A Manual for Writing a Science Research Paper

Grades 7-12

This paper includes all of the topics that need to be covered in a science fair paper. The style of the sample paper is just an example. You may use the preferred style of you school if one exists.

A Word to the Student

The ability to communicate effectively by means of the written word is essential to all scientists. Those investigators who have made contributions throughout history have allowed science to progress to where it is today only because they recorded their discoveries in precise and comprehensive ways.

As a student researcher, you are a practicing scientist of the "new generation." You have conducted a study, performed experiments, gathered and interpreted results. The time has now come for you to communicate to others what you have discovered from your research. The purpose of this booklet is to serve as an appropriate guide for you to report your findings to others. Although the writing style recommended in this booklet is not "etched in stone," it will provide you proper guidance in writing your research paper.

We anticipate that you may be entering your research project in one or more science competitions in the near future (e.g., The Greater Kansas City Science and Engineering Fair, the Kansas Junior Academy of Science, the Missouri Junior Academy of Science, etc.). A research paper written by following the guidelines outlined within this style manual will be acceptable in all such events. You do need to be aware, however, that each competition has its own requirements for entry, and specific entry material must be obtained from the directors of each event you choose to enter.

Table of Contents

I. Introduction

The format of a science paper includes three categories of materials: (1) The Preliminaries, (2) The Text of the Paper, and (3) The References. The various components occur in the order shown below.

Quite often, the sections are described by other names. Not *every* paper contains *all* the items listed. The choice of items depends on your project.

Proper usage of the English language and correct spelling must be observed at all times. You may receive additional help from your science or English teacher in regard to the proper rules of writing.

Third person, past tense should be observed in writing the science paper. You should, whenever possible, avoid direct reference to yourself.

> Incorrect: "I then devised a new method ..." (First person, past tense.)
> Correct: "A new method was then devised ..." (Third person, past tense.)

If you find it necessary to refer to yourself directly, you may do so as: "The writer then devised a new method."

A science paper is usually typewritten. Only one side of each sheet of paper is used.
(See Sample Research Paper, page 8.)

II. General Outline of the Paper

The Preliminaries
- Title Page
- Abstract
- Table of Contents
- List of Tables, Graphs, Figures, or Photographs (if any)

The Text of the Paper
- Introduction of the Investigation
  - Review of Literature
  - Statement of the Problem
  - Hypothesis(es)
- Procedure of Investigation (Experimentation)
- Discussion of Data (Results)
- Statistical Analysis (if applicable)
- Interpretations/Conclusions
- Future

Final Sections
- Appendices (if desired)
- Acknowledgments (if desired)
- References (Literature Cited)

III. Detailed Explanations

The Preliminaries

Title Page

The title should be brief, but accurate and comprehensive. It should be phrased to limit accurately the subject under discussion and promise no more than the investigation attempts to cover. Effective titles are often composed of three or four main words or groups of words. (Refer to the sample title page on page 8).

Abstract

An abstract is to be submitted as part of your paper. It is perhaps the most important section of the paper and the most difficult to write. Although the abstract is usually read first, *it should be written last* to ensure that it accurately reflects the content of the paper. An abstract should be informative, summarizing the principal facts and conclusions of the paper. A person should not have to read the paper in order to understand the abstract. You should assume that the reader has some knowledge of the subject but that he/she is not familiar with the details of your investigation.

The abstract should indicate the subject dealt within your paper and should state the objectives. The methods you used in obtaining the results should be included. The findings should be summarized, remembering that it is better to say, for example, "The heart rate was found to be 82 beats/minute," than "The heart rate was measured." *Do not* include tables, illustrations, preliminaries, descriptive details, numbered equations, or footnotes in the abstract. Finally, keep the abstract to one paragraph and no longer than 250 words.

Center the abstract on the page with right and left hand margins several spaces wider than the rest of the manuscript. Single space the abstract. (See the sample of an abstract on page 9.)

Table of Contents

The relationship between main divisions and subdivisions is shown by the appropriate use of indentation and capitalization. All headings in the Table of Contents should correspond exactly in wording with the headings as they appear in the text of the paper.

