Guidelines for Research
Tour Group 2004-2005
Rice University

http://www.ruf.rice.edu/~kekule/grouppage1.htm

Appendix:

Example Experimental Procedures

Significant Figures Tutorial

I. Group Organization and General Information

Welcome to James M. Tour's group at Rice. This information is provided to help you get acquainted with the group's procedures so that you can get quickly started with your research.

General: The group's labs are in Dell Butcher Hall (DBH) rooms 260 (phone x6249) and 300B (x6251). The group computers are in DBH 300A. See Jake Ciszek, the group's IT person, to get logged onto the group computers. The Tour Group Lab Manager is Dr. Dustin James (DBH 255, x6247). The Group's part-time Office Assistant is Chris Rodriguez (x6248). The Group's Safety Officer is Takashi Sasaki (DBH 300B, x6251). The Chemistry Department Safety Coordinator is Rose Gray-Dye, (Space Science (SS) Room 216, x6236). You may bring your own computer to the lab and obtain web access by getting an IP address assigned to you through Dustin, by contacting Dr. Problem (problem@rice.edu) or by using the Rice IT web page request form.

The Chemistry Department Coordinator is Diana Warren (SS 203, x3277), in the Chemistry Office. Diana does the paper work so that you can get paid each month. Diana will also have the different keys that you will need to get into the labs (get key numbers from Dustin). Diana also maintains petty cash for reimbursement of expenses when you buy materials (with prior approval) for the lab. Leah Benard-Boggs is the Sr. Department Administrator (SS 207, x5850).

The following is a list of basic operating principles that are important. Please follow them to the best of your ability. Gross disregard for these guidelines are cause for dismissal from the group (see dismissal policy in section II).

- Maintain security. Please close and lock all doors when you are the last to leave.
- Please conserve our resources. Turn off nitrogen valves when they are not being used, and when they are; please use the lowest flow rate possible. When you leave at night, turn off your lights and pull the hood sash down.

- Supplies can be purchased from the Chemistry Stock room on the second floor of the Space Science Building. Keep track of how much you spend. You will be asked to periodically review spending reports.
- Be frugal with glassware purchases; all glassware purchases should be pre-approved by Dr. Tour. Catalogs are available in the office, Room 255, or on the bookshelves in the computer room upstairs.
- Tour Group purchase order forms are available from the Group's Office Assistant Chris (Room 255, x6248). Fill out a form with a short explanation of why you want the material. If ordering a chemical have Katherine Price, the group's inventory control person, initial the appropriate spaces. Place the request in Dr. Tour's in-box. After approval from Dr. Tour, then Chris or Dustin will place the order.
- Experiments must be thoroughly documented in a hardbound laboratory notebook, in ink, at the time of completion. Each notebook page should be dated. More information is provided in section IV on lab notebooks and data collection. Office supplies such as lab notebooks, pads, paper, pens, and the like are available in the office. Computer diskettes and zip disks are also available. The chemists will need to start a file system with a manila folder for each compound made or experiment run. Your initials followed by the notebook number and the page number designate compounds and experiments. The first notebook you use is #I. So "JMT-I-1" means the first page of James M. Tour's first notebook. Each manila folder will contain all the spectra recorded for that compound. If more than one compound is made on each page, each compound can be indicated by a letter, such as "JMT-I-1A".
- Computer programmers should use commonly agreed-upon conventions for naming variables in their programs, and should insert comments into their code to indicate the conventions used. Programs written should have a level of documentation and comments such that projects can be taken up and understood by new group members without having to re-write the entire set of code. Back-ups should be made of source code and compiled programs as appropriate.
- All programs placed on computers should be licensed and paid for appropriately. Group computers should never be used for computer games.
- All group members write six-month reports that contain written summaries of their work, plus experimentals for the chemists. The experimentals will contain all spectral information, as if you were writing for *J. Am. Chem. Soc*. See part J below for information about less formal weekly reports for the subgroup meetings. The six-month reports can be written using the software on the group computers.
- Spectral data are to be cross-referenced to the corresponding notebook and labeled with appropriate structural and data collection information. **All** spectra for an experiment should be in one file folder with the same JMT-I-1 number.
- Products from reactions, homemade reagents, and intermediates should be stored in vials, bottles, or flasks (if storage is temporary), which are labeled with an appropriate structure and notebook cross-reference. Anything that will be "on the shelf" overnight must be labeled. No storage in round bottom flasks or NMR tubes is permitted.

- The chemists' group meeting is each Tuesday from 3:00 to 5:30 p.m. The labs are divided into halves or thirds, and each half or third presents their work on the board every fourth or fifth week. At the end of the meeting, one person presents a problem set from the recent literature, with responsibility rotating through the group. That person is also responsible for bringing refreshments to the meeting (sodas, cookies, chips, etc.). The rotation list is posted in each of the labs and is maintained by Austen Flatt.
- There are subgroup meetings every week. Each group member submits a hand-written or word-processed summary of the work they have done in the last week, on a clean sheet of paper. You should list every reaction, with the notebook number and yield that you carried out that past week. Dr. Tour gets a copy for the group files. The chemists meet each Friday at about 1:00 p.m., with each sub-group, such as molecular electronics, nanotrucks, nanotubes, etc. meeting separately with Dr. Tour. The secretary posts a schedule of subgroup meeting order on the bulletin board outside the office.
- Your attendance at all departmental seminars in the field of Organic Chemistry is mandatory and attendance at seminars in other fields is highly encouraged.
- You should plan to spend a minimum of three uninterrupted hours per week reading the current chemical literature.
- The group's Safety Officer is Takashi Sasaki. He will give you forms to read and sign.
- Wear safety glasses in the labs at all times. Lab coats are also required.
- All water lines for cooling must be secured with a double-wrap of metal wire to ensure steadfastness. Keep the flow at a moderately low rate so as not to burst a line.

