

UNIVERSITY OF SOUTH CAROLINA CHEMICAL ENGINEERING LABORATORY

ECHE 460 and 461 LABORATORY MANUAL

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Revised: January 2004

Abstract: ECHE 460 and 461 are the courses in which Chemical Engineering students learn to write technical reports and give oral technical presentations, in the context of learning experimental methods and reinforcing engineering principles. This manual gives detailed instructions regarding these two courses. The learning objectives and the supporting policies and procedures for ECHE 460 and 461 have been established and documented. Safety guidelines are discussed. A major objective is for students to learn to work in teams. To facilitate this, students are expected to rotate responsibilities in roles denoted Engineer 1, 2, or 3. This manual defines the responsibilities of these roles. Rules and guidelines for preparing effective reports and visual aids are given. The grading system, including sample grade sheets, is in the syllabus (a separate attachment) for the benefit of the student.

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1.0 Learning Objectives

The principal objective of the chemical engineering laboratory is to provide the opportunity for students to conduct team-based, hands-on experimental investigations of modest size to reinforce chemical engineering fundamentals. Students will:

- utilize scientific and engineering knowledge in conjunction with planning and critical thinking skills
- gain experience leading and working in teams to achieve common goals
- utilize modern experimental and analytical equipment and statistical methods
- develop the skills required to create and deliver oral and written technical reports
- learn safe laboratory procedures associated with experimental work

1.1 ECHE 460 Course Content

As the first chemical engineering laboratory experience (junior level) for students, ECHE 460 is designed to reinforce fundamental concepts and develop analytical skills using well-defined experiments. This course includes projects in stoichiometry, rheology, heat and mass transfer, fluid mechanics, and thermodynamics.

Beginning with experimental results, students will become proficient in verifying theoretical developments, correlating experimental data with theoretical models, and evaluating fundamental property and design data. They will also become proficient in using modern analytical equipment, analyzing data and models using computer analysis techniques, analyzing data using statistical techniques, and presenting technical information in formal written and oral reports. Emphasis is placed on teamwork and the cultivation of oral and written reporting skills.

1.2 ECHE 461 Course Content

As the second chemical engineering laboratory experience (senior level) for students, ECHE 461 is designed to further reinforce fundamental concepts using more open-ended experiments. This course includes projects in various unit operations, kinetics and reactor design, and process control.

Beginning with experimental results, students will become proficient in verifying theoretical developments, correlating experimental data with theoretical models, developing system flowsheets, and evaluating process design and performance data with simple process models. They will also become proficient in developing factorial experimental designs, analyzing data using statistical techniques, and presenting technical information in a formal report. Trouble-shooting skills, experimental design and parametric studies (*e.g.*, what are the significant process variables) are stressed. Teamwork and oral and written reporting are again emphasized.

2.0 Team Organization

A team is typically composed of three students. Team members will rotate through three positions: Engineer (E) 1, E2, and E3. Since this course includes four projects, each team member will hold each position once. For three person groups, each student will serve as Engineer 1, Engineer 2, and Engineer 3 once during the first three projects. A three person group is free to choose who will serve as Engineer 1, Engineer 2, and Engineer 3 for Project IV. If

needed, two-student teams will be formed at the Instructor's discretion and responsibilities will be adjusted accordingly. For a two person group, each group member alternates twice from serving as Engineers 1 and 2 (combined duties) and Engineer 3.

E1, E2, and E3 each have specific responsibilities to the team. Although a portion of the student's grade depends on individual work, a major portion of the final grade depends on fulfillment of team responsibilities. The explicit responsibilities for each position are outlined below; additional instructions may be given in lectures or in the Course Syllabus. Following the individual duties are a few suggestions on how to function as a team.

2.1 E1 (Team Leader) is responsible for:

1. Scheduling team meetings, monitoring team progress, facilitating communication within the team and between the team and the Instructor, articulating Objectives, and insuring that Results and Conclusions are relevant to these Objectives. E1 is the team leader!
2. Preparing a draft of the "Introduction and Objectives" section of the Technical Report, as described in section 7.2, to be submitted during the 1st laboratory period; this draft will be graded and returned for immediate feedback.
3. Documenting laboratory work by organizing and entering data into the laboratory notebook, insuring that all necessary data are recorded for the calculations, keeping track of units, and keeping a copy of all data on disk. E1 insures that all team members have immediate access to experimental data.
4. Giving the first part of the Team Presentation as described in Section 3.2, including: Title, Introduction, Objectives, and Literature Review.
5. Rewriting the draft "Introduction and Objectives" section for the Technical Report, as well as writing the "Literature Review" for the Technical Report.
6. Preparing the "Laboratory Notebook Appendix," compiling complete literature citations for all sections, and submitting all writing to E2 in a timely fashion so that E2 can assemble and produce the final Technical Report.
7. Assisting E2 and E3 as needed.

2.2 E2 (Technical Writer) is responsible for:

1. Preparing a draft of the "Apparatus and Procedure" section of the Technical Report, as described in section 7.5, to be submitted during the 2nd laboratory period; this draft will be graded and returned for immediate feedback.
2. Giving the second part of the Team Presentation as described in Section 3.2, including: Apparatus, Procedure, Experimental Plan, and Engineering Principles.
3. Finalizing the draft "Apparatus and Procedure" for the Technical Report, as well as writing the "Experimental Plan" section (ECHE 460) or "Statistical Design of the Experiment" section (ECHE 461), "Engineering Principles" section, "Conclusions" section, and "Cover Memo" or "Abstract" section.
4. Collecting and compiling the Technical Report contributions of E1 and E3, writing any remaining sections as described in section 7.0, proofreading the entire report, making corrections, and submitting the complete Technical Report to the Instructor.

5. Assisting E1 and E3 as needed.

2.3 E3 (Calculations and Analysis) is responsible for:

1. Performing all calculations for the experiment, preparing suitable tables and graphs, and giving the last part of the Team Presentation including: Results and Discussion, and Conclusions as described in Section 3.2.
2. Writing the “Results and Discussion,” and “Sample Calculations Appendix” sections of the Technical Report, compiling literature citations for these sections, and submitting all materials to E2 in a timely fashion so that E2 can assemble and produce the Technical Report.
3. Assisting E1 and E2 as needed.

2.4 All members of the Team are responsible for:

1. Understanding the objectives and deliverables of the project.
2. Critical analysis of results and conclusions.
3. Meeting regularly, at least once a week throughout the semester (the unused laboratory time is certainly available to everyone in the team).
4. Assisting each other in collecting, organizing, and reviewing the relevant literature.
5. Developing the experimental plan and carrying out the experiment.
6. Assisting each other in developing an understanding of underlying theory and applying the relevant models to the experimental data.
7. Proofreading each other’s material for the Team Presentation and Technical Report.
8. Completing confidential team evaluations at mid-term and the end of the semester.

3.0 Performance Evaluation

The grading system is described in the Course Syllabus. In general, because the initial presentations and reports will probably be rough, the last three experiments are more heavily weighted than the first one. The Instructor reserves the right to adjust individual grades based on qualitative evaluations of students’ overall performance and contribution to their teams.

