Physics Lab Notebook & Lab Report Information Booklet

How to keep a proper lab notebook & write a lab report

Informational booklet for PHSC 132/233/234 labs.
Prepared by Professor David S. Lee, Summer 2005.

Table of Contents

Table of Contents…………………………………………………………………. 2

Lab Notebook – A reminder of what it should look like…………………………….. 3

Some Example Lab Notebook Pages……………………………………………... 5

Your Lab Reports………………………………………………………………….. 20

Writing a Good Lab Report……………………………………………………….. 21

Lab Notebook – A Reminder of What It Should Look Like

Essentially, the perfect lab notebook would allow another person in your field to repeat your work without any other written resources. That is, that person (what is known legally as "a person who is practiced in the art") could follow only what is in your lab notebook and re-invent your disclosure. All other rules and suggestions follow from this basic idea.

So here are some "rules" (in no particular order) that should be followed for any lab notebook (including yours for this class):

1. The record of your work must be in a book that has a permanent binding. Books that allow for page removal/insertion/substitution are useless in the court of law. If you don't have one, we have a bunch in Physical Sciences that we can sell you cheap! We got them on clearance.
2. All pages should be numbered in order. Do this when the book is new. No pages should ever be removed from the book and the numbering must be sequential, starting from '1'.
3. Electronically kept books are (generally) useless in the court of law. Electronic files or records are helpful for the researcher or engineer, to be sure, but the onus is on you to prove that they have not been altered in any way, and that is very difficult to prove. It is so difficult that people simply do not use electronic records in the court of law.
4. Any electronically generated pages that have been printed out must be dated and glued (or in some way permanently affixed) to a successively numbered page of your permanent book. The attached page should then be signed and dated by a witness across the join. Tape (Scotch, masking, etc) is **not** allowed – the attachment must be 'permanent'. Glue is fine, staples also are fine.
5. Every page is signed and dated at the bottom by the person who did the work.
6. Every page is signed and dated by a witness who has <u>read and understood the material</u> but who is not a potential co-inventor for the material on that page. For our labs, a co-inventor is someone with whom you have shared the workload, i.e., a lab partner. So your lab partner cannot witness your work – someone else in lab must do so, or another person with the training and background to understand what you have done (i.e., a physical science major from another class would be acceptable).
7. Witnessing of the work should be done daily or weekly – a long time period between the witnessing and the work often raises questions. Of course, <u>having your witness sign and date an incorrect date is a violation of the academic integrity standards at Biola, and is more importantly, unethical behavior.</u>
8. Since the records must be permanent, only a ball-point or roller-ball type ink pen is allowed. Black is preferred, but blue is acceptable. Red is generally discouraged unless the ink is specifically labeled as a non-fade. Pencil is never allowed, ever. You can highlight as necessary for your own use, but highlights will be ignored in the court of law.
9. White-out is never allowed, ever. Cross out any mistakes with a single line through the text or a single 'X' through a drawing. Attach a brief text note next to the mistake or cross-out that states where the work continues or another page number as appropriate.
10. Drawn a line across an empty page or space on a page that is not being used. That page must still be numbered, but if it has no information, it does not need to be witnessed.

11. Do **not** try and save paper. Start new experiments with new pages, start new sections within an experiment with new pages.
12. Define all your terms, preferably in a glossary at the start of your lab book. Do not use slang, jargon, abbreviations, etc. The notebook must be understandable not only to patent attorneys, but also judges, jurors and potential licensees.
13. Keep several pages at the start of the book for a table of contents. Update it as the book fills up.
14. Write down everything you do! This is the most painful, most time-consuming, and **most important** part of the lab notebook!!! If you do not write down your procedure (as opposed to the procedure that is given in the handout, which may be different), you will not be able to repeat your experiment exactly in the future. Furthermore, another researcher or engineer will not be able to reproduce your experiment exactly and your company will lose the court battle. It's that simple – make sure everything you do is recorded. If you sneeze over your chemical solution and you think you might have sneezed into the flask, write it down! If you go away for a meal and come back 2 hours later to continue, write that down as it may be important without you even realizing it (ask me about how the Y-Ba-Cu-O family of High-Tc superconductors were discovered).
15. Drawings, formula, chemical reactions, schematics, etc, are all important and must be included.
16. Any work you do on data by hand must be included, such as taking logs or solving equations.
17. Data should be plotted first roughly by hand. Nicer computer-generated plots can come later, and must be attached as per the instructions above.
18. You should try and limit what you record to factual, quantitative and qualitative statements. Opinions are sometimes useful, but generally not so. Phrases like "the idea is obvious" or "this may infringe on patent X by so-and-so" are to be avoided.
19. In our case, there are lab questions to answer. These should be in a separate section that immediately follows the lab experiment data. Make sure you refer the questions back to the appropriate page number in the lab book (ie, if the question is on page 47 and the data is on page 43, say that the data being references is on page 43).
20. Illegible entries are totally worthless, unsigned or undated pages are also of limited value, pages that are not witnessed are as bad as unsigned pages, consecutive pages that are not in chronological order raise questions, missing pages raise questions, erasures and deletions raise questions. Fix mistakes on a later page and include an explanation that references the page with the mistake.

Here are a couple of relevant weblinks with pages that have similar pontifications as what you just read. Some of them have example lab notebook pages for reference.

http://www.upscale.utoronto.ca/GeneralInterest/Harrison/AzumaBook/Azuma.html

http://www.physics.ubc.ca/~phys209/pics/good_writeup/

The best advice I can give you is to stay on top of your lab notebook. Don't wait until later in the term to update or sign it. Answer the lab questions as soon as possible after lab so that things are fresh in your mind.

Some Lab Notebook Example Pages

Contrary to what you may believe or suspect, we would rather be grading your lab notebook on the quality of your understanding of the physics rather than whether or not you remembered to write down units or label or graph axes. Please take a close look at the sample lab notebook pages below to see what comments are made about them – pay particular attention to what the student wrote and what the TA said about it. This will help you to avoid losing points for 'fussy little' things.

Here is one **important caveat:** the student in these examples is far more concerned with simply following the directions in the lab manual than displaying an understanding of the principles or issues involved. She's basically not doing anything beyond what the lab manual instructs her to do. *Anyone* can follow instructions blindly, and we expect better from all of you.