Lab Sign Out Procedure

If you are the last person out of the lab at night, before leaving the laboratory make sure that—

- √ All N_2 Bubblers have a flow rate of 1 bubble per second or less
- √ All of the labs hood sashes are totally closed
- √ All water lines are secured with wires
- √ All faucets are turned off (except for reaction in progress)
- √ All variacs are on cork rings to prevent shorts if a water leak arises
- √ All stills are turned off (THF is turned to low)
- √ All lights are turned off
- √ All doors are locked (including instrument and computer rooms)

Blast shields are available. Always use them for potentially exothermic reactions. Always keep your hood sash down.

Nitrations are a special case. The Tour Lab policy is:

- √ The first time you nitrate a new compound, do it on less than 1g.
- √ Run multiple times at l g scale before scaling up.

- √ 10 g is the absolute upper limit.
- √ Use blast shield(!), safety glasses and safety mask, and green apron when running nitrations and working them up.
- √ When drying a nitrated aromatic, ensure that this takes place in a hood behind a bast shield. Often, explosions occur on drying. Use them as "wet" compounds if at all possible.

Group Responsibilities: the senior members of the group will assign you a group job. The procedures are completing the different jobs that are posted on the web page http://www.ruf.rice.edu/~kekule/grouppage1.htm. Please be responsible and help the group achieve what it needs to achieve by completing your job as needed. The laboratory must be kept clean. It is difficult to do good work on surfaces that are filthy and cluttered. A thorough laboratory clean up will take place three times a year.
Office hours: Dr. Tour has an open door policy. Generally, you are welcome to talk to Dr. Tour at any time, just knock on his door if it is closed. If he is available, he will ask you to come in.
Come to the laboratory to do chemistry. If you want to read in the laboratory, pick up a textbook or scientific journal and learn something new. If you want to read newspapers or novels, do this on your lunch break in a designated eating area. There is no eating or drinking in the lab.
External activities (athletic activities, laundry, shopping) should not interfere with your research.

II. Work Ethic

Graduate Students: Organic synthesis, computer science, and other forms of scientific research and study require a strong work ethic, which means spending much time and effort reading and working in the lab or at the computer. As you proceed through your career you will find that most good scientists are diligent workers with tenacity, fortitude, curiosity, and common sense. Some people have a bit of luck thrown to them, but they have prepared themselves for luck by becoming knowledgeable and observant. It is called "serendipity."

You would not be here if you did not have success in your field as your personal goal. Since it is my personal goal, and the overall goal of Rice University, to produce high quality scientists who can make significant contributions to their fields as well as humanity, I expect the students training in my group to show considerable progress in attaining the targets set before them. In the pages following are some expectations and guidelines for the day-to-day conduct of research that I believe, based on my experience, will help you achieve all of our goals.

Failure to adhere to the guidelines may result in my first talking with you. If the behavior continues, written notification of my dissatisfaction will result. Accumulation of such notices can result in permanent dismissal from the group. Failure to make corrections to inappropriate behavior or technique may also result in written notifications.

Work hours: I expect you to make progress towards the goals we have mutually agreed upon. If you find you are not making progress, it may be necessary to spend more time in the lab and

library; however, no one will keep track of your time in the lab. Part of the maturation process is learning how much time you need to spend on a project to get it accomplished.

Sexual Harassment—See the web-posted Rice Policy No. 830-01 that we will follow precisely.

III. Vacations

I don't monitor vacation days, and I don't expect that it should be necessary. Please send me an email prior to your departure, which notes the days you will be gone, and an emergency contact phone number where you can be reached just in case something happens in your area of the lab that requires us to contact you. As staff, **post docs** will need to keep track of the benefit days they have used each calendar year in order to turn in a Time and Attendance form in January of the next year. At this time staff have 21 benefit days prorated by the number of months you have been at Rice during the calendar year. You are expected to use all your benefit days before you leave Rice.

Personal emergencies and illness are understandable and a completely different matter. Please let me know what is going on when you are able; when you have an illness or crisis I may be able to help you get back on your feet faster, or I may know of someone who can help you, such as the university's counseling center. While research and publications are important to me, without your presence in the group, little would get done, so your health and well being are also important to me. If you are ill, my wife and I will gladly bring you some chicken soup to your home. Please don't hesitate to contact me at my home or cell phone if such an emergency should arise.

IV. Laboratory Notebooks and Data Collection for Chemists

Listed below are the most important guidelines to follow in documenting your research in a laboratory notebook. An example experimental procedure is found in the Appendix. A significant figure tutorial is given in the Appendix.

Use only the hardbound notebooks from the stockroom or the office.

Leave sufficient room at the beginning of the notebook to include an index of experiments done. When you complete a notebook, fill in the index before your start another notebook. Ideally, you should be filling in the index as you go.

Write only in ink and date each page. If you mark something out, initial and date the mark-out. Never completely obscure or remove such mistakes. When an experiment or page is complete, sign your name and note the date at the bottom of the page. Such information can be useful when applying for patents or for proving priority in publications. For new reactions or potential inventions, have another person who is capable of understanding the work sign as a witness.

Do not leave blank pages in your lab notebook. Use the pages in order, and if you have to continue an experiment on a non-sequential page, note "continued on page xx" and "continued from xx" on the appropriate pages. If you inadvertently leave a blank page in your notebook, make a large "X" across the page, and sign and date it. If you leave half a page blank, it is also useful to cross it out so no further additions can be made. These are good habits to develop in graduate school because industry, especially the pharmaceutical industry, requires this type of diligence (and more!) in maintaining a notebook. Your future job could depend on how well you keep your notebook.