The main headings of the Table of Contents are written in full capitals, with no terminal punctuation, and are consecutively numbered in capital Roman numerals. If a heading requires more than one line, the second and following lines are indented five spaces in from the first letter of the first line and are double-spaced.

List of Tables, Graphs, Figures or Photographs (if any)

For each table, graph, figure, or photograph its number, exact caption or title, and page number are given. The first letter of important words is capitalized. Items should be numbered consecutively in the order they appear in the text and the page number for each given.

The Text of the Paper

Introduction of the Investigation

Review of the Literature

You should present a brief review of the history and present status of the subject, citing truly pertinent information. Terms used here, or later in the paper, should be identified. Citing of references is achieved by including the name of the author(s) and the year of publication either in parentheses following that to which it applies or incorporated directly into the text of the paper. (See examples on page 7). All references cited must be properly credited in the References section of the paper.

Statement of the Problem

The statement of the problem begins by relating the information gathered from observations and/or from the literature read that led you to your problem. The problem under investigation or experimentation is stated clearly and completely. This statement should be concise, brief and very carefully composed. Often it is helpful to state it as a question.

Hypothesis(es)

You should use information gained from the review of the literature as a basis for stating a possible solution to the problem. This "tentative" answer to the problem is your hypothesis. Although hypotheses may be written in a variety of ways, it is recommended that you use either the "**If-then**" format or the "**If-then-will**" format in writing your hypothesis. Each helps to organize your thinking and focus on a logical prediction.

The "**If-then** format: This means that you express your hypothesis as an "If-then" statement. The "**If**" part of the statement describes the environmental conditions under which your experiment was set up and identifies the independent (experimental) variable you manipulated in your experiment. The "**then**" part describes what you predicted would happen at the end of your experiment and identifies your dependent variable (i.e., the variable that you ended up measuring).

Example: "**If** the temperature of the water surrounding the fish is increased, **then** the fish will breathe faster."

The **"If-then-will** format: This way of stating your hypothesis is similar to the format described above. It differs in that the "**If**" statement is an *assumption* you made based on some information you found in your literature search. The "**then**" part describes the test or environmental conditions under which your experiment was set up and identifies the independent (experimental) variable in your experiment (i.e., the variable you intentionally changed). The "**will**" part of your hypothesis is a *prediction* of what you thought the results would be at the end of your experiment. It should also identify your dependent variable (i.e., the variable that you ended up measuring).

Example: "**If** raising the body temperature of amphibians (frogs and toads) increases their rate of metabolism, **then** increasing the water temperature surrounding goldfish in an aquarium **will** cause them to breathe faster."

Regardless of which format you choose to use, the thing to remember is to gather data from your experiment that, when analyzed, will allow you to support (accept) or refute (reject) your hypothesis.

Procedure of Investigation (Experimentation)

This section may also be called the Experimental section or the Methods section.
Here, you very carefully record step by step the manner in which the experiment was performed. The key to writing this section is that upon completion, there will be enough detail to allow the experiment to be repeated by others. You should give special care to include critical details (controlled variables) which influence the reliability of the results along with identification of controls, safety measure, etc., where appropriate. A detailed description of materials and equipment used should be included, providing illustrations of any non-standard equipment. Commercially available instruments should be named or listed, but should not be described.

You should describe how your data was collected. Include such things as: how often measurements or readings were made, the units of measurement used, the instruments used to make the measurements, etc. Remember, too, all measurements are to be made in metric units. For experiments involving established procedures, the name of the procedure should be sufficient.

If a procedure, other than a statistical one, was used to test the accuracy of the results, describe it in detail in this section or place it in the appendices section.

Discussion of Data (Results)

In this section you objectively review the data collected. Graphs, plates, and figures may be used to aid in displaying the data to the reader. If included, however, they should be discussed in the written portion of this section.

Any statistical test that was applied should also be discussed, and any important features or limitations of the work should also be noted. All numerical data should be reported in metric units.