3.1 Laboratory Performance

A sample of the “TA Laboratory Grade Sheet” is in Appendix C. The TA assigned to each project will evaluate individual performance in the categories shown and submit this sheet to the Instructor. The written draft material evaluation will be performed by a competent instructor and will be factored into the grading. Deductions will be made for failure to cooperate with the team or the TA, inability to answer questions, unexcused absences, tardiness, failing to wear safety glasses and hard hats, unsafe or disruptive behavior, or any other transgressions (subject to the TA’s judgement).

After each experiment the laboratory must be left clean and orderly and the equipment, chemicals, and supplies must be stored or left in standby mode as required by the TA. The team is not dismissed until the TA has examined the laboratory notebook and signed off in it. Each student will be given a grade of A, B, C, D, F, or 0 (no-show or unexcused absence) for Laboratory Performance. At the end of the semester the Instructor will review these grade sheets and assign an overall grade for laboratory performance.

Additional safety information is given in section 6.0 and in the Chemical Hygiene Plan. Be aware that the Instructor may deduct points from the laboratory performance grade for severe violations. If disregard of safety procedure results in a single instance of student injury or equipment damage, the Instructor may assign a grade of 0 for the laboratory performance portion of the course. For severe violations of safety, the Instructor may assign a grade of F for the entire course. Students should be aware that industry takes a very strict position on safety and behavior in the workplace.

3.2 Team Presentation

The Team Presentation is given approximately one week after the experimental work is completed. Approximately 15-20 minutes is allotted for oral presentations, with visual aids required. All team members participate, with specific responsibilities as follow:

- E1 must present the project Title, Introduction, Objectives, and Literature Review. (6 minutes max.)
- E2 must present the Apparatus and Procedure and Experimental Plan (or Statistical Design), and Engineering Principles. (6 minutes max.)
- E3 must present the Results, Discussion, and Conclusions. (8 minutes max.)

Handouts of all visual aides must be submitted to the Instructor just before the Presentation begins. Copies of these visual aides should not be included with the Technical Report. The Instructor will grade the handout material. Note: slides should be prepared using Microsoft PowerPoint and submitted to the instructor as “Handouts,” printed three to a page, in black-and-white.

At the conclusion of a Presentation, the Instructor may ask questions of *any team member*. The team should therefore ensure that all members are prepared to answer any questions relevant to the project. The Instructor's impression of the responses will be noted on the “Presentation Grade Sheet,” a sample of which is in Appendix D. The Instructor will also evaluate qualitative aspects of the presentations as reflected on the Grade Sheet. The Instructor will assign a letter grade (A, B+, B, C+, C, D+, D, F, or 0 for no-show) for the Presentation, record comments, and review these evaluations with the team or its individual members.

3.3 Technical Reports

The team is required to submit the original paper copy and an electronic copy of the complete Technical Report to the Instructor approximately one week after the Team Presentation is given. The Instructor will set the specific due date and time. Grades are reduced by five points for each day the report is late. All reports, even late ones, must be handed in to satisfy course requirements. Otherwise, a grade of F will be assigned to all team members for the entire course. If it appears that a report cannot be completed on time because of illness or other serious

circumstances then the Instructor should be informed before the deadline so that alternate arrangements can be made.

Each team member must keep a copy of the Report (electronic copy is acceptable) for his or her own use. The Instructor may meet with each team for twenty minutes when the report is handed in to provide immediate feedback. They will read through and discuss the report as a team and the students will hear the most important comments directly from the Instructor. In general, each team member should receive the same grade for the Technical Report. However, the instructor may assign different grades to team members based on the fulfillment of their responsibilities to the team. E2 has the final say in editing and is not excused from responsibility for the sections written by E1 and E3.

Some of the quantitative and qualitative grading criteria are summarized on the “Technical Report Grade Sheet,” included in this manual as Appendix E. Additional instructions and criteria for the Technical Report are given in this manual. All information described in Section 7.0 must be included in the report. The report must also meet high standards of grammar, spelling, overall appearance, and quality of figures and tables. All of these factors will be considered and an overall numerical grade assigned for the report. A report that appears quantitatively sound but suffers from poor prose, unclear figures, or excessive misspellings may earn a C or D. Similarly, a report that is beautiful to behold and written enthusiastically but contains technical errors will receive a low grade.

Students are encouraged to listen to the instructor’s verbal and written comments on the quality of the report, and to respond to his or her requests and personal preferences. This will also be true in the workplace. Co-workers, supervisors, managers, customers, *etc.* will have different likes and dislikes in writing style. The challenge of technical writing is twofold: make results technically and quantitatively correct, and to communicate them clearly.

3.4 Confidential Team Evaluation

Teamwork and cooperation are an important component of this class because they are vital skills in the workplace. Near the end of the semester, team members will rate each other’s performance using a provided Confidential Team Member Evaluation Form. The instructor will use this information, the TA grade sheets, and the instructor’s own personal observations of teamwork to assign each student a grade for teamwork.

4.0 Project IV: The Summary Project

ECHE 460 and 461 each include four projects. Projects I through IV require operating equipment, collecting data, performing calculations, giving Presentations, and writing Technical Reports (see sections 4.2 and 8.0). In addition, Project IV, a Summary Project, requires that one team poll all the other teams for their data and results from a specific experiment (*e.g.*, vapor-liquid equilibrium). The team will then prepare a summary Technical Report and (possibly) make a presentation to review the cumulative results.

Work on Project IV must be initiated soon after work on Project I is finished. Each team is assigned to a specific experiment (typically, the first experiment they perform). Throughout the semester, they go to the other teams that performed that particular experiment and collect their data, presentations, and reports. The goal is for each team to compile the class data, run the experiment, analyze all the data to establish trends, present this compilation to the entire class, and write a Technical Report.

Project IV allows the students to determine trends in the data that could not be ascertained using their data alone. It also illustrates the difference between precision and accuracy, as data sets from different teams may have been obtained under the same conditions. Open discussion follows each Project IV Presentation to allow the class to ask questions and examine results that may otherwise be buried in the individual Technical Reports generated during Projects I to III.

Grading, task assignments, and responsibilities of E2 and E3 for Project IV are similar to those for Projects I to III. E1 is now responsible for collecting the data from each team that has performed the experiment. Although E1 is responsible for data collection, E3 is still responsible for the data analysis and E2 is responsible for compiling the summary Technical Report.