At the top of the page of each new experiment write an equation with starting materials on the left, expected product(s) on the right, and reagents and experimental conditions over and under the forward arrow in the middle. It is usually best to write structures of organic materials since names can be long and difficult to write. Under each chemical write the molecular formula, formula weight, density, molarity, molality, concentration, mmol, equivalents, and/or other useful data that will enable you or someone else to know what is going on at a glance.
It is important to note color changes, formation of precipitants, gas evolution, exotherms or endotherms, or any other observances, and write them down in your notebook. This information can be critical both in scaling up a reaction, and in figuring out what happened if something goes wrong. The information can also be very helpful if you want to repeat an experiment that produced unusual results (sometimes good results!).

In your description of the experiment, you should note at what time you added reagents and reactants, and how fast, i.e. drop-wise, portion-wise, all-at-once, via syringe pump, or whatever. Were gases added under the surface of the liquid or to the headspace? Were liquids added under the surface of the liquid or allowed to drip into the mixture? Was the mixture stirred by a magnetic stir bar or by a mechanical stirrer? Write this information in your notebook.

Record the quantity of solvent and calculated molarity of the reaction. If the solvent was distilled prior to use note this and the drying method, if any, used in the distillation. The source of all starting materials should be clearly noted with either a manufacturer's name or a notebook cross-reference. When using a commercially produced chemical, it is useful to record the lot number. There have been many cases in which one lot number of a particular chemical performed differently than a second lot number of the same chemical

Measure and record the temperature of both the heating or cooling bath and the interior of the reaction mixture if possible. Note whether you carried out the reaction under an inert atmosphere. Did you use oven-dried glassware?

When possible, all reactions are to be monitored by GC or TLC from time zero until the reaction is complete.

If you quench a reaction, note how you did it, i.e. poured onto ice, carefully added acid, sparged with nitrogen, etc. If there was foaming, exothermic activity, or other reaction on quenching, write it down in your notebook. How long did the foaming last? Was it difficult to handle? Did anything spill out that will affect yield later?

When doing an extractive work-up, count the number of extractions and write down the names and quantities of solvents used. It is more efficient to use small quantities of the extraction solvent three times rather than a large quantity one or two times. This also conserves expensive solvents.

Make note of the drying methods employed after work-up (e.g., brine wash, $MgSO_4$, Na_2CO_3, Na_2SO_4 etc.) and how many cycles you went through. Did you filter using a Buchner funnel, a fluted filter paper, through cotton (filtering through a wad of cotton will often catch the last few droplets of water since they will gloom onto the very polar cotton fibers), or what? Was the filtrate cloudy? It may not have been dried well enough. Did you combine all the organic extracts into one, and then dry the whole, or did you dry some extracts separately? What color were the extracts? What color was the aqueous layer, if any? Was the aqueous layer cloudy or clear? A cloudy aqueous layer could mean that separation of the layers after extractions was not as efficient as it could have been.

If you purify by flash column or other method, record the type of chromatography used, the eluant system, the column or prep plate size, and the quantity of silica gel or other solid phase.
If you purify by crystallization, did you dissolve the solid product in hot solvent (at what temperature?) and allow to cool, or did you precipitate the solid by trituration? When you filtered the crystals did you wash them with clean solvent? Did you recover any product from the mother liquor? Write it down.

If a compound is distilled or sublimed at reduced pressure, both the temperature and the pressure should be noted. Also note the literature values and references if they are known. Did you do a short path distillation, use a Vigreux or packed column, take fractions, experience bumping, or set the apparatus such that you used a specific reflux ratio? Write it down.

For each reaction, ensure that you have one spectral file folder that has the corresponding reaction number on it and all the spectra therein.

Calculate a crude weight and obtain a ^1H NMR of the crude reaction mixture.

Following purification, calculate the yield and carry out initial characterization of all products.

For repeat experiments you may list only the reagent/substrate data and pertinent procedural changes. Cross-reference this notebook page to the most recent full experimental that you are following. When changing conditions note the changes and your reasons for making the changes.

When following a literature procedure, whether it is the exact procedure or simply a representative example, list the reference at the top of the page under the equation. Distinguish exact *vs*. representative procedures.

Keep representative HPLC and GC traces in the spectral file. For HPLC, take note of flow rate, solvent system, column type, column size, eluant system, type of elution (gradient or isocratic), and amount of compound introduced per injection. For GC, note injection volume and sample concentration, column type, and oven, injector and detector temperatures.

Each new compound that will appear in print (publication/thesis) must be fully characterized. The characterization data should be stored in a manila folder with a structural representation and checklist of acquired analytical data attached or written on the outside. **For a compound to be completely characterized the folder must contain:**

- Chemical Abstracts name and Chemical Abstracts registry number (if available).
- Experimental procedure (JACS format). See the representative experimental procedures at the end of the Handbook. Follow this format very carefully. Pay special attention to the bracketing method for enclosing the moles and volumes of reagents, the protocol for reporting spectra, the use of General Experimental Procedures if you use the same reaction three times or more, the use of citation methods, etc. If a compound is known in the literature, you must provide a reference for that compound, and you need only obtain the proton NMR. If the specific compound is not known but you used another's protocol, you must cite their protocol. If the compound is not known, you must minimally obtain FTIR, proton and carbon NMR, HRMS or combustion analysis.
- Tabulated data and a hard copy of ^{1}H NMR, ^{13}C NMR, IR, and MS spectral data, and C/H combustion analysis (if not possible, then HRMS data).
- Physical Properties: determine the optical rotation of chiral compounds and melting point of solids and the boiling point of distilled liquids or oils.
- X-ray structure (if obtained). This should include all data in hard copy form as well as a floppy disk containing the structural information in Chem 3D format.

V. Laboratory Safety

Police/Emergency Phone: x6000

See the Tour Group's web page for the Chemical Hygiene Plan for more information on Lab Safety.

