One Hundred Experiments

in

Elementary Agriculture *for* California Schools

By RILEY O. JOHNSON, M.S. (Cal.)
Head of Department of Biology and Nature-Study
State Normal School Chico, California
Sometime Lecturer on Agriculture in the University of California

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(*Revised September 1, 1909.*)

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PREFACE

In this bulletin the writer has attempted to give to teachers in connected form a full and suggestive series of experiments in elementary agriculture, dealing as fully as possible with the physics, chemistry, and biology of the subject. While the work outlined is well suited to the seventh and eighth grades of the elementary school and to the first year of the high school, it will be found that many of the experiments are intelligible to pupils of lower grades, and may profitably be performed by them. If given in the high school the writer would recommend that the entire course be covered in one year; if given in the grades, that Part I be given to the seventh grade and Part II to the eighth grade. In ungraded schools it might be well, especially if crowded for time, to give the work on Friday afternoons (allowing the pupils of the first two or three grades to withdraw), taking two years to complete the course. With pupils who have already done some work in the subject a number of the easier experiments may well be omitted, though repetition is better than lack of clearness in understanding.

In some instances it may seem that exactly the same principle is illustrated by a number of experiments in this course, but on a closer examination it will be seen that each presents the same truth from a little different viewpoint, thus giving the pupil a breadth of understanding not otherwise attained. The materials necessary for the entire series of experiments may be purchased for a small outlay at the local drug store, or ordered through the local druggist. (See list of materials on last page.)

While the writer would lay no claim to originality as to most of the experiments in this bulletin, he believes that the arrangement of material found herein is unique in the literature of the subject. Many books and pamphlets on elementary agriculture are lacking in suggestion on the experimental side, while others which contain much that is suggestive lack in continuity of subject matter. It will be found that the course here outlined remedies both these defects. Correspondence is invited in regard to difficulties to be met in presenting the work.

RILEY O. JOHNSON.

Chico, Cal., Sept. 15, 1908.

INTRODUCTION

The work of the farmer, gardener, and orchardist is concerned mainly with plants. Even though much of the farmer's attention is given to the raising of live stock, he still has much to do with plants, for live stock must be fed and their food consists wholly of plants and plant products. The follower of either of these three vocations, therefore, who would do his work intelligently and thereby achieve the highest success must know something about plants, and other things being equal, the more he knows concerning plants the more profitable will be the results obtained from the raising of them and from their utilization for food and for feeding purposes.

The cultivation of plants to which the three above named classes of people devote so much of their time is in large part only the **supplying of the wants** of the plants. In order intelligently to do this one should know what these wants are and of all the various ways in which they may be supplied which ways are best. It is the purpose of the experiments in this pamphlet to reveal to the pupil the needs of the plant, allowing the plant to speak for itself; further, to show various ways of supplying these needs and among these to point out those which are best. We shall be able best to see the needs of plants by examining them to see what they as a rule contain, and whatever substances they as a whole contain **must,** we then conclude, be necessary to their growth and the plant must have supplied to it either these same substances or others out of which it can make them.

PART I.

THE NEEDS OF THE PLANT.

1. Plants Need Water.

(a) Ask each member of the class to bring in an entire plant or any part of one. Heat various portions of these (leaf, stem, flower, fruit, root and some dry wood) in a hard glass test tube. Notice the minute drops of water on the sides of the tube. Where did this water come from? How do you know it did not come from the tube itself or from the air in the tube? Heat in the same way an empty dry tube. Does water collect on the sides of the tube as before? What does this experiment show?

An alcohol lamp suitable for use in performing the experiments in this pamphlet can easily be made from any tin box or can which will not leak and is provided with a lid. With a nail make a hole through the lid and for a wick twist together two strands of common wrapping twine. Wood alcohol or denatured alcohol may be used, but not kerosene.

Heat the tube slowly at first so that the glass will expand uniformly and not break. This is an opportune time to acquaint the class with the rule that heat expands and cold contracts. Speak of the fact that pendulums of pendulum clocks must be shortened in summer and lengthened in winter (automatically or otherwise) if the clock is to keep uniform time, and that a space is left between the ends of the rails (on a railroad) if laid in the winter. Look the subject up carefully in some good text-book on physics before trying to teach these facts.

(b) Take earth that is known to be rich enough to support growing plants and thoroughly dry a quantity of it on a pan. Put the dried earth in a flower pot and in it set a growing plant which has been carefully removed from the soil so as not to break the roots. In similar soil containing plenty of moisture set a similar plant and give it plenty of water. Examine both plants after a few hours. What difference is noticeable? To what is this difference probably due?

The difference might be due to the fact that fewer perfect roots were left on the one plant than on the other, but it may safely be inferred that lack of water causes the difference. Why did the plant supplied with water wither at all? This was because some of its roots had been broken in removal and it therefore could not get the amount of water to which it had been accustomed. The water enters the root through very small branches of the root called root-hairs, many of which must have been broken away however carefully the plant may have been removed.

* * *

(c) Remove two plants from the soil as in experiment 2 (b) and place one in a vessel of water, but put the second in an empty vessel. After a few hours compare and account for the difference as before. Why does the one in the water not wither so soon as did the one in the moist earth in the last experiment? (Water could more easily gain entrance at every point of the root in this case than in the other.) Why does the one in the water wither at all?

Withering or wilting causes a loss of rigidity or stiffness. We therefore see that one use of water to the plant is to give it stiffness*. The plant, of course, gets some of its most important foods in the water taken in through its roots. To show that it is not the lack of food which has caused the wilting here use distilled water in both cases, which, of course, contains no plant foods. The plant in this case will ultimately die for lack of food, but it will maintain its rigidity for some time after being deprived of food.

* * *

(d) Plant beans or grains of corn in moist soil. Plant other beans and corn in soil of the same kind which has previously been thoroughly dried. Keep both at same temperature (approximately) and in original condition at time of planting as to moisture. Observe results each day for a week. To what is the difference in the behavior of the seeds due?

This experiment shows that plants must have moisture in order to germinate—that is, even to **begin** growing. What is one effect of moisture on germinating seeds? This question is to be answered by our next experiment.

* * *

(e) Place a layer of blotting paper in the bottoms of three cups or tin cans. Soak a number of navy beans over night and place one-third of the number in each vessel. Put enough water in one to cover the seeds, in the second enough to keep the blotter rather moist, and leave the third dry. Make daily observations for several days and tabulate results. How does the water affect seeds? How does it produce this effect? How does the water get into the seed? Which seeds have taken up most moisture? Why? Why is it well to firm the earth around seeds when planting them?

Water gets into the seed through the seed-coat, through the hilum (or scar marking its point of attachment to the parent plant)

*This may be illustrated by forcing water into a rubber tube and making it stand upright.

and through the micropyle, a small opening in the seed-coat through which the young plantlet is to emerge (near the hilum in the lima bean). Notice in this experiment the extent to which the volume of the seeds has been increased by the absorption of moisture. Let us next see how much the weight of seeds may be increased by this process.

* * *

(f) Weigh a quantity of seeds of several different kinds, as peas, beans, corn, clover, etc. Put each kind in water for twenty-four hours and weigh again. Weigh a third time after forty-eight hours. Compute percentages of increase in weight. Which have increased most in weight? Which least? Since mere increase in size or weight can be of little use to the plant (none so far as known), of what use is the absorbed water to the seed? To answer this question taste of seeds which are dry and also some that have been planted for three or four days. What difference do you note?

The seed at first contains a great deal of starch. When water enters the seed it causes this starch to change to sugar for the use of the young plant which is found in every seed. That the material surrounding the young plant (embryo) is used for food by the young plant may be shown in the following manner: Plant several grains of corn and after they have begun to sprout cut away a large portion of some of the grains, being careful not to injure the young plant. Restore all to the soil again and compare the rate of growth of the two lots for several days.

* * *

(g) Fill a small bottle full of dry peas or beans, pour in as much water as the bottle will hold and cork tightly. Wire the cork in so that it cannot be moved. Examine after a day or two. What is the result? What caused it? What further use does the germinating seed make of the water it absorbs?

By expansion the germinating seed loosens the soil about it, thus allowing the more ready penetration of the air, a condition which is very necessary if the plant is to thrive. Also the roots find it easier to make their way about through the loosened soil, as does also the stem which the young plant is sending up.

* * *

(h) Cut several weeds of the same kind and weigh while still fresh. Dry them thoroughly in the sun and weigh again. Compute the percentage of loss. Try two or three other kinds of plants. What is the highest percentage of loss? The lowest? What became of the water which left the plants? Heat each lot in the oven or over an alcohol lamp, taking care not to burn them. Weigh again and again compute the percentage of loss. Do the different kinds of plants use equal amounts of water? How is evaporation hastened? How does heat operate in hastening evaporation?

The molecules of which every substance is composed are in rapid motion and moving with different rates of speed at different temperatures. The higher the temperature the faster and the farther the molecules move. The molecules of water have a strong tendency to cling together (cohesion), but in their rapid movement some of these get so far away from the others that the air catches them up and carries them away. When heat is applied a greater number of the molecules escape from the others, as explained above, and are carried away by the surrounding air.

* * *

(i) Give to one of two potted plants which seem to be in perfectly healthy condition as much water as is needed, but withhold water entirely from the other. Notice the result in a few days in the case of the one without water and account for this result. Now begin watering the withering plant and again notice results. What does this experiment show?