Do not attempt to give inferences or interpretations of this section. That is to come later in the Interpretations/Conclusions section.

Statistical Analysis

When you or any other researcher conducts an experiment, you expect differences or changes to occur in the data that you collect. These differences inevitably lead to the question, "Are the observed differences I am seeing in this data due to the experimental treatment or are they due to chance?" Although you will never know for certain or "prove" the answer to this question, you can gain confidence in deciding the answer one way or the other by analyzing the data statistically.

There are many statistical tests available. The test you end up using will depend on the type of data you plan to collect or perhaps, ended up collecting. It is always best to determine the kind of data you plan to collect and choose the statistical test you are going to use *before* you conduct the experiment, but students often don't realize this until after the experiment is completed. Once you know which test to use, you may check with your math or statistics teacher to learn how to use this test. If, after having done this, you still need assistance, contact Science Pioneers at (816) 460-2261 and we will guide you to a statistician who can assist you.

Interpretations/Conclusions

This is one of the most important sections of your paper. Here you should explain the meaning or significance of your experimental results. Answers to such questions as the following should be presented. What do the data show and what do they mean? Did the data allow you, the researcher, to support or accept the hypothesis or do the data call for the hypothesis to be refuted or rejected? Were you able to accept or reject in a statistical sense your null and alternative hypotheses based on the statistical analysis of your data? What is the relationship between the variable that was changed in the experiment and the variable that was observed or measured (i.e., what was the effect of the independent or experimental variable) or the dependent variable? An important thing to remember is that any interpretation or conclusion you make *must be supported by the data you gathered in this investigation.*

Future

If appropriate at this point, you should include ideas for future investigation of this problem or for new problems posed as a result of this investigation. Remember, science is a continuing process that never comes to an end.

Final Sections

The principal headings in this part of your paper should be typed in the same manner as for the rest of your paper. They should be typed in all capital letters and horizontally centered on the page.

Appendix

The appendix can be used to present supplementary material which (a) are necessary for completeness but which, if inserted in the main body of your paper, would detract from the orderly and logical presentation of the work (e.g., raw data, statistical data, etc.) or (b) may well be omitted by the general reader but would be valuable for the specialist in the field. You may have more than one appendix. If so, the plural form of this word is *appendices*.

Acknowledgments

Contributions of persons, other than co-authors, who have helped you substantially with your investigation should be acknowledged in a separate section in your paper. Recognition of assistance should be stated as briefly as possible. It is customary to acknowledge any financial support that you received for your investigation as well as borrowed materials and equipment.

References (Literature Cited)

This section is to be the last page of your science paper. The two most common headings used for this section are "References" and "Literature Cited." References are listed numerically in the order they appear in the body of the paper. Literature Cited, which *includes only the works cited in your paper,* are to be listed in alphabetical order by author's last names, (see sample on page 18). The articles that you include in your list have either been published, are scheduled to be published, or have been deposited in libraries as theses or dissertations.

The style for a bibliographic list depends upon the system of citation used in the different scientific disciplines. Most journals in the biological sciences uses the author-data system. In the physical sciences a number system is used.

If you choose to use the author-date system, then the name(s) of the author(s) and the year are included in the text of your paper as shown on the following page.

Example:

One author: Bellrose (1950) reported that ... or ... C3 plants use CO2 (Jones, 1965).
Two authors: Smith and Brown (1972) reported finding ...
Three or more authors: Johnston, et. al., (1968) reported that wood ducks were once abundant in Illinois.

In your bibliographic list using the author-date system, the entries are listed alphabetically by author. The main parts of a complete entry for a book are (i) name(s) of author(s), (ii) year of publication, (iii) title of book, (iv) name and city of publisher, (v) number of pages in book (not necessarily in this order).

Example:

Smith, John, and Sue Brown. 1972. *Invertebrate zoology.* McGraw-Hill, St. Louis. 400 pp.

If you choose to use the number system as is customary in the physical sciences, list references in the order in which they are cited in your paper. Number entries and carefully check citation numbers in the text of your paper against the final reference numbers.

