

# Guide to successful research

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## I. Knowing what you're supposed to be doing

In the Combustion Physics Lab we hold weekly meetings on a 3-week cycle:

- Week 1: entire lab meeting (time and location announced as needed) – everyone attends
- Week 2: sub-group meeting – each project sub-group (microcombustion, engines, edge flames, etc.) meets for an hour with PDR. All members of that sub-group attend, including undergraduates. The time for this meeting is scheduled during the lab meeting the previous week.
- Week 3: sub-group meeting – same format as week 2 meeting.
- Week 4 -  $\infty$ : Repeat cycle of weeks 1 – 3.

You have three working documents that should make it clear what your objectives are at any given time and how you are supposed to accomplish those objectives. Refer back to these occasionally to see if you've missed doing something important. **Forgotten  $\neq$  done!**

1. This document. I expect you to read it, know it and understand it.
2. The files named "abc.progress.doc" (abc = microcombustion, MFC, EdgeFlames, etc.) which is our working document of progress, problems and next steps. These documents must be kept on the Dropbox folder for each project. You are expected to add to this document every week before our meeting stating:
  - a. What was accomplished during the previous week
  - b. What the plans are for the upcoming week

Adding weekly entries to these progress documents is absolutely essential, otherwise we have no record of what was tested, what was successful, what was learned and what was tried but didn't work.

3. In most cases, your research project is based on a (successful) proposal to a funding agency. This proposal contains the overall objectives, proposed methods for accomplishing those objectives, references to prior work, etc. These documents are also stored in your Dropbox folder.

## II. Working Safely

1. **General note.** If ever you're not sure about how to use a piece of equipment or apparatus or whatever safely, don't use it until you've been able to ask someone who knows. Also, **not using safety equipment (e.g. safety goggles) because it wasn't handy or was inconvenient it is not a valid excuse.** If we don't have it, or it isn't usable, or you don't know how to use it, get the right equipment and information before you start!

2. **Keeping PDR informed.** Any time there is any safety problem in the lab, you must inform me immediately, any time, day or night! You all have my cell phone number and it's almost always on.

3. **Training.** All CPL personnel must receive USC-approved safety training (in person, in a classroom setting, not on-line) before working in the lab. No exceptions! The website to schedule your training is here:

<http://tinyurl.com/pp88pbx>

From this site, choose "General Lab Safety (GLS)." There is no cost for the training. There may also be other training required to work in other labs (e.g. all chemistry labs require additional safety training.)

### 4. Emergency.

- First call 0-4321 from any campus phone, or 213-740-4321 from your cell phone.
- Next, call USC Environmental Health and Safety, (323) 442-2200.
- Next, call Ana Montes, Viterbi Facilities Coordinator (323) 527-5346 (mobile); (213) 740-4175 (office); [anagonza@usc.edu](mailto:anagonza@usc.edu) (email)
- Then call PDR... you have my cell number, my phone is almost always on.
- See also the EHS website, <http://adminopsnet.usc.edu/department/environmental-health-safety/emergency-notification-protocol-injuries-and-incidents>
- The USC Emergency Preparedness website is <http://preparedness.usc.edu>

5. **Safety goggles. Must be worn at all times when doing experiments.** In the lab we have several types of hazardous materials: flammable, explosive, toxic, corrosives, etc., all of which mandate the use of safety goggles.

6. **Shoes and pants. Closed-toed shoes and long pants are required while working in the lab.** No skin can be exposed, meaning that if you're wearing high-water pants, you need to wear socks as well. This is University and/or Viterbi policy, not mine. (Though I fully agree with the policy.)

7. **Lab coats. Lab coats must be worn while working in the lab.** This is University policy, not mine. (Though I fully agree with the policy.) The lab coats can be washed every week; to do so, place them in the cabinet on the first floor of PCE (near the east door – enter past Neil Armstrong's statue then just inside the building on the left is an unlabeled cabinet with a chute; toss dirty lab coats in there). Attached to the dirty lab coat cabinet is a cabinet for cleaned lab coats – you need a key to get into this cabinet, we keep the key in the PCE 209 lab above the sink in the beaker drying

rack. The lab coats are labeled as belonging to PDR's lab, so only pick up those, and not those belonging to other labs. A good practice would be to take 2 coats for yourself, label them with your name, then wash one each week. The wash is usually collected on Tuesdays and is returned the following Tuesday.

**8. Food and drink. No food or drink is allowed in the lab.** This is University policy, not mine. (Though I fully agree with the policy.)

**9. Windows.** As odd as it may sound, we need to **keep the windows in PCE 209 closed** because the whole ventilation system is balanced assuming that they are closed.

**10. Don't work alone. It is SIMPLY NOT ACCEPTABLE to do combustion experiments, work with high-voltage equipment, or do other potentially hazardous activities while working alone in the lab,** e.g. at night or on the weekends when no one else is in the lab to call for help should there be a problem. (Doing homework, sending emails, etc. or other "safe" activities is OK.) The other person in the lab doesn't have to be knowledgeable about the experiment, it just has to be someone who can call for help if there is a problem.

**11. Gas cylinders.** Close all gas cylinders **AT THE BOTTLE, NOT JUST AT YOUR EXPERIMENT** when not in use (meaning: at the very least when you go home). **ALL BOTTLES MUST BE DOUBLE-STRAPPED TO SOMETHING SO THEY CAN'T FALL OVER, BREAK THE REGULATOR AND BECOME A LETHAL MISSILE!**

## **12. Pressurized gases**

- a) All gas lines must be tested for leaks using non-flammable gases
- b) All fittings must be connected properly - **Teflon tape is used for tapered pipe threads, not Swagelok compression fittings!**
- c) All gas lines must be routed carefully so that they are not pinched or stepped on
- d) The lab ventilation system must be operating at all times. **Never turn it off!**
- e) Proper combustible gas sensors must be installed and operating
- f) All combustion experiments **MUST HAVE A FLASH ARRESTOR** to avoid a fire from "flashing" back to the fuel source. **Not knowing what a flash arrestor is, or not knowing where to find one, is NOT an excuse for not having one in your experiment.**

**13. Gas alarms.** All of our labs are equipped with gas alarms that give off annoying loud sounds when toxic and/or explosive gas(es) are detected. When the alarm goes off, the concentrations of gas(es) are low enough that there is not an immediate danger, but you cannot ignore that warning. You must deal with the issue as follows:

- a) First you must stop whatever you are doing that is creating the condition - turn off the experiment, close all gas valves, re-position the exhaust vent hose. Then reset the alarm.
- b) If the alarm comes back on again, then reset it one more time. If the alarm goes on a third

time, then you have an uncontrolled situation. Instruct everyone to leave the room and not to re-enter. **Call campus emergency 0-4321!**

- c) If the alarm does NOT come on again after the first reset, then you can restart your experiment. If the alarm goes off again once you run your experiment, stop your experiment again. Contact me about how we can make the experiment safer. Do not operate your experiment until we have determined what is causing the problem and have corrected it.
- d) We have to be sure that the gas alarms are working, so they must be inspected every few months.