VI. Departure From The Group (Note New Instructions for Thesis Format)

Upon completion of your stay please do the following:

- Be sure all spectral files are labeled with a notebook cross-reference and a structure. Put them in banker-type boxes and coordinate with Dustin to have them properly filed in our storage facility on South Main Street. Your notebooks will be kept in Dr. Tours office.
- If you have not already done so, prepare characterization folders for all compounds *(vide supra).*
- Clean out your freezer space saving samples of all useful characterized intermediates. Place these in the plastic storage boxes, labeled with your name. Insert a chemical inventory list of the box's contents, with the number of grams or mg for each compound, into the box itself. Give a copy of the complete inventory list of your compounds to Dr. Tour.
- Large quantities of potentially useful intermediates should be put in brown bottles, labeled accordingly, stored in the appropriate freezer or shelf location, and added to the chemical inventory.
- Put all computer files in one folder on the computer with your name, and provide them on a zip disk to Dr. Tour.
- Return all keys to Dustin or Diana Gomez, and arrange for mail forwarding with the Human Resources office through paperwork you will fill out with Diana.
- Wash and return all glassware to the proper storage location.
- Return all chemicals to the proper shelf or freezer location and update the chemical inventory as needed.
- **In addition to whatever Rice requires, you must have a hard copy of your thesis bound with the following specifications:** solid Royal Blue color (Rice Color), with gold writing on the spine of the binding (you can also have information on the cover of the thesis); a) Your Name (top of the spine, horizontal print so it can be read without twisting your head to the side) b) Ph.D. (or M.S.) Rice University (middle of the spine, horizontal printing) c) Month, Year (of graduation, at bottom of spine, horizontal print). A suggested bookbinder is **A.V. Emmott & Sons Bookbinders, 5700 Mitchelldale St., Houston, Texas 77092. Telephone 713-956-0211**.
- In addition to hard copy of thesis, give an electronic copy of thesis and reports to Dr. Tour.

Some Advice from Dr. Tour

Technique: Good laboratory skills are a very important part of the chemist's career development. Even if you don't end up working in the lab after you graduate, you may be directing others who are. It is easier to teach others when you've done it yourself. Organic synthesis involves complex tasks that must usually be done in a certain order. Plan each experiment carefully, especially if it is one you've never done before. When you plan carefully, and make as many observations as possible, the reason for a negative result can be more readily ascertained. Plan your day properly. Before leaving after a day's work, make a list of reactions

to be run on the following day, and get as far as possible in preparing to run them. Then, when you enter the next morning, you can begin your work without delay.

Non-research time: Get out of the chemistry building in your free time. Learn something about art, literature, sports, religion or music. Get to know other people in the Rice community by participating in various campus activities. If you have a significant other, pay attention to them, let them know you are thankful for their support. A breath of fresh air and relaxation in the sunshine can often clear the way for a break-through in your thought process.

Personal Hygiene: Although not customary in all countries, Americans generally bathe at least several times per week. As a result, many Americans are offended by the infrequent bathing habits of others (whether Americans or internationals). Thus, you may be leaving a negative impression of yourself without ever knowing it. Unfortunately, bad impressions are often difficult to overcome. Likewise, be sure to use an underarm deodorant since most Americans find body odor to be most offensive. I have seen people causing themselves to be ostracized by others simply because of poor personal hygiene habits.

Goals: People are visual by nature. Set high, obtainable goals for yourself and *visualize yourself achieving those goals*. Athletes are commonly known for doing this, but it can work for scientists also. By visualization, you are forced to form a plan, and by planning, you ready yourself for each step in the process.

Peers: Gossip reflects poorly on you, and consumes time needlessly. Saying bad things about others to build yourself up yields negative results in the end, and people will tend to steer away from you. It is a surprisingly small world out there and you never know when you will run into a former lab partner or graduate schoolmate. You may be relying on them for your next job.

Recommendations: When you request that I write a recommendation letter on your behalf, the quality of my recommendation will be directly related to the quality and effort of your research. Minimal effort will result in a recommendation with minimal support. I won't risk my reputation, and the reputation of other group members, by writing letters that do not accurately reflect a person's skills, effort, knowledge, and results.

These Guidelines: These guidelines are designed to ensure that everyone knows what is expected and that the same things are expected of everyone. This is not a comprehensive outline of how to conduct oneself in graduate school. Always use common sense and remember, "do unto others as you would have them do unto you." A corollary is "work hard for me and I will work hard for you."

Parts of this information have been extracted from the group handbook produced by Prof. John L. Wood of Yale University.

Sample Experimental Procedure

General. All reactions were performed under an atmosphere of nitrogen unless stated otherwise. Alkyllithium reagents were obtained from FMC. Pyridine, methyl iodide, triethylamine, and *N*,*N*-dimethylformamide (DMF) were distilled over calcium hydride, and stored over 4 Å molecular sieves. Toluene and benzene were distilled over CaH_2. Methylene chloride and hexanes were distilled. Ethyl ether and tetrahydrofuran (THF) were distilled from sodium benzophenone ketyl. Triethylamine and diisopropylethylamine (Hünig's base) were distilled over CaH_2. MeOH was dried over oven dried 3 Å molecular sieves. Gravity column chromatography, silica gel plugs, and flash chromatography were performed using 230-400 mesh silica gel from EM Science. Thin layer chromatography was preformed using glass plates precoated with silica gel 60 F_{254} with a layer thickness of 0.25 mm purchased from EM Science. Combustion analyses were obtained from Atlantic Microlab, Inc., P. O. Box 2288, Norcross, GA 30091.