Note that there is a progression here – in 132 labs we will be more instructive and forgiving of this approach. By 233 lab, you'll be far more adept at keeping a proper, formal lab notebook (with a semester of practice already behind you), and you will be graded accordingly. The concepts covered in 233 labs are more abstract than those in 132, so a higher quality notebook is necessary to show your understanding. By the time 234 lab rolls around, you will be writing a full technical report on one lab and a full journal article on another – both of these require serious attention to detail in your lab notebook and effort way beyond simply following instructions. You will make your WCR assignments far less complicated and difficult if you keep a properly executed lab notebook – ask anyone who's already been through it.

Do all this and you'll be ready for any upper level lab courses you may take at another engineering school, in graduate school somewhere, and in our advanced lab course (PHSC 480). Maybe more importantly, you'll be versed in what is expected of you in any industry lab setting, and that will save your employer time, effort and heartache – and is a competitive advantage you will probably have over many of the people applying for the same job to which you are applying.

Example Lab Notebook Pages*

(see caveat on previous page)

Put the title and date on the top of every page

60

Expt A - Introduction to the Oscilloscope — Oct 14, 2003

List of equipment:

Tektronix 2225 50 MHz Oscilloscope
Topward digital function generator 8112
two 50Ω ±10% resistors
One 1μF ±10% capacitor
BNC cables
Fluke multimeter 85 III

Always include a list of equipment, including make and model number, right at the beginning of your lab book

Part I - Voltage and frequency measurements

"mini-objective"

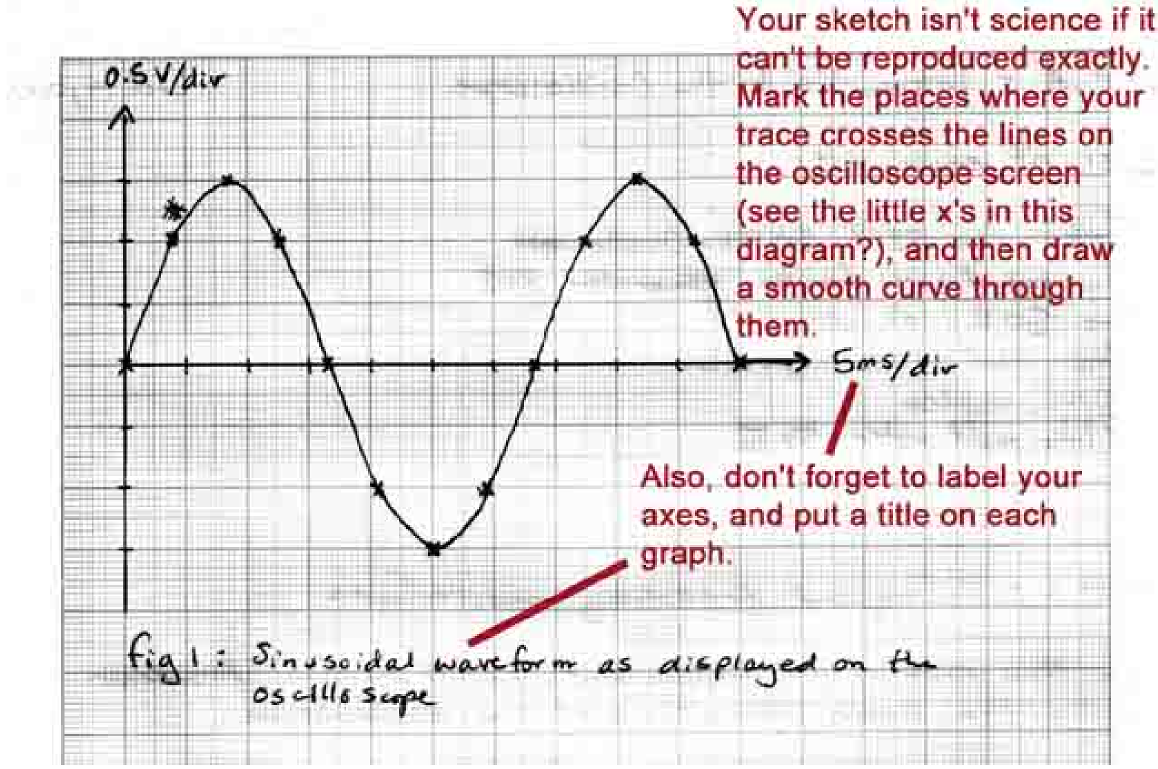
- In this part of the experiment, I will become familiar with the basic operations of the oscilloscope.

I connected the function generator's output to ~~show~~ the channel 1 input of the oscilloscope.
I connected the "sync out" on the function generator to the trigger of the oscilloscope

I set the oscilloscope's vertical mode to channel 1, "normal"
I set the vertical scale to 0.5 V/div (on the 'scope)
I set the horizontal scale to ~~1ms/20ms/div on the scope~~ (~~5ms~~ 5 ms/div on the 'scope)
The input coupling is set to "DC", the trigger mode is set to "P-P auto" and the trigger source is set to "external" on the 'scope.

I set the function generator (FG) to a sinusoidal output, at a frequency of 300.0 ± 0.1 Hz. The FG's output is adjusted so that the trace on the 'scope's screen is 6 divisions from peak to peak.

Here the student is including her equipment settings. You could do this in a more terse fashion: for example, in point form, in a well-labelled table. Just make sure all the information is there, and that it is clear what the information that you're recording *is*.


Your sketch isn't science if it can't be reproduced exactly. Mark the places where your trace crosses the lines on the oscilloscope screen (see the little x's in this diagram?), and then draw a smooth curve through them.
0.5 V/div
5ms/div
Also, don't forget to label your axes, and put a title on each graph.
fig 1: Sinusoidal waveform as displayed on the oscillоscope

Expt A - Intro. to the oscilloscope Oct 14, 2003

~~I turned t~~
Next, I turned the input coupling on the 'scope to "ground" and adjusted the vertical position knob on CH 1 until the line was right on top of the horizontal line on the oscilloscope screen

Do write down any little tricks you learned; or were told.

The TA suggested this so that the trace would be centred on the middle line.

I turned the input coupling back to "DC" and the trace was indeed centred on the middle line (see fig 1, opposite page)

I turned the trigger adjust knob until the trace ~~star~~ was starting right on the middle line. I had to flip the trigger switch from negative slope to positive slope, to get the sine wave to be going upward on the left-hand edge of the screen, rather than downward. See fig 1.