**14. Using oxygen.** NEVER USE POLYETHYLENE PLASTIC TUBING FOR OXYGEN! ALWAYS USE COPPER, STAINLESS STEEL OR TEFLON ONLY! Also, USE ONLY (OIL-FREE) REGULATORS APPROVED FOR USE WITH OXYGEN. Both of these procedures are essential to prevent possible explosions when using pure oxygen.

**15. Pressure vessels.** Compressed gas stores a lot of energy and if your chamber breaks, that energy goes into kinetic energy of the pieces of chamber - not good! All pressure vessels must be hydrostatically tested AT LEAST ONCE PER YEAR AND WHENEVER CHANGES ARE MADE TO THE VESSEL (e.g. new holes drilled, new windows, etc.) to a pressure 1.5 times the maximum possible working pressure. We have a hydraulic tester in the lab.

**16. Fume hood.** Many experiments that may potentially produce undesirable fumes must be done inside the fume hood. Ask PDR if you're not sure if your experiment fits in this category.

**17. Laser.** The argon-ion laser is a Class IV laser that is entirely capable of burning a hole in your retina. Wear the orange laser goggles that block the blue, green and violet light from the laser. Also make sure that no one else in the lab can be zapped by a misguided, reflected beam. Enclose your experiment in a box made of the orange Plexiglas (that's what it's for – blocking argon ion laser light.) So then how can you look at your experiment? Use a video camera and a monitor! Better to blind a video camera than your eye!

**18. Tripping hazards.** Wires or cords crossing the floor through the middle of the room need to be covered, taped or removed to prevent tripping hazards.

**19. Electrical shock hazards.** Always disconnect electrical equipment from AC power before working on it so there is no possibility to get a shock. If you must have it plugged in to test it, ALWAYS disconnect AC power, attach test equipment (such as a multi-meter), then reconnect AC power and DON'T TOUCH THE WIRES WHILE YOU'RE DOING THE TESTING. If you need to move the test equipment, remove power and repeat the process. **All equipment with AC power must be inside a box and the lid must be on the box while you're operating it! I'm thinking particularly about the mass flow controller boxes whose lids never seem to stay on for more than a day out of each year.**

**20. Fire extinguisher and safety shower.** The fire extinguisher must be mounted to the wall and unobstructed at all times. We have one fire extinguisher by each door in PCE 209, and one by the doors in OHE B8 and B9. Know where the safety showers are (in the lab and another just outside the lab and down the hall to the left if you're exiting the lab) and how to use them.

**21. Chemical inventory.** Whenever you bring a new substance into either lab please be sure to record it using the online Chemical Inventory. **You must be connected to the USC network via an Ethernet line or via “USC Wireless Plus” which requires a USC login – the public “USC Wireless” network won’t work.**

- Ask PDR to add you to the authorized access list for our chemical inventory
- Go to <https://srm.usc.edu/rmcsapps/ChemInv/>.
- Log on using your USC ID
- Click on “Online Chemical Inventory Program”
- You’ll be asked to enter your USCNet ID and password. Do so.
- From the page that loads after you enter your login information, select “Lab Safety” then “Chemical Inventory”
- Select the room in which the chemical is stored.
- Enter or delete the information as appropriate

If you are replacing a chemical that has been used up, please cross out the old chemical listing and enter the replacement chemical with the new information.

**22. Hazardous waste.** We generate some semi-toxic and semi-hazardous waste. Put it in VERY SECURE bottles and store in a safe place (in or under the fume hood). This stuff cannot just be poured down the sink. Period. When the bottles start to fill up and need to be disposed, or if we have a chemical spill, dispose of waste properly. Information about hazardous waste collection is available at this URL:

<http://adminopsnet.usc.edu/department/environmental-health-safety/request-hazmat-pick>

**23. USC safety personnel.** Our contact with regard to safety is

Megan Utley  
Lab Safety Specialist  
Viterbi Business Affairs – Facilities Division  
3710 McClintock Ave., RTH 411, MC: 1454  
<http://viterbi.usc.edu/facilities/>  
Office: (213) 821-8307  
Mobile: (213) 663-8379  
[meganutl@usc.edu](mailto:meganutl@usc.edu)

### III. Communicating

1. Use email to send files electronically. It’s much easier for me (or anyone) to keep track of and retrieve electronic files than paper files).

2. Give each file a name other than “results1.dat” or 239480298520099875.xyz (you have no idea how many files I get with names like that...) Use CH4Air1atmFlameSpeedVsPhi.xls or something like that will uniquely identify what you’re sending to me. Make the filename less than 31 characters total so the Mac doesn’t cut off the end of the file name and that all-important extension. Make sure that the extension is correct, and corresponds to some reasonable format (pure text data, word,

excel, powerpoint, kaleidagraph, etc.) *Files of type.gif, .jpg, etc. picture formats are fine for photographs, but if it's a plot, please send it in kaleidagraph or excel format so I can change things! I can't add, remove, extract or replot data from a picture file!*

3. Often I get information like “the mixture was 6.2 grams of x and 14.6 grams of y and 53.4 grams of z.” This isn't very useful –tell me the mass fractions or mole fractions of the chemicals in the mixture (and the total mass of mixture if that is relevant).

4. Whenever we get a new piece of equipment, the **very first thing** to do is **make a copy of the manual and give it to me**. Manuals have diffusion coefficients higher than hydrogen gas, leave the lab almost instantly, and are never seen again, so my copy is essential. Please give me an electronic version of the manual if it exists, or if not scan the original and send me a copy. Also upload a copy to the Dropbox folder for the project.