5.0 Laboratory Operations

The following general rules must be followed at all times while experiments are in progress in the Chemical Engineering Laboratories:

- Operating equipment must be attended continuously by at least one team member.
- Procedures and limitations prescribed by the Instructor or TA must be followed.
- The team is not allowed to begin work in the laboratory unless all team members are present. If a team member cannot be present during the laboratory period, special arrangements must be made in advance with either the Instructor or TA. Documented illnesses or family emergencies will be excused. Team members may be excused for school-related activities, but advance notice is still required.
- Either the Instructor or TA must be present whenever any work is being done in the laboratory. Operation of equipment outside normal laboratory hours is generally not allowed. However, under certain circumstances, either the Instructor or TA may approve it.
- At the end of a three-hour experimental session, utilities must be shut off. This includes steam systems, which must be vented to the atmosphere. Each workstation must be cleaned and equipment properly stored before the team may leave the laboratory. Failure to observe these procedures may result in a failing grade for the project.
- It is illegal to pour any chemicals into sink or floor drains. There are proper procedures for disposing of all chemicals and these procedures will be followed in this laboratory course at all times. The Instructor or TA must be consulted before disposing of any chemicals.

6.0 Safety

Safety must be taken seriously and is considered of paramount importance in this laboratory course. A safety orientation will be given before experimentation begins. Hazardous chemicals and equipment are used in the Chemical Engineering Laboratories. Refer to the Chemical Hygiene Plan for more details. The following safety practices must be followed at all times:

- Approved safety glasses or chemical goggles must be worn in the laboratory at all times. There are NO exceptions.

- Clothing that may be caught in moving machinery such as long sleeves worn unbuttoned, neckties, scarves, long skirts, or loose dresses should not be worn in the laboratory. Likewise, long hair must be put up or securely tied back.
- Shorts may not be worn in the laboratory at any time. Do not wear high-heeled, open-toed, or sandal-type shoes that provide little foot protection from chemical spills or impact. Students who are not properly dressed for the lab will be sent home to change clothes, and the TA will deduct from the laboratory performance grade.
- Students working on the lower laboratory levels must wear hardhats. There are NO exceptions. Tools or other items may easily drop through the grating to floors below. Those working in these gridded areas should exercise caution when handling tools.
- Hazardous chemicals are used in some of the experiments. Appropriate chemical-resistant gloves should be worn when handling them. The two books listed below are good general references and should be consulted when experimenting with new materials. Note that the first book is a more general laboratory safety text.
 - Steeve, N. V., ed., *Handbook of Laboratory Safety*, 2nd ed., The Chemical Rubber Co., Cleveland, 1976.
 - Sax, N. I., *Dangerous Properties of Industrial Materials*, 5th ed., Van Nostrand Reinhold, New York, 1979.
- Any chemicals spilled on any part of the body should be washed off immediately with large amounts of water. Each student should become familiar with the locations of the safety shower and eyewash, which are always operational, in each laboratory.
- If any injury occurs, no matter how minor, the Instructor or TA must be informed immediately. A first aid kit is provided in each laboratory.

7.0 The Technical Report

The Technical Report is aimed at specialists who need to know everything about the work being done. In industry, for example, Technical Reports are confidential, in-house documents that report work done in the laboratory or pilot plant. Such reports are passed on to design teams (for plant/process design), to the legal department (for patent consideration, for ascertaining regulatory compliance), or to engineering teams (for detailed design work, including piping and vessel design, selection of materials, *etc.*). Government agencies and industries that fund outside research often require Technical Reports as a condition for continuing the contract. Technical Reports may have very limited circulation; however, those who read it have a great deal of expertise and a keen interest (often economically motivated) and will review the reports exhaustively.

7.1 Required Sections and General Format

The required sections and general formatting requirements of the Technical Report are given below. The Technical Report grade sheet follows this same outline. Detailed descriptions of the content of each section follow in subsequent sections of this manual.

- A. Cover Memo
- B. Introduction and Objectives

- C. Literature Review
- D. Apparatus and Procedure
- E. Engineering Principles and Working Equations
- F. Experimental Plan (ECHE 460) / Statistical Design of the Experiment (ECHE 461)
- G. Results and Discussion
- H. Conclusions
- I. Literature Cited
- J. Appendices

Technical Reports must include all of these sections and must not exceed twenty-five typed, double-spaced pages, excluding tables, figures, and appendices. Margins should all be one inch and the font should be 12 points. The “Header” section of each page must contain the following information: Group number, Section Number, Project Number (I through VI), and date. The “Footer” section of each page must contain the following information: Team member names and roles (E1, E2, E3), page number, and report due date. If you are unfamiliar with using Headers and Footers, consult the Microsoft Word help files. Any extra headers or footers automatically included on Microsoft Excel or PowerPoint output should be removed.

All written material in the Technical Report must be original, including apparatus drawings. Do not include scanned diagrams from the laboratory handouts. The only photocopies of any kind that should appear in the report will be in an appendix as described in section 7.10.3.

Schematics, figures, and tables must be computer-generated. A minimum of hand lettering for symbols will be accepted.

When describing the work done in the experiment, use the past tense (since what was done is in the past). The present tense can be used to describe current beliefs and conclusions about the experiment.

Although it is permitted to use first person pronouns (I, we) in technical writing, this should not be overdone. Use of the first person is most common in the Introduction, Experimental Procedure, and Conclusions sections. Examples of first person are: “We measured the liquid height versus time,” or “I think the literature values are inaccurate.” The passive voice can be used, but passive voice sometimes leads to awkward or long sentences. Examples of passive voice are, “The liquid height was measured as a function of time,” or “It is believed that the literature values are inaccurate.” More active voice construction is desired if possible, for example: “The essential raw data required is the height of liquid in the tank as a function of time.” “The literature values appear to be unreliable.”

Your instructor prefers to treat the word “data” as a plural noun. Synonyms for “data” include the words “numbers” and “values.” ALWAYS do a word search on the final document to make sure that the verb used with “data” is plural. Incorrect: “The data is shown in Table 3...” “The data shows that there is an inverse relation...” Correct: “The data are shown in Table 3...” “The data show that there is an inverse relation...”

The project and the experimental work are not to be referred to as a "lab," the terms "project", "investigation," "study," or "experiment" are preferred. "Lab" is an abbreviation for laboratory, a type of room.

Some words and phrases to avoid if possible: really, basic, basically, parameter. Be careful of vague references and pronouns with unclear antecedents.

The purpose of this course is to give the student extensive experience in writing. Therefore, the direct quoting of material from other sources will not be allowed. However, paraphrasing the source material is permitted, as long as the work is cited properly.

No binder or other cover should be used. Reports should be stapled or clipped in the upper left-hand corner. Reports should not be folded.

7.2 How to state your objectives and deliverables

Past students have suffered major difficulties in speaking and writing because they never understood the project objectives and deliverables. It is absolutely essential that each team member understand the SPECIFIC OBJECTIVES AND DELIVERABLES of your project. If you do not understand these, it is impossible to write a good report or give a good presentation.

"Objectives" are the end results or goals to be achieved. "Objectives" should be stated in the context of overall relevance or usefulness. "Deliverables" is a similar term but it usually refers more specifically to a result that can be subsequently used by others. For instance, a new engineering correlation, a calibration curve, a specific conclusion, or even the report itself can be a deliverable. A team has met its objectives when it produces all of the deliverables AND it places those deliverables in a context of overall relevance.