More equipment settings

Another "mini-objective"

The next part of the experiment is to check that the oscilloscope is correct by displaying the signal sent to it by the function generator

A "mini-procedure"

First I check if the frequency is right.
I do this ~~my~~ by measuring the period of the sine wave on the screen, and then converting this to a frequency Then I compare it to the frequency I set the function generator to.

I'll do this for three different frequencies, as suggested in the lab manual.

1:45 pm
(Note: I had to adjust the sec/div knob to get a trace that only had 1 or 2 periods on it when I changed the frequency)

The student is recording something she learned; this is an important thing to do in your lab write-up.

She almost forgot to put a title on her table, but squeezed it in.

Experiment A – intro. to the oscilloscope Oct 14, 2003

Table 1: Comparing frequency of wave to function generator's

frequency set on function generator (Hz) ± 0.1 Hz	Period of wave on screen (ms)	frequency of wave on screen (Hz)
200	5.0 ± 0.1 div × 1ms/div = 5.0 ± 0.1 ms	200 ± 4 Hz
500	9.9 ± 0.1 div × 200μs/div = 1.98 ± 0.02	505 ± 5 Hz
1000	5.0 ± 0.1 div × 200μs/div = 1.00 ± 0.01	1000 ± 10 Hz

Don't forget your units

If the uncertainty is the same for every value, put it in the heading

This is a great way to record data in a table; the equipment setting, the number of divisions on the oscilloscope screen, and the voltage are all recorded.

Sample calculation:

$$\text{frequency} = \frac{1}{\text{period}} \Rightarrow f = \frac{1}{T} \quad \frac{1}{5.0\times10^{-3}\,\text{sec}} = 2\times10^{2}\,\text{Hz} = 200\ \text{Hz}$$

error calculation:

$$f = \frac{1}{T} \Rightarrow \frac{df}{dT} = \frac{-1}{T^2} \Rightarrow df = \left|\frac{-1}{T^2}\right| dT$$

$$\Rightarrow \left|\frac{-1}{(5\times10^{-3})^2}\right| \cdot (0.1\times10^{-3}) = 4\ \text{Hz}$$

$$\Rightarrow \text{frequency of wave on screen} = \boxed{f = 200 \pm 4\ \text{Hz}}$$

When you've done some calculating as part of a table, always include a sample calculation, with uncertainties. You only need to show one; the rest can be done by hand, or spreadsheet, and just filled in.

All of my frequencies agreed within the limits of uncertainty with the frequency I had set on the function generator.

She's compared her data in the correct manner - by saying whether or not the values agree within the limits of the uncertainties she calculated.

The picky TA will poke you in the eye if he/she catches you saying things like "value x was *close* to value y". Close? CLOSE?!?!! <apoplectic fit>

"Close" is not scientific. Either the values agree within the limits of uncertainty (and are thus considered to be identical), or they don't (in which case they are irreconcilably different).

And yes, this does mean that you *must* calculate uncertainties. For everything.

63

Expt A - Intro. to the oscilloscope   Oct 14, 2003

"mini-objective"

Now I'm going to check that the voltage displayed on the oscilloscope is the same as the voltage being sent to it from the function generator.

States what she's doing, as she is doing it; this is a good lab note-taking procedure.

First I took the BNC ~~wire~~ cable off the oscilloscope's ~~~~ output and plugged it into the multimeter.
I set the multimeter to the $\tilde{V}$ setting, which measures AC voltages.

The multimeter reads: 1.062 ± 0.0005 V

I ~~had~~ hooked up the oscilloscope again, without changing anything on the function generator, and the trace was still 6 divisions from peak to peak.
This means the voltage is:

$$6 \pm 0.1 \text{ div} \times 0.5 \text{ V/div} = 3.0 \pm 0.5 \text{ V}$$

Again, a great way to record data; every piece of information is preserved.

Your lab book is supposed to be a permanent record of your work; if you make an error, simply cross it out, and keep going. No white-out!

~~Our voltage for as measured on the oscilloscope does NOT agree with the multimeter's value within the limits of uncertainty!~~
~~This might be due to some unknown form of uncertainty, or the oscilloscope might not be calibrated right or~~

The measurement on the oscilloscope is a peak-to-peak voltage, while the multimeter measures an RMS value. I have to convert one of them before I make a comparison.

Show your work

$$\frac{3.0 \pm 0.5\text{V}}{2} \cdot \frac{1}{\sqrt{2}} = 1.0607 \pm 0.18 = 1.1 \pm 0.2 \text{ V}$$

The value of voltage measured on the oscilloscope agrees within the limits of uncertainty with the value measured on the multimeter, but the multimeter's measurement is much more accurate (much smaller uncertainty).

Compares her data values correctly, and makes a pertinent observation too. This shows that she's thinking about what her numbers mean, and pickyTA's *loooove* that.

Expt A - Intro to the oscilloscope Oct 14, 2003

"mini-conclusion"

I conclude that the oscilloscope accurately displays the signal sent to it from the function generator, but that it's not always ~~an accurat~~ the most accurate way to obtain a value.

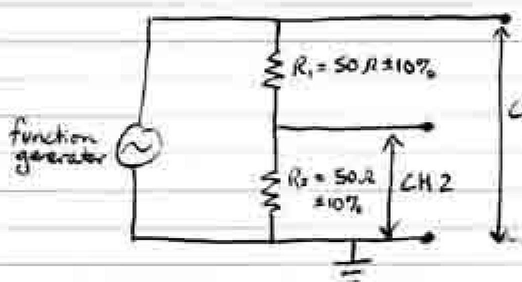
2:15pm For engineering students in particular, write down the time occasionally. It's best to do it every hour, but acceptable to do it at the end of each

PART 2 - Phase measurement exercise.

"mini-objective"

In this part of the experiment, I'm going to observe the phase difference between two signals I measure ~~one~~ in a circuit containing two resistors in the first part, and two resistors and a capacitor in the second part.

I set up the following circuit. Circuit is



Draw a diagram every time you have a complicated setup, especially for circuits. Label everything in the diagram. Also, for circuits, include the values of your components, including tolerances.

Channel 2 is measured from between the 2 resistors to ground. Channel 1 is measured basically across the function generator. (The lab manual could have been a bit clearer about this, grumble, grumble...)