5. Short reports of results are always appreciated, especially when the results are good. *Give me instant gratification!*

6. **Having meetings.** Usually you're meeting with me, so I will enforce proper meeting procedures, but if you're having a meeting with some other group, here are my rules for having technical meetings. Specifically every meeting **MUST** have three things:

- ◆ *An agenda.* What is it that needs to be discussed at the meeting? If it isn't written down, some items will be forgotten or will get dropped as the meeting runs over its time limit, so a written agenda is usually needed. Sometimes everyone knows the agenda items (as in a weekly meeting, for example), or the list of things to be discussed is very short, so a written agenda isn't needed.
- *Minutes.* What was said and what was decided at the meeting? There definitely needs to be a permanent record of this, because you **WON'T** remember a week later what was said or what was decided. (More likely, you will remember but your recollection will be different from everyone else's.)
- *Action items.* Who will do what as a result of the meeting? When is it needed? **What will people do that is different than what they would have done without a meeting?** Think about that last question – if no one is going to do anything different as a result of the meeting, what was the purpose of the meeting?

If you don't have all three of these items, then you have to ask yourself, why did you meet? What were you trying to accomplish by meeting? Was it a meeting or just a party, seminar, etc.?

## IV. Building an experiment

1. **Try the simplest thing first.** If you plan on using Coherent Anti-Stokes Raman Spectroscopy to measure flame temperatures in a turbulent three-dimensional sooting flame, start with a Bic lighter and a thermometer. Make sure you can make a flame and measure something resembling a temperature. Then graduate to a Bunsen flame and a thermocouple, using a volt meter to read the thermocouple voltage. Then graduate to a propane torch and an interferometer, etc. Don't spend a lot of time trying to build a complicated apparatus from the beginning, there is a 100% chance that it won't work and a 200% chance that it won't be what you really needed anyway, as you'll discover the

first time you finally get it working. **Design something simple, build quickly, test crudely, modify, improve, repeat. Ask yourself from the very beginning, what is the absolutely positively SIMPLEST thing I can do to get some insight into this phenomenon? Then do something much simpler than that.**

2. Never lose sight of the fact that any measurement system consists of three basic parts

- Transducer
- Data acquisition
- Algorithm for data processing

For example, if you're measuring temperature using a thermometer, the transducer is the mercury in the thermometer, the data acquisition system is your eye (to see which line on the scale is at the same level as the mercury) and the algorithm is to count the lines between the numbers (e.g. 3<sup>rd</sup> line between 20°C and 25°C corresponds to 23°C.) Another temperature measurement approach is to use a thermocouple to transduce the temperature, an amplifier, analog to digital converter and computer to acquire the data, and a polynomial fit of voltage vs. temperature to process the data to determine temperature. *All three parts of the measurement process must be based on valid principles and working properly, otherwise the measurement is guaranteed to be invalid.* It is useful to define your measurements in terms of these three parts, and make sure you understand (and trust) each part.

3. Do NOT use black electrical tape for electrical connections. It leaves a terrible sticky dirty residue that gathers dirt, and soon unravels anyway leaving bare wires exposed to shorting (or electrocution). Use crimp-on type or solder-type connectors with heat-shrink tubing to cover exposed wires.

4. Every piece of electrical equipment that you build **must have a fuse, must have a fuse, must have a fuse** that is of the proper rating for the device (typically 150% of the maximum expected current draw).

5. For those of you that use air for combustion experiments in PCE 209, **DO NOT** use the compressed air from the lines on the wall. This air is filthy dirty with oil, water, dust and who knows what. This may be one of the reasons we have so many problems with flow controllers. Use BOTTLED AIR only.

6. Some chemicals that we use (for example potassium hydrosulfite and ammonium persulfate) have limited shelf life, particularly when you keep opening the bottle to take out a little, expose the reactive material to air, then close the bottle again. For such chemicals you need to (1) store the chemicals in the refrigerator, (2) rotate supplies, that is get new chemicals every 6 to 12 months even if you haven't run out, (3) when you get a new bottle of chemicals, put it into smaller (clean!) bottles and use those up one at a time so you don't have to keep opening one storage bottle all the time and constantly expose it to air.

## V. Rules for experimentation

[The first 3 of these are from a course taught by Prof. Donald Coles of Caltech. I didn't really see the merit in these rules when I first learned them from him, but I certainly do now...]

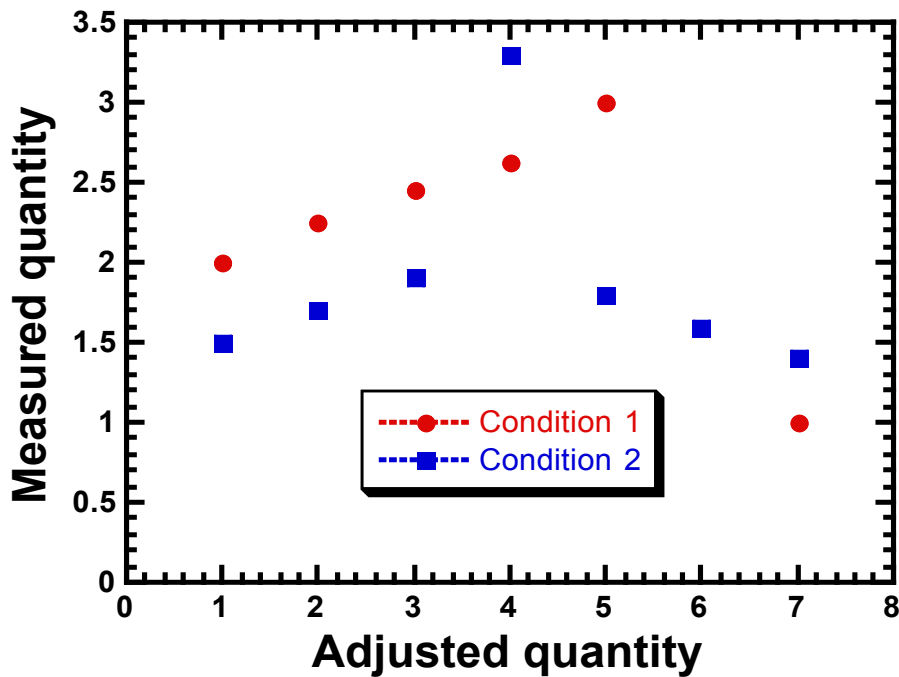
1. **Never trust any instrument.** How do you know your measurement system is working? (Answer: you don't until it's verified.) Always assume that your instrument is wrong until proven accurate by comparison with some independent measurement with another instrument. *The fact that the measurement system is expensive, was just used by a Nobel laureate, was "guaranteed" by someone, is new, looks impressive, was recently painted, etc. means nothing.* If two completely independent devices give nearly the same result, you're probably ok. Also, you can compare your measurement to known conditions. For example, if you're measuring temperature, see if your system gives 100°C in boiling water and 0°C in ice water. If you're measuring pressure, make sure you read zero with a vacuum and 1 atm at ambient pressure.