In this experiment we have proved conclusively that the withering is due to the lack of water, and not to any condition of the roots, as may have been inferred from previous experiments. Water should be added in this instance, as it should always be added to growing plants, viz., placed in the saucer in which the pot stands. In the case of the neglected plant, it will be observed that the plant begins to droop while the soil still contains a perceptible amount of moisture. Bear this in mind, as we shall have need to refer to it later on.

(j) Divide a shallow wooden box into two parts by a partition with an auger hole below its middle line. Put enough sawdust into the box so that the opening or hole will be below the surface. Plant peas or beans on one side of the partition. After they have germinated give them just enough water to keep them alive. Keep the sawdust in the other side well soaked with water. Examine the roots of the seedlings after a few days, noticing in what general direction (with regard to the hole) they all extend. Why do they extend in this direction?

Recall in this connection the fact that tile drains and sewers often become so clogged with the roots of trees growing over them (especially those of the soft maple) that it is necessary to take up the drains and remove the roots. Many cities have an ordinance regulating the distance at which certain trees must be planted from sewers and drains. What is the effect of sprinkling plants either in pots or gardens? Either one will, by so doing, induce the roots of the plant to spread out near the surface of the earth or else he will give too much water in trying to saturate the soil below the roots. When too much water is given, air, which the plant roots must have, is excluded from the soil. Watering potted plants from below and field and garden plants from ditches between the rows saturates the soil below the roots and induces them to grow downward.

Plants which have developed a shallow root system will have to be watered all through the rainless season in dry climates. If watered from ditches they will keep sending their roots downward till at last they are in many instances able to obtain water from the lower strata of the soil for themselves. The alfalfa plant has been known to send its roots downward more than fifty feet into the soil; it is, therefore, a plant well adapted to dry regions.

2. Plants Need Air.

(a) Place in each of two bottles of water a cutting of Wandering Jew or of some other plant which will take root easily. Pour melted wax or paraffine into one bottle so as to cover the water surface entirely and shut out the air. Examine after a few days. What difference is noticeable?

The one may develop roots but the other will not. Why a difference? The water level in both cases after a few days will also be seen to have been lowered. What has become of the water in each case? The cutting surrounded by paraffine will likely die if it does not send out roots. In that event, what has probably caused its death?

(b) Place a very small potted plant in a Mason fruit jar, partly filling the jar with water, but see that the water does not reach the brim of the pot. Screw the top on tightly and leave for a few days. What is the result? Why? Compare with a man closed up in an air-tight room.

We may infer from this experiment that the plant needs either the air itself or something **contained in the air.** In either event the plant must have air. The leaves use up all the air in the jar (or rather the oxygen contained in the air) and give back carbon dioxide in its place. The abundance of water in the soil about the plant excludes the air from the roots, and these are as much in need of oxygen as are the leaves, so we have here a plain instance of suffocation.

(c) Place twenty-five to fifty soaked beans or peas in each of two wide-mouthed bottles of the same size(six to twelve ounce sizes will do). Cork and seal one and leave the other uncorked, taking care to keep the seeds equally moist in the two cases. Watch for one week and record results daily. Why is there a difference in the behavior of the two lots?

(d) Cover seeds in one dish to twice their depth in water and in another dish to one-half their depth. Compare results for two days. What difference is observable? What accounts for this difference?

In the first instance the water has excluded the air, or nearly all of it (that is, there was some air dissolved in the water); in the second lot at least one-half the surface of each seed has been in contact with the air. The supply of water should be kept as nearly constant as possible in this experiment.

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(e) Plant radish seed in soil that is wet enough to be easily worked like soft putty. Pack the soil closely about the seeds. In a similar experiment leave the soil loose but give water as needed. Compare results for some days. Why did germination proceed so slowly (or not at all) in the first instance? What need of the plant is revealed by this experiment? In what condition should soils be at time of planting? Why? Try making a paste of the three kinds of soils, viz., loam, sand, and clay. Which kind will not form a paste? Which forms the most perfect paste? Why should care be taken in stirring clayey soils after a rain?

A clay soil which has been producing good crops for any number of years may be so seriously injured by one injudicious plowing in a wet time as to ruin it for the growing of crops for two or three years. See Bulletin 119, Cornell Agr. Exp. Station, Hort. Div., Ithaca, N. Y.

(f) Put a flourishing plant into a tin can or pot of earth and keep the soil saturated with water. Keep watch for a few days. What is the result? Why?

The water has entirely excluded the free air from the soil, and though there is much air, comparatively speaking (enough to keep fishes alive), it is not sufficient for the purposes of the plant. We learn from this experiment that the plant will not thrive unless there is plenty of free air in the soil. About one-half the total pore-space (space between particles) of soils should be open for the circulation of air through the soil.

3. Plants Need Warmth.

(a) Plant seeds in two boxes or cans of moist soil of the same kind. Keep conditions similar in both except to place one in a cold place (outside the house if cold weather or in an ice-chest) and keep the other in a warm room. Watch results for three days. What difference is noticeable? To what is it due? What three needs of the plant have our experiments revealed thus far?

It is not difficult to see that man can to a certain extent control the moisture content of the soil and also the circulation of air through the soil. Let us now see whether he can control the temperture of the soil.

(b) Tie a piece of cloth around the bulb of a thermometer, hang this above a bottle of water so that the cloth is in the water and the bulb a little above it. The water should be about as warm as the room. Leave the other thermometer as it is. In about fifteen minutes read both thermometers and take the temperature of the water. What is the temperature of the air? Of the wet-bulb thermometer? Of the water? Why is the wet-bulb thermometer colder than either the air or the water? Why do one's hands feel cold when wet? (The warmth has been used in evaporating the water from the hands.) Of what value is perspiration? (The surplus of heat in the body when one perspires is used in evaporating the perspiration and the temperature of the body is thus lowered.) Call attention to the great amount of heat used up in evaporating a kettle of water. Which will be the cooler, other things being equal, a wet soil or a dry one? We shall see later on that clay will hold more water than sand in proportion to its volume, and will therefore retain water longer than will sand. When the ground thaws out in the spring and evaporation becomes more rapid, which would be the warmer soil? Why? Sandy soils are commonly spoken of as "warm" soils and clay as "cold" soil. Which is best adapted to growing early garden or truck crops? Early spring plowing loosens the soil so that evaporation of water from within the soil is hastened, hence plowed soil becomes warmer—that is, provided the soil is not so wet when plowed that it becomes puddled. Why?

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(c) Fill two tomato cans (one of which has a number of holes punched in the bottom for drainage) with the same kind of soil. Wet the soils thoroughly. Insert the bulb of a thermometer an inch under the surface of each and set them in direct sunlight. Take readings from each thermometer every two hours for two or three days and record temperatures. Compare the readings and see what results follow as the moisture disappears from the can provided with drainage. What is your conclusion as to the temperatures of drained and of undrained soils? Which could be worked earlier in the spring? In which would early spring plantings grow better? In which would late growing crops do best? Consider fall rains.

Would it be possible to lengthen the growing season by draining wet soils?

* * *

(d) Fill two boxes nearly full of soil (crayon boxes will do). Bury the bulb of a thermometer about an inch deep in each. Cover the soil in one with chalk dust and the other with soot. Read the thermometers from time to time. Which is warmer? Why? Which color of clothing is warmer in summer? Why? (Black objects absorb a large part of the heat rays while white objects reflect them. In spite of this, however, a light-colored sand may be warmer than a dark-colored clay. Why?

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(e) Fill three boxes about a foot square and six or eight inches deep with the same kind of soil and set them in the sunlight side by side with the same exposure, except that one is level, one tilted about thirty degrees to the south, and the other tilted about thirty degrees to the north. Insert the bulb of a thermometer about one-half inch under the surface of the soil in each box, take readings every hour during a sunny day, and compare results. In which box were the highest temperatures recorded? Explain. What practical bearing has this upon the selection of farms? With other conditions alike, which would be ready to work earlier in the spring, a north slope or a south slope?

* * *

(f) (Preferably on a bright day in spring about the time that spring plowing begins) take the temperature on a north and on a south slope; also of clay and of sand; of unplowed and of freshly plowed fields; of grass land and of tilled fields. (To take these temperatures bury the bulb of the thermometer about three inches deep in the soil and leave for ten to twenty minutes.) Use care in each case to get soils which differ only in the two things mentioned above to be compared. It will most likely be found that the one mentioned second is each case will be found to be the warmer. Why?

4. Plants Need Light.

(a) Place a growing plant in a box from which all light is carefully excluded, but which will allow air to enter freely. Or make a cone of black paper large enough to fit down carefully over the plant. Water as often as needed. After a few days examine. What change has taken place? Why? Try cones of various colors and see if results are the same in every case.

* * *

(b) Fill a small box with earth and in it plant a few seeds. After the plants have sprung up and begun to grow cover them with a box having an opening toward the light on one side only. Now reverse the box in which the plants are growing and examine after another twenty-four hours. What change has taken place? Why?

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(c) Cover some growing grass with a board and another small area with a piece of glass. After a week compare results. Why is there a difference? How does the absence of light affect growing plants? Remove the board from the grass and notice the result after another week. Account for the change.

This experiment is likely to turn out poorly unless the glass is shaded at all times from the direct rays of the sun. The latter passing through the glass heat the earth and the glass hinders the free radiation of the heat, which kills the grass, spoiling the experiment.

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(d) Cut various letters and figures from black paper and pin or sew them to the surfaces of green leaves. Remove the papers after a week. What is the result? Why? From day to day after the papers have been removed notice the distinctness of the figures and letters on the leaves. What change is taking place? Why?

Disks of cork may be used in the same way, putting one piece on each side of the leaf and fastening the two together with a pin. Nasturtium leaves will be excellent leaves to use in this experiment.