General Procedure for the Coupling of a Terminal Alkyne with an Aryl Halide Using the Palladium-Copper Cross-Coupling (Castro-Stephens/Sonogashira Protocol).[1] To an oven-dried round bottom flask equipped with a water cooled West condenser and magnetic stir bar or to a screw cap pressure tube with a magnetic stir bar were added the aryl halide, a palladium catalyst such as bis(triphenylphosphine)palladium(II) dichloride (3-5 mol % per halide), and copper(I) iodide (6-10 mol % per halide). Triphenylphosphine was used in some reactions to keep the palladium in solution. The vessel was then sealed with a rubber septum (flask) or capped (tube) under a N_2 atmosphere. A solvent system of THF and/or benzene and/or methylene chloride was added depending on the solubility of the aryl halide. Then base, triethylamine or diisopropylethylamine, was added. Finally, the terminal alkyne (1-1.5 mol % per halide) was added and the reaction was heated until complete. Upon completion of the reaction, the reaction mixture was quenched with water, a saturated solution of NH_4Cl, or brine. The organic layer was diluted with methylene chloride or Et_2O and washed with water, a saturated solution of NH_4Cl, or brine (3×). The combined aqueous layers were extracted with methylene chloride or Et_2O (2×). The combined organic layers were dried over $MgSO_4$ and the solvent removed in vacuo to afford the crude product that was purified by column chromatography (silica gel). Eluents and other slight modifications are described below for each material.

General Procedure for the Iodination of Triazenes.[2] To an oven-dried screw cap tube was added the corresponding triazene and iodomethane. The mixture was degassed by slowly bubbling nitrogen for more than 15 min. After flushing with nitrogen, the tube was capped and heated at 120 °C overnight. The reaction mixture was cooled and diluted with hexane. The mixture was passed through a plug of silica gel. After evaporation of the solvent in vacuo, purified product was obtained by chromatography. Eluents and other slight modifications are described below for each material.

4,4′-Di(ethynylphenyl)-1-(thioacetyl)benzene (4) (JMT-I-27). See the general procedure for the Pd/Cu coupling reaction. The compounds used were copper(I) iodide (0.042 g, 0.22 mmol), bis(dibenzylideneacetone)palladium(0) (0.063 g, 0.11 mmol), triphenylphosphine (0.115 g, 0.44 mmol), **3** (0.64 g, 2.3 mmol) 1-ethynyl-4-(ethynylphenyl)benzene (0.44 g, 2.2 mmol), diisopropylethylamine (1.7 mL, 10.0 mmol), and THF (10 mL) at 50 °C for 3 h. The residue purified by flash liquid chromatography using silica gel (1:1 hexanes: methylene chloride) yielding 0.57 g (74%) of the titled compound. IR (KBr) 3435.9, 3138.5, 2215.4, 1697.4, 1656.4, 1507.7, 1379.5, 1353.8, 1128.2, 1107.7, 1015.4, 943.6, 838.6, 828.1, 759.0, 756.7, 692.0, 620.5 cm^{-1}. ^1H NMR (300 MHz, C_6D_6) δ 7.54-7.50 (m, 2 H), 7.39 (d, *J* = 8.5 Hz, 2 H), 7.34 (d, *J* = 2 Hz, 3 H), 7.24 (d, *J* = 8.5 Hz, 2 H), 7.16 (br s, 1 H), 7.03-6.98 (m, 3 H), 1.81 (s, 3 H). ^{13}C NMR (400 MHz, C_6D_6) δ 190.94, 134.24, 132.01, 131.62, 131.58, 128.91, 128.35, 127.21, 126.96, 124.12, 123.60, 123.28, 122.93, 91.87, 91.01, 90.90, 89.52, 29.55. HRMS calcd for $C_{23}H_{16}SO$: 352.0922. Found 352.0921.

1-Diethyltriazenyl- 4-ethynylphenylbenzene (7) (JMT-I-42). See the general procedure for the Pd/Cu coupling reaction. **6** (2.56 g, 10.0 mmol), phenylacetylene (1.21 mL, 11.0 mmol), bis(dibenzylideneacetone)palladium(0) (0.26 g, 0.280 mmol), copper(I) iodide (0.21 g, 11.0 mmol), triphenylphosphine (0.83 g, 2.75 mmol), and diisopropylethylamine (7.65 mL, 44.0 mmol) were reacted in THF (10 mL) at room temperature for 2 d and 70 ºC for 3 d. An additional portion of phenylacetylene (0.60 mL, 5.5 mmol) was added and the mixture was stirred at 70 ºC for 1 d. The crude product was purified by flash chromatography on silica gel (hexane-ether 19:1) to afford desired product (2.64 g, 95%) as a yellow oil. FTIR (neat) 2976, 2359, 2213, 1594, 1393, 1237, 1201, 1162, 1097, 841, 756, 690 cm^{-1}. ^1H NMR ($CDCl_3$) δ 7.51 (dd, *J* = 7.7, 1.7 Hz, 2 H), 7.48 (dt, *J* = 8.5, 1.6 Hz, 2 H), 7.38 (dt, *J* = 8.5, 1.6 Hz, 2 H), 7.36-7.26 (m, 3 H), 3.76 (q, *J* = 7.2 Hz, 2 H), 1.26 (br t, 3 H). ^{13}C NMR ($CDCl_3$) δ 151.1, 132.3, 131.5, 128.3, 128.0, 123.6, 120.4, 119.4, 90.1, 89.1. (Two carbons are missing due to the quadropolar effect of nitrogen.) HRMS calcd for $C_{18}H_{19}N_3$: 277.1579. Found: 277.1582.