2. **Turn only one knob at a time.** That is, if you want to measure the effect of x on y and z, keep z constant while varying x, then measure y. Then go to a different value of z, vary x, and measure y. Don't change x and z together, because then you don't know whether x or z had the most effect on y.

3. **Skip around.** Don't take measurements at  $x = 1, 2, 3, 4, \dots$  in that order. Take measurements at  $x = 1, 4, 2, 3, 2.5, \dots$  Otherwise, you can fool yourself into thinking there is a trend when there is none, and bias your results accordingly. Also, people tend to take tiny steps to find a limit condition (or other interesting condition.) For example, let's suppose some limit in reality occurs at  $x = 12$ , but you took for first data point at  $x = 1$ . You'd probably go 2, 3, 4, ... up to 12, which is a waste of time and effort. You should have tried 1, 20, 10, 15, 13, 11, 12 instead to hone in on the interesting condition and saved a lot of effort!

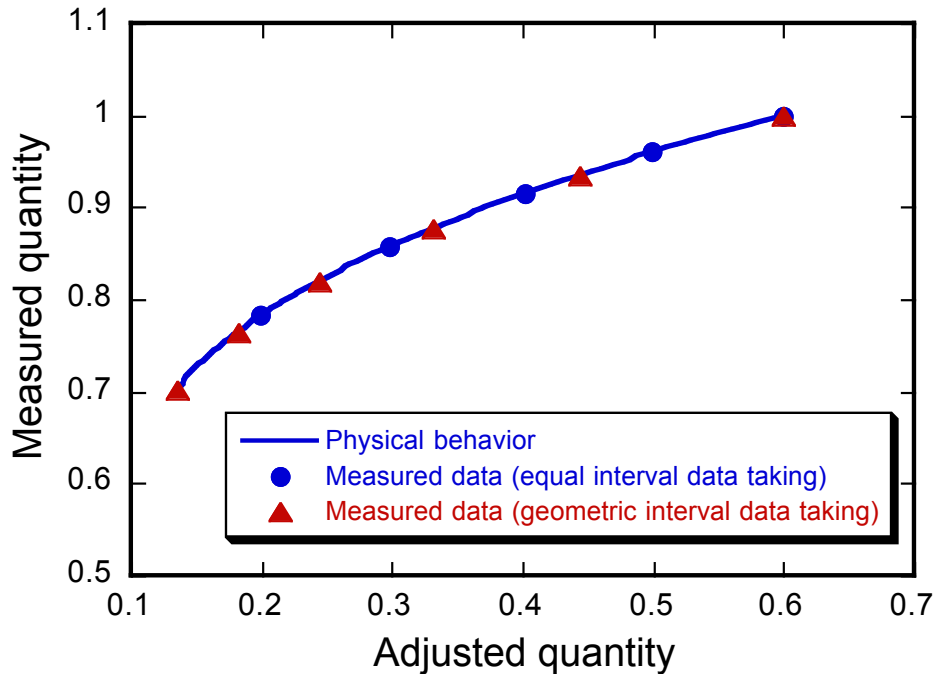
4. **Plot as you go and choose your test conditions widely.** This way any unusual trends will appear immediately and so you'll take more data where things are changing rapidly, and less where they aren't. Often I see plots like this:





This plot leaves many unanswered questions. For condition 1, is the point at adjusted quantity = 7 a real result (in which case more points need to be taken between 5 and 7 to see where the drop occurs) or an error in the measurement (in which case it needs to be repeated) (and why was no data point taken at 6???) Similarly, for condition 2, is the point at 4 a real spike in the data or just a bad measurement? Find out by taking more measurements around 4! *There is no necessity to take equally spaced data points. For condition 2 shown here, a lot of time was wasted by doing so (taking data at 1, 2, 3 and 5, 6, 7 where nothing was changing much) and still the potentially important behavior around 4 was not tested.*