Use numbers enclosed in parentheses to key each entry in your bibliography as in the following examples.

A full understanding of the cause of the darkness of the night sky was not obtained until Harrison published his solution to the problem in 1964 (12).

or

More recently Charles (9) has given a detailed explanation of the hierarchical structure of the universe.

The main parts for a journal entry in this system are (i) name(s) of author(s), (ii) title of article, (iii) name of journal with volume, (iv) initial page number, (v) year of publication. Each entry is preceded by a numeral keying the reference to the paper and followed by a period. An example is:

2. G. E. Doe and P. S. Roe, "The development of the beatron," *Am. J. Phys. 20*, 298 (1952).

Proper usage of the English language must be observed and all words must be correctly spelled. You may receive help from your science or English teacher.

A general reference book or style manual for expository writing may be useful. Check with your English teacher for suggestions. The most extensive reference is the *CBE Style Manual*, prepared by a committee of the Council of Biology Editors and published by the American Institute of Biological Sciences, Washington, D. C. The American Chemical Society has a *Handbook for Authors*, and the American Institute of Physics publishes a *Style Manual*.

When citing Internet resources you need to include the date you viewed it, as some pages can change over time. For more details on citing web pages go to, www.sciencebuddies.org/science-fair-projects/project_biblio.shtml for latest instructions.

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The Effect of Darkness on the Stomata of Leaves

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A Science Paper

Presented to

The Greater Kansas City Science and Engineering Fair
(This may vary depending upon the science event you are entering).

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by

Student's Name

ABSTRACT

This study was concerned with the effects of darkness on the opening and closing of stomata in plant leaves. The researcher selected *Tradescantia zebrina*, a type of monocot commonly called Wandering Jew, for the investigation. Four *Tradescantia zebrina* plants were taken from under a light bank where they had been exposed to simulated sunlight for 12 hours. Two of the four plants were exposed to visible light and the other two were placed in the dark simultaneously for a period of one hour. At the end of one hour, the upper and lower surfaces of the three leaves closest to the base of the stem of each plant were painted with a thin coat of collodion. This was to make collodion imprints of the stomata in the upper and lower epidermis of each leaf. After drying, the collodion was peeled off of each leaf and the stomata imprints examined with a compound light microscope at 400X to determine the percentage of open stomata. The imprints showed that all stomata were open. These results led the researcher to increase the amount of time the plants were kept in the dark. Thus, this procedure was repeated with the time of darkness increased to three hours. Collodion imprints of the leaves of each were again made and examined microscopically for the presence of open and closed stomata. It was found that one hour of darkness has little effect on the closing of stomata in *Tradescantia zebrina*; however, three hours of darkness caused closing of 60% of the stomata studies, which was statistically significant at the .01 confidence level.

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INTRODUCTION OF THE PROBLEM

Statement of the Problem

Stomata, the microscopic pores or openings in the epidermis of terrestrial plant leaves, play an important role in a plant's metabolism since they permit the exchange of gases between cells of the leaf and the surrounding atmosphere (Miller, 1994). Indeed, the carbon dioxide that terrestrial plants use to make glucose and the oxygen they produce in the process pass through these micropores. If the cause of their opening and closing can be learned, perhaps the rate of the plant's photosynthetic process could likewise be increased, thus increasing the rate of plant growth and/or crop production in the world (Campbell, 1993).

The above information led the researcher to study the effects of darkness on the opening and closing of stomata in plant leaves.

Review of Literature

York (1969) found that stomata of corn leaves would remain closed during daylight hours in winds of over 5 mph if the relative humidity was less than 50%. Little (1972), in a study of 36 species of deciduous hardwood trees, found that leaf stomata were closed within three hours after sunset. However, this study was conducted in Florida where the relative humidity is very high (75%-85%) during the growing season for these trees. Adams (1974) discovered that temperature did affect the opening and closing of stomata in rye grass in a relative humidity of 50%.