Bis(3,5-diiodophenyl)methane (JMT-II-7). To a solution of bis(3,5-dibromophenyl)methane (484 mg, 1.0 mmol) in dry THF (1.0 mL) was added under nitrogen at -78 °C *n*-butyllithium (1.58 M in hexane, 3.2 mL, 5.0 mmol). The solution was stirred at -78 °C for 1 h. After chlorotrimethylsilane (1.27 mL, 10.0 mmol) was added, the solution was stirred at -78 °C for 30 min and at room temperature overnight. The solution was poured into water and extracted with ether. The extract was dried over magnesium sulfate. After filtration, the solvent was evaporated in vacuo to afford a brown oil. The oil was separated by flash chromatography on silica gel (hexane-ethyl acetate 19:1) to afford bis(3,5-bistrimethylsilylphenyl)methane (377 mg) as a yellow oil. The oil contained a small amount of impurity but it was used for next reaction without further purification. To a solution of bis(3,5-bistrimethylsilylphenyl)methane (332 mg, 0.73 mmol) in carbon tetrachloride (10 mL) was added at room temperature iodine monochloride (0.16 mL, 3.2 mmol) in carbon tetrachloride (5.0 mL). The solution was stirred at room temperature for 1 h and poured into an aqueous solution of sodium thiosulfate. The aqueous solution was extracted with dichloromethane. The solution was dried over magnesium sulfate. After filtration, the solvent was evaporated in vacuo to afford a brown oil. The oil was washed

with a small amount of dichloromethane to afford the desired product (209 mg, 36%) as a white solid. Mp 219-221 °C. FTIR (KBr) 1560, 1542, 1412, 1384, 712 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ 7.91 (s, 2 H), 7.42 (t, *J* = 1.5 Hz, 4 H), 7.42 (d, *J* = 1.5, 4 H), 3.71 (s, 2 H). ^{13}C NMR ($CDCl_3$) δ 143.6, 137.1, 94.8, 39.8. HRMS calcd for $C_{13}H_8I_4$: 671.6805. Found: 671.6802.

Following are Summaries from Two Chemistry Education Web Sites Concerning Significant Figure Rules

From http://dbhs.wvusd.k12.ca.us/SigFigs/SigFigRules.html

There are three rules on determining how many significant figures are in a number:

Non-zero digits are always significant.
Any zeros between two significant digits are significant.
A final zero or trailing zeros in the decimal portion ONLY are significant.

Focus on these rules and learn them well. They will be used extensively throughout the remainder of this course. You would be well advised to do as many problems as needed to nail the concept of significant figures down tight and then do some more, just to be sure.

Please remember that, in science, all numbers are based upon measurements (except for a very few that are defined). Since all measurements are uncertain, we must only use those numbers that are meaningful. A common ruler cannot measure something to be 22.4072643 cm long. Not all of the digits have meaning (significance) and, therefore, should not be written down. In science, only the numbers that have significance (derived from measurement) are written.

If you're not convinced significant figures are important, you may want to read this Significant Figure Fable.

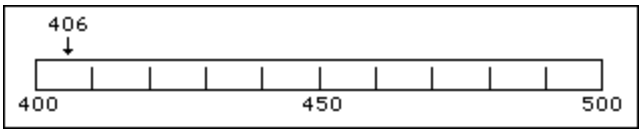
Rule 1: Non-zero digits are always significant.

Hopefully, this rule seems rather obvious. If you measure something and the device you use (ruler, thermometer, triple-beam balance, etc.) returns a number to you, then you have made a measurement decision and that ACT of measuring gives significance to that particular numeral (or digit) in the overall value you obtain.

Hence a number like 26.38 would have four significant figures and 7.94 would have three. The problem comes with numbers like 0.00980 or 28.09.

Rule 2: Any zeros between two significant digits are significant.

Suppose you had a number like 406. By the first rule, the 4 and the 6 are significant. However, to make a measurement decision on the 4 (in the hundred's place) and the 6 (in the unit's place), you HAD to have made a decision on the ten's place. The measurement scale for this number would have hundreds and tens marked with an estimation made in the unit's place. Like this:



Rule 3: A final zero or trailing zeros in the decimal portion <u>ONLY</u> are significant.

This rule causes the most difficulty with ChemTeam students. Here are two examples of this rule with the zeros this rule affects in boldface:

0.005**00**
0.0304**0**

Here are two more examples where the significant zeros are in boldface:

2.3**0** x 10^{-5}
4.5**00** x 10^{12}

What Zeros are Not Discussed Above

Zero Type #1: Space holding zeros on numbers less than one.

Here are the first two numbers from just above with the digits that are NOT significant in boldface:

0.**00**500
0.**0**3040

These zeros serve only as space holders. They are there to put the decimal point in its correct location. They DO NOT involve measurement decisions. Upon writing the numbers in scientific notation (5.00 x 10^{-3} and 3.040 x 10^{-2}), the non-significant zeros disappear.

Zero Type #2: the zero to the left of the decimal point on numbers less than one.

When a number like 0.00500 is written, the very first zero (to the left of the decimal point) is put there by convention. Its sole function is to communicate unambiguously that the decimal point is a decimal point. If the number were written like this, .00500, there is a possibility that the decimal point might be mistaken for a period. Many students omit that zero. They should not.

Zero Type #3: trailing zeros in a whole number.

200 is considered to have only ONE significant figure while 25,000 has two.

This is based on the way each number is written. When whole number are written as above, the zeros, BY DEFINITION, did not require a measurement decision, thus they are not significant.

However, it is entirely possible that 200 really does have two or three significant figures. If it does, it will be written in a different manner than 200.

Typically, scientific notation is used for this purpose. If 200 has two significant figures, then 2.0×10^2 is used. If it has three, then 2.00×10^2 is used. If it had four, then 200.0 is sufficient. See rule #2 above.

How will you know how many significant figures are in a number like 200? In a problem like below, divorced of all scientific context, you will be told. If you were doing an experiment, the context of the experiment and its measuring devices would tell you how many significant figures to report to people who read the report of your work.

Zero Type #4: leading zeros in a whole number.

00250 has two significant figures. 005.00×10^{-4} has three.

Exact Numbers

Exact numbers, such as the number of people in a room, have an infinite number of significant figures. Exact numbers are counting up how many of something are present, they are not measurements made with instruments. Another example of this are defined numbers, such as 1 foot = 12 inches. There are exactly 12 inches in one foot. Therefore, if a number is exact, it DOES NOT affect the accuracy of a calculation nor the precision of the expression. Some more examples:

There are 100 years in a century.

