responses are given in three cases:

*Case* 1. D.H. Boy. Age: 14-8. I.Q. 109. Grade 9.

Q. What do you think Heat is?
A. Hot air, warmed air.
Q. What makes you think that?
A. Why....that's the kind of heat we have.
Q. Where?
A. In our house.
Q. But isn't there Heat outside too?
A. Yes....air that has been warmed by the sun.
Q. But can't you have hot iron or hot water?
A. Yes.
Q. Well, what is heat in that case?
A. It must be something in the iron.

*Case* 2. F.S. Boy. Age: 14-5. I.Q. 110. Grade 9

Q. What do you think Heat is?
A. Hot air.
Q. Why do you think so?
A. You can see Heat over a radiator.
Q. Is that the *Heat* you see?
A. Yes, the hot air that rises from the radiator.
Q. When a thing is hot do you always see that hot air rising?
A. No, but it is hot.
Q. What is hot?
A. The air near it.
Q. Supposing it were a piece of iron, wouldn't the iron itself be hot?
A. Yes.

Q. Then why do you think heat is hot air?
A. It must be something in the iron.

*Case* 3. M.F. Girl. Age: 14-11. I.Q.87. Grade 9.
Q. What do you think Heat is?
A. Hot air.
Q. Why do you think so?
A. Because hot air is used to heat houses.
Q. But can't you heat houses with fires?
A. Yes, but the fire heats the air.
Q. But isn't the fire itself hot? Won't it burn you if you put your hand in it?
A. Yes.

---

Of the thirteen cases examined all but two associated Heat with either the heating of houses or the temperature outdoors. The two pupils who had thought of Heat as "hot gas or vapor" said that it was given off by fires or burning things. The cause of this erroneous notion, therefore, seems to be that the most common associations of Heat in the mind of the student are erroneously taken to be, in an unreflective way, equivalent to Heat itself.

In the case of Light, the responses differ from each other in practically the same way. Certain subject matter such as reflection, color, etc., is closely associated with Light and embodied in the responses. A rough examination of the responses of Group 9Y after the additional instruction shows that their responses have changed in kind, reference being now made to ether waves, etc. A closer analysis, however, will show that these new notions are extremely vague. Responses like the following show this vagueness: "Light is very small ether waves given off by the sun which travels to us through the air", "Small light waves in the air and reflected to the eye". "A substance which travels through ether in the air".

Three students readily gave the Corpuscular Theory, or something resembling it, given in the development during the additional instruction. Three stuck to their previous ideas although they were perhaps worded in a slightly different way.

From personal observations in the classes while teaching, the writer would say, firstly that extreme difficulty was encountered in the additional teaching of Light. The idea of a luminiferous ether, as a "universal jelly so thin as to pass readily through any known substance and to permit the densest substance to pass through it......a jelly so thin that it has no appreciable weight" to quote from Hoadley's Physics, seemed fairly ludicrous to the class. It was difficult to get them to appreciate why existence of ether had to be assumed or why the corpuscular and other theories were untenable or how we know that light travels in waves and why not in rays. Pains were taken to stress the term "theory", to explain what a theory means and also to mention the fact that until some other explanation same forth, we would believe the existing theory.

Secondly, in the additional instruction in Heat, the difficulties were not so unsurmountable. The experience of the pupils could be called in, such experiences as friction, compressing the air in a bicycle pump, and the connection between the energy expended or work done and the heat generated could be formed.

Romford's observations in the boring of cannon and Black's experiment in rubbing two pieces of ice together were really not so strange to these pupils. The discussion of the molecular theory was not quite as easy, but the difficulties encountered were small in comparison to those met with while discussing theories of light, for in the latter it was almost impossible to call in the aid of the child's experience.

From the results of the experimental teaching and the individual examinations, the writer makes the following conclusions:—

(1) The ordinary course in Heat as part of General Science did not appear to change the naïve concepts of the experimental groups to scientific ones. Additional instruction on the nature of Heat, however, causes the majority of pupils to form scientific notions. In other words, special instruction as to the nature of Heat has to be given in the ordinary General Science course, for scientific notions.

(2) The ordinary course in Light as a part of General Science did not appear to give children a scientific concept of Light. Unlike in the case of Heat, additional instruction in Light to one group failed generally to produce scientific notions. The old notions were changed but to extremely vague ones.

## CHAPTER XII.

## ADDITIONAL DATA ON DEW FORMATION.

The concepts of Dew given in Part 1 of the study (Table 8) were by no means generally scientific in the General Science and Physics grades. Only about a third of Physics and about 15 % of General Science students had scientific notions of Dew formation while erroneous and vague notions were very common.

Does this mean that the concept is too difficult to be formed by pupils of these grades? Another question is just why and how are wrong notions formed. For the pre-science child to think that dew falls from the clouds like rain is perhaps only natural and it may be said that the science student having this notion probably formed it in a similar way.

One would expect, however, that such wrong notions would be discarded after treatment of the subject matter in the classroom. But do such wrong notions automatically disapear or have we to exert special efforts to clear the minds of our pupils of their misconceptions?

In an effort to throw some light on these questions, methods of classroom teaching were controlled in the following manner: Group IIX was instructed in the usual way about Evaporation and Condensation and their application, the plan of presenting subject matter following that of most texts of Physics and given below. Dew formation was not taken up in greater detail than rain, or snow formation, for instance.

Group IIY followed with the same plan of subject matter presentation, but with the exception that special attention was given to the erroneous notions held in general and in particular by the group—these having been previously determined. The adequacy of these wrong notions were put to the test either by experiment or classroom discussion.