It has been further observed by earlier investigators (York, 1969; Adams, 1974) that stomata are generally open during the day and closed at night. One might assume that visible light (i.e., electromagnetic radiation with wavelengths between 380 and 720 nm) or darkness is the controlling factor that causes this. However, since temperature usually decreases while humidity increases at night, these variables should also be considered.

Young (1995) discovered that the concentration of glucose inside of the guard cells that surround stomata increased relative to the concentration of glucose in epidermal cells during daylight hours. This indicates that photosynthesis may be taking place in guard cells more so than in the surrounding epidermal cells. This increase in glucose concentration leads to an increase in turgor pressure inside the guard cells, which, in turn, opens the stomata (Campbell, 1993).

Hypothesis

This information led the researcher to formulate the following hypothesis:
If visible light is needed to increase the turgor pressure in guard cells in terrestrial plant leaves, then placing *Tradescantia zebrina* plants in the dark will cause their stomata to close.

PROCEDURE OF INVESTIGATION

The plant *Tradescantia zebrina*, commonly called Wandering Jew, was chosen for this investigation because it was recommended by several references and it is easily grown in the laboratory (Ganong, 1985). Ten plants having six leaves each were used in all – eight for the experiments and two for back-ups. Each was planted in a mixture of six parts garden loam and three parts sand in a 250 ml styrofoam cup with five holes punched in the bottom for drainage.

Next, a tent was built in which to put the plants for the experiment. The tent was constructed of a wooden frame with a transparent, plastic covering as shown in figure 1.

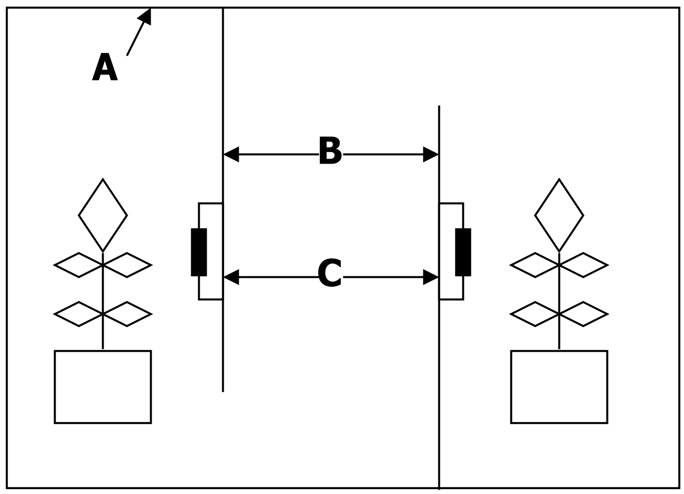

Figure 1. Tent used for tests.

(A) Transparent plastic covering (B) Partition made of plywood
(C) Wet-bulb hydrometer and thermometer

For each test the tent was placed by a window in an indoor room of the tent. A wet-bulb hydrometer and thermometer were placed in each compartment so that relative humidity and temperature could be monitored.

A dark cloth was placed over one side of the tent. At the end of one hour of every test the humidity, temperature, and light intensity readings were measured and recorded. Next a light meter was used to calibrate these light intensity readings into foot-candles. A foot-candle is the amount of light thrown on a surface one foot away, which is illuminated by a candle 7/8 inches in diameter (Anonymous, 1975).

On March 3, a trial test was made. Four *Tradescantia zebrina* plants were taken from under a light bank where they had been exposed to simulated sunlight for 12 hours. Two of the four plants were exposed to visible light and the other two were placed in the dark simultaneously for a period of one hour. At the end of one hour, the upper and lower surfaces of the three leaves closest to the base of the stem of each plant were painted with a thin coat of collodion. This was to make collodion imprints of the stomata in the upper and lower epidermis of each leaf. After drying, the collodion was peeled off of each leaf and the stomata imprints examined with a compound light microscope at 400X to determine the percentage of open stomata. The imprints showed that all stomata were open.

Based on these results, the researcher decided to put the plants under the tent for a longer period of time. This time the same procedure was followed, but the plants were left in the tent for three hours instead of one hour. Two more tests like the one described were made.