* * *

(e) Set a growing plant (preferably one with weak stems) in a window where there is a strong light. After twenty-four hours notice the position of the leaves and then turn the plant right about. At the end of another twenty-four hours notice the position of the leaves. What change has taken place? Why?

Radish seedlings will be good for use in this experiment. Ask the children to try this experiment with some potted plants at home. Recall how potatoes sprouting in the cellar send their sprouts sometimes for a yard or more in the direction of the light Notice the struggle of forest trees to send their branches up to the light. There will be exceptions, of course—some trees and shrubs seem to do well under the cover of other trees, but in the main those trees which are shut off from the direct rays of the sun do not thrive. It will be an instructive object lesson to visit a forest or grove and notice how on the edge of the woods the large limbs on all the trees are on the side next to the open field Why do trees growing in the thick forest become so much taller and more spindling than trees of the same variety growing in the open field? Does this habit of trees have any important economic bearing? Are trees with long, straight, clean trunks more or less valuable for timber than trees with low, bushy tops?

5. Plants Need Carbon.

Burn in the flame of an alcohol lamp various portions of the plants brought for Experiment 1. Observe that the burned portion is black and leaves black marks when drawn across white paper. This black substance is carbon. Has it any odor? Any taste? Can it be dissolved in water? Can it be made to burn up entirely?

Carbon can be found in various forms. Lamp black, obtained by holding a piece of white dish over the flame of a lamp, is one common form. Graphite, the substance in lead pencils commonly called "lead," is another form; the diamond is still another, and soot another. In testing any substance for solubility in water put it into a bottle containing water and shake vigorously.

6. Plants Need Nitrogen.

(Note.—On account of the difficulty of performing tests to show directly that nitrogen and sulphur are present in all plants the two following experiments are given to show that fact indirectly.)

Burn in the flame of an alcohol lamp a piece of the hoof of a horse (obtained from a horse-shoer) or a piece of horn or some hair and note the odor. This odor is due to the presence in these things of a substance containing much nitrogen. Although nitrogen is found in every cell of all plants and in animals, it is not present in large enough quantities to reveal itself so easily as in the particular things used in this experiment. It has been found that animals cannot use the nitrogen of the air direct (the air is made up largely of two gases, nitrogen and oxygen), and there is no nitrogen in water, so it becomes evident that these animals must have obtained their nitrogen from the food which they ate—that is, from the plants. Even the nitrogen used by flesh-eating animals comes ultimately from plants. Show how.

When beans are allowed to boil dry and scorch one may detect a strong odor, which is due largely to the nitrogen contained in these seeds.

7. Plants Need Sulphur.

(a) Lay a very small piece of sulphur, about the size of a pea, on a silver coin and touch with a match. Notice the color of the flame, also the odor. When the sulphur has burned away look at the coin. What has happened? What caused it?

The black substance on the coin was made by some of the sulphur uniting with the silver in the coin and forming a substance called silver sulphide. Some of the sulphur also united with the oxygen in the air and formed the ill-smelling gas which made you cough. This gas is called sulphur dioxide.

(b) With a silver spoon mince a hard boiled egg or place some of the egg on a brightened silver coin. Leave for a few minutes and remove. What change has taken place in the silver? Why? Which seems to blacken the coin more, the white of the egg or the yolk? What does this show?

The black substance on the coin was made by some of the sulphur of the egg uniting with the silver of the coin and forming silver sulphide as in Experiment 7 (a). When an egg decays some of the sulphur in it unites with a substance called hydrogen also found in the egg and the two form a very ill-smelling gas called hydrogen sulphide. It is the accumulation of this gas within the egg which often causes decayed eggs to burst with a loud report and which gives them their disagreeable odor.

Sulphur is found quite generally in the bodies of animals and since there is seldom any of it in the air they breathe or in the water they drink they must get it in the food they eat which we can trace back to the plants as in the case of nitrogen. Examine some sulphur. What is the color? Has it any odor? Taste? Will it dissolve in water? While it is true that sulphur will not dissolve in water it will do so when combined (made into a compound) with some other substances.

The foregoing experiments have shown us that the plant needs and that therefore it must have the following substances, namely: Air, water, carbon, nitrogen and sulphur. These substances are of three kinds. Carbon is said to be a simple substance because it is not made by a combination of other substances and cannot, therefore, be analyzed by a chemist. Carbon is therefore called an element, as are also nitrogen and sulphur. Water can be analyzed, since it can be made by a combination of two other substances, namely, hydrogen and oxygen, and it is therefore called a compound. The air is composed almost entirely of oxygen and nitrogen, but since these two substances are not combined (that is, the one can easily be separated from the other, as is the case in breathing) air is called a mechanical mixture.

There are altogether about eighty elements, or elementary kinds of matter, as they are sometimes called. That is to say, if all the earth and all things upon the earth could be analyzed by a chemist and each of the simplest substances thus obtained (called elements) were kept separated we should find that there would be only about eighty different kinds of matter. These elements, however, unite in such a multitude of ways that they form thousands upon thousands of different substances.

In order to understand the difference between compounds and mechanical mixtures it will be necessary to know something about the structure of matter. All matter of whatever kind and all material things are made up of very minute particles called molecules—particles so small that they cannot be seen even with the aid of the strongest microscope. Lord Kelvin, a famous student of physics, speaking of the size of molecules, has said that if a drop of water could be magnified to the size of the earth the molecules of which it is made up would be about the size of tennis balls. Each molecule in its turn is made up of atoms, the number of atoms to the molecule differing with different compounds, but always the same in number in the same compound. Every molecule of water, for instance, is made up of two atoms of hydrogen and one atom of oxygen; of hydrogen sulphide two atoms of hydrogen and one of sulphur; of silver sulphide two atoms of silver and one of sulphur; and of sulphur dioxide one atom of sulphur and two of oxygen. In air, which we have said is a mechanical mixture, the atoms of nitrogen and of oxygen do not unite, hence the atoms of the one are easily separated from those of the other. Animals and plants can breathe the oxygen of the air, but the oxygen which goes to make up the molecule of water cannot be made use of in this way. The oxygen which fishes use for breathing purposes is merely dissolved in the water—that is, it forms a mechanical mixture with the water.

Examining the substances thus far seen to be needed by the plant, we see that plants need carbon, hydrogen, oxygen, nitrogen, and sulphur. Further experiments which we cannot now perform, but which have been performed many times, show that the plant also needs eight other elements (thirteen in all), namely, phosphorus, silicon, chlorine, iron, calcium, magnesium, sodium and potassium. Some of these elements are in solid form, as carbon and sulphur, and some in the form of gases like nitrogen, while still others like hydrogen and oxygen unite to form liquids. Oxygen is the only element which the plant uses in the uncombined form. Carbon is taken into the plant in the form of a gas known as carbon dioxide. The remaining elements are all taken into the plant in the form of compounds and all in water solution. We shall next notice some of the elements which have not already been examined.

8. Preparation of Oxygen.

(a) Fill a small crucible (made by twisting a piece of wire about a thimble or large cartridge shell) half full of chlorate of potash and hold in the flame of the alcohol lamp. Oxygen will come off as the potash melts. The gas will come off more rapidly if equal parts of clean, fine sand are mixed with the potash.

* * *

(b) Hold the glowing (not blazing) end of a stick close over the crucible while the oxygen is coming off and the stick will burst into a brilliant flame. Blow out the flame and thrust in again. Again it bursts into a flame. This is the test for oxygen. Do you perceive any odor about oxygen? Any color? Is it a solid, a liquid or a gas? Is it soluble in water? (Think of the breathing of the fish when answering the last question.)

Loop some wire about a small bit of sulphur and light it, observing it as it burns in the air. Describe the color of the flame. Now hold the burning sulphur close over the crucible in which the potash is being heated. Why does the sulphur burn so brightly? (The burning of sulphur is simply the uniting of the sulphur with oxygen. It unites much more rapidly with pure oxygen than with the oxygen of the air, hence the brighter flame. Some other substances, as for instance iron, unite with oxygen so slowly that no light or heat can be perceived, though some heat is always given off when oxidation occurs.)

* * *

(c) Put enough red oxide of mercury into a hard glass test tube to fill the round end of the tube. Hold the tube in a horizontal position over the flame of the alcohol lamp and shake it to spread the powder out. When a change in the color of the mercury is noticed insert a glowing stick as in (b). If there is no change heat strongly and test again. What is the result? What is thus shown to be present?

Oxygen will unite with nearly every one of the (approximately) eighty known elements. When one atom of oxygen unites with two atoms of hydrogen a liquid (water) is formed; when two atoms of oxygen unite with one atom of carbon (as it does so constantly in the bodies of plants and of animals) carbon dioxide, a gas (sometimes called carbonic acid gas), is formed; when four atoms of oxygen unite with three atoms of iron, iron oxide, a solid, is formed. This union of oxygen with other substances is known as oxidation, which will be illustrated in our next experiment.

Oxygen is the most abundant and widely known of the elements. About one-fifth of the air (by volume) and eight-ninths of water (by weight) are made up of it. Nearly one-half of the earth's crust is composed of it, mostly in union with silicon in the form of sand. Oxygen is absolutely necessary to all forms of animal and plant life, with the possible exception of some of the bacteria. It also assists some of the bacteria in the work of bringing about decay.

9. Illustration of Oxidation.

Expose to the air for some time bright pieces of iron, lead, zinc, or copper (iron is best), or better, lay them in damp earth for several days. What change has taken place in the appearance of the metal? To what is this change due?

