PHY340 Data Analysis Feedback:

Group P11 doing Problem P1

# Data Analysis

You have taken a sensible approach to the data analysis: in a situation where the best way to determine the quantity of interest is not clear, using several methods and comparing the results is a good idea. It does, however, appear to be more usual in the literature to use a log-log plot rather than a linear plot to determine the transit time—see, for example, the figure below (Lorrmann et al. 2014).

*Figure 1: Mobility and transit time, from Lorrmann et al. (2014). Note the use of the log-log plot. In the modified Scott method, the transit time distribution is obtained by extrapolating the plateau and differentiating the ratio: .*

The advantage of the log-log plot is that the lower voltages are easier to fit:

*Figure 2: The data for −17 and −16 V, plotted on a linear scale (left) and a log-log scale (right); note that the right-hand plot only covers times from 0.8 to 2.0 µs, and so omits the initial peak.*

In the linear plot, it would be difficult to fit a good straight line after the cut-off, and in the −16 V data there is a pronounced curve even before the cut-off. In the log-log plot, both datasets give good straight lines before and after the cut-off. This is because a straight line in a log-log plot actually corresponds to a power law, *V* = *V*0*tx*, where *x* is given by the gradient of the line and *V*0 by its intercept. Not all curved lines are power laws, but in this case it seems that they are.

The principal problem in your account of your data analysis is that there isn’t one. You say “all group members measured the transit time by eye”, but you do not say how they did so: in fact, nowhere in the report do you explain how the transit time relates to the voltage traces. Your descriptions of your computational methods are unclear (what do you define as “end of signal”, for example?), and need illustrations to convince the reader that they are valid (you say that you select “the greatest distance from the line” and “the most negative” change in gradient: whether simply selecting the maximum is a good strategy depends entirely on how noisy the data are, and this is impossible to evaluate without some plots).

Having gone to the trouble of obtaining seven independent transit time determinations, you then fail to make effective use of them. The most obvious thing to do is to check for consistency, as below. This shows that in fact the consistency of the different measurements leaves some­thing to be desired: while most of the lines are in a pack, line “eye 3” and computational method 2 are clearly out of line: “eye 3” has a major excursion between voltages −28 V and −24 V, and computational method 2 does not see the decrease of mobility with decreasing field that is observed by all other methods/observers.

 *Figure 3: comparison of individual mobility determinations.*

You then have two choices: either you average everything, or you remove the outliers and average the remaining five. In either case, you can use the standard deviation to calculate the error on the mean, and you should really *use* this error when fitting your straight line.

I fitted your data using an unweighted least-squares fit, which is suboptimal but should not be too bad (the error bars do vary, but not systematically), and the results are shown in figure 4. Somewhat fortuitously, the two fits agree very well: if you look at figure 3, you can see that this is because the two outliers largely cancel each other out: eye 3 would produce a steeper slope, and computational method 2 a shallower one, so overall they make little difference.

*Figure 4: hole mobility as a function of The straight lines are unweighted least-squares fits with a gradient of (2.17±0.25)×10−5 cm5/2 V−3/2 s−1 and intercept (5.8±0.6)×10−3 cm2 V−1 s−1 for the overall mean, and gradient (2.15±0.20)×10−5 cm5/2 V−3/2 s−1 and intercept (5.5±0.5)×10−3 cm2 V−1 s−1 for the mean excluding outliers.*

 The error bars on your figures 4 and 5 are clearly wildly overestimated, based on the rule of thumb that the best fit should go through only 2/3 of the error bars. It is extremely unclear what you mean by “the average difference of the mobility at each bias”—average difference from what?—but in any case it *is* clear that the error bar should not be the same for each point: for example, the spread in estimates for −30 V is from 0.0113 to 0.0124, about 10%, whereas the spread for −26 V is from 0.0109 to 0.0146, about 30%, and this difference should be reflec­ted in the error bars (it suggests that the −26 V data are for some reason more difficult to ana­lyse than the −30 V data). You do not specify the error you adopted for the time offset, but it should be small—I got 0.664±0.002 µs using your definition of the halfway point on the initial rise.

Finally, when you have gone through all your calculations and plots, *you do not actually quote your results*. All you say is that your calculated mobilities are “of the order of magnitude of 10−2 cm2 V−1 s−1” and that they are “proportional to the square root of the electric field”, which they most certainly are ***not*** (this would mean that , which definitely is not the case: in fact, , and *µ*0 is non-zero to about 10*σ*). The only quantitative result you quote is the size of your error bars, which is clearly wrong by inspection, and is given to twice as many significant figures as it should be.

This is a pity: you have made a nice job of obtaining the data, but you have not made good use of what you have done, and you have not reported it well at all.

Average mark for this section: 35/50

# Data Presentation

The data presentation is unfortunately poor. As noted above, the computational methods need plots to demonstrate that they are performing well, and you need to explain the procedure you used for your “by-eye” estimates. Figure 3 is particularly useless: because you have plotted the entire data stream, most of the figure contains no useful information, and the main signal is squashed into the left-hand third. This makes it *extremely* difficult to identify the salient fea­tures, and this is not helped by the fact that the labels “1” and “2” do not appear to be labelling anything in particular. In order to convey useful information, this plot needed to be restricted to the time range 0.5−1.5 µs, so that the points being measured could be clearly indicated.

The axis labels are too small on all the plots, and the gradient and intercept of the fitted lines need to be stated on figures 4 and 5, as does the fit method; presumably, given that for some reason you decided to assign equal errors to all points, this was an unweighted least-squares fit, but you do need to say so. (It should also be noted that in figure 5 you are combining data that are not internally consistent: an unweighted fit to computational method 1 gives a gradient of (2.21±0.38)×10−5, whereas computational method 2 gives (−0.68±0.43) ×10−5. These are incon­sistent at the level of 5*σ*, so it is not at all appropriate to combine them.)

Average mark for this section: 14.5/30

# Style

The report is well structured and has the right subheadings, but simply does not contain the right material. The abstract does not include a summary of the numerical results (and repeats the incorrect statement that ), and the results and analysis section contains too little in­for­mation on the analysis and essentially no results. It is nice to see a discussion of the method used to obtain the data, but this needs a reference and figure 2 needs a source. As in your litera­ture review, your introduction grossly overstates the impact of organic semiconductors: there are some applications where organic semiconductors really are a better solution, but at the moment their low mobilities—exactly the property you are studying!—make them very slow, and so not suitable for many applications where fast operation is a requirement (e.g. compu­ters). Your smartphone chip is not fabricated using an organic semiconductor, and probably won’t be for some time. The introduction is also rather under-referenced: no reference is provided for the assertion that mobility increases exponentially with temperature, or for the discussion of the effect of electric field. Although you apparently *know* that there should be a linear relationship between mobility and *E*1/2, because that’s what you plot, you never state this in the introduction, nor do you quote an appropriate equation (for example Fong et al.’s equation 2, , which approximates to for ).

You should have noticed that your “fluorine copolymer” didn’t actually contain any fluorine—(C51H61N)n is noticeably lacking in F. This is because it is *not* a “fluorine” copolymer: it is a ***fluorene*** copolymer, and fluorine and fluorene have absolutely nothing in common. This may be a Word autocorrect gone mad, but you should have corrected it during proof-reading.

Average mark for this section: 10.5/20

Average overall mark: 60%