DISCUSSION OF DATA (RESULTS)

The data showed that up to 60% of the stomata closed after being in the dark for three hours. This compared to 36% that were closed when left in the light for the same length of time. The average results of these tests appear in Figure 2.

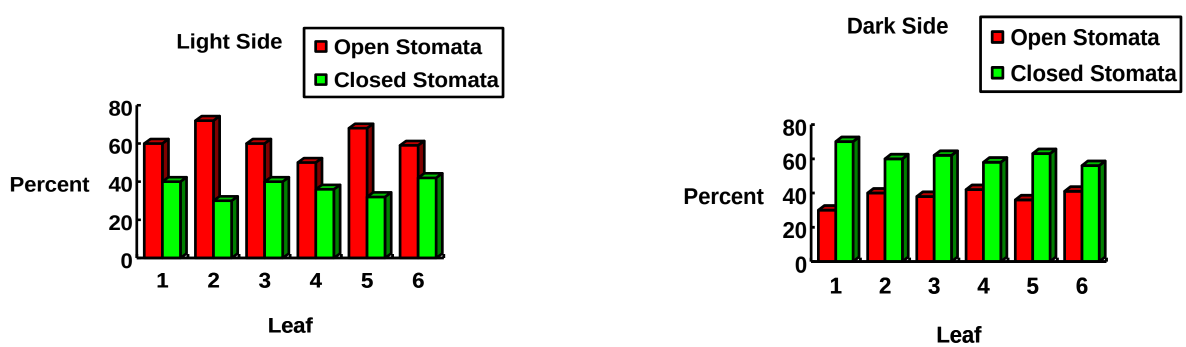

Figure 2

On the third test, most of the stomata on the light side of the tent as well as on the dark side were closed. This was accounted for when it was noticed that the light intensity had dropped from 70 foot-candles to 8.75 foot-candles. Table I shows the conditions of all three tests.

TABLE I

Table of Conditions

	1st Test	2nd Test	3rd Test
		First of Test	

Condition	Dark Light Side Side	Dark Light Side Side	Dark Light Side Side
Humidity Temperature Light Intensity	64% 67% 70° 67° * 35 ft-candles	66% 74% 65° 63° * 12.0 ft-candles	36% 62% 82° 83° * 70 ft-candles
Humidity Temperature Light Intensity	64% 67% 70° 69° * 26.25 ft-candles	Last of Test 71% 74% 66° 64° * 70 ft-candles	69% 65% 71° 72° * 8.75 ft-candles

*Light intensity was too low to register.

STATISTICAL ANALYSIS

The data indicate that there was a difference in the percentage of open and closed stomata between those plants exposed to three hours of light and those in the dark (See Fig. 2.). A higher percentage of stomata were open in the leaves that were in the dark (mean=61.7%) than those in the light (mean=36.3%).

These differences were analyzed statistically using the Mann-Whitney U statistical test. The results of this test were statistically significant at the .01 alpha level, which means there is less than 1% chance the differences observed in the data were due to chance. The null hypothesis was therefore rejected and the alternative hypothesis accepted.

INTERPRETATION/CONCLUSIONS

From the data it appears that darkness of more than one hour and up to three hours does affect the stomata by causing them to close (Figure 2). The researcher was unable to account for so many stomata being closed in the leaves that received three hours of light. It seems that some other mechanism besides turgor pressure may be responsible for opening stomata and keeping them open. The data collected in this investigation, upon being analyzed using the Mann-Whitney U statistical test, shows that there is better than a 99% chance that darkness of up to three hours does indeed cause stomata in leaves to close. The result of this investigation support the researcher’s hypothesis to this problem.

FUTURE

The researcher plans to expand this project by testing the stomata under other conditions such as varying the amount of water given to the plant, increasing the amount of carbon dioxide, or by varying the temperature. It also would be worthwhile to set up some equipment so the stomata could be studied while in the process of closing.

ACKNOWLEDGMENTS

The researcher greatly appreciates the guidance, patience, and careful criticism of Mr. Edward Smith in conducting this investigation.

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