The rusting of metals on the surface of the earth is due largely to the union of the metal with the oxygen of the air. The rusting of metals beneath the surface of the earth is due to the union of the metal with the oxygen which is found free in the air of the soil. Iron will not rust as rapidly in a deep well as in a damp soil because the water does not contain so much free air as does the soil.

10. Preparation of Hydrogen.

(a) Place some bits of zinc (a handful of bits of old zinc will do) in a wide-mouthed empty bottle and cover with water. Add about one-fifth as much sulphuric acid as water used (never add water to the acid). Bubbles of hydrogen, a gas, will be given off. Has hydrogen any color? Any odor?

In the above experiment it is well to have the bottle in an earthenware dish so that in case of accident the acid will not come in contact with the desk or floor. Should any do so or touch the clothing apply water very freely, or better, use ammonia till the effects of the acid are overcome. The bottle in which the hydrogen is being prepared should not be held in the hands. Wrap a towel or other cloth about the bottle to prevent glass from flying in case of an explosion. Do not leave acid in a metal receptacle.

* * *

(b) Standing well back, apply a lighted match to the mouth of the bottle in which the hydrogen is being prepared. The hydrogen generally explodes on account of being mixed with the air. After the explosion look carefully to see if the hydrogen is still blazing, and if so, hold over the flame a piece of cold glass (which should be ready at hand), and look immediately for particles of moisture on the glass. These particles show that water is formed when hydrogen and oxygen unite (we have here only another example of oxidation). Notice that in this instance two gases combine to make a liquid. The explosion which generally follows when hydrogen is ignited is usually harmless.

Hydrogen is said to be only slightly soluble in water. It is the lightest substance known, and for this reason is often used in inflating balloons. One-ninth by weight of water is hydrogen. For another compound of hydrogen see second paragraph under 7 (b).

11. Preparation of Nitrogen.

Attach to one end of a piece of wire about a foot long a wad of cotton the size of the thumb and saturate the cotton with alcohol. Bend the wire into a V-shape and place the closed end downward in a glass half full of lime water. Now light the cotton and place over it a homeopathic vial (or other small bottle with a comparatively large mouth), open end downward so that the open end of the vial is below the surface of the water. The bottle now contains nitrogen.

What color is it? Note that it has no odor, and will not support combustion—that is, it puts a flame out. To show that the latter statement is true light the cotton after the vial has been removed and note that it will still burn in the air. Why did it cease to burn before?

The bottle at first contained air. The air is made up of about four-fifths nitrogen, about one-fifth oxygen and about four parts in ten thousand of carbon dioxide. The oxygen was all used up in burning the cotton and the carbon dioxide of the air, as well as that resulting from the burning, went into the lime water—see Exp. 13 (c). Thus we see that only nitrogen is left. (The other gases normally present in the atmosphere may be ignored in this connection.)

Every cell of all animals and all plants contains nitrogen, hence all organisms require a great deal of it. But animals and all plants (except some microscopic ones as noted before) cannot use it just as it is when found in the air as they can in the case of oxygen. Plants must get their nitrogen from the soil in the form of compounds and the animals, obtain it by feeding upon the plants or upon other animals which in their turn have fed upon plants. The microscopic plants named above (called bacteria), however, can use the nitrogen of the air and in doing so they make it over into compounds which the higher plants can use as food. Many of these nitrogen-using bacteria, which are very commonly found in soils, penetrate the roots of peas, beans, clover, alfalfa and other members of the family to which these plants belong (viz., Leguminosae) and cause the swellings commonly found on the roots of these plants. The swellings or tubercles, as they are often called, range in size from that of a pin's head to that of a pea. In these live thousands upon thousands of bacteria which use the free nitrogen of the air found in the soil as food, consequently they are always adding, as they die, large quantities of nitrogen to the other plant foods in the soil.

Nitrogen can be made to combine with oxygen and hydrogen by passing an electric spark through a mixture of the three gases forming ultimately nitric acid and ammonia. This accounts for these substances and others related to them being found in the rain which falls during a thunderstorm. A great deal of nitrogen is imparted to the soil in this way.

When stable manure is plowed under there is one kind of nitrogen-using bacteria which feed upon a part of it and make it over into ammonia; another kind use the ammonia and make it over into nitrous acid; a third kind use this substance as food and make it over into nitric acid. The nitric acid thus formed readily unites with any calcium, magnesium, potassium or sodium found in the soil, forming compounds known as nitrates. These nitrates constitute one class of foods which the plant uses and all of the nitrogen used by the plant is taken in any or all of these forms.

When one atom of nitrogen unites with three atoms of hydrogen, ammonia is formed; when two atoms of oxygen and one of hydrogen unite with one atom of nitrogen, nitrous acid is formed; when three atoms of oxygen and one of hydrogen unite with one atom of nitrogen, nitric acid is formed. Nitrogen also combines with carbon, hydrogen, oxygen, sulphur, and phosphorus to form a compound called protein, one of the most important foodstuffs for animals, since this compound is found in every cell of all animals.

12. Preparation of Lime Water.

(To be used in test for carbon dioxide.)

(a) Put a piece of quicklime (unslaked lime) about the size of the clenched hand, or the equivalent of this amount, in a quart bottle half full of water and let it stand for several hours. Now shake well, cork tightly and set it away till it settles. After performing the next experiment tell why the bottle in this experiment is to be kept corked tightly.

* * *

(b) Burn a stone known to contain lime—found by applying the test in 13 (b). Make lime water from this as directed in 12 (a) and test as directed in 13 (d). If the water is thereby turned milky the stone contains lime.

13. Preparation of Carbon Dioxide.

(a) Place a teaspoonful of soda in a glass half full of water, add a few teaspoonfuls of vinegar and stir. The gas which comes off in bubbles is carbon dioxide, sometimes called carbonic acid gas.

* * *

(b) Add sulphuric or hydrochloric acid (not too strong) to a piece of bone, or a bit of the shell of a dead crayfish, or of a sowbug, or to a bit of marble. Carbon dioxide comes off in each case.

Stones found in the field may be tested for lime by pouring upon them, or better, by pouring upon a small fragment of the stone finely pulverized, one of the acids named above. If bubbles are given off the stone contains lime. Test the bubbles with a drop of lime water suspended in the end of a small glass tube. The bubble may be suspended by placing the thumb tightly over one end of the tube and then removing it after immersing the opposite end of the tube in the lime water.

(c) Pour some of the carbon dioxide in 13 (a) into a bottle containing lime water (the gas is heavier than air and can be poured like water). Stopper the bottle and shake. The milkiness of the water is due to the carbon dioxide, which always produces this effect when poured or forced into or mixed with lime water.

* * *

(d) Blow the breath into a small quantity of lime water through a straw or a tube of any kind, making it bubble for a minute or so. What effect is produced in the water? What does this indicate? Where does this carbon dioxide come from?

There is carbon dioxide in the breath of all animals, and it is also given off to some extent by plants. It is made in the cells of the bodies of these organisms by the union of the oxygen of the air (taken in by breathing) with carbon found in various compounds in every cell of the organism. It is then brought by the blood from the cells to the lungs, where it is given off into the air.

* * *

(e) By means of a bicycle pump force air into a small quantity of lime water for a few minutes. What is the effect on the lime water? What does this indicate? How does the amount of carbon dioxide in the air compare with that in the breath? Why is there more in the latter?

* * *

(f) Place a little lime water in a saucer or some other shallow vessel and leave exposed for some hours in the schoolroom. What change has taken place in the water? What does this indicate? Breathe upon it directly for a few minutes and note results. Should you expect results in both cases? Why?

* * *

(g) Shake a little lime water for a minute or two in an empty bottle. What is the result on the water? Now light a splinter and introduce carefully into the bottle. Leave it there till the flame goes out. Now shake again and note results. What does the latter part of this experiment show? Since the bottle was open while the carbon dioxide was forming, what does it show about the weight of this gas as compared with air?

The oxygen of the air united with the carbon in the stick—that is, oxidized it, forming carbon dioxide just as the carbon dioxide in (b) was formed by the oxidation of the carbon in the cells of the human body. A great part of the carbon dioxide found in the air comes from these two sources.

* * *

(h) Place a handful of soaked peas or beans on moist blotting paper in the bottom of a Mason fruit jar and leave over night. Shake up a small quantity of lime water in the jar next morning and note results. Where did the carbon dioxide in this experiment come from?

PART II.

SUPPLYING THE NEEDS OF THE PLANT

We have seen that some of the elements which the plant needs are supplied from the air, while others are found only in the soil, and that at least one of these, namely, nitrogen, though found abundantly in the air, must be obtained from the soil, since it is taken into the plant only in the form of compounds in water solution. So the plant is seen to have two feeding grounds, the air and the soil. Carbon, which forms nearly half, by weight, of the dry matter of all plants and plant products, comes from the carbon dioxide of the air and is taken into the plant through minute openings in the leaf called breathing pores, or stomata. Some of the oxygen used by the plant is also taken directly from the air. Though none of the remaining elements are used to so great an extent as is carbon, they are none the less important. The relative amounts of different elements required by the plants and some of the forms in which they are taken in is well illustrated in the case of a bundle of wheat just as it comes from the self-binder. It weighs about ten pounds, and nearly nine and one-half pounds of this material are taken from the water and carbon dioxide of the air. The other approximate half pound contains ten simple substances (no two of which are present in equal amounts) as follows:

	Grains.
Nitrogen in the form of sulphate ammonia.......	771
Potash in the form of potassium oxide.........	461
Phosphorus in the form of phosphate of lime...	347
Sulphur in the form of calcium sulpate..........	123
Sodium in the form of sodium carbonate........	55
Chlorine in the form of sodium chloride........	285
Iron in the form of iron oxide...............	2
Silicon	1754
Lime	162
Magnesium	126

These materials, of course, all come from the soil and a large part of the farmer's labor is devoted to supplying these ten elements which go to make up this half pound.