Do clarify things that you found confusing. Your lab book should be complete enough that another person could reproduce the experiment based just on what you wrote - and they would find all your bits of advice useful, right?

Plus, you might have to write a formal report on this experiment in a few months, and if you had trouble understanding what the lab manual was saying now, then you might have trouble then, also.

Again, the axes are labelled, the graph has a title, and the student has marked off actual points that correspond to what she saw on the oscilloscope screen. Also, she's labelled both of her traces clearly.

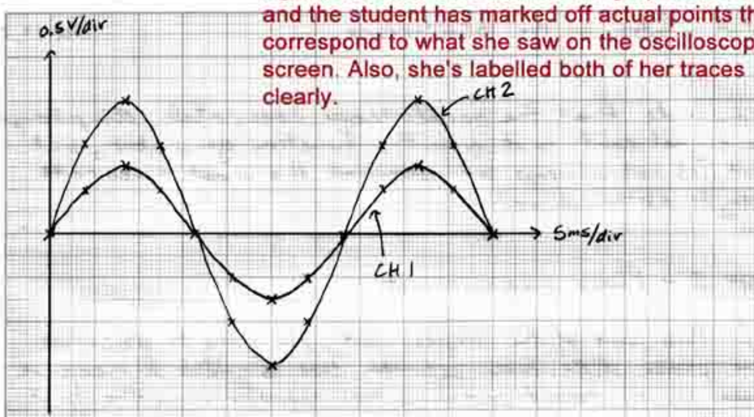


Fig 2 : Two traces measured in circuit 1, with no capacitor present, at 30 Hz

55

Expt A - Intro. to the oscilloscope Oct 14, 2003

Equipment settings listed, and a good diary kept of what the student is doing

I set the frequency to 30 Hz on the F.G.

I set the V/div scale to 0.5 V/div ~~at~~ on both channels of the oscilloscope, and the sec/div scale to 5 ms/div. The input coupling for both channels is set to "DC"

I switched both channels to "ground", and made sure they were exactly on the centre line of the oscilloscope screen. This is very important if I want to measure the phase difference between the two signals along the centre line.

Then I switched both channels back to "DC".

I adjusted the amplitude knob on the function generator until I had (peak-to-peak) 3 ± 0.1 div $\times$ 0.5 V/div = 1.50 ± 0.05 V on channel 1

Channel two had a voltage of 6 ± 0.1 div $\times$ 0.5 V/div = 3.00 ± 0.05 V (peak to peak)

See fig 2 (opposite page) for a diagram of the traces.

The two traces cross the middle line (where I'm measuring the phase difference) at exactly the same place. Furthermore the peaks and troughs line up exactly also.

My phase difference δ, in seconds, is:

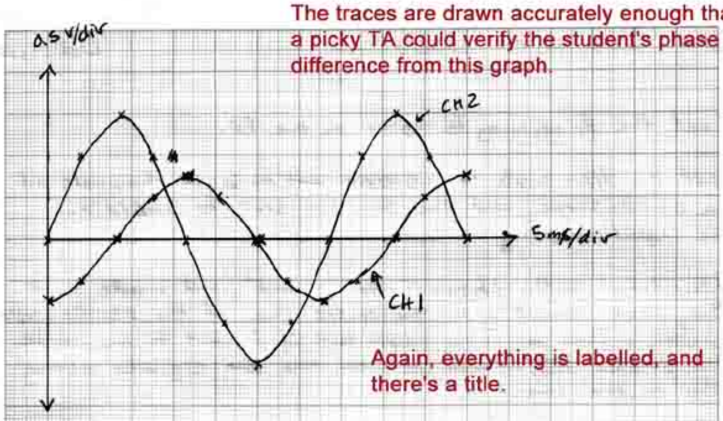
If you make an error, just cross it out.

$$\delta(\text{seconds}) = \cancel{0 \pm 0.1 \text{ div} \times 0.5 \text{ V/div} = 0 \pm 0.05 \text{ V}}$$
$$= 0 \pm 0.1 \text{ div} \times 5 \text{ ms/div} = 0 \pm 0.5 \text{ ms}$$

Even zero has an uncertainty (and units)

I need to convert this to degrees now.

The traces are drawn accurately enough that a picky TA could verify the student's phase difference from this graph.



Again, everything is labelled, and there's a title.

Fig 3: two traces measured in circuit 2, with the capacitor present, at 30 Hz

She found an error after carrying on with the next part. No space to fix it! Oh no; what to do? Simple: cross it out, put the corrected calculation on another page, and reference its location so that the TA knows where to look for it.

Expt A - Intro. to the oscilloscope Oct 14, 2003

~~Idea~~ ~~$\frac{\delta(\text{seconds})}{T} = \frac{\delta(\text{degrees})}{360°}$~~

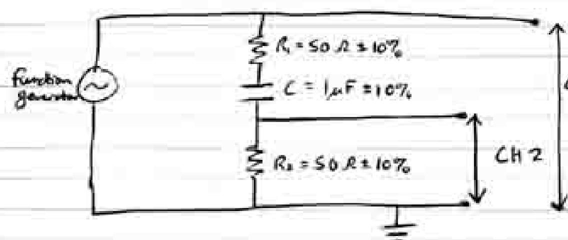
~~$\Rightarrow \frac{0 \pm 0.5\text{ ms}}{33.3 \pm 0.1\text{ ms}} = \frac{\delta(\text{degrees})}{360°} \Rightarrow \delta(\text{degrees}) = 0 \pm 5°$~~

~~$f = 30 \pm 0.1$ Hz~~
~~$T = \frac{1}{f} \Rightarrow 30\text{ Hz} \rightarrow 33.3\text{ ms}$~~
~~$dT = |\frac{-1}{f^2}| df \Rightarrow \frac{1}{30^2}(0.1\text{ Hz}) = 0.1\text{ ms}$~~

I found a mistake in my error calculation. Please see redone calculation on page 68

~~The phase difference between the two signals in circuit 1 is $\delta(\text{degrees}) = 0 \pm 6°$~~

Now I build the following circuit: circuit 2



Again, label all the components in the diagram, and include their tolerances.

I carefully zeroed my traces again, and measured the horizontal displacement of the two traces on the middle line. See fig. 3 for a diagram.

I found it easier to measure the phase difference when I changed channel 2's V/div setting so that ch. 2's trace was about the same size vertically as CH1. The diagram shows the traces on the same scale however.

