LABORATORY MANUAL
FOR
ELEMENTARY BOTANY

BY

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PREFACE

No written series of directions or manual for the student, however skillfully compiled, can be successfully used as a substitute for good teaching on the part of the instructor himself. The temptation is perhaps to lean too heavily upon text-books and laboratory outlines, especially in large elementary courses where certain of the methods of "mass production" must necessarily be employed, and to regard the instructor, particularly in laboratory courses, rather as an executive whose duty is to make a well-organized machine run smoothly than as a personal guide and stimulus to the individual student. All teaching would be more effective if there were no intermediary between teacher and learner, but where the instructor is responsible for large classes in the laboratory, with the often involved and technical procedure there required, it is essential that a means be found for relieving him of some of the more mechanical details of explanation and direction. To supplement the work of the instructor, but by no means to supplant it, is thus the purpose of any laboratory manual.

The present Manual has been written in response to requests for a series of laboratory exercises to accompany the author's "Botany: Principles and Problems," and is in large part a codification of the laboratory procedure which has been worked out in his own course. Most of the experiments and descriptive exercises will be familiar to teachers of elementary botany, but they are here simplified as much as possible and presented in a form which experience has shown to be most workable and effective. A minimum of expensive apparatus and material is called for, though of course superior equipment will improve the quality of the work. The author has made frequent use of Professor W. F. Ganong's valuable series of normal apparatus.

The exercises in general follow rather closely the presentation of topics in the author's book, but they could well be used to accompany any standard elementary text. They are by no means exhaustive, and exigencies of equipment or material may necessitate omissions, substitutions, or changes in order.

An attempt has been made to avoid the chief danger of most laboratory work—a degeneration into mere mechanical routine—by requiring the student to find answers to a considerable series of questions about his material and to record his experiments in a thorough and critical fashion.

The author wishes to extend thanks to his colleagues, all of whom have been of valuable assistance in the development of the laboratory course on which this Manual is based; and especially to Professor G. S. Torrey for many suggestions and for a critical reading of the manuscript.

E. W. SINNOTT.

CONNECTICUT AGRICULTURAL COLLEGE,
July, 1927

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Laboratory work is in many respects the most important part of a course in botany, for by its means the student becomes acquainted with plants through direct study of the plants themselves and not from someone else. To help him in taking intelligent advantage of the opportunities offered by laboratory study is the object of a Laboratory Manual. Such a book should by no means tell anyone what to see but should suggest to him some of the important objects for which to look and formulate the problems which he will endeavor to solve. It should also provide directions for a satisfactory procedure whereby to accomplish these ends.

Rightly used, such a Manual may be of great service and is often indispensable; but there is grave danger that any set of suggestions and directions may tend to become a substitute for active thought and that the laboratory work may thus degenerate into a merely mechanical process of grinding out certain required notes and drawings and thus entirely fail of its purpose. To avoid this the student should endeavor to maintain constantly an attitude of thoughtful interrogation. He must "ask the plant," using the Manual or the instructor only for information which cannot be otherwise obtained. In the present book a considerable number of such questions are proposed; but many others will occur to one who approaches his task with real interest, and in finding the answers to these he will gain far more than the mere completion of a required laboratory routine can ever give. When one acquires an automobile, he naturally becomes intensely interested in learning how it is put together and how it "works." If in the same spirit he approaches a study of the structure and operation of the plant as a living machine, he cannot fail to acquire a real understanding of plant morphology and physiology.

Characteristics of Good Laboratory Work.—The important objective of laboratory work is an understanding of plants and their activities, but in order to crystallize and clarify the results and conclusions obtained there and to record them in suitable form for future reference, it is necessary to make somewhat extensive written notes and drawings. Certain desirable qualities in these laboratory records should always be borne in mind.

Neatness.—Neatness in a laboratory report is an indication of care in its execution and is the mark of a certain mental orderliness indispensable for scientific accomplishment. A careless and "sloppy" record is not only unsatisfactory in itself but betokens the lack of a proper attitude toward one's work. Cleanliness of execution, an abstention from soft, smudgy pencils, and a little thought as to arrangement of the notes and drawings will add vastly not only to their appearance but to their value.