Before instruction began, the pupils were asked to answer, amongst others the question "Tell how Dew gets on the grass". The explanations given were then recorded. Three weeks after conclusions of instruction on this subject matter, the same question was again answered by the pupils.

The whole experiment was repeated with the 9th Grade groups, Group Y in this case again receiving remedial instruction but not Group X.

The plan of teaching was outlined as follows:

1. Evaporation and Condensation—discussion based on every day experience of pupils.
2. Laws of Evaporation and Condensation.
3. Air and saturation.
4. Explanation of common phenomena.
   a. Rain, Fog, Mist, Snow, Hail, Dew.
   b. Experiment to find Dew Point.
   c. Explanation of experiment.

The following erroneous notions were found in the groups before instruction, and especially emphasized in the teaching process:

1. Dew falls out of the clouds.
2. Dew comes out of the ground.
3. Dew comes out of the grass, given off by the grass.
4. Falls out of the air when it gets cold at night.
5. From fog, mist, etc.

In the tables that follow, the notions of every pupil before and after instruction are given, the numerals preceding the notions have reference to the pupils (Tables 57 and 58):

# Table 68.

Responses of pupils before and after instruction to the question: "Tell how *Dew* gets on the grass."

## GROUP IIX.

| *Before* IIX. | *After* IIX |
|---|---|
| 1. Falls from the clouds | 1. Vapor condenses on grass which is cooler than the air |
| 2. Grass or any cold object chills the air until it deposits moisture | 2. (Same as 1) |
| 3. By condensation | 3. Grass colder than air and vapor in air condenses on the grass |
| 4. Moisture falls on grass at night | 4. Condensation of water vapor on grass |
| 5. Moisture in air cooled falls on the grass | 5. Moisture in air cooled to dew point by cold grass and condenses on the grass |
| 6. Condensing of air | 6. Condensation of water vapor in air on cold grass when dew point is reached |
| 7. Heavy fog or mist leaves drops of water in grass | 7. Fog changes to drops of cold water |
| 8. By evaporation of water by night | 8. Condensation of water vapor on grass which is cooler than surrounding air |
| 9. Falls from the clouds | 9. (Same as No. 1) |
| 10. Low temperature at night condenses vapor in air | 10. (Same as No. 1) |
| 11. Vapor touching cold grass changes to moisture | 11. (Same as No. 1) |
| 12. Falls from clouds | 12. Falls out of the air at night |
| 13. Condensation of water vapor | 13. Condensation of water vapor |
| 14. Fog or clouds give up some of vapor in form of Dew | 14. Air becomes saturated with vapor and so gets on grass |

## Table 69.

Responses of pupils before and after instruction to the question: "Tell how *Dew* gets on the grass".

### GROUP IIY.

| *Before* IIY | *After* IIY |
|---|---|
| 1. By condensation | 1. Grass cools more rapidly than air at night and if air is almost saturated the cooling will condense some vapor on the grass |
| 2. Moisture condenses | 2. (Same as No. 1) |
| 3. Like rain from clouds or air at night | 3. By condensation |
| 4. Condensation of water vapor | 4. Condensation of water vapor |
| 5. Cold at night so dew forms on grass | 5. (Same as No. 1) |
| 6. Cooling at nigh draws water from the ground | 6. Condensation of vapor of air on grass which is colder than air |
| 7. Transpiration of grass at night | 7. Condensation of vapor from air on cool grass |
| 8. Fog or mist leaves drops on grass at night, from the clouds | 8. (Same as No. 1) |
| 9. Falls from damp air at night | 9. (Same as No. 1) |
| 10. Deposited by wind laden with moistore | 10. Condensation of vapor on cold grass |
| 11. Moisture falls and wets grass at night | 11. (Same as No. 1) |
| 12. From the clouds on a cold night | 12. (Same as No. 1) |
| 13. Water evaporates during and condenses at night | 13. When temperature reaches dew-point, dew is formed |
| 14. Low temperature condenses vapor in air at night | 14. Condensation of water which is in the air on grass which is colder than surrounding air |

## Table 70.

Responses of pupils before and after instruction to the question: "Tell how *Dew* gets on the grass".

| *Before* 9Y | *After* 9Y |
|---|---|
| 1. Out of the clouds | 1. Water in clouds condensed by the cold air of night |
| 2. From the clouds | 2. It is condensed |
| 3. The sun evaporates moisture in the early mornng | 3. The vapor in air changes back to water because grass cools the air |
| 4. Moisture from air gets on grass in the early morning | 4. Condensation of vapor in cold morning on grass which is cold enough |
| 5. Falls from clouds like kind of rain | 5. Condensation of vapor on grass cooled to the dew point |
| 6. Through the stomata leaves of the grass | 6. By condensating the moisture in the air |
| 7. Dampness from the ground | 7. Moisture in the air is condensed on cold grass |
| 8. Dew is nothing but fog or mist | 8. The condensation of a kind of fog, on the grass which is cold |
| 9. Moisture falls out of air in early morning | 9. Dew is moisture from the air forming on the grass which is colder than air |
| 10. Condensation of moisture on the grass | 10. (Same as No. 3) |
| 11. Fog wets the grass at night | 11. Vapor is condensed on the cold grass |
| 12. Out of the damp ground | 12. When Dew point is reached vapor in air forms drops of water on grass |
| 13. Grass gives off drops of water called Dew | 13. By evaporation and condensation |
| 14. Dew is moisture brought by chilly winds | 14. Vapor is condensed back to water |
| 15. Dampness in air changed to drops | 15. Condensation of moisture on grass which is older than air |
| 16. Air condenses when the night is cold | 16. By the condensation of evaporated water |
| 17. From moisture in the air | 17. (Same as No 3) |
| 18. From moisture in the air | 18. The vapor in the air which is saturated is cooled by the grass and falls on it |
| 19. Sun draws water into air and when sun sets water falls out again | 19. The cold of the night takes moisture from the air |
| 20. Out of the clouds | 20. Vapor condensed just like steam changed to water. The grass is cold enough to condense it |
| 21. Falls out of sky at night | 21. Grass cools the air so much that it loses its moisture |