Making note of a trick she's learned.

Expt A - Intro. to the oscilloscope Oct 14, 2003

I measured the phase difference to be:

1.6 ± 0.1 div × 5 ms/div = 8.0 ± 0.5 ms

I need to get this in degrees now:

$$\frac{\delta(\text{seconds})}{T} = \frac{8.0 \pm 0.5\text{ ms}}{33.3 \pm 0.1\text{ ms}} = \frac{\delta(\text{degrees})}{360^\circ}$$

References where to find the corrected work

$$\Rightarrow \delta(\text{degrees}) = 86.486^\circ$$

Error calculation: → $\boxed{\text{See page 69 for the rest of this calculation.}}$

if I have $g(x,y)$, where x,y have uncertainties $\Delta x, \Delta y$, and I want to calculate Δg, I do it like this:

$$\left(\frac{\Delta g}{g}\right)^2 = \left(\frac{dg}{dx}\right)^2 \Delta x^2 + \left(\frac{dg}{dy}\right)^2 \Delta y^2$$

So, let $f = \frac{\delta \pm \Delta\delta}{T \pm \Delta T} \Rightarrow \Delta f$

So: let $g = \frac{\delta \pm \Delta\delta}{T \pm \Delta T} \times \cancel{360} \Rightarrow \Delta g = \sqrt{\left(\frac{1}{T}\right)^2 (\Delta\delta)^2 + \left(\frac{-\delta}{T^2}\right)^2 (\Delta T)^2} \times g \cancel{360}$

$$\Rightarrow \Delta\delta(\text{degrees}) = \Delta g = \left(\left(\frac{1}{33.3}\right)^2 (0.5)^2 + \left(\frac{8}{(33.3)^2}\right)^2 (0.1)^2\right)^{\frac{1}{2}} \cdot \frac{8}{33.3} \cdot \cancel{360} = 3.61 \times 10^{-3}$$

$$3.61 \times 10^{-3} \times 360^\circ = 1.3^\circ$$

The phase difference between the two traces from circuit 2 at 30 Hz is 87 ± 1°

Do you see this mess? D'you *see* this mess? Your TA does NOT CARE about this mess. Resist the urge to erase! Throw away your white-out! Eeeevil white-out. You do not *need* it.

As long as the TA can read your work, and find everything that he/she needs to find, a messy lab book is NOT a problem.

Your lab book is meant to be a permanent record of your work, errors and all. Don't obliterate anything.

Still putting the title and date on every page.

Expt A - Introduction to the oscilloscope Oct 14, 2003

It's good to point this out.

$$\frac{\delta(\text{seconds})}{T} = \frac{\delta(\text{degrees})}{360^\circ}$$

THIS CALCULATION IS A CORRECTION OF THE ONE ON PAGE 66

$\Rightarrow$ ~~Oscilloscope~~

$f = 30 \pm 0.1$ Hz

$T = \frac{1}{f} \Rightarrow T = \frac{1}{30\,\text{Hz}} = 33.3\,\text{ms}$

$dT = \left|\frac{-1}{f^2}\right| df \Rightarrow \Delta T = \frac{1}{(30)^2}(0.1\,\text{Hz}) = 0.1\,\text{ms}$

$\Rightarrow T = 33.3 \pm 0.1\,\text{ms}$

$$\frac{\delta(\text{sec})}{T} = \frac{0 \pm 0.5\,\text{ms}}{33.3 \pm 0.1\,\text{ms}} = \frac{\delta(\text{degrees})}{360^\circ}$$

~~Using the error calculation formula I derived on page 67.~~

$$\cancel{\Delta\delta(\text{degrees}) = 360^\circ \times \frac{\delta(\text{seconds})}{T}\sqrt{\left(\frac{\Delta\delta}{T}\right)^2 + \left(\frac{\delta \cdot \Delta T}{T^2}\right)^2}}$$

$$\cancel{= 360^\circ \times 0}$$

Hmm... this doesn't work either.

The TA said to do it this way:

Aren't TA's lovely? We won't do your thinking for you, but if you're stuck, then come and ask one of us for help. You're here to learn, not to bang your head on the table in frustration.

$$\frac{d\,\delta(\text{deg})}{d\,\delta(\text{sec})} = \frac{360^\circ}{T}$$

She shows all her work, as well as the final calculation and answer.

$$\frac{d\,\delta(\text{deg})}{dT} = -\frac{\delta(\text{sec})\,360^\circ}{T^2} = 0$$

So:

$$\Delta\delta(\text{deg}) = \sqrt{\left(\frac{360^\circ}{T}\right)^2(\Delta\delta(\text{sec}))^2 + \left(\frac{360^\circ}{T^2}\right)^2(\delta(\text{sec}))^2(\Delta T)^2}$$

$$= \frac{360^\circ}{T}\Delta\delta(\text{sec}) = \frac{360^\circ \cdot 0.5\,\text{ms}}{33.3\,\text{ms}} = 5.4^\circ \approx 5^\circ$$

Exactly what I had before! Argh!

"mini-conclusion"