All plants require all the thirteen elements named above, but they do not require them in the same proportions. It is also a fact that some plants can find these elements in the soil more readily than can others, and this accounts for the fact that some plants may grow exceedingly well on a soil in which other plants grow very poorly. Although some carbon dioxide and oxygen (much oxygen in the case of young plants) are taken in gaseous form from air in the soil, all other foods in the soil must be taken into the plant in the form of compounds dissolved in the water. However, not all compounds containing an element (as for instance iron) can be used by the plant. It is readily seen, therefore, that not only must the necessary elements be present in the soil, but they must have entered into the proper compounds and also be in water solution. Since the roots through which these foods pass have no openings in them it is at first a bit puzzling as to how this process is accomplished. This will be shown by our next experiment.

14. Illustration of Osmosis.

(a) Remove about one-fourth of one square inch from the shell at the large end of an egg, being careful not to break the membrane. Make an opening at the small end of the egg large enough for the purpose and empty out the contents. Fill the empty shell half full of red ink and watch it for a few minutes to see that none of the ink filters through, then set in a large mouthed bottle which has been filled to the brim with water. The neck of the bottle should be large enough to permit the immersion in water of the exposed membrane at the large end of the egg. Leave it for two or three days and watch for results. What seems to be happening? Did the colored water leak through the holes in the membrane? How, then, did it get through?

The molecules of which all substances are made up are conceived to be spherical. This being the case there must always exist spaces between molecules however close together the latter may be. It is believed that osmosis can take place only when the molecules of the liquid used are small enough to pass between the molecules of the membrane. Teachers should read up the subject of osmosis in some good text-book on physics before beginning the above experiment.

* * *

(b) In a similar manner as in (a) remove a portion of the shell from the large end of the egg, but only slightly crack the other end over a very small area. Over this cracked area, which should be at the very tip of the small end, set on a piece of candle about an inch long from which the wick has been removed. Seal the candle to the egg by melting the paraffine all around at the line of contact with the shell. Now thrust a glass tube (one-eighth inch in diameter or thereabouts) down through the hole left by the wick and push it a short distance into the egg through the cracked area. Melt the candle at the line of contact with the tube, sealing the latter in. Place the egg in a bottle of water as directed in (a) and leave for several hours. What has happened? Explain.

In this experiment we have a means of measuring the amount of water which has passed through the membrane.

* * *

(c) Tie a piece of intestine or the bladder of any animal over the end of a glass tube so as to form a bag and after filling with water which has been colored with red ink suspend upright in a glass of water. Watch results for several hours.

Instead of the bladder a piece of parchment or the membrane of an egg may be used. To obtain the latter open the small end of an egg, pour out the contents and set the shell in a weak acid for several hours to remove the shell from the membrane. The bubbles seen coming off as the shell dissolves are bubbles of carbon dioxide.

* * *

(d) Fill a homeopathic vial or any small bottle with a syrup made of sugar and water and tie tightly over its mouth a piece of softened bladder, intestine, parchment, or the membrane of an egg obtained as in (e). Immerse the small bottle entirely in a larger bottle or glass of water and after a few hours taste from time to time the water in the larger vessel. What is the result? Account for the sweet taste. Try the same experiment by reversing the conditions—that is, by putting the syrup in the larger vessel and the pure water in the smaller. Does it work this way also?

* * *

(e) In an apparatus like any of the above mentioned use starch in the smaller vessel and see if osmosis will take place? What is your conclusion? Try some starch which has been thoroughly mixed with saliva. What is the result?

The foregoing experiment reveals the fact that while starch is not capable of passing through a membrane (osmosis) the sugar which is formed when saliva acts upon starch is capable of osmosis. The plant stores in its seeds food for the young plantlet largely in the form of starch, but before this can be taken into the cells of the growing plant it must be changed to sugar. This is accomplished by the action of a substance called diastase (an enzyme or unorganized ferment, so called to distinguish it from a bacterium, or organized ferment), an organic compound which is capable of bringing about a chemical change without itself being changed in the process. The enzyme in saliva which changes starch to sugar is called ptyalin.

* * *

(f) Cut off the lower end of a potato and pare the remainder upward from the cut end for about one-fourth its length. Beginning at the opposite end, bore a hole to within three-fourths of an inch of the cut end and also a small hole at the side and in the latter insert a small L-shaped glass tube. Make the joint where the latter joins the potato air-tight with paraffine or vaseline. Place sugar in the hole at the top and insert a cork. Put the potato into a dish and surround with water to the depth of three-fourths of an inch. After a few hours taste the water in the dish. What has taken place? Explain. Can any particles of sugar be found outside of the potato? What does this indicate? Try a piece of carbon, also one of sulphur, instead of the sugar. What is the result? Why?

The foregoing experiments illustrating osmosis go to show that substances in solution are capable of passing through a membrane while substances which cannot be dissolved will not do so. It further shows us that carbon, and sulphur as such, cannot be taken into the plant. We now see one reason why it is so necessary that plants should have plenty of water, for without it they cannot make use of the foods stored in the soil and must die of starvation. Many of the complex compounds found generally in plants as starch, fat, sugar, protein, cellulose and fiber were not taken into the plant in these forms, but were built up out of elements and other compounds taken from the soil and the air. All plant foods except oxygen are taken in in the form of various compounds, a few of which were enumerated in the first paragraph of Part II.

It is not always possible, nor is it practicable in most cases even where possible, to give to the plant these foods in the form of the compounds enumerated there. For instance, the nitrogen which is found in wheat in the form of sulphate of ammonia is put upon the soil usually in the form of potassium and sodium nitrates because the plant can easily appropriate these materials as food. Similarly the phosphorus which is found in wheat in the form of phosphate of lime is added to the soil in the form of phosphoric acid (a compound known to the chemist as phosphorus pentoxide). Potassium found in the wheat plant in the form of oxide of potassium is added to the soil in the form of chloride or sulphate of potash.

We shall next see how these last three compounds which are favorite plant foods may be prepared.

15. Preparation of (Crude) Phosphoric Acid.

Obtain some bones of any kind and burn them until white. This white substance is practically a combination of phosphoric acid and lime. The lime may now be removed by pulverizing the bu.ned bone very finely, placing it in a bottle, covering it with water and adding a small quantity of sulphuric acid. The lime will combine with the acid and settle to the bottom and the clear liquid above it will contain phosphoric acid. This liquid is sufficiently pure for illustrative purposes.

16. Preparation of Potash.

Pour two or three quarts of water over a pan one-half full of wood ashes and stir the water and ashes together thoroughly. Set aside for a time and stir again. Repeat several times in order completely to dissolve the potash contained in the ashes. When the latter have finally settled pour off the clear liquid on top into another vessel, set it on the stove, or over an alcohol lamp and evaporate to dryness. The dry white substance found in the bottom of this vessel is potash. A little of it dissolved in water will make the water feel "soapy."

17. Preparation of Saltpeter.

Add caustic potash to a dilute solution of nitric acid in the right amount to neutralize it exactly (see Exp. 20) and evaporate to dryness. The dry substance remaining is saltpeter or potassium nitrate (nitrate of potash). Saltpeter is a good example of soluble nitrates and is one of the common forms in which the plant takes its supply of nitrogen. Other nitrates used by the plant are magnesium, sodium and calcium nitrates, all formed when nitric acid in the soil comes in contact with the elements named respectively or with their compounds.

Have the children make a collection of plant foods and encourage them to become familiar with the substances contained in this collection. Have each kind of food placed in a separate bottle and properly labeled. The exhibit should embrace the following: Lime, salt, oxide of iron (rust), soda, silica (sand), magnesia, ammonia (a few cents' worth of each of the last two may be purchased at a drug store), vinegar (an example of an organic acid, sulphuric acid (an inorganic acid), and what remained over at the end of each of the last three experiments. The pupils have seen oxygen and carbon dioxide prepared among the experiments in this course. These two foods being gases cannot, of course, be added to the exhibit.

There are three kinds of substances to be found among these plant foods, namely, bases, acids and salts. We shall acquaint ourselves with these next.

18. Illustration of and Test for Acids.

(a) Add a few drops of dilute sulphuric acid to half a tumbler of water. Do the same with nitric acid. Compare the taste of each with that of vinegar. (Add the acid drop by drop, tasting each time until the flavor can be distinguished.)

(b) Put red and blue litmus paper into the three substances above named. Is either affected? Which one? How? This is a sure test for acids. Similarly test lemon and other fruit juices; also milk that has stood for twenty-four hours in a warm room. Test cream of tartar, baking powder, saleratus, and the juices of sorrel and of dock. Crush the body of an ant on each of the two kinds of paper. Hold a bit of each for a minute or two in the entrance to an ants' nest. What does the result indicate?

* * *

(c) Pulverize and dissolve in a small bottle partly full of alcohol a teaspoonful of cochineal. This liquid (like litmus paper) is called an indicator. An acid added to a small quantity of it will turn it brown, an alkali purplish blue.

19. Illustration of and Test for Alkalies.

(a) Rub over the fingers a little of the potash made in Experiment 16. How does it feel? Do the same with a little sodium or potassium hydroxide dissolved in water. How do they feel?

* * *

(b) Test all these substances with both kinds of litmus paper and the cochineal indicator made in (c) of the last experiment. Which paper is affected? How? Test limewater and potash.