2 molecules of hydrogen react with 1 molecule of oxygen to form 2 molecules of water.

There are 500 sheets of paper in one ream.

Interestingly, the speed of light is now a defined quantity. By definition, the value is 299,792,458 meters per second.

A. Are Significant Figures Important? A Fable

A student once needed a cube of metal that had to have a mass of 83 grams. He knew the density of this metal was 8.67 g/mL, which told him the cube's volume. Believing significant figures were invented just to make life difficult for chemistry students and had no practical use in the real world, he calculated the volume of the cube as 9.573 mL. He thus determined that the edge of the cube had to be 2.097 cm. He took his plans to the machine shop where his friend had the same type of work done the previous year. The shop foreman said, "Yes, we can make this according to your specifications - but it will be expensive."

"That's OK," replied the student. "It's important." He knew his friend has paid $35, and he had been given $50 out of the school's research budget to get the job done.

He returned the next day, expecting the job to be done. "Sorry," said the foreman. "We're still working on it. Try next week." Finally the day came, and our friend got his cube. It looked very,

very smooth and shiny and beautiful in its velvet case. Seeing it, our hero had a premonition of disaster and became a bit nervous. But he summoned up enough courage to ask for the bill. "$500, and cheap at the price. We had a terrific job getting it right -- had to make three before we got one right."

"But--but--my friend paid only $35 for the same thing!"

"No. He wanted a cube 2.1 cm on an edge, and your specifications called for 2.097. We had yours roughed out to 2.1 that very afternoon, but it was the precision grinding and lapping to get it down to 2.097 which took so long and cost the big money. The first one we made was 2.089 on one edge when we got finshed, so we had to scrap it. The second was closer, but still not what you specified. That's why the three tries."

"Oh!"

B. Rules for Rounding Off

Now that "everyone" has a calculator that will give a result to six or eight (or more) figures, it is important that we know how to round the answer off correctly. The typical rule taught is that you round up with five or more and round down with four or less.

THIS RULE IS WRONG!

However, please do not rush off to your elementary school teacher and read 'em the riot act!

The problem lies in rounding "up" (increasing) the number that is followed by a 5. For example, numbers like 3.65 or 3.75, where you are to round off to the nearest tenth.

OK, let's see if I can explain this. When you round off, you change the value of the number, except if you round off a zero. Following the old rules, you can round a number down in value four times (rounding with one, two, three, four) compared to rounding it upwards five times (five, six, seven, eight, nine). Remember that "rounding off" a zero does not change the value of the number being rounded off.

Suppose you had a very large sample of numbers to round off. On average you would be changing values in the sample downwards 4/9ths of the time, compared to changing values in the sample upward 5/9ths of the time.

This means the average of the values AFTER rounding off would be greater than the average of the values BEFORE rounding.

This is not acceptable.

We can correct for this problem by rounding "off" (keeping the number the same) in fifty percent of the roundings-even numbers followed by a 5. Then, on average, the roundings "off" will cancel out the roundings "up."

The following rules dictate the manner in which numbers are to be rounded to the number of figures indicated. The first two rules are more-or-less the old ones. Rule three is the change in the old way.

When rounding, examine the figure following (i.e., to the right of) the figure that is to be last. This figure you are examining is the first figure to be dropped.

If it is less than 5, drop it and all the figures to the right of it.
If it is more than 5, increase by 1 the number to be rounded, that is, the preceeding figure.
If it is 5, round the number so that it will be even. Keep in mind that zero is considered to be even when rounding off.

Example #1 - Suppose you wish to round 62.5347 to four significant figures. Look at the fifth figure. It is a 4, a number less than 5. Therefore, you will simply drop every figure after the fourth, and the original number rounds off to 62.53.

Example #2 - Round 3.78721 to three significant figures. Look at the fourth figure. It is 7, a number greater than 5, so you round the original number up to 3.79.

Example #3 - Round 726.835 to five significant figures. Look at the sixth figure. It is a 5, so now you must look at the fifth figure also. That is a 3, which is an odd number, so you round the original number up to 726.84.

Example #4 - Round 24.8514 to three significant figures. Look at the fourth figure. It is a 5, so now you must also look at the third figure. It is 8, an even number, so you simply drop the 5 and the figures that follow it. The original number becomes 24.8.

When the value you intend to round off is a five, you MUST look at the previous value ALSO. If it is even, you round down. If it is odd, you round up. A common question is "Is zero considered odd or even?" The answer is even.

Here are some more examples of the "five rule." Round off at the five.

3.075

3.85

22.73541

0.00565

2.0495

This last one is tricky (at least for high schoolers being exposed to this stuff for the first time!). The nine rounds off to a ten (not a zero), so the correct answer is 2.050, NOT 2.05.

Would your teacher be so mean as to include problems like this one on a test? In the ChemTeam classroom, the sufferers (oops, I mean students) have learned to shout "YES" in unison to such easy questions.

Lastly, before we get to the problems. Students, when they learn this rule, like to apply it across the board. For example, in 2.0495, let's say we want to round off to the nearest 0.01. Many times, a student will answer 2.04. When asked to explain, the rule concerning five will be cited. However, the important number in this problem is the nine, so the rule is to round up and the correct answer is 2.05.

C. Math With Significant Figures

Addition and Subtraction

In mathematical operations involving significant figures, the answer is reported in such a way that it reflects the reliability of the least precise operation. Let's state that another way: a chain is no stronger than its weakest link. An answer is no more precise that the least precise number used to get the answer. Let's do it one more time: imagine a team race where you and your team must finish together. Who dictates the speed of the team? Of course, the slowest member of the team. Your answer cannot be MORE precise than the least precise measurement.

For addition and subtraction, look at the decimal portion (i.e., to the right of the decimal point) of the numbers ONLY. Here is what to do:

1) Count the number of significant figures in the decimal portion of each number in the problem. (The digits to the left of the decimal place are not used to determine the number of decimal places in the final answer.)