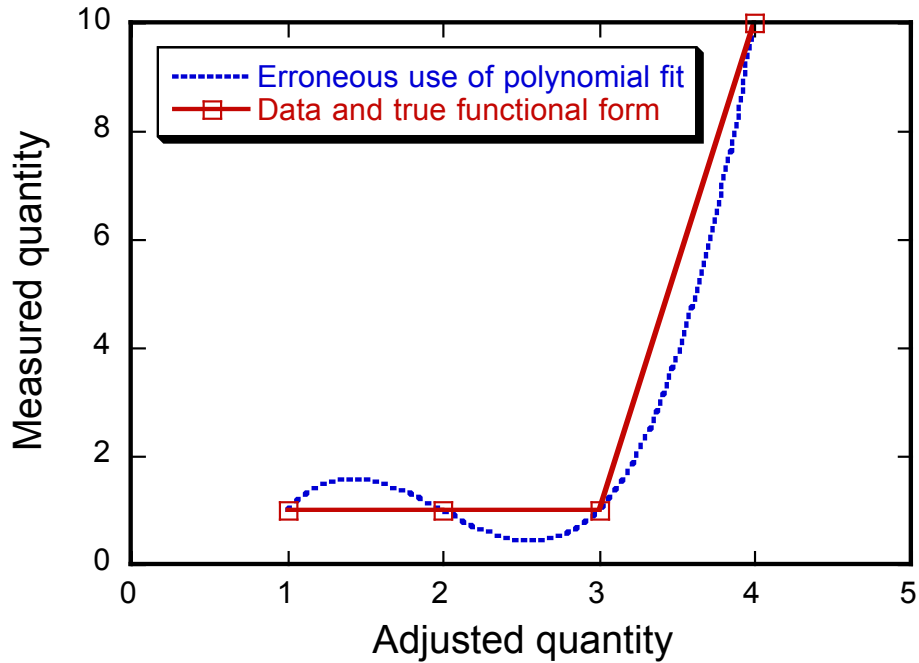
Also, many people take data at adjusted quantity = 1, 2, 3, ...10 even though the difference between 1 and 2 is huge (a factor of 2) whereas the difference between 9 and 10 is tiny by comparison (only 11%). *Determine the range of the adjusted quantity over which you want to take data, then space the data evenly in a geometric sense, not a linear sense.* For example, if you want to take  $n$  points over the range of adjusted quantity from  $x_1$  to  $x_2$ , a linear spacing would be  $x_1, x_1+(x_2-x_1)(1/n), x_1+(x_2-x_1)(2/n), x_1+(x_2-x_1)(3/n), \dots, x_2$  or 10 points over the range of adjusted quantity 1 to 10 would be 1, 2, 3, ..., 10. A geometric spacing over this range would be  $x_1(x_2/x_1)^{1/n}, x_1(x_2/x_1)^{2/n}, x_1(x_2/x_1)^{3/n}, \dots, x_2$ . In this case 10 points over the range 1 to 10 would be 1.00, 1.26, 1.58, 2.00, 2.51, 3.16, 3.98, 5.01, 6.31, 7.94, 10.00. The plot below shows how one can miss information by using equally spaced data intervals. The solid line correspond to the physical phenomenon of interest (in this example, I picked an equation relevant to the effect of fuel concentration on flame speed in the presence of heat losses.) The circles correspond to data taken in equal intervals over the range 0.1, 0.2, ..., 0.6. The triangles correspond to data taken in geometric intervals over the same range. Since measured quantity = 0.1 was below the flammability limit for this fuel, in neither case was data obtained at this condition. With equal interval data sampling, only at 0.2 was the next data point taken and all of the important properties of near-limit flames was missed. With geometric intervals, the important near-limit information was obtained.



Fun fact: the standard “well-tempered” musical scale consists of 12 geometrically-spaced frequencies over one octave, each note  $2^{1/12}$  times higher frequency than the previous one, for example:

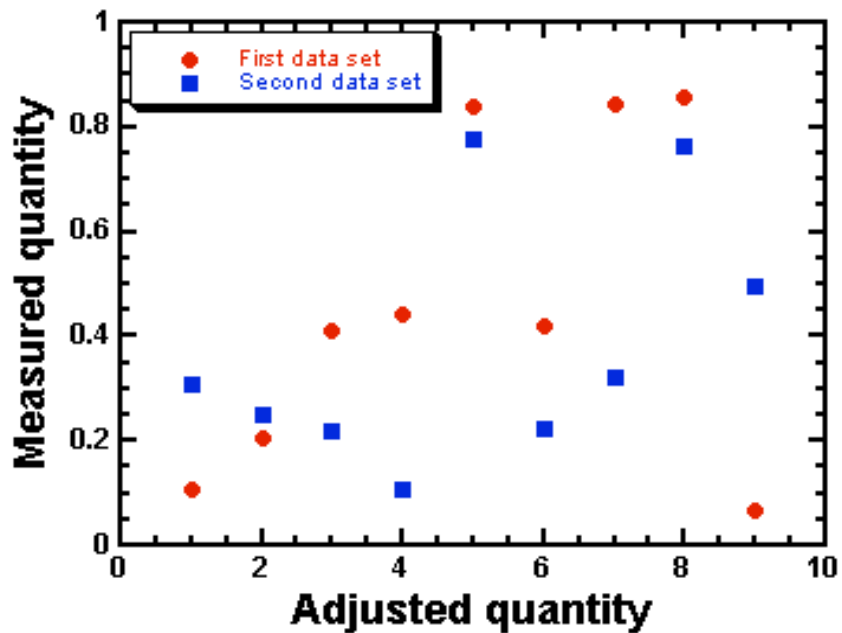
A above middle C												
	A#	B	C	C#	D	D#	E	F	F#	G	G#	A
440.00	466.16	493.88	523.25	554.37	587.33	622.25	659.26	698.46	739.99	783.99	830.61	880.00

Also, *use caution on fitting curves to data*. Many times I have seen the conclusion that a response is linear based on two data points (any two points define a straight line), or has a “wobble” based on four data points with a cubic polynomial fit (any cubic polynomial has a wiggle in it) as seen below. The “true” shape of this data (solid red line) is one flat straight line from 1 to 3 and another line with positive slope between 3 and 4. If you fit a high-order polynomial to this data (the maximum possible being 3<sup>rd</sup> order with 4 data points), you’ll always get wiggles (dashed blue line) that are meaningless. Your plotting program doesn’t know about the physics of your problem and can’t possibly determine that there is a wiggle based on just four points. If it’s important to know for sure whether there’s a wiggle or not, you need to take more data points!



5. **Turn the knobs as far as you can** (safely!) to the right and to the left. Don't just measure  $y$  for  $x = 2$  to  $3$  if there is no reason you can't do  $x = -7$  to  $x = 12$ . The most interesting results are almost always at the extreme conditions.

6. **Check the repeatability of your results.** Do exactly the same experiment 10 times in a row on the same day and see how much the results vary. You wouldn't believe how often I get data sets like the red circle data set below:



and the conclusion is that the measured quantity increases up to 8 then decreases. After inherently trusting this data and basing a whole research project on it, many months later a second data set (the blue squares) was taken and shows a completely different trend. Why? In this case I generated both data sets using a random number generator; there is no pattern at all to either data set. Probably in an experiment this would have occurred because in both cases the data cable was not properly connected to the computer and so the computer was just reading noise. Also, do the same experiment one day and then a week later and see how they compare. If any previous results (e.g. from a previous student) are available, repeat exactly one of their conditions and see if the results agree or not. Otherwise, how do you know if your results are valid or not? **Bottom line: check your results to see what are random variations and what are systematic trends.**

7. **Writing programs to control experiments.** When writing a control program for an experiment (say an engine control program), often students will have one version for one test condition (say natural gas fuel at 1800 RPM), another one for a different test condition (say gasoline fuel at 2400 RPM), etc. This usually results because the program was originally written for only one fuel and one RPM, with all of the relevant numbers hard-coded, then another version had to be generated each time a new set of test conditions was needed. It is impossible to keep all such versions of a program current, with all the latest additions and bug fixes. *Have only one version of your program that is completely general and doesn't use hard-coded numbers, and add functionality only to that one.* Of course this is much more painful in the short run but infinitely less painful in the long run.