The objectives cannot be stated just one time. The objectives are the common theme that binds the project together. In a well-written report or presentation, the objectives will be re-visited and re-stated several times, namely in the Cover Memo, Introduction and Objectives, Results and Discussion, and Conclusions. They should not be repeated in exactly the same words, but they should re-appear either explicitly or more subtly throughout the report.

Many students suffer because they confuse objectives with the intermediate experimental steps, calculations, and tabulations necessary to achieve the objectives. An example of what not to do will be given shortly.

The laboratory handouts suggest some objectives, but the handouts are not sufficiently precise or specific. This is done on purpose! As you work on your project, your TA or instructor may make some suggestions that are not in the handout. You may fail to meet some objectives that you originally set out to accomplish. As you critically evaluate your results, you may discover something new that you did not originally anticipate. The bottom line is that your oral reports and presentations must present the objectives that you actually, finally managed to accomplish! Thus, it is quite common that a team is not able to produce an exact, correct statement of objectives until all the work is done! This does not seem logical but it is frequently true.

The first thing that your instructor will do on any report or presentation is to examine the objectives. Are they clear, relevant, concise? Do the objectives mention specific, quantifiable deliverables? Do all team members present the same objectives? Are the conclusions consistent with the objectives? If the answer to all these questions is "Yes" then your team is well on its way to a good grade.

Here are some hypothetical examples. Consider these objectives carefully as you write the Cover Memo, Introduction and Objectives, or Results and Conclusions.

Examples:

- Vague, non-specific, abstract, irrelevant objective: The objective of this project was to study turbulent flow in a heated nozzle. *(Terms like "study," "evaluate," and "investigate" are vague and require elaboration so the reader knows how the "study" was conducted and what the specific criteria of the study were. What specifically was measured, and why? The supervisor doesn't know why the study was done, or why it was important for his company to spend money to fund the study.)*
- Confusing intermediate steps with objectives: The objectives of this study were to flow nitrogen through a nozzle, measure the inlet and outlet temperatures, plot the results, and compute the heat capacity and isentropic compressibility. *(This is just a list of steps; there is no importance given to the work. What useful deliverable or conclusion will result? What is the big picture? The writer was so preoccupied by doing the calculations and drawing graphs that he/she forgot about any engineering relevance.)*
- Good, specific objectives: The goal of this project was to study turbulent flow in a heated nozzle. The pressure drop, temperature profile, fluid velocity, heat transfer coefficient, and isentropic compressibility were determined for nitrogen flowing in a converging/diverging nozzle. *(Now the specific, quantifiable measures of performance are named.)* These results were used to evaluate both the Smith-Jones and the Williamson-Thompson theories of nozzle design. *(The authors also show how measurements will be analyzed and compared to external information.)* We sought to determine the best theory for use in designing a converging/diverging nozzle. *(The authors also give a "big-picture" justification for their work, and show how it relates to the real world of engineering. Supervisors will be looking for this.)*
- Vague, non-quantitative results: The required parameters were measured. A plot of outlet temperature versus velocity was produced. The Smith-Jones theory was found to be the best. *(The word "required" is written from the student viewpoint, that is, it sounds like the author was a mere drone, doing only what someone else told them to do. "Parameters" is vague, non-specific, and overused. Why is a plot of temperature important? Your supervisor doesn't know or remember what the "required parameters" were. What were the actual measurements? What quantitative data were found? Words like "best" and "optimum" are by themselves vague. They imply a comparison, but the authors do not explain the standard or metric by which "best" is to be determined.)*
- Good, quantitative results: The measured pressure drop covered a range from 0.5 to 3.0 bar, and agreed with the Smith-Jones theoretical prediction to within 10%. The Williams-Thompson theory was worse; agreement with data showed errors as high as 40%. The Smith-Jones model was also validated as a model for the heat transfer coefficient. The isentropic compressibility was 10 cm³/mol/bar, which did not agree with the value reported by Davis. Overall, it appears that the Smith-Jones theory would be most reliable for design of a converging-diverging nozzle for a wind tunnel. *(Specific measurements are named, and numbers or ranges of numbers are assigned to the measurements. Comparison to theory is quantified in terms of percentage difference, which is a very common measure of agreement. An overall, "big-picture" conclusion is given, having been previously justified in terms of measurable results.)*

7.3 Cover Memo or Abstract

The Cover Memo or Abstract should be written in the form of a business memo (i.e., Date:, To:, From: and Sub:) to a supervisor from a team of engineers summarizing the entire Project. The project title will serve as the memo subject. The body of the memo should concisely state the project objective(s) and the most important results and conclusions (*aka* deliverables). The Cover Memo should also include the most important point(s) of the Procedure, Discussion, and Conclusions from the Technical Memorandum. It should present both qualitative and precise quantitative results. It is the last thing written, but the first thing read. There should be no reference to the main body of the report (example: do not write “it will be shown,” or “it will be discussed later...”). Also, it should not contain any graphs or tables. The Cover Memo or abstract should be at least one page but not more than one page long.

7.4 Introduction and Objectives

This section should begin with one or two paragraphs of general discussion and examples illustrating the importance of the technical subject. The first couple of paragraphs are typically “motherhood and apple pie” in nature. The text should then flow logically to a statement of the specific objectives and deliverables of your team’s project. Objectives should be written from the viewpoint of an engineer, not a student, and should be directed at a technical supervisor, not the laboratory instructor. The problem-solving approach should be briefly described as well – what general types of equipment were used, what general techniques were employed. However, do not give details of the specific apparatus or procedure, or mention any specific results or conclusions.

This section should get to the bottom line in simple, direct terms. If it does not explain the importance, specific objectives, and general approach to the problem in three to five clearly written paragraphs, the reader will probably get lost!

7.5 Literature Review

The Literature Review is intended to be a brief review of three peer-reviewed research articles that show current research in the same general area as the project. In this section, E1 will elaborate upon the relevancy of the work by reviewing three relevant, recent journal articles or articles from technical books. Web sites, textbooks, and standard technical manuals are not acceptable as the basis for the Literature Review. (Note that these materials may be cited in other sections of the report to help explain theory and procedure and as sources of comparative results.) See Appendix A for additional information about searching for peer-reviewed research literature. This section must cite the original references, using a format recommended by the American Chemical Society *Style Guide*.

7.6 Apparatus and Procedure

The purpose of this section is to explain to the reader what experimental equipment was used, how it was used, what data were collected, and how these data were important in achieving the project objectives. This section also explains what supplies (chemicals, thermometers, etc.) were used in conjunction with the equipment. Note that chemicals and small items like thermometers and stirrer bars are not equipment items but are supply items.

Before writing any text, E2 should first draw a diagram of the apparatus, and insure that he/she understands its operation. The apparatus diagram is NOT a picture of what the apparatus actually looks like!! It is typically not drawn to scale. The apparatus diagram is a technical schematic or line drawing of the major sub-components that illustrates their functions and relevance to the necessary data. The major equipment items and their function should be described, but there should be no detailed description of familiar items (e.g., potentiometer, thermometer). If they were important these items can be mentioned, but not described.