## Table 71.

Responses of pupils before and after instruction to the question: "Tell how *Dew* gets on the grass."

| *Before* 9X | *After* 9X |
|---|---|
| 1. From clouds at night | 1. Falss out of the air when it gets cold |
| 2. Out of ground at night | 2. Out of the ground when it condenses |
| 3. Falls from clouds at night | 3. Condensation of water on grass which is colder than surrounding air |
| 4. Low clouds wetting the grass | 4. Mist condensing in early morning on the grass which is at a low enough temperature |
| 5. Dampness falling on grass at night | 5. When temperature falls vapor condenses |
| 6. Clouds in air lost some of their moisture during the night | 6. Falls from the sky when air cannot hold its moisture |
| 7. Caused by meeting of cold and warm air at night | 7. The air is too cold to hold the moisture so it falls on the grass |
| 8. Fog settling on grass in cold of night | 8. Grass is cold and condenses moisture in the air |
| 9. Dampness gets on the grass at night | 9. Water vapor is condensed on cold grass a night |
| 10. Leaves of grass sweat like all plants | 10. The grass cannot hold the moisture before sunrise |
| 11. Clouds decend on grass wetting it | 11. From the clouds when the Dew point is reached |
| 12. Moisture in air is condensed | 12. The cold grass is at the Dew oint and condenses the water vapor in the air |
| 13. Sun is not out to hold moisture in the air so it settles on the grass | 13. In daytime water is evaporated by sun and at night the grass condenses it |
| 14. From the clouds like rain. | 14. By evaporation and condensation, when clouds become saturated with moisture |
| 15. Evaporation of moisture at night | 15. The sweating of grass like a pitcher |
| 16. From the clouds | 16. Out of the clouds or a fog |
| 17. Dew is nothing but fog | 17. Condensation of fog or mist in early morning on grass which is colder |
| 18. By the heat of the air | 18. It falls when the moisture in the air gets too heavy |
| 19. When sun rises in the morning vapor in the air condenses | 19. Condensation of vapor on the cold grass |
| 20. Dampness in the air at night | 20. By both the evaporation and condensation of water |
| 21. Moisture falling on grass at night | 21. The air loses its moisture which is deposited on grass at night |

## ANALYSIS OF RESULTS ON DEW.

For convenience in comparing the groups as a whole, the notions have been classified as correct, vague and erroneous in accordance with the method adopted for Table 8, Part 1 of the study on Dew.

The percentage of responses then are:—

| | IIX | | *IIY | | 9X | | *9Y | |
|---|---|---|---|---|---|---|---|---|
| Correct | 14.3 | 64.3 | 0.0 | 80.0 | 0.0 | 33.3 | 0.0 | 61.9 |
| Vague | 35.7 | 21.4 | 46.7 | 20.0 | 9.5 | 28.6 | 23.8 | 28.6 |
| Incorrect | 50.0 | 14.3 | 53.3 | 0.0 | 90.5 | 38.2 | 76.2 | 9.5 |

In both the IIY and 9Y groups the percentage giving a correct response after instruction is higher than in the IIX and 9X groups, although two students in Group IIX had correct notions before instruction started.

In group IIX two students were left with incorrect notions after instruction, in group IIY none. In group 9X, however, 38.2 % still have erroneous notions, whereas in group 9Y only 9.95 %. In group IIX and IIY, the percent giving vague notions is decreased by instruction, in groups 9X and 9Y increased. This is caused as follows: Both methods of instruction have caused most of the 11th Grade pupils to change their previously vague and erroneous notions to correct ones, whereas in Grade 9X although 38% of pupils change their erroneous notions to vague ones, 38.2 % retain erroneous ones. For Grade 9Y the percents are 28.5% and 9.5%.

The significant factor about the two 9th Grades is that in 9X, 38.2 % retain wrong notions ,whereas in 9Y, only 9.5 % do this. This significant difference does not exist in the two 11th Grades.

This would mean that the special emphasis on erroneous notions did not appear to make as significant a difference in the 11th as in the 9th grades.

(* Groups with remedial instruction).

In the 9th Grades, the change from erroneous notions to correct is small compared to that from erroneous to vague notions.

The explanation involving "condensation" only, without any elaboration was classified as vague, and the majority of vague notions of Grades 9X and 9Y after instruction are of this nature. Had the student been forbidden to use the term condensation, the responses probably would have been more explicit. The writer feels, however, that even a change from an erroneous to this "condensation" notion, if not to a scientific notion, is significant in the teaching process.

The fact then that the percent of vague notions after both methods of instruction is large, does not mean that no change has been wrought in the pupil's notions, or that special emphasis on erroneous notions increases vagueness in pupils, for vagueness as used in connection with this particular concept may be, and is, in this case, where condensation is involved, preferable to misconception.

These results lead to the following conclusions:

(1) Special 'remedial' treatment of erroneous notions held before instruction was efficacious in that it not only left the 9Y group with a much greater percentage of scientific notions but also with a significantly smaller percent of wrong notions. Although these differences are also found between the IIX and IIY groups, they are not as significant.

(2) Although methods of instruction were similar to corresponding 11th and 9th graders, a larger percent of the former than of the latter are left with scientific notions, the difference being greater between the groups that had no 'remedial' instruction.