8. **Know what your units are.** This sounds pretty elementary, but often I get results showing measurements without any units. Is the length in meters, cm, mm,  $\mu\text{m}$  or ????. Or I get a result that “the gas flow rate was 7 volts.” My response: “Volts is a unit of electrical potential, not flow rate. 7 volts was your transducer reading. For your transducer, how many volts correspond to 1 liter per minute?” Reply: “uuhhhhh....”

9. **Keep a meticulous lab notebook.** There is no way you'll remember the test conditions without a notebook (paper (ok) or electronic (better)). It's hard to get your papers published when the key results are scribbled on the back of scrap paper and can't be found when you need them to verify results or add additional information about the test conditions. **Saying, “I have it written down somewhere” is equivalent to “I lost the information.”**

10. **Make a backup copy of your lab notebook and data files - always ask yourself, “what would happen if I lost this notebook or computer file right now?”**

Bottom line: ask yourself, “*does this result make sense? Can I trust it? Will I be able to interpret it? (even if I can't explain it.) Can I reproduce it?*”

## VI. Machine shop

There is a machine shop available to graduate students. The facilities are not the best, but it's better than nothing and better than what we have in CPL. The location is SSC 109. To be allowed to use the facility, you need to be trained first. Contact Don Wiggins ([dwiggins@usc.edu](mailto:dwiggins@usc.edu)) to schedule the training.

Undergraduates may use the Viterbi Student Fabrication Laboratory (“Fab Lab”) in RRB 114 (see <http://viterbi.usc.edu/students/undergrad/research/fablab/>). The Fab Lab is open during regular 9 am – 5 pm working hours when the manager, Dan Cordova (ernestco@usc.edu) is available; contact him in advance to be sure the Lab is open at any particular time you want to go there. Training is required before working on any of the equipment; Dan or one of his assistants will train you as their schedules permit. Long pants and closed-toed shoes are required. The Fab Lab has basic hand tools, machine tools (drill press, bandsaw, grinder, etc.) plus four 3D printers, a 5-axis CNC mill and a laser cutter.

## VII. Facilities

For matters relating to facilities (that usually means fixing doors, windows, plumbing, electrical systems, heating and air conditioning, etc.) contact:

Ana Montes  
(213) 740-4175 (office)  
(323) 527-5346 (mobile)  
anagonza@usc.edu (email)

## VII. Purchasing stuff for your experiment

1. **Monitor your consumables, and order in advance.** This sounds really basic, but it is amazing how often I hear something like, “I ran out of xxx and it will take 3 weeks to get more.” Monitor your consumption of chemicals, gases, test tubes, etc. and order more before you run out, far enough in advance so you won’t be shut down!
2. Buy what we need – don’t wait around because we don’t have a screwdriver, a sheet of aluminum, a tubing fitting, BUY IT! Your time costs a lot more than that...
3. Purchasing is now handled through an online system at

<http://ame-www.usc.edu/intranet/poForm/>

**You must use this system for ordering stuff.** This is required because of the new rules on compliance with Federal and USC regulations. When you request that something be purchased, I will get an email asking me to approve the purchase; when I approve it the wheels will start turning and before you know it your stuff will be waiting for you.

4. For ordering gases, there’s a special online form (you’ll need to log on with your USC username and password):

<https://procurement.usc.edu/mailing/material-management/compressed-gases/>

## VIII. Scrutinizing your analysis

I often see analyses that I can tell within 5 seconds must be wrong. I have three tests, which should be done in the order listed, for checking and verifying results. These tests will weed out 95% of all

mistakes. I call these the “smoke test,” “function test,” and “performance test,” by analogy with building electronic devices.

1. *Smoke test.* In electronics, this corresponds to turning the power switch on and seeing if the device smokes or not. In analytical terms, this corresponds to **checking the units**. You have no idea how many results people report to me that can’t be correct because the units are wrong (i.e. the result presented to me was 6 kilograms, but they were trying to calculate the speed of something.) **You will catch 90% of your mistakes if you just check the units.** For example, if I just derived the ideal gas law and predicted  $Pv = R/T$  you can quickly see that the units are wrong. There are several additional rules that must be followed:

- Anything inside a square root, cube root, etc. must have units that is a square (e.g.  $m^2/sec^2$ , cube, etc.)
- Anything inside a log, exponent, trigonometric function, etc., must be dimensionless (I don’t know how to take the log of 6 kilograms)
- Any two quantities that are added together must have the same units (I can’t add 6 kilograms and 19 meters/second)

2. *Function test.* In electronics, this corresponds to checking to see if the device does what I designed it to do, e.g. that the red light blinks when I flip switch on, the meter reading increases when I turn the knob to the right, the bell rings when I push the button, etc. – assuming that was what I intended that it do. In analytical terms this corresponds to determining if the result gives sensible predictions. Again, there are several rules that must be followed:

- Determine if the sign (+ or -) of the result is reasonable. For example, if your prediction of the absolute temperature of something is  $-72$  Kelvin, you better check again.
- Determine whether what happens to  $y$  as  $x$  goes up or down is reasonable or not. For example, in the ideal gas law,  $Pv = RT$ :  
 At fixed  $v$ , as  $T$  increases then  $P$  increases – reasonable  
 At fixed  $T$ , as  $v$  increases then  $P$  decreases – reasonable  
 Etc.
- Determine what happens in the limit where  $x$  goes to special values, e.g. zero, one or infinity as appropriate. For example, consider the equation for entropy change  $S_2 - S_1$  of an ideal gas with constant specific heats:

$$S_2 - S_1 = C_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$$

note that for  $T_2 = T_1$  and  $P_2 = P_1$  (no change in state) then  $S_2 - S_1 = 0$  or  $S_2 = S_1$  as it must. Also, in the limit  $S_2 = S_1$ , the allowable changes in state correspond to

$$\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{\cancel{R}/C_p} = \left(\frac{P_2}{P_1}\right)^{\gamma - 1/\cancel{R}}$$

which is the isentropic relation for an ideal gas with constant specific heats.