20. Illustration of and Test for a Salt.

In Experiment 17 potash is added to nitric acid till the latter is exactly neutralized—that is, until the mixture will not change the color of either shade of litmus paper. In this case a salt was formed. Form a salt by adding soda to vinegar, potash to vinegar, lime to vinegar.

Soils become either acid or alkaline, according to the predominance of the one or the other of these substances. There are, in California, vast tracts of alkali soils, the reclamation of which is going on extensively at the present time. In the case of soils planted to one crop for long periods the soils are likely to become acid.

21. Tests for Acid and Alkali Soils.

(a) Boil a sample of the soil in a small quantity of water and allow it to settle. When perfectly clear pour off the water into a white dish and test with both kinds of litmus paper. Leave the paper in the water for five or ten minutes, as the soil may not be either strongly acid or alkaline.

* * *

(b) Test soils in the field with two kinds of litmus paper. With some sharp-edged tool as a spade or a hoe (a knife will do) make a crevice in the soil. Put in the paper and press the soil back firmly against it. Examine the paper after five or ten minutes.

22. How to Correct an Acid Soil.

Stir into a soil known to be acid by test a small handful of slaked lime or of wood ashes and test with litmus paper to find out when enough has been added. What remedies might be applied to an acid soil?

In connection with the collection of plant foods previously enumerated it is interesting to know that seedling plants will grow and do well in a solution made up as follows:

Distilled water	100 cubic centimeters
Potassium nitrate	1 gram
Sodium chloride	.5 gram
Calcium sulphate	.5 gram
Magnesium sulphate	.5 gram
Calcium phosphate	.5 gram
Ferric chloride	.005 gram

This solution, called a nutrient solution, will be seen to contain all the thirteen elements previously mentioned as being necessary to plant growth except carbon, which comes from the air, and silica, which is used by plants, but is not absolutely necessary to their growth. Experiments have also been made which seem to show that plants can also grow to maturity in the absence of chlorine and soda.

Water as usually obtained from the soil (as, for instance, well water) may be shown to be nothing more nor less than a weak nutrient solution. In passing through the soil it has taken up some of the various plant foods with which it came in contact.

23. Soil Water Holds Plant Food.

Boil rain water to drive off dissolved gases. Boil well water to concentrate it. Fill a can or other vessel with each, cover with wire gauze, and on the gauze put a number of wheat plants previously germinated so that the roots are immersed in the water. Watch results for several days. As the water evaporates add more of the same kind. What difference is noticeable in the plant? To what is it due? What is the only reason that the plants grow at all in the rain water? (The seeds still contained a small amount of food.) From what source did the well water originally come? How did it reach the well? How has it changed in passing through the soil? What is the effect of percolation on the plant foods in the soil? May that which runs off into streams have a similar effect? (Carries food, soil, and all.)

Since the plant takes in practically all of its food in water solution, we shall turn our attention next to the water found in the soil. Of all the water which falls to the earth in the form of rain or snow a very small amount passes off again into the air (evaporates), some runs off into streams, while a third portion sinks into the soil. Of the water which sinks into the soil, some is drawn downward (percolates) through the soil on account of the action of gravity till it reaches an underground drain (natural or artificial). This is called free, bottom, gravitational, hydrostatic or ground water. A second portion of the water which sinks into the ground remains in the spaces among the soil particles to be explained later, and is known as capillary water. A third portion collects about the very small particles of soil forming a thin film (some kinds of soil contain as many as nine billions of these small particles to the gram—a small child's thimble full) and can be made to leave the soil only by applying great heat to it. This is called hygroscopic water.

24. Amount of Water Found in Films Dependent on Size of Soil Particles.

Fill a glass with marbles or small pebbles and pour in as much water as is necessary to wet them—that is, to form water films around each without leaving any free or standing water. Now crush the pebbles as fine as possible to form coarse sand and see how much water is now required to wet them. Which requires more water? Why? Does a coarse or a fine soil hold more water in the form of films about the particles? What hint does this give us concerning the condition in which the soil about growing crops should be kept?

25. To Show One Good Effect of Percolation.

Prepare an alkali soil by mixing soda or potash with dry sandy soil. Test with litmus paper to see that it is alkaline. Place this soil in a tin can with holes in the bottom through which the water may escape. Set this can in a dish, pour water on the soil from the top and test that which drains through by means of litmus paper. What is the effect on the litmus paper? What does this show? What suggestion does this give us as to the treatment of alkali soils to make them productive?

Remember that when water is put upon the soil it must have some way of escape after percolating through it. Underdrainage is therefore seen to be as necessary as is irrigation in reclaiming alkali lands. Considerable areas of the alkali lands of California are being reclaimed by this method.

26. Percolation in Different Kinds of Soils.

On one side of a box (one five by ten or twelve inches will do) make three holes, each large enough to pass the smaller portion of a student lamp chimney through. Fill one of the chimneys with sand, another with clay, and the third with soil containing considerable vegetable matter (humus), keeping the soils in by means of a piece of thin cloth (scrim will do) held over the end of each tube by means of a rubber band or string wound tightly about it. Place an empty tumbler under each lamp chimney and pour water into each chimney. How much water will each soil hold before it begins to drip? Why will the clay hold most? Why does the sand hold least? Which requires the shortest time for the water to pass through? Why? The longest time? Why? Which soil dries out the fastest? Why? the slowest? Why? What must have been the effect of percolation in each case on the amount of plant foods in the soil? Is percolation desirable? Under what circumstance? When plant foods have been removed from the soil by percolation or by plants how may the supply be renewed? (Stable and green manures, earthworms, ants, gophers, etc.,—story of how each animal named helps by bringing up soil from below.)

In the foregoing experiment the water which passes through corresponds to free or gravitational water in the soil, and that which remains, giving a darker color to the soil, is capillary water. Hygroscopic water was already present in the soil when the experiment was begun. To demonstrate the truth of the last statement put some soil which seems perfectly dry into a hard glass test tube and heat. Notice drops of moisture collecting on the sides of the tube. This water is a part of that contained as surface films on the minute particles of the soil. If the soil is weighed before and after the heating the exact amount of water existing in the hygroscopic form may be determined. When soil dries in the sun it loses only its capillary water. The hygroscopic water dissolves the plant foods which are found on the surface of the soil particles and passes them on to the capillary water, which in turn carries them to and into the roots of the plants, and from the roots to every cell in the plant structure. We shall see next how the capillary water is able to move through the soil with this plant food.

(Read up the subject of water in soils in some advanced text on the soil.)

27. Illustration of Capillarity.

(a) Secure two pieces of window glass, each having one straight edge at least five inches long. Put the straight edges together vertically in a pan of water so that the pieces form an angle of five or ten degrees with each other. Describe what takes place. Where does the water rise highest?

The teacher should read up the subject of capillarity in some good text-book on physics before giving the experiments which illustrate that principle.

* * *

(b) Obtain five or six different sizes of glass tubes having internal diameters ranging from one-sixteenth to three-fourths of an inch. Set these on end, side by side, in a pan of water, the bottom of which has been covered with fine gravel. Describe what takes place in the tubes. In which tube does the water rise highest? In which does it rise least? See if the water rises only on the **inside** of each tube, or both on the inside and outside. Place two of the tubes side by side and as close together as possible. What effect does this have on the rise of the water on the outside of the two tubes? Explain.

* * *

(c) Fill a bottle with dry earth and saturate the earth with kerosene or with alcohol. Apply a lighted match to the mouth of the bottle. How is the flame enabled to continue burning?

The bottle should be filled to the very brim else the flame will not get air enough and will fail to burn. The capillary rise of the oil may be observed as the flame continues to burn. This represents very accurately (though somewhat too rapid) the capillary rise of water in the soils to replace that used by the plant or that which is constantly evaporating from the surface of the soil.

* * *

(d) Place side by side two large-mouthed bottles of equal height. Fill one with colored water. Connect the two bottles with a lamp wick that has previously been thoroughly wetted. What takes place?

In passing out of bottle number one capillarity acts in opposition to gravity; in passing into the other bottle it acts with gravity. Capillarity is here seen to act in at least three directions, so it may readily be inferred that it will act as easily in all directions. Colored water is used so that the experiment may be observed better from a distance.

* * *

(e) Place one of two blocks of loaf sugar on top of the other in a saucer containing black or red ink. What takes place? Does the ink pass into the upper block? Does it pass as readily **into** this as it passed **through** the other block? Why not? Does capillarity act more readily between small or between large particles of the sugar?

(f) Arrange an apparatus as directed in Experiment 26, but instead of pouring water into the top of each tube pour the water into the tumbler under each tube, keeping each of the tumblers full of water. Begin with perfectly dry soil in each tube. In which does the water rise most rapidly? In which least rapidly? How is rapidity of rise correlated with size of soil particles?

Leave the tubes in 27 (f) for several days, having removed the tumblers from below as soon as the water has reached the top of each, and tie oiled paper over the lower end of each tube. Watch the color of the soil through each tube. Is it changing? Why?

28. Evaporation Illustrated.

(a) Take a few grains of soil from one of the tubes in 27 (f) and scatter them about over the bottom of a saucer. Look at them after a few hours. What has happened? Explain.

* * *

(b) In a similar manner expose a few grains of soil (not too wet) and keep a fan moving vigorously over the saucer for a few minutes. What is the result as compared with (a)? Why is there a difference? Is a windy day or a quiet one the better for drying newly laundered clothing, hay, or the earth's surface after a rain?