(3) Almost the same percent of 9th Grade students who had had remedial instruction had scientific notions of Dew as of 11th Graders who had had no such instruction, (61.9%—64.3%.)

(4) Scientific notions of Dew are not too difficult to be formed by both General Science and Physics students.

(5) It seems to the writer that it is desirable to combat erroneous notions directly and not indirectly, that is, not to trust only to the efficacy of new subject matter, as such, to rid a pupil of his old notions. If new subject matter is a direct challenge to his old beliefs, it may lead him to reconstruct them, but the mere presentation of new subject matter may or may not affect his preconceived notions of long standing.

## CHAPTER XIII.

## ADDITIONAL DATA ON EBULLITION.

In Part I of this study the results of test questions on Boiling were given with certain conclusions. Two wrong notions that were found to a significant extent were (1), that tepid water can be boiled without heating by pouring cold water over the container. (2), that the bubbles in boiling water contained air. Further, it was found that the number of General Science students and, for that matter, Physics students, who understood the relation between Boiling Point and air pressure, was relatively small.

To account for the erroneous notions by examination of results of Part 1 is a matter of conjecture. Notion No. 1 above is probably the result of an experimental demonstration that was referred to before. It is not likely that the notion of "air bubbles" in boiling water is formed during the study of Physics or General Science for the notion is almost as common among pre-science students. The fact remains that the study of Boiling in a Physics course does not dispel this notion. The notion may be formed, in the opinion of the writer: (1) by drawing attention to the fact that early in the boiling process bubbles of dissolved air are forced out of the water. (2) by not understanding thoroughly the boiling process itself. (3) by other factors.

It is hardly likely that (1) above would cause this in view of the fact that pre-science students also hold this notion. The second reason seems more plausible, for, after all, children's notions of boiling are very vague. Moreover, it is very likely that science teachers would not take the time to describe in detail a phenomenon with which they think every child is familiar.

It was to try to explain notions like these that the writer decided to resort to actual teaching of groups under controlled conditions of method.

*Procedure*: Groups IIX and IIY, 9X and 9Y were given the test questions on boiling of Part 1 before instruction. The groups were taught the ordinary subject-matter relating to change of state (Melting, Freezing, Evaporation, Condensation, Ebullition) as part of the course on Heat, with the following exceptions:

(1) Groups IIX and 9X were given a different experiment (to be described) to demonstrate the effect of pressure on the boiling point from that given to Groups IIY and 9Y.

(2) In the case of Groups IIY and 9Y water was actually boiled and the phenomenon described in detail. In the case of the X groups this was not done. Otherwise instruction was as nearly the same for both as conditions would permit. Two weeks after instruction had ended, the groups were again given the test questions on boiling and also a set of additional questions to be described later.

The fact that water will boil at a lower temperature when the air pressure is decreased is demonstrated by one of two, or by both, methods in most Physics classes. This too, happens to be about the only laboratory demonstration that is given in connection with the study of Ebullition. They may be described as follows:

*Demonstration* X (given to X groups). A flask half full of water boils, a thermometer showing the Boiling Point to be 100°C. While boiling, a one-holed stopper with a thermometer is inserted into the neck of the flask and flame removed. Boiling stops. Cold water is now squeezed over the flask by means of a sponge and water again boils—the thermometer showing a temperature below 100°C.

*Demonstration Y* (given to Y groups). Water is boiled in a flask and a thermometer shows temperature to be 100°C. Water is allowed to cool until temperature is (say) 85°C. Flask and water then put under receiver of air pump. Receiver is partly exhausted of air. Water again starts to boil, temperature being below 100°C.

In addition to the ordinary set of test questions, given after instruction, the groups answered the following special questions:

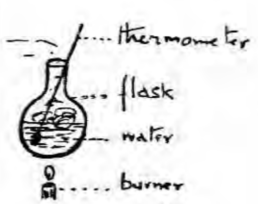
(*Part* 1.)

1) Under what conditions will water boil at a lower temperature than usual? Describe an experiment that would demonstrate this.

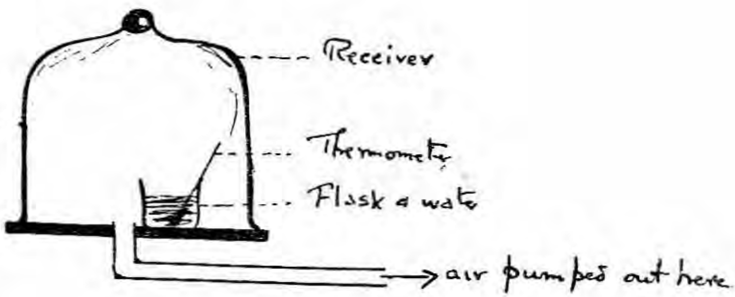
(Hand in when finished for Part 2.)

(*Part* 2.)

1) Water is boiled in a flask, a thermometer in flask shows the temperature to be 100°C. After the water has been boiling for a while the thermometer is removed, put through a rubber stopper and the stopper and thermometer inserted into the neck of the flask. The flame is removed at the same time. The water stops boiling. After a few minutes, cold water from a sponge is squeezed over the flask and the water starts boiling again although the thermometer shows a temperature of about 85°C. Explain in detail why the water started to boil again.




2) A flask of water having a temperature of 85°C is placed under the receiver of an air pump. The air is gradually pumped out of the receiver and the water starts boiling although the temperature is only 85°C. Explain why?




The object of giving these additional questions was to find out:—

1) How well each demonstration was remembered and understood.

2) Whether pupils could explain the demonstration they had *not* seen.