3. *Performance test.* In electronics, this corresponds to determining how fast, how accurate, etc. the device is. In analytical terms this corresponds to determining how accurate the result is. This means of course you have to compare it to something else, i.e. an experiment, a more sophisticated analysis, someone else's published result (no guarantee of course that their result is correct just because it got published, but you need to check it anyway.) For example, if I derived the ideal gas law and predicted  $Pv = 7RT$ , it passes the smoke and function tests with no problem, but it fails the performance test miserably (by a factor of 7).

## IX. Scrutinizing your computations

Similar to analyses, I often see computational results that I can tell within 5 seconds must be wrong. **It is notoriously easy to be lulled into a sense of confidence in computed results, because the computer always gives you some result, and that result always looks good when plotted in a 3D shaded color orthographic projection.** The corresponding “smoke test,” “function test,” and “performance test,” are as follows:

1. *Smoke test.* Start the computer program running, and see if it crashes or not. If it doesn't crash, you've passed the smoke test, part (a). Part (b) of the smoke test is to determine if the computed result passes the *global conservation test*. The goal of any program is to satisfy mass, momentum, energy and atom conservation *at every point in the computational domain* subject to certain constitutive relations (e.g., Newton's law of viscosity) and equations of state (e.g., the ideal gas law.) This is a hard problem, and it is even hard to verify that the solution is correct once it is obtained. But it is easy to determine whether or not *global conservation* is satisfied, that is,

- Is mass conserved, that is, does the sum of all the mass fluxes at the inlets, minus the mass fluxes at the outlets, equal to the rate of change of mass of the system (=0 for steady problems)?
- Is momentum conserved?
- Is energy conserved?
- Is each type of atom conserved?

If not, you are 100% certain that your calculation is wrong. You would be amazed at how many results are never “sanity checked” in this way, and in fact fail the sanity check when, after months or years of wasted effort, someone finally gets around to checking it.

2. *Performance test.* Comes before the function test in this case. For computational studies, a critical performance test is to *compare your result to a known analytical result under simplified conditions*. For example, if you're computing flow in a pipe at high Reynolds numbers (where the flow is turbulent), with chemical reaction, temperature-dependent transport properties, variable density, etc., first **check your result against the textbook solution** that assumes constant density, constant transport properties, etc., by making all of the simplifying assumptions (in your model) that the analytical solution employs. **If you don't do this, you really have no way of knowing if your model is valid or not.** You can also use previous computations by yourself or others for testing, but of course there is no absolute guarantee that those computations were correct.

3. *Function test.* Similar to function test for analyses.

## X. Giving oral presentations

1. Use a laptop-based powerpoint presentation. Much easier to combine/split previous presentations, add color, animations, sound effects, etc. But the most valuable aspect is probably that it allows you make last-minute changes. Also it is useful because then you can email the presentation to interested people, or post it on your website.
2. **Do not use 5-point font! Reduce the amount of material presented and use big fonts! Make sure everything is legible. A good rule of thumb is that if the slide is printed on standard 8.5" x 11" paper, you should be able to put the page on the floor and read everything on the page while standing up and looking down at the page.**
3. When showing multiple plots of similar results, use the same scales. For example, if showing the burning velocities of methane-air and propane-air mixtures as a function of fuel concentration on separate plots, use the same scale for burning velocity on each unless they have drastically different ranges.
4. Include movies. Why limit yourself to static presentations when you have the power of a computer? A picture is worth a thousand words, and a movie is worth a thousand pictures.
5. Address the audience. Say things like, "this plot shows **you** the effect of x on y..." rather than "this plot shows the effect of x on y..."
6. Keep reminding the audience of your nomenclature. That is, if you show an equation

$$E = mc^2$$

don't say "this equation shows that eee equals emm cee squared," (the audience can already see that). Instead say, "this equation shows that the energy of a substance is equal to its mass times the speed of light squared" (the audience has forgotten your definitions of E, m and c that you gave 12 slides back).

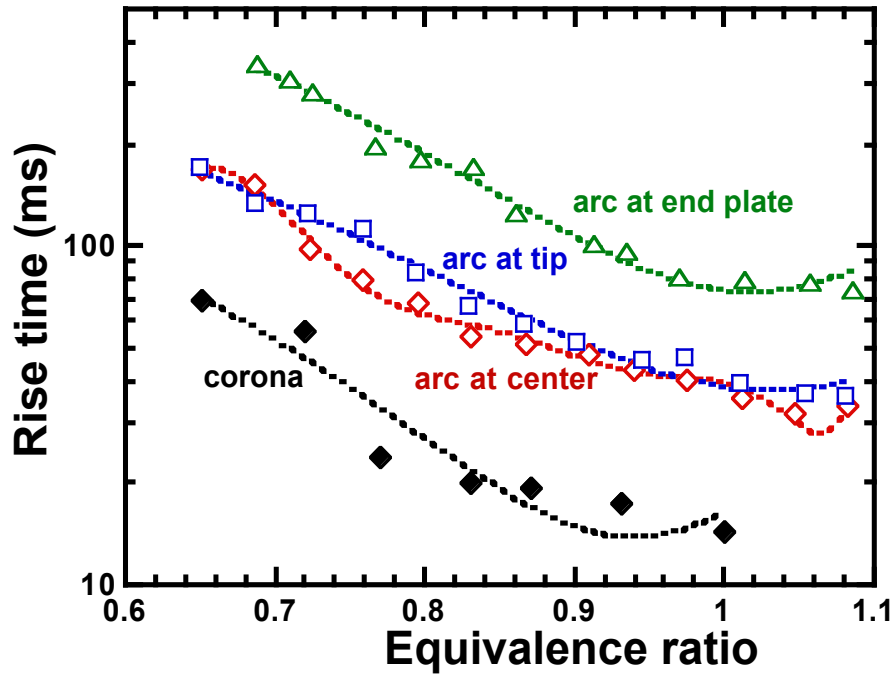
Bottom line: ask yourself, *if I were in the audience seeing this for the first time, would I understand this presentation???*