* * *

(c) Put a few grains of soil as in (a) and (b) into a pan and set over the alcohol lamp or on the stove. Compare the results with those obtained in (a) and (b). Why is there a difference? What two things have we found to be aids to evaporation?

* * *

(d) Fill two tubes similar to those used in 27 (f) with clay of same quality as that used in the experiment mentioned. Wet the soil in these and also in the one used in that experiment until saturated. Smooth the surface of one so that it will form a crust. Put an inch of dry, very finely pulverized, clay over the soil in the second. Leave the third as it is. Compare the rates of evaporation in the different tubes. In which tube is it most rapid? Least rapid? Why? How may evaporation be hindered? How assisted? What is the effect of evaporation on capillary action? One reason why evaporation is desirable? (Keeps bringing plant foods to the surface.) Two reasons why undesirable? (None or too little water left in the soil to bring food to the roots of plants, and as in the case of alkali lands, the chemical substances in the soil become so concentrated that plants cannot grow.)

(e) Place some wet straw over ground that has recently been dug up and some more over ground that is hard and dry on the surface. Place a piece of heavy board (so it will lie close to the earth) over another small area. After two or three days report the result. Why has moisture gathered in each case? When might it be desirable to use such a device (mulch) for conserving moisture?

Closely planted orchards are often covered with a layer of straw, leaves, tanbark, or manure for this purpose. These are more like the mulch which nature uses, especially the leaf mulch found in the forests. Take the temperature (in summer) of soil covered by a mulch of straw and of soil not so covered. Why is a mulch sometimes undesirable?

* * *

The amount of plant foods found dissolved in the soil water at any one time is very small. It is necessary, therefore, for the plant to take in extremely large quantities of water in order to obtain sufficient food. Though from eighty to ninety per cent of the green weight of plants is composed of water, yet the plant would not be able to retain in its structure all the water which is taken in with the food. It is said that one acre of corn uses in the course of a season's growth nine hundred tons of water, enough to make a layer over the entire acre about eight inches deep. A comparatively small amount of this is retained by the plant. Plants have numerous very minute openings in their leaves called stomata (singular, stoma), by means of which they get rid of the water which they do not need to retain. That water does pass off from plants is shown by the following experiment:

29. Transpiration in Plants.

(a) Encircle a growing potted plant with a piece of oil cloth or of oiled paper large enough to cover the top of the pot. Now invert a glass jar (a Mason's fruit jar will do if large enough) over the plant so that the mouth is covered with the oilcloth or paper. Examine the inner surface of the jar after some hours. What has happened? Where did this water come from? How do you know it did not come from the soil? As a check experiment try exactly the same apparatus minus the plant.

* * *

(b) Put a plant with long roots into a bottle nearly full of water. Put paper around the stem and cover it with paraffine so as to make the bottle air tight. Measure the height of the water and weigh the whole. Measure and weigh again after another week. What has become of the water?

The foregoing experiment might be varied by placing the plant and bottle on one pan of a balance and putting weights in the other till the pans balance. After leaving in a sunny window for several hours note the position of the pans and remove weights until the pans balance. By this means the quantity of water given off (transpired) by the plant in a given time may be ascertained.

(c) Pass the petiole of a green leaf through a cardboard cover into a glass of water. Seal the space between the petiole and the cardboard with grafting wax or vaseline. Why not with paraffine? Invert another glass over the first. After an hour examine the upper glass. What has been going on? Explain.

(d) Fill two small bottles with water to the same height. Insert in the neck of one through a cardboard cover several twigs. Leave the other bottle open. Observe the relative quantities of water in the two bottles after a few hours. What does this indicate?

Several varieties of trees, notably Eucalyptus, are planted in swamps for the purpose of draining them. One of the bad effects of weeds in a crop is that besides crowding, shading, and taking plant foods from useful plants they also rob the soil of moisture.

(e) Cut off two bean seedlings at the surface of the ground. Put the stem of one into a bottle of water and that of the other into an empty bottle. Examine after a few hours. Account for the difference in appearance. What three things are shown by this experiment? (That plants must have a constant supply of water; that water reaches the leaves through the stem; and that water comes in through the roots and not through the sides of the stem.)

* * *

(f) Immerse one leaf of a freshly cut bean seedling in water and allow the others to hang over the edge of the vessel containing the water. What happens to the other leaves? What does this show with respect to the taking in of water? Has the immersed leaf probably taken in any water? What might its greener appearance indicate? (That it has not lost the water it had as easily as did the remaining leaves.)

The experiments under 29 show that water does pass out of plants through their leaves. The evidence would be somewhat more conclusive if the stems in each case were covered with vaseline. It will now be interesting to know if the water is given off from one or both surfaces of the leaf.

30. To Find Where Transpiration Occurs.

Obtain leaves of the same size and weight from the same large leaved plant. Cover the upper surface of one leaf and the lower surface of the other leaf and the leaf stems (petioles) of both with vaseline. Balance the two leaves on the pans of a balance which has previously been put in a dry sunny place. Watch results for an hour or two. What has happened? Why? What does this show?

31. Water Rises Through the Plant Stem.

(a) Find a place where the soil is perfectly dry and yet covered with vigorously growing weeds. Cut some of these off a little below the surface with a hoe, leaving the ground level. After a few hours note the condition of the soil immediately around the plant. Where did the moisture come from? Place the freshly cut end of another plant against dry soil and see if the latter becomes moist. What do these two experiments show?

* * *

(b) Put the stem of a lily or snowball or of some other white flower in a vase of water colored with red ink. Observe the flower after several hours. A freshly cut clover plant or Impatiens (called touch-me-not and balsam) will give similar results. What is the result in each case? What does it show?

* * *

(c) Place in red ink the ends of several pieces cut from the young shoots of asparagus or of any other monocotyledon (for a list of monocotyledons see any botany) and watch for an hour or two the rise of the coloring matter by taking pieces of stem from time to time and cutting each back from the upper end until the colored portion is reached. Examine the cut surfaces and the outside of each stem from time to time with a magnifying glass and describe exactly the distribution of the coloring matter.

32. Transpiration Exerts a Lifting Power on the Water in the Stem.

Fit a one-holed rubber stopper into one end of a glass tube and through this hole pass the stem (freshly cut under water) of a leafy branch from an actively growing tree. Seal the stem in with paraffine. Fill the tube with cool boiled water and immerse the open end of the upright tube in a cup of mercury. Observe after a few hours. What has happened? Explain.

33. How the Plant Lessens Transpiration.

Allow a vigorous corn plant about a foot high to go without water for several hours. What is the effect? What one use of water to the plant is indicated by the drooping of the leaves? (Gives rigidity.) What effect does the rolling of the leaf have upon the amount of leaf surface exposed? How is this beneficial to the plant?

In passing through a field of corn on a very warm day many of the leaves will be seen to be very closely rolled. This is a very common phenomenon in the corn-growing states of the Mississippi Valley.

Among the uses of water to the plant we have observed the following: 1. Dissolves the plant foods contained in the soil so that the plant is able to use them. 2. Carries these foods into the plant through the root by the process of osmosis. 3. Distributes these plant foods to all the cells of the plant. 4. Gives rigidity to the plant, especially to the more succulent portions as leaves and flowers. 5. It is the most essential plant food in that it composes about eighty per cent of the green weight of the mature crop. 6. By transpiration removes the excess of heat produced in the plant cells by chemical and life processes (a function similar to that of perspiration in the human body).

Besides the uses mentioned above, water is known to be used along with carbon dioxide by the chlorophyll of the leaf in the making of grape sugar. The last named is one of the important foodstuffs of the plant and is stored up in the form of starch. We shall now try to find out some of the conditions necessary to the formation of starch by the plant.

34. Chlorophyll Necessary for Starch-Making.

Pour tincture of iodine diluted with water on a piece of cornstarch. Notice that iodine turns starch blue. Take a few blades of grass which have been covered by a board long enough to have lost all green coloring mater (chlorophyll), soak well in (wood) alcohol and then pour diluted iodine upon them. Treat green blades of grass similarly with alcohol and iodine. Is starch present in these? To what is the difference due? What is one thing necessary to the formation of starch by plants?

35. Sunlight Necessary for Starch-Making.

Pin or sew several strips of black cloth, such as alpaca, over the leaves of a growing geranium. Place the plant in a sunny window for several days. (This may be reduced to hours if the plant has previously been kept in a totally dark room for a day or two.) Place a few of these leaves so covered in wood alcohol until they become colorless and test for starch. Test some of the green leaves likewise. To what is the difference due?

36. Air Necessary for Starch-Making.

Take any small plant (as rose or lilac) whose leaves possess stomata on the under surface. Leave the plant in the dark room for several days (a box of proper size to accommodate the plant and totally darkened will do) so that the starch in the leaves may be completely used up. Remove the plant from the dark room and cover the lower surface of two or three leaves with vaseline. After a few hours' exposure to sunlight pick off the vaselined leaves and also some others from the same plant. Wash them in wood alcohol and then place them in iodine. What has happened in the case of the vaselined leaves? In the case of the other leaves? What does this experiment show?

The chlorophyll which we have found to be necessary in starch-making absorbs carbon dioxide through the stomata of the leaves and this it causes to unite with water under the influence of the absorbed energy (sunlight) to produce grape sugar. The following explanation is believed, at least, to approximate the correct one: Every molecule of carbon dioxide contains one atom of carbon and two of oxygen and every molecule of water contains two atoms of hydrogen and one of oxygen. When six molecules of carbon dioxide unite with six molecules of water they form one molecule of grape sugar, which contains six atoms of carbon, twelve of hydrogen and six of oxygen, and twelve atoms of oxygen are set free in the process. The oxygen returns to the air, as shown in the next experiment.