The Apparatus and Procedure section should commence with a brief description of what kind of equipment was used. E2 should then refer the reader to the properly titled and labeled apparatus diagram. Then one or more paragraphs should be written to explain, in an orderly and detailed manner, the functioning of the various pieces and sub-units of the apparatus. It is NOT sufficient just to include a drawing; E2 MUST discuss and explain the apparatus.

After the reader understands the functioning of the equipment, E2 can present the experimental procedure. The description of the apparatus is NOT the same as the description of the procedure. The procedure explains to the reader how the apparatus was used, how the samples were prepared, the order in which certain steps were performed, etc. The procedure should be specific enough for the reader to reproduce the work, but general enough so it does not read like an Operating Manual. The procedure should be presented in paragraph form (not numbered or bulleted list form). It should be a general run-down of what was done, what was measured, how it was measured, and in what sequence. The reader should be made to understand how the measurement and procedure allowed the collection of the necessary data.

The experimental handouts contain step-by-step second-person instructions to the student. For example: Turn on the apparatus, let it warm up for fifteen minutes, calibrate the thermometer, *etc.* This is NOT how the procedure should be written for the Technical Report!! The purpose is NOT to instruct the reader on the step-by-step operation of the apparatus but to explain and justify that the team's general approach and equipment were adequate to obtain the results that support the conclusions. DO NOT copy the procedure from the handout into the Technical Report!!!

7.7 Engineering Principles and Working Equations

A discussion of the physical and chemical principles and working equations involved in the experiment must be presented here. For example, if the objective of the experiment is to measure the isentropic compressibility of nitrogen gas, then the thermodynamic definition, physical meaning, and empirical correlations or methods of calculating the compressibility (including implicit assumptions) should be included in this section. This section should explain how the raw experimental data will be manipulated to give the required quantitative results and deliverables. It is most important to relate the experimental measurements to the variables in the equations.

Equations must be assigned numbers for easy reference. All equation quantities and symbols should be described in the text. Once a symbol has been described, it can be referred back to in subsequent discussion; do not redefine a symbol every time it appears within or after this section.

It is certain that some of the theoretical material will be taken from textbooks or handbooks; the reference should be included in the "Literature Cited" section. It should be assumed that the reader is technically proficient, but not necessarily acquainted with the background needed to understand the particular experiment being discussed. Derivations may or

may not be appropriate. If there is an important but lengthy derivation that is difficult to put in the main body, it may be presented in a separate appendix.

7.8 Experimental Plan (ECHE 460) or Statistical Design of Experiment (461)

The projects in this course are not simple. Their complexity and size require thought and planning well before the day they are performed. Each experiment will be defined by a set of process variables (or “factors”). Typical variables are temperature, pressure, composition, flow rate, velocity, pH, viscosity, *etc.* Students must distinguish between independent variables (those that are set by the operators) or dependent variables (those resulting responses that are measured by the operators).

The Experimental Plan is an explicit, quantitative description of the conditions for each experimental run. E2 must identify the independent process variables and state the levels at which they were set. The laboratory handout lists some, but not necessarily all, of this information. Additional information and instructions may come from the instructor and the TA, so teams must record this information and put in the Experimental Plan what they actually did, not what the laboratory handout suggested. For some experiments, the most important variables and their set or expected levels are not identified. In these cases, the team must identify this information. The team should also need to determine the total number of experimental runs.

At a minimum, this section should include a table showing each independent process variable (temperature, pressure, *etc.*), its units, and the range of specific values that were investigated. For a “Statistical Design of the Experiment” (ECHE 461), additional requirements will be given in lectures and handouts.

7.9 Results and Discussion

This is the heart of the report, where quantitative results from the laboratory, theoretical predictions, literature data, and are brought together, analyzed, and presented. The purpose of this section is to show in detail how the objectives of the project have been met and how the results relate to meeting (or not meeting) these objectives. This section leads the reader through your process of analysis and decision making; you want to persuade the reader to agree with your conclusions. This is where the value of the work that was done can be demonstrated, including indicating awareness of the implications of the work. Assessment of the accuracy, validity, and scientific meaning of the results should be included. Critical thinking is an absolute requirement.

Each team will present results and conclusions during the Team Presentation and there will be questions and discussion concerning the results at that time. Each team member should pay close attention during the Team Presentation because it forms the basis of the written “Results and Discussion.”

Writing a technical discussion can be difficult for beginners. Here are some brief hints:

- Begin with a review of the stated objectives of the experiment. If the experiment has several objectives, introduce the first objective and deal with it first. After satisfactory and complete discussion of the relevant results and analysis of the first objective, proceed to the subsequent objectives and treat them the same way.
- Look at the calculations, tables, and figures and decide what information relates to the given objective. Pick out the appropriate information, sort it, and think about how to logically lead the reader from the tables, figures, and observations to the results and conclusions. Eliminate

intermediate calculations, extraneous graphs, and unnecessary columns in tables that do not directly address the objectives.

- The writer's goal is to persuade the reader to accept the results, and conclusions as being scientifically valid. Therefore, make sure that you discuss thoroughly each figure and table that you present. By "discuss thoroughly" I mean explain the figure or table. Tell what is in the figure, and what it means. Talk about the shape of the curves, the physical meaning (if any) of the slope and the intercept, or the inflection points, or the maxima and minima. Do the curves have the expected shape? Can you plot a theoretical prediction on the same axes as the data? If so, how do measurements and theory compare? Does the graph show the expected behavior? Is there any asymptotic or limiting behavior that is physically meaningful? Are the data reproducible or reliable? Similarly for tables, explain each row or column in the table. Explain the units. Ask yourself: is each row or column relevant to supporting my analysis and discussion? Eliminate rows and columns that show only intermediate data or calculations. Explain what trends are evident in the table. If theoretical predictions are available, tabulate these next to the experimental results and compare. A good way to compare is to show the percentage difference between experiment and theory. Then discuss the percentage differences. Are they unexpectedly high, or do the differences appear to be acceptable?
- Know the audience. The audience is NOT the Instructor; this report is written to a scientifically literate supervisor who does NOT know in advance the objectives, theory, procedure, or results in detail. The supervisor WILL NOT give you the benefit of the doubt; he or she IS NOT going to struggle to understand a poorly worded sentence or a poorly constructed table or figure. Your supervisor does not have any pre-conceived idea of the minimum amount of work needed for to make an 'A,' and does not have the experiment handout to use as a guide. The report must be written from a team of engineers (not students!) writing to their supervisor. The Instructor, in grading the report, will NOT treat the team like students or give them the benefit of the doubt if the report is lacking.
- Take the writing one small step at a time. The major features of each calculation, figure, or table should be discussed in turn instead of trying to discuss them all at once. A good rule of thumb is to dedicate at least one good, solid paragraph to each figure, table, or important calculation. In some cases, it may be prudent to discuss the implications of two or three closely related figures together.
- Each paragraph should have a strong topic sentence (e.g. "Figure 2 shows how the heat transfer coefficient varied with flow rate through the converging/diverging nozzle") followed by the discussion. If a table has several columns, describe to the reader what is in the columns, why this data is included, and its significance.