Accuracy.—It seems hardly necessary to say that the laboratory records should be as accurate as it is possible to make them, but accuracy seems not to be a natural and easy virtue. One is often tempted to be satisfied with a given observation or result if it is approximately correct. There is also a persistent tendency to be biased in an observation by the thought of what one ought, or expects, to see. The ability to observe and to describe a fact exactly as it is constitutes a valuable scientific accomplishment and should be one of the important by-products of laboratory work.

Completeness.—In every laboratory exercise there is a certain series of objectives, set forth in the Manual or by the instructor, which must be attained; but these represent only the *minimum* results that may be gained. A keen observer will be able to see much more than these, not only as to actual facts but as to the various implications which these facts suggest. There is more to be found in all the exercises than appears at first glance, and the success of a student in the laboratory will be measured very largely by the thoroughness and completeness with which he covers the field.

Laboratory Notes.—Good notes are first of all neat and legible; and when written with pen or medium soft pencil they will be much easier to read than if the drawing pencil is used. If notes are confined to only one side of the paper, and only one laboratory exercise is presented on each page, the danger of confusion is minimized.

Care should also be taken in the composition itself not only to attain correct spelling, punctuation, and grammar, but to present every statement with clarity and conciseness. Many laboratory reports are injured by being excessively "padded" with superfluous and poorly written material.

New technical terms, introduced from time to time in the laboratory work, must be understood and made familiar. A good glossary is useful for this purpose, but perhaps a more effective means is for the student to build up his own glossary, adding thereto each new term as it appears and defining it in his own words. A few pages at the back of the notebook may be reserved for this purpose and will make a valuable addition to the laboratory record.

Laboratory Drawings.—It is not meant that an undue length of time should be spent in making drawings, but a certain amount of effort thus devoted will stimulate one to observe more carefully and exactly than he otherwise might and will tie the facts into his mind more firmly. Good drawings also constitute a valuable record of work for future reference.

Successful scientific drawing is by no means difficult of accomplishment if a few simple rules are observed.

Drawings made with a rather hard pencil, 4H or 6H, are much more satisfactory than those with a softer one, for the latter smudge badly and soon look very untidy. The pencil point must be kept sharp, and every effort exerted to make all the lines of the drawing clear, clean, and firm. If the hand and forearm are rested on the table, and trembling thereby eliminated, such a line is much easier to attain. If the drawing is constantly turned so that the convex side of the curves is always away from the hand, the wrist or elbow may be used as a pivot and a much smoother result secured. It is often useful to sketch in a drawing with a light line until it is satisfactory, then erase almost to invisibility and finish with a smooth dark line.

Irregular and "scratchy" lines often conceal more than they reveal, and frequently give an erroneous impression. Make every line represent an actual fact in the object studied. Shading and other means to produce "artistic" effects are time-consuming and very difficult to use successfully, and they may often be a positive hindrance. Simple line drawings, in many cases even semi-diagrams or diagrams, are far more satisfactory, for by their means the essential facts to be portrayed may be brought out and emphasized and the irrelevant details eliminated. Much of the skill in scientific drawing consists in knowing what *not* to draw.

A common excuse for poor laboratory drawings is that the student has no artistic ability; but training and natural aptitude are by no means essential for satisfactory attainment here. Drawings of this kind are merely the record and measure of what the observer sees; and if he can see an object clearly and understand it thoroughly, he will be able to portray it in an accurate and satisfactory manner. Seeing a thing is really very much harder than drawing it!

Drawings of scientific apparatus should be made with a ruler wherever possible. Sectional views or elevations, such as are used in simple mechanical drawings, which show the internal construction of the apparatus, are not only very much clearer and more useful than external pictures but are far easier to make.

It is very important to plan the size of the drawing and to lay out its proportions on the sheet before any of the actual work upon it is commenced. Drawings that are too small are hard to decipher and very large ones tend to be awkward. In many cases the relative size of parts in a drawing of apparatus may be changed so as to make a more compact and understandable representation without losing any essential fact. Where more than one drawing is placed on a page, care should be exercised to have them well spaced and harmoniously arranged. It is best to use only one side of the paper.