So the phase difference between the two traces in circuit 1 is $0 \pm 5^\circ$

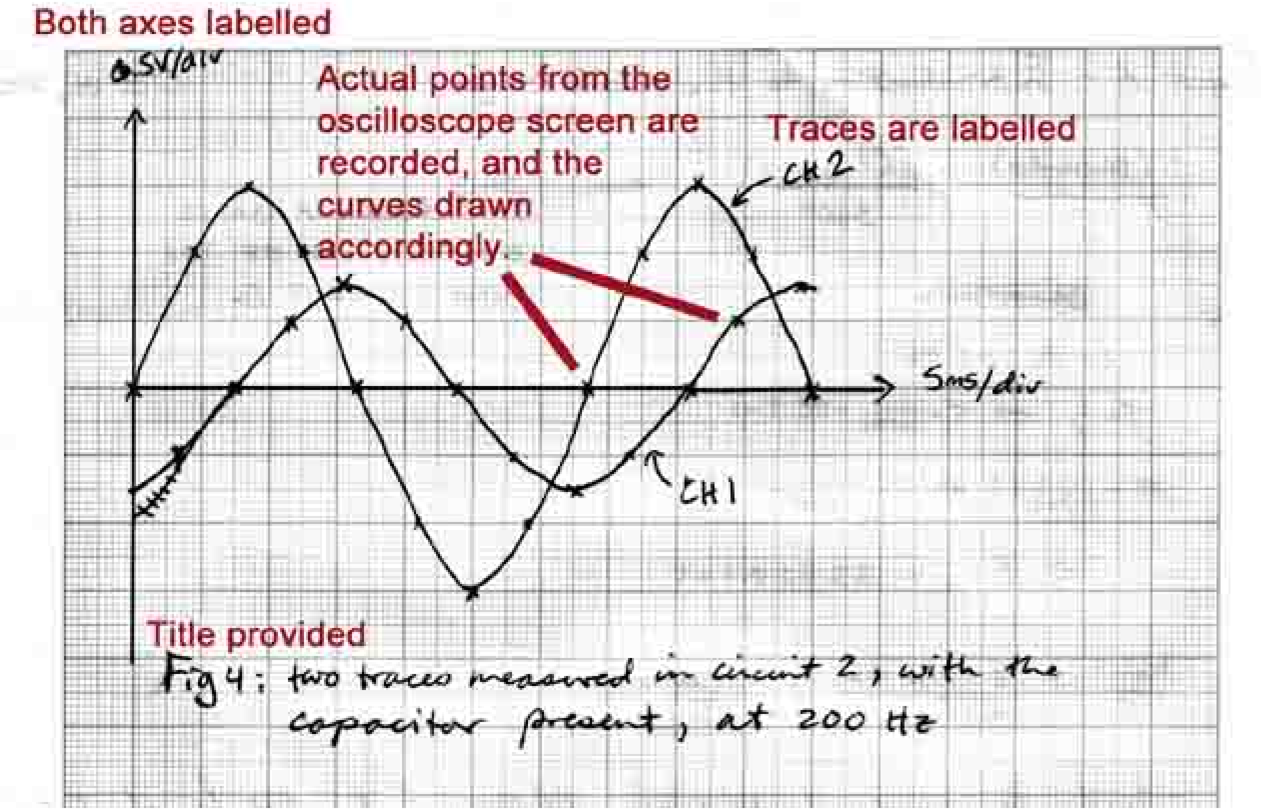


Fig 4: two traces measured in circuit 2, with the capacitor present, at 200 Hz

Expt A - Intro. to the oscilloscope Oct 14, 2003

THIS CONTINUES ON FROM PAGE 67 A good thing to note

Error calculation :

The entire theoretical calculation is shown, and then numbers are substituted in explictly, and then the final answer is given. This is how sample calculations *should* be done.

if $\delta(\text{deg}) = 360° \cdot \dfrac{\delta(\text{sec}) \pm \Delta\delta(\text{sec})}{T \pm \Delta T} = 360° \cdot \dfrac{8.0 \pm 0.5\text{ ms}}{33.3 \pm 0.1\text{ ms}}$

then $\Delta\delta(\text{deg}) = 360° \cdot \left[\left(\dfrac{d\,\Delta\delta(\text{deg})}{d\delta(\text{sec})}\right)^2(\Delta\delta(\text{sec}))^2 + \left(\dfrac{d\,\Delta\delta(\text{deg})}{dT}\right)^2(\Delta T)^2\right]^{\frac{1}{2}}$

$$= 360° \sqrt{\left(\frac{1}{T}\right)^2(\Delta\delta(\text{sec}))^2 + \left(\frac{-\delta(\text{sec})}{T^2}\right)^2(\Delta T)^2}$$

$$= 360° \sqrt{\left(\frac{1}{33.3\text{ms}}\right)^2(0.5)^2 + \left(\frac{-8}{(33.3)^2}\right)^2(0.1)^2}$$

$$= \cancel{10} \; 5.4°$$

"mini-conclusion"

So the phase difference between the two traces in circuit 2 at 30 Hz is 87 ± 5°. CH2 also LAGS CH1 (Starts later than CH1)

4:40 pm - Eek! Records the time

"mini-objective"

Now I switch the frequency to 200 Hz and find the phase difference again. See ~~fig~~ fig 4 for sketch of traces.

$\delta(\text{seconds}) = 1.5 \pm 0.1 \text{ div} \times 5\text{ ms/div} = 7.5 \pm 0.5\text{ ms}$

She did the calculation in detail already, so is justified in just substituting in numbers now.

$$\delta(\text{deg}) = 360° \cdot \frac{7.5}{33.3} = 81.1°$$

$$\Delta\delta(\text{deg}) = 360° \left[\left(\frac{0.5}{33.3}\right)^2 + \left(\frac{7.5}{(33.3)^2}\right)^2(0.1)^2\right]^{\frac{1}{2}} = 5.4°$$

The phase difference between the two traces in circuit 2 at 200 Hz is 81 ± 5°. CH 2 LAGS CH 1 again.

"mini-conclusion"

Expt A – Intro. to the oscilloscope Oct 14, 2003

Now I'll check to see how well my experimental values for δ compare with the theoretical value:

$$\delta = \tan^{-1}\left(\frac{1}{2\pi f RC}\right) \quad \text{where } R = R_1 + R_2$$ (from the lab manual)

References where she found the equation

Shows all her work

$$R_1 + R_2 = 2\,(50\,\Omega \pm 10\%) = 100\,\Omega \pm 10\% = 100 \pm 10\,\Omega$$

$$C = 1\,\mu F \pm 10\% = (1.0 \pm 0.1)\times 10^{-6}\,F$$

When $f = 30 \pm 0.1$ Hz

$$\delta = \tan^{-1}\left(\frac{1}{2\pi(30)(100)(1\times10^{-6})}\right) = 88.92^\circ$$

Makes note of a useful and important fact

error calculation: Note: This formula gives me my uncertainty for δ in RADIANS, and I have to then convert to degrees.