The discussion should continue with an analysis and interpretation of what is shown, including whether or not the trends are as expected and the results agree with theory or with data of other investigators. If data or figures were provided with the equipment, discuss whether the experimental results agree with the equipment manufacturer's data.
- A discussion of the major errors that probably influenced the experimental measurements and the computed results should conclude this section. Such errors should be assessed realistically - the data should not be "forced" to fit the theory. It is more important to

recognize, acknowledge, and analyze the errors in “bad data” correctly than to try and make it look like “good data.”

Usually, several assumptions are made in developing the theoretical equations used to analyze the experimental data. Were all of these assumptions appropriate for this experiment? If not, analyze how not making some or all of these assumptions would have affected the results.

Errors should be assessed quantitatively if possible, both in individual measured variables and in the key results they are used to calculate. Quantitative error analysis can be difficult and involved in certain cases; whether or not such an analysis is reasonable should be determined for each separate experiment.

- Quantitative results should be stated using a reasonable number of significant figures (three or four). The format of spreadsheets and graphics should also adhere to this rule. The proper number of significant digits should be shown in ALL tables, even those prepared for the appendices and sample calculations. Be careful not to round off numbers until all calculations are finished and the final result has been obtained.

Successful discussion relies heavily on preparing effective figures and tables. In presenting results, choose the form that is most effective and allows the reader to grasp the nature of the results quickly and accurately. Figures are often preferred to show trends, while tabular data are preferred when it is important to convey the results with high precision.

In the text, figures should be referred to as "Figure 1" *etc.* (i.e., capitalized). If a figure is referred to without a number, do not capitalize the word "figure" (e.g., ...as shown in the figure below...). Refer to tables in the same way. Placing graphics on separate pages will simplify the formatting of the report text.

Figures should include a descriptive title at the bottom, logically spaced numerical axis labels, "tick marks" on the major scale divisions, labels on each line or curve drawn through the data points, and different symbols (boxes, circles, *etc.*) for different sets of data. Be informative, descriptive in making up titles – NEVER entitle a figure simply "y versus x". Use computer graphics packages whenever possible, but do not accept all the default formatting rules that are built into these packages. Learn the programs and make them prepare a figure that is in accordance with all of the instructor's expectations.

Figures should be readable vertically, or by turning the report 90° clockwise. To compare model predictions with experimental data, plot the modeling results as a solid line and the experimental results as individual, unconnected data points. Use a legend to distinguish them.

Beware the use of color in drawing figures (and in making oral presentations)! If the computer and projector are used to make a PowerPoint presentation, the projected color is always more dim than it appears on the monitor. It is better to use different line weights (thin, thick) and styles (solid, dotted, dashed, *etc.*) than colors to distinguish between lines. Also be aware that, while color may do well for an oral presentation, color does NOT reproduce on a black-and-white printer or copier, and therefore the reader will be completely unable to interpret a figure that depends on use of color!!

Tables should be set up with a descriptive title at the top, informative column headings (with units), and footnotes as necessary. Tables should be placed in the center of the page from left to right. ALWAYS review your tables to make sure that only a suitable number of significant digits (3 or 4) is used.

The Technical Report will have only figures and tables. Do not use phrases or notation such as “Graph 3,” “Sketch 2,” “Schematic 4,” “Figure #1,” or “Table No. 3.”

7.10 Conclusions

This section recaps the objectives and deliverables, and re-states these specifically but succinctly. This section should be written in a conventional narrative style (not just a bulleted or numbered list). This section should contain repetitive information, drawn from the “Objectives” and “Results and Discussion.” An interested reader (the boss) should be able to read only the “Introduction and Objectives” and “Conclusions” and get the main idea of the project.

All conclusions should have been previously discussed and justified in the "Results and Discussion." A common writing mistake is to introduce new ideas, data, and arguments in the "Conclusions" section. Do not do this! Make all arguments and interpretation in the previous section and use this one to re-state them concisely.

7.11 Literature Cited

The Literature Cited section comes at the end of the report text. It is intended to give the reader sufficient information to find all of the original references that were cited in the text of the report. The *ACS Style Guide* must be consulted both for methods of calling out citations in the text, and for acceptable methods of listing complete bibliographic information in this section. Complete bibliographic information (in particular, all authors names) must be given in the Literature Cited. A corresponding documentation appendix should be created as described in section 7.12.3.

7.10 Appendices

The Appendix is submitted as an integral part of the Technical Report. The Appendix contains one or more sections, the individual appendices. Long derivations and/or other background material not essential to the body of the report are often placed in an appendix and referred to in the body. The word "appendix" should be capitalized when it is referred to in the report only if it is followed by the letter designating the specific appendix (example: “See Appendix F for the derivation of this equation.”). Each appendix always starts on a new page with the letter and title of the appendix at the top (for example, see the appendices at the end of this manual).

There are three required appendices as described below; others may be included at the Team's discretion. Examples of discretionary appendices include those containing detailed derivations or extensive data tables.

7.12.1 Sample Calculations Appendix

The instructor and TA will use this appendix to determine if your group did the calculations correctly. Engineering calculations establish methodologies used and relationships developed to derive important values. It is therefore important to include all calculations in the Technical Report. Sufficient material must be included such that any qualified reader can interpret them.

This appendix must contain, in a neat and orderly fashion, all calculations associated with the data analysis. In addition to giving the equation and listing symbol definitions and units, it is required to show a single sample of every type of calculation using experimental data. It is NOT required to show the calculation of every number in every table, only an example of each.

Note that detailed derivations can be placed in this section and referenced directly from the main body of the report. This requires considerable coordination between the team members in preparing a well organized report, including the appendices, as E3 is responsible for assembling and coordinating the Technical Report, while E2 is responsible for the Sample Calculation Appendix. Although individual grades are given for E2 and E3, if (for example) the report mentions sample calculations that are missing from the appendix, both grades are reduced.

Also include in the Sample Calculations appendix any computer programs, spreadsheets, *etc.* that have been written specifically to perform the data analysis and calculations. This computer-generated output must be documented in a manner that is consistent with accepted programming practice. You are **ALLOWED** and **ENCOURAGED** to hand-write on computer output to make the calculations easier to follow. It is not necessary, and usually impossible, to provide the source statements for commercially available software. If commercial software is used for data analysis, then this must be noted. Mathcad and spreadsheet formats can both be used to present sample calculations. However, beware that all formulas and units must be identified, which makes spreadsheets difficult (but not impossible) to use for this purpose. It may be prudent to show sample calculations to the Instructor before submitting the Technical Report to make sure they are in an acceptable format.

7.12.2 Laboratory Notebook Appendix

Each team is required to keep an official laboratory notebook. It must contain numbered pages that cannot be easily torn out. Suitable laboratory notebooks are available for purchase at one of the local bookstores. The notebook must be filled out according to the guidelines given below.