There is much opportunity for the use of good judgment in the amount and character of the labelling. If the words used are written or printed horizontally, at some distance from the drawing itself but connected therewith by straight dotted lines, they serve their purpose well without detracting from the neatness and clarity of the drawing.

The Descriptive Exercise.—Those laboratory exercises which have as their object a study of the structure of plants are necessarily descriptive in character and consist chiefly of a careful observation of the plants themselves, either by the naked eye, the hand-lens or the microscope. At the beginning of such an exercise it is important to study the material very carefully, seeking answers not only to the questions asked in the Manual but to as many others as may come to mind. Certainly before notes or drawings are begun, it is essential that there be a clear perception of just how the particular plant or plant part under observation is constructed. Wherever possible, it is also highly desirable to gain a knowledge of the functions of the various parts observed; for by this means their structures will be much more easily understood and the student will be continually reminded that the plant itself is a living, active organism even though the material which he is studying happens to be dead. An ability to put one's self "inside the plant" is very useful for a comprehension of its construction.

The Use of the Microscope.—For the study of many of the smaller types of plants and of the details of structure of the larger ones, the use of a compound microscope is essential. The instructor will explain the construction of the instrument and the way in which it should be used. A few suggestions, however, may perhaps be emphasized here.

Adequate Light.—In setting up the microscope, be sure that a satisfactory source of light is accessible and that it is properly projected through the instrument by the mirror. Never be satisfied unless the whole field of vision, as seen through the low-power objective, is brilliantly illuminated, even though it may later be necessary to reduce the size of the light opening. With the high-power objective, the concave mirror should almost always be used.

Clean Glass Surfaces.—Unless the lenses of ocular and objective, and the surfaces of slide and cover-glass, are entirely clean, the usefulness of the microscope will be very seriously hampered. Dirt and grease not only reduce the light and blur the image, but may conceal objects of importance. The microscope magnifies dirt as well as it does everything else, and a skilled microscopist is known by the scrupulous care with which he keeps his slides and lenses clean. The lens surfaces should never be polished by anything harsher than lens paper. An old, soft cloth is excellent for cleaning slides and cover-glasses.

Proper Magnification, Aperture, and Focus.—Even with excellent light and clean glass surfaces, full advantage of the microscope cannot be obtained unless its mechanism is used intelligently.

The penalty for the increased magnification which the microscope secures is a much reduced field of view, and the higher the magnification employed, the smaller this field becomes. For this reason, objects should always be located by use of lenses of relatively low power and studied, so far as possible, by the same means.

With these low powers and particularly with bright light, the objects are more sharply defined if the size of the light aperture is reduced, and this should always be regulated so as to give the best results in each case.

When a low magnification is insufficient and a higher one must be used, particular care is required. The most brilliant illumination possible is usually necessary and to this end the diaphragm should be opened widely and the concave mirror employed. Furthermore, the technique of focussing is of very great importance under these conditions. At a given position of the lenses the level at which objects can be seen sharply, or are in focus, is a very narrow one, and objects just below or just above this level are much blurred or quite invisible. Since the lens is so close to the slide, a relatively slight change in the height of the objective alters markedly the level of sharp focus; and thus by a careful manipulation of the micrometer screw, or fine adjustment, the entire depth of the preparation on the slide may readily be explored. It is quite impossible to study an object under the high power of the microscope satisfactorily, particularly if it has any considerable depth, without careful and constant focussing; and the experienced microscopist may always be recognized by the fact that when he uses a high power he is continually turning the micrometer adjustment of his instrument up and down, and thus exploring the various levels of his preparation.

Cautions.—In endeavoring to locate an object under the microscope, particularly when using a high power, one should never focus *downward*, for in so doing he may pass the focal level without discovering it and ruin his preparation by forcing the face of the objective against the cover-glass. This danger may be avoided by setting the objective below the focal level and focussing upward till this is reached.

The eyes will tire much less rapidly in microscopic work if the observer does not squint but keeps both eyes open; and with a little practice it is possible to do this readily, heeding what is seen by the eye looking into the instrument and disregarding the images in the other eye.