The responses to the two tests and to the one just described appear in the following pages. "Scoring" was carried out as in Part 1. For each group there are two columns of percents, the first being the results of the test before instruction.

# Table 72.

Percentage frequency of responses to questions.
"What is meant by the Boiling Point of a Liquid?"

| GROUPS | IIX | | IIY | | 9X | | 9Y | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Temp. at which vapor pressure equals or exceeds pressure of air above it .. | 0.0 | 21.4 | 0.0 | 13.3 | 0.0 | 9.5 | 0.0 | 4.0 |
| Temp. when liquid has greater pressure than the air | 0.0 | 14.3 | 0.0 | 13.3 | 0.0 | 4.8 | 0.0 | 9.5 |
| When liquid changes to steam or vapor .. .. .. .. | 14.3 | 14.3 | 13.3 | 20.0 | 9.5 | 23.8 | 9.5 | 19.5 |
| When its temperature is 100°C or 212°F .. .. .. | 0.0 | 21.4 | 6.7 | 26.7 | 0.0 | 28.6 | 0.0 | 33.3 |
| The hottest it can become | 14.3 | 0.0 | 20.0 | 0.0 | 19.0 | 4.8 | 14.3 | 4.8 |
| When bubbles rise to the top .. .. .. .. .. .. .. .. | 28.6 | 0.0 | 33.3 | 0.0 | 23.8 | 4.8 | 33.3 | 9.5 |
| When air in liquid is expelled (or) when it gives off oxy. hyd. etc. .. .. .. | 7.1 | 7.1 | 0.0 | 0.0 | 0.0 | 4.8 | 0.0 | 0.0 |
| When it boils .. .. .. .. .. | 7.1 | 0.0 | 0.0 | 0.0 | 9.5 | 0.0 | 9.5 | 0.0 |
| Miscellaneous .. .. .. .. .. | 0.0 | 14.3 | 0.0 | 20.0 | 4.8 | 9.5 | 9.5 | 14.3 |
| No answer .. .. .. .. .. .. | 14.3 | 0.0 | 6.7 | 6.7 | 9.5 | 4.8 | 4.8 | 0.0 |

## Table 73.

Percentage frequency of responses to other questions** in test before and after instruction.

| | IIX | | IIY | | 9X | | 9Y | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| *Question:* | | | | | | | | |
| 2) Bubbles in boiling water contain: air, CO-2 oxygen, etc. | 64.3 | 50.0 | 73.3 | 26.7 | 57.1 | 47.6 | 66.7 | 33.3 |
| Steam, vapor | 14.3 | 28.6 | 20.0 | 66.7 | 14.3 | 23.8 | 9.5 | 59.4 |
| 3) Bubbles in boiling alcohol contain air, CO-2, oxygen, etc. | 42.9 | 35.7 | 40.0 | 13.3 | 38.0 | 33.3 | 42.9 | 19.0 |
| Alcohol vapor, steam from alcohol, etc. | 14.3 | 21.4 | 13.3 | 53.3 | 9.5 | 19.0 | 9.4 | 52.4 |
| 4) Boiling Point of water is 100°C | 35.7 | 100. | 40.0 | 93.3 | 28.6 | 95.2 | 19.0 | 100. |
| 5) Boiling Point of water is 212°F | 14.3 | 85.7 | 20.0 | 80.0 | 4.8 | 66.7 | 9.5 | 71.4 |
| 6) All liquids boil at same temp. False | 71.4 | 92.9 | 46.7 | 93.3 | 61.9 | 81.0 | 52.4 | 85.7 |
| 7) 1 lb. of water boils at a lower temp. than 2 lbs. of water. False | 50.0 | 100. | 46.7 | 93.3 | 42.9 | 90.5 | 52.4 | 85.7 |
| True | 42.9 | 0.0 | 53.3 | 0.0 | 23.0 | 9.5 | 33.3 | 14.3 |
| 8) Boiling Point of water constant. More heat only changes it to steam but does not raise its temperature | 35.7 | 92.9 | 40.0 | 100. | 42.9 | 90.5 | 38.0 | 95.2 |
| 9) There is no difference between boiling and evap. False | 35.7 | 100. | 40.0 | 93.3 | 33.3 | 81.0 | 23.8 | 76.2 |
| True | 57.2 | 0.0 | 46.7 | 0.0 | 47.6 | 19.0 | 38.0 | 23.8 |
| 11) Water boils below 100° in an airship. Because air pressure is less | 0.0 | 92.9 | 0.0 | 86.7 | 0.0 | 66.7 | 0.0 | 71.4 |
| *Quest.* 1, *Part* 2. To boil water below 100°C. | | | | | | | | |
| 1) Reduce pressure above it | 0.0 | 28.6 | 0.0 | 40.0 | 0.0 | 14.3 | 0.0 | 28.6 |

*TABLE* 73.—*Continued.*

| | IIX | | IIY | | 9X | | 9Y | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 2) Put in air pump. .. | 0.0 | 0.0 | 0.0 | 46.7 | 0.0 | 0.0 | 0.0 | 57.1 |
| 3) Flask experiment .. .. | 0.0 | 64.3 | 0.0 | 0.0 | 0.0 | 76.0 | 0.0 | 0.0 |
| *Quest. 2, Part 2.* To boil water above 100°C | | | | | | | | |
| 1) Increase press. .. .. | 0.0 | 85.7 | 0.0 | 80.0 | 0.0 | 47.6 | 0.0 | 61.9 |
| 2) Erroneous .. .. .. | 57.2 | 14.3 | 46.7 | 13.3 | 38.0 | 38.0 | 28.6 | 14.3 |