## XI. Writing papers

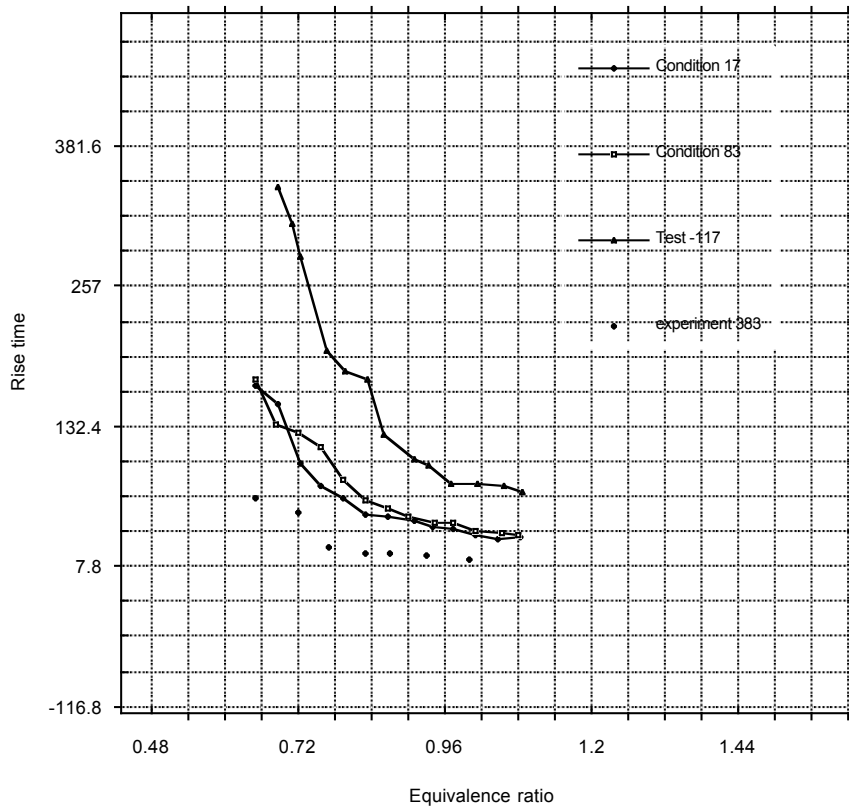
1. The usual organization of the paper is
  - A. Heading: title, authors, affiliations
  - B. Abstract: explains what was done and what the main conclusions are. Must be short (a few hundred words at most), no matter how long and how complicated the paper is.
  - C. Introduction:
    - i. Explain what your problem is and why it is important.
    - ii. State what is known about the subject.
    - iii. *Complain about what is lacking in the current state of knowledge*
    - iv. *Explain what you will do that is better* (may be in a separate Objectives section).
  - D. Method: experimental apparatus, numerical model, whatever



- E. Results: what you found and how it compares with previous works
  - F. Conclusions: what you learned
  - G. Future work (optional)
2. Every symbol in the text
    - A. is defined in a Nomenclature section (if used) or defined at its first appearance in the text
  3. Every equation that is set apart from the text
    - A. has a number
    - B. has all of its symbols defined if not already or defined in a Nomenclature section (if used)
  4. Every word
    - A. is spell-checked
    - B. is defined the first time it is used if it is a “buzz word” or acronym
  5. Every figure
    - A. is assigned a number – “Figure 1,” “Figure 2,” etc.
    - B. is referred to in the text
    - C. is called “Figure x” if it appears at the beginning of a sentence, otherwise it is called “Fig. x”
    - D. has a sensible scale on each axis (i.e. 0, 1, 2, 3; not -0.37, 0.15, 0.67)
    - E. Uses a logarithmic scale if a large numerical range of data (more than one decade) is covered (otherwise all the data having low numerical values are squashed together)
    - F. has the units defined on each axis
    - G. has a caption
    - H. has all relevant conditions (pressure, gravity level, the time during the test when the data was taken....) stated
    - I. has all plot symbols (squares, circles, filled or open, ...) and curves (solid, dotted, dashed,..) defined either in a legend box within the figure (preferred method) or in the caption
    - J. Does not have a lot of “white space”
    - K. if it is a picture, it has a scale on the picture or has a statement in the caption such as “field of view is xxx cm by yyy cm”
    - L. must be readable - caution on pictures!!!**



*Reasonable figure*



*Terrible figure (same data)*

What's wrong with this figure?

- The scales on each axis are terrible – weird numbers, not 1, 2, 3, ...
- Units are not defined on the vertical axis
- The plot symbols are defined using meaningless notation (“Condition 17” means nothing to the reader.)
- There is a tremendous amount of “white space”
- Most of the data squashed together because a linear scale was used - the scale has to be large enough to cover the large values of rise time in “Test –117”, which goes up to 300, but most of the data is in the 10 – 50 range
- There are tick marks inside, outside, all over the place (I prefer tick marks on the inside only). Also, the major and minor tick marks are the same length so it's hard to distinguish between them.
- The plot symbols are too small to see
- The numbers are too small to read
- All of the grid lines make it hard to read the data and legend. (I don't like grids at all, they clutter the figure – if someone really wants to pick points off your graph, they can draw their own grid lines or ask you to email the data file to you.)
- There are ugly looking jagged lines connecting the data points (rather than a smoothed curve)
- The axes and tick marks are too thin

A big part of the problem is that most people just let their plotting program make bad plots using all the default settings, and somehow try to rationalize that still a good plot.

6. Every reference cited in the text

- A. appears in the reference section
- B. is a plain number (i.e. 11, 12, 13; not 11, 11a, 11b) or follow the Harvard system (e.g. Smith and Jones, 1953) depending on the instructions to authors
- C. if a number, may be superscript or in [brackets] or (parenthesis) depending on the instructions to authors

7. Every reference in the reference section

- A. is called out in the text
- B. has the journal name or book title (journal titles may or may not be abbreviated depending on the instructions to authors)
- C. has the page number (may be just the first page or inclusive pages depending on the instructions to authors)
- D. has the journal issue number (if a journal article)
- E. has the publisher (if a book)
- F. has the year
- G. may or may not have the title of the article depending on the instructions to authors

8. Items 2. and 3. from Oral Presentations apply to written papers too.

Bottom line: ask yourself, *if I were reading this paper for the first time, and I were not already aware of the results, would I understand this paper???*

Bottom bottom line: think **quality, quality, quality** if you expect to be taken seriously by the research community. Be your own worst critic, unless you prefer that someone else be your worst critic.