The utmost care should be taken of the lenses, particularly those of the objectives. No objective should ever touch a cover-glass. If wetted by liquid in which the material is mounted, it should be carefully dried with lens paper. Objectives are to be removed from the instrument only when it is absolutely necessary to do so, and every precaution should be taken to keep dirt from entering them. When the microscope is not in use it is well to set the low-power objective over the aperture and place the instrument under a dust-proof cover.

The Experiment.—An experiment involves not only careful observation of a given object but the performance of a definite *test* of that object, under controlled conditions, to answer a definite question. We conduct experiments with plants primarily to determine what they *do*. Observation alone will ascertain the facts of a plant's structure, but to discover its activities and functions we must make it perform some of these under experimental conditions. In order to learn the structure of a leaf, for example, one needs only to examine it carefully with the naked eye, hand-lens and microscope. To determine whether starch is manufactured by the leaf, however, or whether water is evaporated from its tissues, or to learn how fast these processes take place, carefully planned and controlled experiments are necessary.

The value of an experiment will depend on a number of factors, such as the character of the material used, the quality of the apparatus, the skill of the experimenter, and the manner in which the experiment is planned.

A good experiment endeavors to answer only a single question, and in as simple a form as possible. To do this, all the conditions except one should be kept constant, and this one carefully controlled. In determining whether light is essential in the production of starch in leaves, for example, a plant may be transferred from the light to a dark chamber, but it is important to see that no other environmental factors, such as temperature, humidity or soil moisture, are changed at the same time. In many cases it is possible to set up, beside the experiment itself, a *control*, in which all the apparatus and conditions of the experiment are duplicated except the particular one under investigation; and to this latter factor, rather than to any uncontrolled conditions, may then safely be ascribed any differences between the results obtained in the experiment and the control.

Ideally, all experiments should be performed by the student himself, but in many instances they must be carried out by the instructor alone. In any case, it is well to follow a rather definite and uniform method in the recording of experiments, for they all have certain features in common. A useful series of subdivisions of the experimental record is as follows:

Object
Apparatus
Procedure
Results
Sources of Error
Conclusion
Significance

In the report of any experiment these headings (or similar ones) should each be written, preferably on ruled paper; and may well be set off in some way, as by paragraphing or underlining. Under each heading is then to be made a concise statement for the particular experiment in question.

A few suggestions may be offered as to the important points to note and record under each of these headings.

Object.—This gives the purpose of the experiment or the question which it is designed to answer. In the present Manual the object is always stated.

Apparatus.—The apparatus used in the conduct of the experiment may sometimes be described simply and completely in words. In most cases, however, drawings, preferably made separately from the notes and on sheets of drawing paper, will also be found necessary. Drawings of the mechanical portion of the apparatus should be as simple and workmanlike as possible, and in every case portray the object as if seen in section, by this means making clear the structure and arrangement of parts which cannot be observed from the outside. Every piece of apparatus used should be enumerated, but certain familiar though complicated items, such as platform balances and electric ovens, may merely be mentioned.

The living plants or plant parts studied, although not apparatus in the strict sense, should be described and drawn here.

Procedure.—Here is to be made a complete statement of the manner in which the experiment is carried out. Reasons should also be given, in every case, for performing the experiment in one way rather than another, when two possible courses are open; and for such precautions as are taken to guard against erroneous results.

Results.—Here are to be stated the actual results of the test or tests which are made in the experiment. They should be recorded promptly at the time they are obtained. Whenever possible, results should be expressed in terms of some unit of measurement, and if thrown into the form of a table or graph they are usually much more clearly presented. In many cases, drawings of the material or apparatus, showing the result of the experiment, must also be made. Care should always be taken not to confuse results with the conclusion to be drawn from the results.

Sources of Error.—Inaccuracy of measurement or lack of skill in manipulation may lead to worthless results; but there are other sources of error, inherent in the experiments themselves, which cannot be overcome by faultless procedure and may seriously vitiate the results. Although he may not be able to overcome these, the careful experimenter will always strive to recognize their existence and will take them into consideration in evaluating his results. In an experiment to determine the rate of evaporation from leaves, for example, by the use of a shoot cut off and placed in water, there is an unavoidable source of possible error in the fact that a shoot may behave very differently under these conditions from the way it would if attached to its own roots. Probably no biological experiment is entirely free from errors of this kind, and they have often led to serious discrepancies in the results of presumably