**For test questions see Chapter VIII.

## Table 74.

Percentage frequency of responses to question: "Tepid water can be made to boil without heating it." Is this true? Why?

| RESPONSES. | IIX | | IIY | | 9X | | 9Y | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| True .. .. .. .. .. .. | 28.6 | 100. | 33.3 | 100. | 19.0 | 95.2 | 23.8 | 100. |
| False .. .. .. .. .. .. | 64.3 | 0.0 | 53.3 | 0.0 | 66.7 | 4.8 | 61.9 | 0.0 |
| No choice .. .. .. .. .. | 7.1 | 0.0 | 13.3 | 0.0 | 14.3 | 0.0 | 14.3 | 0.0 |
| *Reasons.* (True) | | | | | | | | |
| 1) If pressure of air is decreased .. .. .. .. .. .. | 0.0 | 35.7 | 0.0 | 46.7 | 0.0 | 14.3 | 0.0 | 23.8 |
| 2) By putting it in air pump etc. .. .. .. .. | 0.0 | 0.0 | 0.0 | 53.3 | 0.0 | 0.0 | 0.0 | 66.9 |
| 3) Putting it in flask, put stopper on and pour cold water over flask .. .. .. | 0.0 | 28.6 | 0.0 | 0.0 | 0.0 | 38.0 | 0.0 | 0.0 |
| 4) Put in flask, boil water, etc. .. .. .. .. .. .. .. | 0.0 | 21.4 | 0.0 | 0.0 | 0.0 | 33.3 | 0.0 | 0.0 |
| 5) Add chemicals .. .. .. | 14.3 | 0.0 | 6.7 | 0.0 | 9.5 | 0.0 | 9.5 | 4.8 |
| 6) Miscellaneous .. .. .. | 0.0 | 0.0 | 6.7 | 0.0 | 9.5 | 0.0 | 4.8 | 0.0 |
| *Reasons* (False) .... .. | | | | | | | | |
| Heat is necessary for boiling .. .. .. .. .. .. | 42.9 | 0.0 | 40.0 | 0.0 | 52.4 | 0.0 | 42.9 | 0.0 |
| It must be heated to its B.P. (which is 100°C etc.) | 7.1 | 0.0 | 0.0 | 0.0 | 0.0 | 4.8 | 0.0 | 0.0 |
| No reason .. .. .. .. | 35.7 | 14.3 | 46.7 | 0.0 | 28.6 | 9.5 | 42.9 | 4.8 |

## Table 75.

Percentage frequency of explanations to:—
"Tell why a change in air pressure causes a change in the Boiling Point of water."

| | IIX | | IIY | | 9X | | 9Y | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 1) Pressure above not so great therefore pressure of vapor won't have to be so great to overcome it. It will overcome it at a lower temp. | 0.0 | 21.4 | 0.0 | 26.7 | 0.0 | 4.8 | 0.0 | 4.8 |
| 2) The less the pressure the easier it is for steam to escape, or for the bubbles to rise .. .. .. .. .. .. .. .. .. | 0.0 | 35.7 | 0.0 | 26.7 | 9.5 | 14.3 | 0.0 | 19.0 |
| 3) Molecules can escape more easily if pressure is greater .. .. .. .. .. .. .. | 0.0 | 7.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4) Because the lower the presure the lower the B.P. | 14.3 | 14.3 | 6.7 | 13.3 | 9.5 | 23.8 | 0.0 | 33.3 |
| 5) Because it does not take so long to boil .. .. .. .. .. | 14.3 | 7.1 | 26.7 | 0.0 | 14.3 | 42.9 | 19.0 | 23.8 |
| 6) Same as No. 1 in form but incorrect .. .. .. .. .. | 0.0 | 14.3 | 0.0 | 20.0 | 0.0 | 4.8 | 0.0 | 9.5 |
| 7) No response .. .. .. .. .. | 71.4 | 0.0 | 66.7 | 13.3 | 66.7 | 9.5 | 71.4 | 9.5 |

## Table 76.

Results of special question showing percent of X—Y groups doing correctly questions relating to the experiment they had and had not seen.

| *Demonstration X. Groups* | IIX | 9X | IIY | 9X |
|---|---|---|---|---|
| Correct explanation .. | 42.9 | 28.6 | 14.2 | 4.8 |
| Incorrect explanation | 57.1 | 61.9 | 42.9 | 47.6 |
| No explanation .. .. .. | 0.0 | 9.5 | 42.9 | 47.6 |
| *Demonstration Y. Groups* | IIX | 9X | IIY | 9X |
| Correct explanation .. | 92.9 | 85.7 | 93.3 | 90.5 |
| Incorrect explanation .. | 0.0 | 4.8 | 6.7 | 4.8 |
| No explanation .. .. .. | 7.1 | 9.5 | 0.0 | 4.8 |

## SURVEY OF RESULTS.

It must be borne in mind that whereas the teaching of the senior grades resembled that usually given to Physics classes, the General Science students received more detailed instruction than they would in an ordinary General Science course. As far as was possible, however, the subject matter given and the methods of instruction were similar for both types of students.

In accumulation of facts such as the Boiling Point of water—Centigrade and Fahrenheit, the constancy of the Boiling Point, the varying of the Boiling Point with pressure, the 9th Graders do as well as the senior pupils. In defining Boiling Point a larger percentage of IIX and IIY students change their old notions to those involving relationship between pressure of the air and of the vapor of the liquid than do the General Science students. The latter prefer to use the "changing to steam" or "100°C Boiling Point" in their definition.