37. Growing Plants Give Off Oxygen.

Fill with water a glass funnel by immersing it entirely in water and corking at the small end before removal. Without allowing any of the water to escape invert the funnel in a (glass) jar of water over some pond scum or some other plant which grows naturally submerged in water and suspend it so that the large end will be just below the surface of the water. Leave in a sunny window for to or three days or until the bubbles which will be seen constantly to arise have displaced most of the water in the funnel. Remove the cork and quickly insert a glowing stick as directed in Experiment 8 (b). What is the result? What does this experiment show?

When the stored food (starch) is demanded for food by the plant it is again changed to grape sugar, for as we have seen in Experiment 14 (e) the starch cannot pass through the membranes which form the cell walls, while sugar can do so. In changing from grape sugar to starch each molecule of grape sugar loses a molecule of water. This leaves a molecule containing six atoms of carbon, ten of hydrogen and five of oxygen, which is the chemical composition of starch, so it is believed that the sugar is thus turned to starch. In changing back again from starch to sugar one molecule of water is added to each molecule of starch.

38. Test for Starch.

On the cut surface of potato, or the seeds of corn, beans, oats, and other seeds (leaves may be used) apply a minute drop of iodine. Is starch shown to be present? If not, boil in water the substance to be tested. By means of a splinter add to the water a drop of iodine. Stir again and look for a blue color. (A white earthenware dish would better be used in performing this experiment, or a piece of broken dish may be allowed to rest at the bottom of the liquid to be tested.) Is starch now shown to be present? (The boiling has broken down the cell walls within which the starch was contained so that the iodine could the more easily act upon it.)

Other parts of the plant than those tested contain starch, but its presence is more easily detected in the parts used because there is a greater supply of it to be found in seeds and leaves, especially in the former. The starch in seeds composes a large part of the food stored there for the young plantlet until it is able to get its own food from the soil and the air. Of course the new cells of the young plant cannot use the food in this form any better than can the cells of an older plant. The starch must therefore be changed to sugar before the young plant can appropriate it as food, and this change, as has been said in another place, is brought about by the enzyme diastase.

39. Test for Sugar.

Taste the seeds of rye, wheat, corn, sweet corn, pumpkins, and various other seeds (especially when just beginning to germinate), also various of the root crops, as radish, turnip, carrot, parsnip, etc. The slightest sweet taste indicates the presence of sugar in some form. How does the amount of sugar in a dry seed compare with that in a germinating seed?

Another compound which is made by plants is called protein (the different kinds of protein are referred to as proteids). This is a very important compound, because it is found in every cell of all plants and all animals and is about the only compound containing nitrogen used by the plant as building material. The plant makes proteids by combining sugar with nitrogen, phosphorus, and sulphur. Protein is therefore seen to contain at least six different elements. Animals must obtain all their proteids from the plants or from other animals which in their turn have obtained them from plants, because plants are the only organisms which can make this foodstuff. On the other hand, animals do manufacture within their bodies a kind of **starch** called animal starch or glycogen (formerly called liver sugar) which closely resembles that made by plants.

40. Test for Proteids.

[Two solutions are necessary for this test. To make solution No. 1, dissolve about one-fifth of an ounce of caustic potash (potassium hydroxide) in a two-ounce bottle of warm water (taking care not to let the potash or the liquid come in contact with the hands or clothing). Make soluion No. 2 by dissolving a piece of copper sulphate (bluestone) about one-half inch in diameter in a two-ounce bottle of warm water.]

(a) Pour a small quantity of the white of an egg, which is the best example of protein, on a white plate and barely cover with solution No. 1. Now warm the dish, but do not cook the egg. Next add a little of solution No. 2 and stir with a clean splinter. At first a greenish blue color will appear (due to the bluestone) and in ten or fifteen minutes a bright violet color begins to appear and to spread to all parts of the dish covered by the egg white.

* * *

(b) In a similar manner test seeds of wheat, rye, corn, flax, bran (the broken coat of the seeds of wheat, rye, and other cereals), etc., after they have been crushed or ground finely. Heat these for some time in solution No. 1 before adding solution No. 2. The purple color may not appear for several hours, so the experiment should be set carefully aside for observation later.

Explain the general presence of proteids in plants as was done in the case of starch.

A third compound found commonly in plants is fat. This, like starch, sugar, cellulose (the material out of which cell walls are made) and fiber (the material out of which the thread-like tissues like those of cotton and flax are made), is made up of the elements, carbon, hydrogen and oxygen, but all having a different number of atoms to each molecule.

41. Test for Fat.

Crush various seeds (castor bean, flax, cotton, corn) on a piece of clean white paper. If a grease spot appears fat must be present. If, in any case, this test should fail place the crushed seeds and paper in a tin plate and place over the alcohol lamp for a short time, taking care not to scorch the paper. Test nuts similarly.

It is the presence generally in plants of these three compounds, fats, starch (or sugar) and proteid, which makes them so valuable as food for animals, for the animal cannot manufacture any of these except the starch, as before mentioned.

42. Regions of Food Storage.

Test a cross section of parsnip with iodine. In which part is starch stored? Test another part with nitric acid and ammonia. Which part contains stored food (proteid)?

This series of experiments may well close with the subject of the storage of food since the food which the plant has stored up for itself in seeds and in fleshy roots is that which is also used for food by man and constitutes the sole aim of the farmer in the cultivation of most plants.

Teachers who take up the work outlined in this pamphlet should send to the United States Department of Agriculture, Office of Experiment Stations, Washington, D. C., and ask for Bulletin 180, entitled, "List of Publications of the Agricultural Experiment Stations of the United States." In this is given the title of every bulletin published by each of the various state agricultural experiment stations from the time of its establishment down to June, 1906. A glance through this list will reveal scores of helpful bulletins on various subjects suggested in this course, all of which may be had absolutely free by addressing the respective stations.

Each teacher should also ask to have sent to her address each month as issued a list of the publications issued by the United States Department of Agriculture itself and also the monthly list of publications issued by the state experiment stations. Both these lists may be had free upon application to the department at Washington. The bulletins issued from time to time by the California Agricultural Experiment Station, at Berkeley, will also be found to be very helpful because they deal with local conditions. A number of very valuable bulletins may be obtained from the Bureau of Soils, which is one of the bureaus of the United States Department of Agriculture.

Books Recommended.

[Any of the books named below may be obtained at list prices of Cunningham, Curtiss and Welch, Booksellers and Stationers, San Francisco.]

Experiments With Plants (Osterhout), MacMillan.

First Principles of Agriculture (Goff & Mayne), American Book Company.

Rural School Agriculture (McGill-Warner Company), St. Paul.

Agriculture (Soule & Turpin), B. F. Johnson Publishing Company, Richmond.

First Principles of Agriculture (Voorhees), Silver, Burdett & Co.

Among Country Schools (Kern), Ginn & Co.

Agriculture for Beginners (Burkett, Stevens & Hill), Ginn & Co.

Principles of Agriculture (Bailey), MacMillan Company.

First Principles of Soil Fertility (Vivian), Orange Judd Company.

The New Earth (Harwood), MacMillan Company.

New Creationes in Plant Life (Harwood), MacMillan Company.

More advanced texts:

Rural School Agriculture (Davis), Orange Judd Company.

Agriculture Through the Laboratory and School Garden (Jackson & Daugherty), Orange Judd Company.

Soils (Hilgard), MacMillan.

Soils (Burkett), Orange Judd Company.

Soils (Fletcher), Doubleday, Page & Co.

The Soil (King), MacMillan Company.

The Soil (Hall), E. P. Dutton & Co.

Physics of the Soil (King), F. H. King, Madison.

Pamphlets.

Course in Nature Study and Agriculture for the Elementary Schools of California, Riley O. Johnson, Chico, California.

Exercises in Elementary Agriculture (Crosby), Bulletin 186, Office of Experiment Stations, Department of Agriculture, Washington, D. C.

Simple Exercises Illustrating Some Applications of Chemistry to Agriculture (Hatch), Bulletin 195, same address.

(Practically all of the experiments in Mr. Hatch's bulletin have been woven into the course outlined in this pamphlet).

COMPLETE LIST OF

Materials Necessary for Experiment Work

[These materials may be purchased from Justinian Caire Company, Dealers in Laboratory Supplies, 573 Market St., San Francisco, Cal., at an approximate cost of $5.00.]

2 only, Ordinary Test Tubes 5-inch.
1 only, Hard Glass Test Tube 5-inch.
1 pint Alcohol (denatured).
1 lb. Paraffine.
1 only, Bottle Vaseline.
2 only, Thermometers 110 C.
1 Charcoal Stick.
¼ lb. Sulphur.
¼ lb. Chlorate of Potash.
1 oz. Red Oxide of Mercury.
¼ lb. Zinc.
1 lb. Ammonia.
1 Book, each, Litmus paper (red and blue).
1 oz. Cochineal.
1 oz. Potassium Hydroxide, pure sticks.
1 oz. Sodium Hydroxide, pure sticks.
1 oz. Iodine.
3 only, Students' Lamp Chimneys.
2 only, Glass Tubes 6 inches long and ⅛-inch internal diameter.
5 only, Glass Tubes 8 inches long and varying from 1-16 to ¾-inch internal diameter.
1 only, Glass Tube 12 inches long, ¾-inch internal diameter and 1-hole rubber stopper to fit.
1 only, Glass Funnel 5-inch.
¼ lb. Copper Sulphate.
1 lb. Mercury.