Shows her theory in detail

$$\frac{d\delta}{df} = \frac{d}{df}\tan^{-1}\left(\frac{1}{2\pi f RC}\right) = \frac{1}{1+\left(\frac{1}{2\pi f RC}\right)^2}\cdot\left(\frac{-1}{(2\pi f RC)^2}\right)\cdot 2\pi RC$$

$$= \frac{-2\pi}{(2\pi f RC)^2+1}\,RC$$

$$\frac{d\delta}{dR} = \frac{-2\pi}{(2\pi f RC)^2+1}\,fC$$

$$\frac{d\delta}{dC} = \frac{-2\pi}{(2\pi f RC)^2+1}\,fR$$

$$\Rightarrow \Delta\delta(\text{rads}) = \frac{2\pi}{(2\pi f RC)^2+1}\sqrt{(RC)^2(\Delta f)^2 + (fC)^2(\Delta R)^2 + (fR)^2(\Delta C)^2}$$

71

Still putting the title and date on every page

Expt A - Intro. to the oscilloscope Oct 14, 2003

Substitutes in numbers

$$\Delta\delta(\text{rads}) = \frac{2\pi}{(2\pi(30)(100)(10^{-6}))^2+1}\left[(100)^2(10^{-6})^2(0.1)^2 + (30)^2(10^{-6})^2(10)^2 + (30)^2(100)^2(0.1\times10^{-6})^2\right]^{\frac{1}{2}}$$

$$= 2.665\times10^{-3}\text{ rads}$$

$$\frac{2.665\times10^{-3}\text{ rads}}{2\pi\text{ rads}} = \frac{x\text{ degrees}}{360°} \Rightarrow 0.15°$$

"mini-conclusion"

So the phase difference calculated for the system at 30 Hz is 88.9 ± 0.2°

The measured value was 87 ± 5°

These values agree within the limits of uncertainty.

When f = 200 ± 0.1 Hz

All work shown

$$\delta = \tan^{-1}\left(\frac{1}{2\pi(200)(100)(10^{-6})}\right) = 82.84°$$

$$\Delta\delta = \frac{2\pi}{(2\pi(200)(100)(10^{-6}))^2+1}\left[(100)^2(10^{-6})^2(0.1)^2 + (200)^2(10^{-6})^2(10)^2 + (200)^2(100)^2(0.1\times10^{-6})^2\right]^{\frac{1}{2}}$$

$$= 0.0175\text{ rads}$$

$$\frac{0.0175\text{ rads}}{2\pi\text{ rads}}\cdot 360° = \Delta\delta(\text{degrees}) = 1°$$

"mini-conclusion"

The theoretical phase difference for the system at 200 Hz is 83 ± 1°.
The experimental value was 81 ± 5°.
These values agree within the limits of uncertainty

I conclude that the theoretical equation models the experimental results well. 5:12 PM

Notes the time again

A terribly weak conclusion! *Your* picky TA will expect a lot better from you. Put some thought into what your data indicate, and what conclusions you can make. Prove that you understand the physics, because just following the instructions in the lab manual is NOT enough. We're training you to be a scientist, and scientists *think*.

Your Lab Reports

On the bookshelf in the back of lab, I have put a couple of books as references for technical writing. Please refer to these for more information and background. The references are as follows:

Pocket Book of Technical Writing for Engineers & Scientists, by Finkelstein, has a nice solid discussion in chapter 9, which begins on page 145.

A Guide to Writing as an Engineer, by Beer & McMurrey, also contains a good discussion of an engineering report. It is found in chapter 6, which begins on page 123.

Also, I have included some suggestions on technical report writing found on the web that are very good and that you might find helpful.

Whether the report is called an 'engineering report' or a 'laboratory report' or a 'technical report' isn't so important. As you will see from reading the above selections, there is a common approach and structure – and that must be followed.

We have examples of good lab reports for you to see, and we have examples of good lab notebooks as well.

The next section of this document is a brief introduction to writing a good lab report.

Finally, note that we do not cover proper error analysis in this document, but it is expected that full and proper error analysis will accompany all lab reports. Error analysis should make up a large part of your lab notebook in general, and if you develop the good habit of keeping proper significant figures, propagating errors whenever you do a calculation, putting uncertainty ranges on your data points in graphs, etc, you will save yourself a lot of time and effort when it comes time to write up a lab report (or do your WCR papers sophomore/junior year).

Writing a Good Lab Report*

(*taken from the University of Connecticut website – distributed to 132/233/234 labs and Intro to Engineering class)

INTRODUCTION.

As a practicing engineer, you must write reports, proposals, scientific papers, and electronic messages. Writing is perhaps the most important way in which you will convey your ideas to managers, other engineers, and customers. Your communication skills will therefore determine how successful you are as an engineer, perhaps even more so than your technical expertise!

This booklet describes briefly how to write an effective engineering report. As you read this booklet, keep in mind that there is always more than one way to convey the same idea. In many situations, there is not necessarily a “right way” and a “wrong way.” However, there may be a preferred way.

REPORT ORGANIZATION.

Good report organization should promote readability and reflect the scientific method of attack, which proceeds with objective, method, results, and conclusions. It is logical to report a project in the sequence in which it is done, and many engineering reports are organized on this basis. Two improvements to the logical sequence are the addition of an abstract or summary and the insertion of headlines. These two features facilitate “scanning” of the report. Thus, a busy executive or engineer may quickly assess the major findings and conclusions of the report, and then easily find further details as required.

In writing a full-length engineering report, you should start with a report outline, then proceed to a rough draft. The outline defines the organization of the report, and the rough draft serves to avoid omissions. Once the content is established, the rough draft is refined for clarity and conciseness. After proofreading and correction of minor mistakes, the finished product is produced. This entire writing process is most easily done using a word processor. “Spell checkers” are particularly useful in removing spelling or typographical mistakes.

The outline for a general full-length engineering report contains the following items:

1. Title
2. Objective
3. Summary or Abstract
4. Introduction
5. Theory and Analysis
6. Apparatus / Materials
7. Experimental Procedures
8. Data and Results
9. Discussion
10. Conclusions and Recommendations
11. Acknowledgments
12. Bibliography
13. Appendix

Usually, you can combine or omit some of these thirteen items without a loss of completeness. For example, the results and discussion sections may be combined. As another example, often the object is described in the introduction. The individual sections of the report will have headings, which are made to stand out with underlined, bold, italic, or large size print, and may be centered. The names of the sections may be more descriptive than the generic names listed above. Headings may be numbered, especially in longer reports, theses or books. Longer documents may also have subheadings within sections.

A title page should be used with full identification including names and dates. If the report is long, a table of contents should follow the title page.

The abstract should summarize the major points in the report in concise manner and should allow the reader to make a decision on whether or not to read the full paper. The first sentence should state what was accomplished. The abstract is not a condensation of the entire paper, but rather a clear statement of the project scope, results achieved, and the conclusions and recommendations drawn from the results.