The majority of General Science students know that the pressure of the air affects the Boiling Point but only two students know why, in spite of the fact that this was explained in the classroom discussion. Response No. 2 in Table 75 may be taken as partly correct, as was done in Part 1 of the study, although it would hardly explain the lower *temperature* of boiling

The results, irrespective of methods of teaching, seem to show that the differences in achievement between the Senior and 9th Grade pupils are not great, with these exceptions:- (a) In defining Boiling Point more Seniors show a scientific notion than do General Science pupils. (b) The seniors do better than the 9th Graders in understanding the relation between pressure and boiling point although the extent to which they show understanding is not so encouraging.

In general, the results of the test questions are very similar to those in Part 1. As in Part 1, however, they do not throw light on certain findings. In order to interpret the results of this teaching experiment, it will be necessary to examine the results where instruction differed.

*How did the two demonstrations affect the pupils?*

(1) 28.6 % of IIX and 35% of 9X students would make tepid water boil without heating by applying cold water. No IIY or 9Y students suggest this. These results confirm the suspicion advanced in Part 1 of the study, viz:— that the particular demonstration is responsible for this. The demonstration evidently gives the student a mental set, for 21.4 % and 33.3 % of these respective grades describe or mention the "flask experiment" in which they first heat the water, although the question asks "How boil water *without* heating it?"

In other questions in which an answer of "reduce or increase the air pressure" would suffice, more pupils of Groups IIY and 9Y give it than of the corresponding IIX and 9X Groups.

(2) After instruction and testing were concluded the pupils were asked to describe an experiment to show that water may be made to boil at a lower temperature than usual. Then each pupil was asked to explain both demonstrations, one of which he had not seen.

Every pupil described the experiment that was demonstrated to him. This is to be expected, as no student of one group had seen the experiment of the other group or had had an opportunity to read of it in a textbook. Table 76 shows the results of an attempt to explain both the experiments.

In explaining *Demonstration Y* (air pump) the X groups do not do as well as the Y groups although they had not seen it demonstrated. In explaining *Demonstration X,* however, the case was very different. Only 42.9 % and 28.6 % of group IIX and 9X could give a correct explanation of the experiment they had seen demonstrated. Only 14.3 % and 4.8 % of Groups IIY and 9Y respectively could give reasonably correct explanations.

This means that when two different experiments were performed to demonstrate the same phenomen the results were not the same. The air pump experiment is a plain demonstration in which the two elements in the situation that have to be borne in mind are obvious. The operation involved in decreasing the air pressure is a simple and obvious one. In the "flask" experiment the situation is very different and complex. Perception of the water boiling while tepid or below 100°C is easy, but the "reduced air pressure" element is not obvious in the situation. This operation of getting the pressure of the air reduced is complex. The fact of the matter is that this experiment is really a difficult application of "Boiling", as very few pupils who had not seen the experiment were able to explain it.

This happens to be one of the hundreds of experiments in Physics and is probably not so important and fundamental as most others. It illustrates well, however, that in a demonstration the important elements of the situation should be fairly obvious and not inbedded in a complex manner.

It is not always possible, however, to do this. Thus we employ the pendulum or inclined plane to demonstrate that the gravity acceleration at one place on the earth is constant. The writer has often noticed in his classes that students fail to understand how the "Pendulum experiment" proves this and special efforts must be made to show just why and how it does.

*Erroneous notions of air bubbles in boiling water:—*

During the instruction period the boiling process was described in detail to the Y groups but not to the X groups, that is, it was assumed that the pupils of the latter groups were familiar with what was taking place in a flask of water being boiled.

The results of the two questions relating to the bubbles in boiling water and boiling alcohol given in Table 73 show that in the groups that had the remedial instruction there is a marked decrease in the frequency of the notion that the bubbles contain air, oxygen, etc., whereas in the other groups the decrease is slight.

Even with this special instruction, however, there are still about a third of the students who hold on to this erroneous notion. The writer, therefore, decided to question individually and orally those pupils of Grade 9X who finally held this erroneous notion, with a view to tracing this notion to its genesis.

A few samples of the type of questioning and responses follow:

*Case* 1. Boy. Age: 15—8. I.Q. 95. Grade 9X.

Q. When water is boiling large bubbles rise to the surface. What is in these bubbles?
A. A gas.
Q. What kind of a gas?
A. Oxygen or hydrogen.
Q. Why do you think so?
A. Water contains hydrogen or oxygen, it is $H_2O$
Q. But supposing the boiling liquid is not water?
A. You would have to know what it contained.
Q. Where do you think the steam from boiling water comes?
A. It evaporates from the water.
Q. And the bubbles contain air?
A. Yes.

---

*Case* 2. Girl. Age: 15—0. I.Q. 94. Grade 9Y.

Q. When water is boiling large bubbles rise to the surface. What is in these bubbles?
A. Air.
Q. Why do you think so?
A. Why you can see the air bubbles.
Q. But how do you know they are air bubbles and not bubbles of something else?
A. Aren't the bubbles in water always full of air?
Q. Where does the steam come from when water boils?
A. The heat changes the water to steam.

*Case* 3. Girl. Age: 14—11. I.Q. 95. Grade 9X.

Q. When water boils bubbles rise to the surface. What is in these bubbles?

A. Air.

Q. How do you know?

A. I just know it. What else could there be?

Q. Where does the steam come from when the water is boiling?

A. From the water, the water is changed to steam.

Q. And where does the air in the bubbles come from?

A. Out of the water.

---

*Case* 4. Girl. Age: 14—11. I.Q. 95 Grade 9X.