2) Add or subtract in the normal fashion.

3) Round the answer to the LEAST number of places in the decimal portion of any number in the problem.

WARNING: the rules for add/subtract are different from multiply/divide. A very common student error is to swap the two sets of rules. Another common error is to use just one rule for both types of operations.

Multiplication and Division

The following rule applies for multiplication and division:

The LEAST number of significant figures in any number of the problem determines the number of significant figures in the answer.

This means you MUST know how to recognize significant figures in order to use this rule.

Example #1: 2.5 x 3.42.

The answer to this problem would be 8.6 (which was rounded from the calculator reading of 8.55). Why?

2.5 has two significant figures while 3.42 has three. Two significant figures is less precise than three, so the answer has two significant figures.

Example #2: How many significant figures will the answer to 3.10 x 4.520 have?

You may have said two. This is too few. A common error is for the student to look at a number like 3.10 and think it has two significant figures. The zero in the hundedth's place is not recognized as significant when, in fact, it is. 3.10 has three significant figures.

Three is the correct answer. 14.0 has three significant figures. Note that the zero in the tenth's place is considered significant. All trailing zeros in the decimal portion are considered significant.

Another common error is for the student to think that 14 and 14.0 are the same thing. THEY ARE NOT. 14.0 is ten times more precise than 14. The two numbers have the same value, but they convey different meanings about how trustworthy they are.

Four is also an incorrect answer given by some ChemTeam students. It is too many significant figures. One possible reason for this answer lies in the number 4.520. This number has four significant figures while 3.10 has three. Somehow, the student (YOU!) maybe got the idea that it is the GREATEST number of significant figures in the problem that dictates the answer. It is the LEAST.

Sometimes student will answer this with five. Most likely you responded with this answer because it says 14.012 on your calculator. This answer would have been correct in your math class because mathematics does not have the significant figure concept.

Example #3: 2.33 x 6.085 x 2.1. How many significant figures in the answer?

Answer - two.

Which number decides this?

Answer - the 2.1.

Why?

It has the least number of significant figures in the problem. It is, therefore, the least precise measurement.

Example #4: $(4.52 \times 10^{-4}) \div (3.980 \times 10^{-6})$.

How many significant figures in the answer?

Answer - three.

Which number decides this?

Answer - the 4.52×10^{-4}.

Why?

It has the least number of significant figures in the problem. It is, therefore, the least precise measurement. Notice it is the 4.52 portion that plays the role of determining significant figures; the exponential portion plays no role.

For practice with significant figures, go to:

http://science.widener.edu/svb/tutorial/sigfigures.html

From http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch1/sigfigs.html

It is important to be honest when reporting a measurement, so that it does not appear to be more accurate than the equipment used to make the measurement allows. We can achieve this by controlling the number of digits, or **significant figures**, used to report the measurement.

Determining the Number of Significant Figures

The number of significant figures in a measurement, such as 2.531, is equal to the number of digits that are known with some degree of confidence (2, 5, and 3) plus the last digit (1), which is an estimate or approximation. As we improve the sensitivity of the equipment used to make a measurement, the number of significant figures increases.

Postage Scale	3 ±1 g	1 significant figure
Two-pan balance	2.53 ±0.01 g	3 significant figures
Analytical balance	2.531 ±0.001 g	4 significant figures

Rules for counting significant figures are summarized below.

Zeros *within* a number are always significant. Both 4308 and 40.05 contain four significant figures.

Zeros that do nothing but set the decimal point are not significant. Thus, 470,000 has two significant figures.

Trailing zeros that aren't needed to hold the decimal point are significant. For example, 4.00 has three significant figures.

If you are not sure whether a digit is significant, assume that it isn't. For example, if the directions for an experiment read: "Add the sample to 400 mL of water," assume the volume of water is known to one significant figure.

Addition and Subtraction with Significant Figures

When combining measurements with different degrees of accuracy and precision, *the accuracy of the final answer can be no greater than the least accurate measurement.* This principle can be translated into a simple rule for addition and subtraction: **When measurements are added or subtracted, the answer can contain no more decimal places than the least accurate measurement.**

150.0 g H_2O (using significant figures)

+ 0.507 g salt

150.5 g solution

Multiplication and Division With Significant Figures

The same principle governs the use of significant figures in multiplication and division: the final result can be no more accurate than the least accurate measurement. In this case, however, we count the significant figures in each measurement, not the number of decimal places: **When measurements are multiplied or divided, the answer can contain no more significant figures than the least accurate measurement.**

Example: To illustrate this rule, let's calculate the cost of the copper in an old penny that is pure copper. Let's assume that the penny has a mass of 2.531 grams, that it is essentially pure copper, and that the price of copper is 67 cents per pound. We can start by from grams to pounds.

$$2.531\ g \times \frac{1\ lb}{453.6\ g} = 0.005580\ lb$$

We then use the price of a pound of copper to calculate the cost of the copper metal.

$$0.005580\ lb \times \frac{67¢}{1\ lb} = 0.3749\ g$$

There are four significant figures in both the mass of the penny (2.531) and the number of grams in a pound (453.6). But there are only two significant figures in the price of copper, so the final answer can only have two significant figures.

Rounding Off

When the answer to a calculation contains too many significant figures, it must be rounded off.

There are 10 digits that can occur in the last decimal place in a calculation. One way of rounding off involves *underestimating* the answer for five of these digits (0, 1, 2, 3, and 4) and *overestimating* the answer for the other five (5, 6, 7, 8, and 9). This approach to rounding off is summarized as follows.

If the digit is smaller than 5, drop this digit and leave the remaining number unchanged. Thus, 1.684 becomes 1.68.

If the digit is 5 or larger, drop this digit and add 1 to the preceding digit. Thus, 1.247 becomes 1.25.