An introduction is desirable to indicate the background of the project and the reasons for undertaking it. Some information on previous work is usually included.

In the theory and analysis section, pertinent principles, laws, and equations should be stated and unfamiliar terms should be defined. Analytical diagrams such as theoretical cycles or flow and field patterns should be shown here. Be sure to include all necessary supporting theory without adding deadwood.

The apparatus / materials section is important in a report on equipment performance or a manufacturing process. In a performance test of a new component or system, give full and accurate identification, including model and serial numbers or other unique identification. In a report on a process or fabricated device, give a full description of materials and chemicals, including manufacturers, lot numbers, and impurity analyses.

The experimental procedures section may encompass apparatus and materials. Instrument types, ranges, and identification numbers should be indicated. A sketch of the test setup showing relative positions, connections, and flows should be included. Preliminary results, equalizing periods, duration of runs, and frequency of readings should be indicated. Special precautions for obtaining accuracy and for controlling conditions should be described. Conformity with or divergence from standard test codes or procedures should be clearly stated.

The data and results section should summarize the important findings with supporting tables, graphs, and figures. Original data or extensive data tables should be included in appendices. Graphical representation is very important in conveying quantitative results. The use of logarithmic or other special scales should be considered. Deviations from smooth curves should be carefully checked. Apparent discrepancies should be pointed out and explained. Error analysis should be clearly carried throughout the data & analysis sections

The discussion section should describe the accuracy and importance of the results. Sources of measurement error should be evaluated. Results should be critically compared with theory, and differences greater than the experimental errors should be explained. Limitations of the theory and tolerances in engineering values should be considered. A proper conclusion takes into account the errors in the experiment and the error analysis performed. Conclusions should be supported by specific references to data and results, quoting numerical values, and guiding the reader from facts to conclusions. Conclusions should follow directly from the numerical results quoted, without the need for mental arithmetic by the reader. Omit any part of the discussion which could be written without performing the experiment.

The conclusions and recommendations section should summarize the conclusions which have been drawn. These conclusions may be supported by brief reference to data or results. Recommendations are often more important than conclusions. Few experimental projects are an end in themselves. Either the results are to be used for a purpose, or the experimenter sees more work that could be done. In student reports, recommendations on improving the laboratory experiments, equipment or procedures are accepted gratefully.

Acknowledgments are usually unnecessary in a student report. They are very important in theses, journal articles, or company reports. Always acknowledge all other contributors to the work, people who have contributed ideas or materials, and sources of financial support.

The bibliography must list sources to which direct reference was made in the text. Other general references may also be given. Numbered footnotes, or preferably endnotes, are used to list sources in the order of reference.

REPORT STYLE.

For many years, it was customary to write scientific papers in the third person, passive voice, past tense. Even today, this style is preferred by many. More and more, however, the first person, active voice, past tense is becoming the preferred style. Consider some examples:

<u>Not Recommended:</u> Clean the gallium arsenide substrates by boiling them in trichloroethylene.

<u>Not Recommended:</u> I clean the gallium arsenide substrates by boiling them in trichloroethylene.

<u>Acceptable:</u> The gallium arsenide substrates were cleaned by boiling in trichloroethylene.

<u>Recommended:</u> We cleaned the gallium arsenide substrates by boiling them in trichloroethylene.

Simple technical English should be used. Engineering and trade terms may be used, but the style should be dignified. Short sentences are preferred. Acronyms may be used but only if they are defined at the first appearance.

For further guidelines on style, see Appendix A, or refer to a writing handbook such as <u>The Little, Brown Handbook</u>, by H. R. Fowler (Boston: Little, Brown and Company, 1980), <u>The Elements of Style</u>, by William Strunk and E. B. White (New York: Macmillian, 1979), or <u>Style: Ten Lessons in Clarity and Grace</u>, by Joseph Williams (Glenview, IL: Scott, Foresman, 1981).

REPORT MECHANICS.

As a matter of general mechanics, you should use the following: uniform page size (8.5” x 11”); prominant headings; well-displayed tabulations with titles; well-displayed figures with titles; ample margins; and numbered pages. Reports submitted in University of Connecticut writing courses such as EE 209W or EE 262W must have letter-quality print produced by a laser printer or ink jet printer.

Numerical results should be reported with due regard for the experimental accuracy with which they were obtained. For instance, 0.75 $\pm$ 0.01 Ampere is acceptable but 5.3275 $\pm$ 0.01 Volt is not. In the absence of explicitly stated errors, the error is assumed to be plus or minus one in the least significant digit. Hence 5.33 V means the same as 5.33 $\pm$ 0.01 V.

Graphs should be numbered and completely labeled and titled. The title should be brief and descriptive, such as “Motor Speed as a function of Torque.” The independent variable should be shown on the abscissa (horizontal axis) and the dependent variable should be shown on the ordinate (vertical axis). Scales should be labeled with the name, symbol, and units of the quantity involved. Each of the curves on a sheet should be clearly identified, and all of the experimental points shown.

Graph scales should be chosen for easy reading but with due regard to the accuracy of observed and computed quantities, so that variations are neither concealed nor exaggerated. For instance, if temperatures can be read only to the nearest degree, the smallest subdivision on the graph paper should be one degree or greater. Major scale divisions should be chosen so that interpolation is easy. The subdivisions should preferably represent 2, 5, 10, 20, 50, 100 etc. Most scales should start from zero; if they do not, a broken axis must be used.

Smooth curves should be drawn with no extrapolation beyond the experimental points. Any discontinuities or points of inflection should be examined with suspicion. Methods of plotting that give straight lines are preferred.

CONCLUDING REMARKS.

Use this booklet as a guide, but remember that it can not take the place of good judgment. Every report is different. The unique content of a report may dictate the style or organization of the report.

REFERENCES.

H. R. Fowler, The Little, Brown Handbook (Boston: Little, Brown and Company, 1980).

William Strunk and E. B. White, The Elements of Style (New York: Macmillian, 1979).

G. L. Tuve and L. C. Domholdt, Engineering Experimentation (New York: McGraw-Hill Book Co., 1966).

Craig Waddell, Basic Prose Style and Mechanics (Troy, NY: Rensselaer Press, 1990).

Joseph Williams, Style: Ten Lessons in Clarity and Grace (Glenview, IL: Scott, Foresman, 1981).