Q. When water boils bubbles rise to the surface. What is in these bubbles?

A. Air.

Q. How do you know it?

A. ————

Q. Where does the steam come from while the water is boiling?

A. Out of the bubbles, I suppose.

Q. Well, what made you think there was air in the bubbles?

A. I don't know.

Q. Where did you think the steam came from?

A. From the bubbles?

---

What then did the teaching of subject matter of Boiling reveal in addition to the results of Part 1 of the study?

*Firstly*: The experiment (Demonstration X) in Physics classes to demonstrate that the boiling point is decreased under reduced pressure is not readily understood by pupils. The less common demonstration, (Demonstration Y) in which the pressure of the air is directly reduced, is readily understood. Furthermore, that the former demonstration seems to be the direct cause of the peculiar response to Question 10 of the set of questions on Boiling in Part 1, namely that tepid water can be boiled without further heating by the application of cold water.

*Secondly*: The prevalent notion of bubbles in boiling water containing air is not ordinarily discarded after formal study of Boiling unless teaching is consciously directed to destroy the notion. One method of remedying this condition would be to describe in greater detail, the actual phenomenon of Ebullition. There are other causes of this misconception, however, one of which appears to be a strong association between "bubbles" and "air".

*Thirdly*: When General Science and Physics students are instructed in similar ways, differences in extent to which concepts of Boiling become scientific are not so great as those found to exist in Part 1 of the study.

## CHAPTER XIV.

## GENERAL CONCLUSIONS.

Detailed interpretation of results was given in both Part 1 and Part 2 of this study, hence it will not be necessary to restate them. Certain general impressions, however, seem appropriate at this stage.

There is little doubt in the mind of the writer about the efficacy of High School Physics in developing certain concepts from the vague to the scientific stage, although the extent to which this takes place is not so encouraging, especially in the case of the concept Mass. That all concepts do not become scientfic to the same extent raises the question as to just what per cent of a group should justify the conclusion that the concept has generally become scientific in that group. The writer has taken 50 % as a standard; this, however, is arbitrary and a 60 % standard may just as well have been set, for we are hardly likely to be satisfied with a mere majority of a class holding scientific concepts after formal instruction.

Taking this arbitrary standard, however, it is found that concepts of Acceleration, Specific Heat, Dew and Rainbow formation, Light and Mass do not generally become scientific through the study of Physics.

The effect of the General Science course in developing certan concepts cannot be questioned, but the extent to which notions have become scientific is small.

In no case did the majority of these students hold scientific concepts. We may not feel discouraged that notions of Acceleration and Mass are mostly vague and erroneous as there is really little effort or desire in a General Science course to build up scientific concepts of this type. But it was found that notions of Dew and Rainbow formation were also vague and erroneous. Irrespective of whether General Science students should be expected to form certain concepts or whether subject matter is not presented to these students as it is to Physics students, one is forced to conclude that the majority of General Science students do not form scientific concepts, as far as the subject-matter of this study is concerned.

The majority of pupils who have not studied General Science or Physics were found to have vague and erroneous notions. Even common concepts like Weight, Evaporation and Boiling were found to be extremely vague or erroneous. One could hardly expect students who had never studied these sciences to have built up scientific concepts. As far as these pre-science students are concerned, however, the important outcome of this study is not the fact that these students do not generally have scientific concepts, but the knowledge of just what types of notions exist, for it is on these vague and naive notions that more complete and ultimate scientific concepts will have to be built.

The fact that a concept has not become scientific through the study of science does not necessarily mean that no conceptual development has occured. In some cases it is possible to trace development in significance from "absolute absence of content," as Chambers would describe it, through various stages of vague notions up to perfectly scientific concepts. For example, in the case of Rainbow formation, the following stages in the development of notions could be traced:—

a. No idea of how it is formed.

b. The phenomenon is merely described, e.g. a coloring in the sky or a colored ribbon.

c. Totally erroneous notions, e.g. "reflection of lightning from raindrops".

d. Vague or naive notions e.g. "sun shines on the rain giving the colours" or "interaction of sun and rain".

e. Scientific (incomplete) e.g. "refraction of sunlight in raindrops".

f. Scientific (complete) e.g. "solar spectrum caused by refraction of sunlight in raindrops" or "dispersion and total internal reflection in raindrops".

It is obvious from the above illustration that there may be a gradual development in the significance of concepts in the case of many pupils. Even if the General Science course is not instrumental in changing a notion from the naive to the completely scientific stage, it may still be valuable in the process of reconstruction of old notions. In such cases it must be assumed that development in significance of concepts has taken place in spite of the fact that scientific concepts have not been formed.

In Part 2 of this study the writer tried to indicate how practical use could be made in the class-room of the results of an analysis of subject matter along the lines presented in Part 1 of the study. Certain common, vague or erroneous notions of science students were found to have been held before the period of formal science instruction, that is, the presentation of the appropriate subject matter appeared to have had no effect on original notions. Instruction specially directed at these erroneous notions seems to be necessary in addition to the ordinary presentation of subject matter. The mere statement of a fact or hypothesis or the routine laboratory demonstration may not necessarily induce the pupil to reconstruct his preconceived notions of long standing, in fact, it may even confuse him still more. Thus it was shown why almost one-fourth of the Physics students would proceed to boil tepid water by pouring cold water over the container when not a single pre-science student would attempt to do such a foolish thing; or that the usual text-book definition of Mass causes misunderstanding and confusion in spite of the warning not to regard mass as weight or volume.

In the opinion of the writer two things that are not only desirable but absolutely necessary in the interests of General Science and High School Physics are, firstly, an analysis and classification of existing notions of pre-science pupils on the lines indicated in this study and embracing the entire fields of study, and secondly, examination of pupils' concepts after the necessary subject matter has been treated and immediate application of remedial teaching, if necessary.

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