The title and purpose of the experiment and the experimental procedure must be transcribed (not cut and pasted) from the laboratory handout into the notebook. This is the only information that may be transcribed into the notebook. All raw data must be recorded directly into the notebook, including any unusual observations made during the course of performing the experiment or analyzing the data. This notebook must be a complete record of laboratory work, which can be understood and repeated if necessary. The data collected for Project VI must come directly from each team's notebook.

In addition to providing a complete record of experimental work, a notebook should be designed to afford maximum patent right protection. Several practices must be followed to give the notebook value as a legal document in possible patent litigation. Although the work contained in the book may not result in a patent application, observance of these practices will provide a clear record for reports, publication, or future reference. The instructions for entering information, correcting errors, and witnessing the notebook are given below. They should be strictly followed.

- Enter all data directly in the notebook; it is permanently bound with numbered pages so those pages cannot be substituted or deleted. Do not record data elsewhere for transfer into the book. Write in ink, and never make erasures. This will ensure that the integrity of the record will not be in question.
- Record sufficient information. All procedures, reagents, apparatus, sketches, conditions, references, *etc.* should be entered into the notebook as the work is done. The purpose and significance of the experiment as well as observations, results, and conclusions should be made clear. What may seem trivial at the time may later prove of critical importance.

Entries should be clear and complete enough for someone else who is "skilled in the art" to read and comprehend what has been accomplished. Avoid sweeping negative statements, e.g., "this procedure is worthless," which could later limit the scope of claims made.

- Not only is the conception of an invention important, but the diligence shown in making a working model or demonstrating that the idea works (reducing to practice). These two elements of invention must be witnessed. The inventor's records are not enough. Each page of the notebook should be read, witnessed, and dated (daily, if possible) by someone who is competent to understand it, but who does not claim to be a co-inventor. Charts, tables, *etc.*, should be complete and lines should be drawn through any blank spaces prior to witnessing. It may be wise to perform key experiments in front of one or more witnesses. Spectra, charts, *etc.*, should be signed, dated, and witnessed, and if they can not be permanently attached to the notebook, they should be referred to with an entry in the book and kept on file. Dates and witnesses can establish your priority of invention.
- To delete an entry, draw a line through it so that it is still legible. Corrections should be made adjacent to the deleted entry, and they should be initialed and dated by the experimentalist and the corroborating witness. Changes made after the page has been witnessed should also be initialed and dated by the experimentalist and the witness. Always use the current date.
- The notebook and its contents are to be considered confidential and of great value. Exercise every care in preserving them. Report the loss or theft of a research notebook to the Instructor or TA immediately.
- Index the contents at the beginning of each notebook, and store it in a safe place.

A photocopy of each notebook page used for a given experiment must be submitted as an appendix to the Technical Report. Make sure the photocopies are legible and the page numbers are visible. The pages must be placed in the appendix in numerical order, with no page numbers skipped or missing.

7.12.3 Documentation Appendix

This appendix should contain a complete photocopy of the three journal articles reviewed by E1 during the presentation and cited in the "Literature Cited" section. E1 is responsible for making these copies as the literature is consulted, then turning the copies in to E2 who compiles the appendix. It is E2's responsibility as report-writer to make sure E1 supplies all the necessary documentation. It should NOT be E2's responsibility to hunt down E1 or E3's sources.

8.0 Appendix

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Appendix A: Searching for Peer-Reviewed Technical Literature

You may cite textbooks, handbooks, and other information throughout your report to support writing of the Introduction, Theory, and Results and Discussion. You may even find some interesting material at a World Wide Web site. However the Literature Review section of the report requires that you review at least three “peer-reviewed” articles that are related to your project. “Peer-reviewed” means that the authors submitted the paper to a scientific or engineering journal, and the editor in turn sent the paper out to experts who reviewed the paper anonymously. Peer-review supplies the editor and the author with helpful comments on the scientific validity and usefulness of the work. Peer-reviewers may even recommend that a paper not be published if it contains serious mistakes, unfounded claims, or relates trivial or well-known information.

Most of you know how to use Yahoo!, Excite, and other search engines to find information on topics posted on the web. These may be useful and lead to interesting information. However, a web site does not (usually) provide peer-reviewed information. You may certainly look for useful information on the web, but do not base your literature review on web pages!

The purpose of this handout is to give you some tips on how to search for peer-reviewed literature using the Internet. There are several specialized search engines that take you directly to the peer-reviewed scientific and engineering literature. This is important to build your life-long learning skills so that you can keep up with recent developments. The methods and tools described below help you. All USC students should already know how to use USCAN to find out which journals are in the USC holdings.

1. Look at the references given in your textbooks and handbooks. Frequently there are journal articles listed there that you could look at for more details. Also, look at the name of the journal and go browse through some recent volumes of that journal in the library. A simple scan of the table of contents of a leading journal in the field might turn up an interesting article. Some journals that might be of interest are: J. Chemical & Engineering Data; AIChE Journal; Chemical Engineering Science; and Separation Science and Technology.
2. Use the specialized databases (CD ROM) available in the library. If you are in the library you can obtain the CD ROMs themselves... Ask at the Science desk. Lists of the various specialized databases are given at the Science Library home page (<http://www.sc.edu/library/science/science.html>). Students can log in to the USCAN server using the TCP 3270 program and selecting Menu Choice #3, which takes you into the available CD ROM databases instead of USCAN.
3. There is a web-based, journal search engine called UNCOVER (or UNCOVER WEB) which is maintained by the Colorado Association of Research Libraries (CARL). This is one of the menu options on the USC Library Computers. You can also access UNCOVER if you have a PC and a web browser; the URL is <http://uncweb.carl.org/>. The instructions are given there. CARL allows you to search the recent literature by topic. It also allows you to specify a certain journal, and it will provide you with the tables of contents of recent journal issues. This is a quick way to scan the table of contents of journals so that you can decide whether you want to trek to the library to find a specific article.
4. Another interesting place to look is in the patent literature. IBM recently established a web-based patent search engine that provides titles, abstracts, and in some cases complete images of the patents. This is a neat place to look around. Searching is by keyword, and advanced searches can be done using Boolean operators. The URL is <http://www.patents.ibm.com/ibm.html>.

5. Web of Science is a powerful tool for searching for recent literature, and particularly for searching for names of authors and for papers that cite known authors. You can find it by accessing the Science Library home page <http://www.sc.edu/library/science/science.html> and click on Web of Science. Follow the directions from there. This service allows you to search by author name or subject name. You can use Boolean operators (AND, OR, NOT) and there are some example searches there as well. Sometimes the article abstract is available for you to view. The neatest thing is that it allows you to see all the subsequent papers that have cited the paper you are currently viewing. Thus if you have a good, relevant article you can follow citations FORWARD in time to see even more recent papers that are citing the work you are interested in. This allows you to find the relevant literature very quickly!
6. The final web-based literature search engine used by some of the faculty is at <http://cpxweb.ei.org/>. This is the Compendex index.

These hints should be helpful. Try one or two out for your first report.

Web of Science is a subscription service. Only 10 USC users can be logged on at one time so you may experience some delays. Also, there must be some mechanism which prevents non-subscribers from using the service. If you are accessing Web of Science from the University network you should be OK. If you are using your personal AOL or other account from a non-USC system you might experience problems. Please keep these things in mind.

TA LABORATORY GRADE SHEET

TA Name _____
 Experiment _____
 PCC Rep. _____

Project # (I-IV) _____
 Section _____
 Group _____

Part 1: Laboratory Performance. Assign a grade of A, B, C, D, F, or 0. Consider the following points:
 Student arrived on time? Remained until dismissed? Was properly dressed and used safety equipment?
 Behaved safely? Understands equipment? Understands calculations? Had lab notebook signed?
 Performed assignments before class as needed? Cooperated with team and with TA?

Students' Names	E1:	E2:	E3:
Lab Grade			
Period 1 Comments			
Period 2 Comments			

Part 2 Writing Assignment. Assign a grade of A, B, C, D, F, or 0. Corrections and suggestions should be given directly to the student on the rough draft. You may use this sheet to make additional comments to the Instructor if deemed appropriate.

E1 Name: E1 Grade :	Comments on draft of "Introduction and Objectives"
E2 Name: E2 Grade:	Comments on draft of "Apparatus and Procedure"

TEAM PRESENTATION GRADE SHEET

Project _____
Date _____

Project # _____
Section _____
Group _____

E1: _____

E1 Grade: _____

Introduction	Interesting, relevant, correct. Don't repeat lab handouts
Objectives	Clear, specific, big picture. Methods & approach outlined. Critical thinking.
Literature Review	Research literature, relevant, correctly understood.
Delivery, poise	Use of um, ah, OK, etc. Voice projection. Word choice. Smooth transitions. Eye contact. Confident. Body language and mannerisms. Pointer. Knowledgeable. Correct. Answer questions. Stay on schedule.
Visual aids	Readable. No excessive color or animation. Table and figure titles and legends are sensible. Adequate detail, not excessive. Not too busy. Significant digits. Clear symbols and lines. Data distinguished from predictions. Colors vivid and clear. Use of pointer and equipment.

E2: _____

E2 Grade: _____

Apparatus and Procedure	Apparatus sketch understandable. Understand & explain apparatus. Describe important aspects of procedure. Relate equipment to data needs. Critical thinking.
Experimental Plan and Working Equations	Relate clearly to objectives. Relate to data needed. Variables identified. Critical thinking. Discuss all working equations and relevant theory.
Delivery, poise	Use of um, ah, OK, etc. Voice projection. Word choice. Smooth transitions. Eye contact. Confident. Body language and mannerisms. Pointer. Knowledgeable. Correct. Answer questions. Stay on schedule.
Visual aids	Readable. No excessive color or animation. Table and figure titles and legends are sensible. Adequate detail, not excessive. Not too busy. Significant digits. Clear symbols and lines. Data distinguished from predictions. Colors vivid and clear. Use of pointer and equipment.

E3: _____

E3 Grade: _____

Results and Discussion	Clear, specific, quantitative results. Relate clearly to objectives. Orderly and logical presentation. Understand physical meaning of equations & results. Critical thinking.
Conclusions	Supported by results. No new ideas or lines of reasoning introduced. Related to objectives. Honest and frank. No whining.
Delivery, poise	Use of um, ah, OK, etc. Voice projection. Word choice. Smooth transitions. Eye contact. Confident. Body language and mannerisms. Pointer. Knowledgeable. Correct. Answer questions. Stay on schedule.
Visual aids	Readable. No excessive color or animation. Table and figure titles and legends are sensible. Adequate detail, not excessive. Not too busy. Significant digits. Clear symbols and lines. Data distinguished from predictions. Colors vivid and clear. Use of pointer and equipment.

TECHNICAL REPORT GRADE SHEET

Experiment _____
Date _____
Report Grade: _____
E1: _____ **E2:** _____ **E3:** _____

Project # _____
Section # _____
Group # _____

Cover Memo or Abstract (10)	Complete. State objectives. Gives precise “big picture” statement of most important results and conclusions. State methods as needed.	
Intro. & Objectives (10)	Interesting, relevant. Objectives clear, concise, quantitative, specific to project.	
Literature Review (10)	Three research articles. Relevant. Concise but informative summary.	
Apparatus and Procedure (10)	Good schematic and discussion thereof. Relates measurements to data needed to meet objectives. No 2 nd person. Not written to operator or technician. Does not assume Instructor has prior knowledge.	
Principles/Equations (10)	Complete and correct. Relates to objectives. Shows physical meaning. Relates to experiments. Equations numbered. Standard symbols used. Sufficient references. Does not assume instructor’s prior knowledge.	
Experimental Plan (5)	Concise but clear description of the conditions, levels, exact runs performed. Total number of runs.	
Results and Discussion (20)	Logical and orderly. Relates to project objectives. Each figure and table called out & discussed thoroughly. Good topic sentences followed by strong paragraphs. Each observation and conclusion supported. Thorough. Does not assume Instructor has prior knowledge. Critical Thinking!	
Conclusions (5)	Supported by Results and Discussion. Consistent w/ Objectives. Repeat quantitative, specific findings. Relevant and useful. Critical Thinking	
Literature Cited (5)	Cite all relevant journal articles, books, handbooks, etc. wherever needed in the main body. Use standard (ACS Guide) methods to call out citations. Provide complete bibliographic info. In the Lit. Cited section. No footnotes. Minimize direct quotes. No titles cited in the text.	
Appendix I (10) Appendices II and III (5)	Copies of Laboratory Notebook pages and Sample calculations: correct, complete, readable with units and significant digits. Copy of three articles cited in Lit Review.	
	<u>RAW TOTAL</u>	
Points may be deducted from the report for deficiencies in the following areas		
Lab Notebook Appendix	Submit raw data; copy pages from notebook	
Documentation Appendix	Document sample calculations; provide sufficient narrative, working equations, units, etc. so that TA can follow the calculations.	
Appearance	All required sections. Margins observed. Neat handwriting if necessary. Stapled or clipped. Neat. Conform to Lab Manual instructions	
Figures	Informative titles and legends. Only 1 title per fig. Clear symbols and lines. Corrected Excel or PowerPoint defaults. Margins. Large enough to read. No excessive frames or borders. Discuss every figure. Capitalize “Figure x”	
Tables	Informative titles and headings. Describe content of tables (columns & rows). Only 3-4 significant digits. Show units. Useful information. Corrected Excel or PowerPoint defaults. Margins. Large enough to read. No excessive frames or borders. Discuss every table. Capitalize “Table y”	
Grammar and Spelling	Check verb use with “data.” Complete sentences. Homonyms. Apostrophes. Minimal use of possessives. No 2 nd person. Noun / verb agreement.	