

Writing Scientific Reports for Junior Lab Using L^AT_EX

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This paper is a written summary and template document for use by MIT Physics Junior Lab students like you in preparing your experimental reports. It uses L^AT_EX (pronounced *lay-tek* or *lah-tek*, but never *lay-teks*) and the REV_TE_X macro package from the American Physical Society to produce a professional quality document. REV_TE_X is the standard package used to prepare most articles in the Physical Review and many other journals as well. This example template demonstrates several common L^AT_EX “tricks”, but the extent of the examples may be too much for first time L^AT_EX users. A simpler “minimal example” template is also available from the Junior Lab web pages. In regards to content, the individual summary you hand in should show evidence of your own mastery of the entire experiment. It should also possess a neat appearance with concise and correct English. The abstract is essential. It should briefly mention the motivation, the method, and most importantly the quantitative result and its uncertainties. Based on those elements, readers may draw their own conclusion. The length of the paper should be no more than two double-sided pages including all figures. With your instructor’s advanced permission, appendices can be used for additional plots of raw data, but should not be used to simply extend turgid prose!

An important part of your education as a physicist is learning to use standard tools which enable you to share your work with others. In Junior Lab, you will be instructed in the use of L^AT_EX on either MIT’s Athena environment or your own personal computer. You will learn to write scientific papers in a widely accepted professional style. The source file for this document may be used as a template for your Junior Lab papers. Spending a few hours studying and altering this document will allow you to develop sufficient mastery of L^AT_EX to easily generate all manner of technical documents. Specific instructions for compiling L^AT_EX documents on various operating systems are contained in the Appendices.

The writing process [1] involves at least four distinct steps: prewriting, drafting, revising, and editing. Given the tight time constraints in Junior Lab, you are advised to begin the drafting process *before* finishing your lab sessions. While final results and analysis are not possible, much of the draft can be accomplished during the latter sessions of an experiment.

This is the introductory section of the paper. Your introduction should *succinctly* report the motivation, purpose, and relevant background to the experiment in way that is accessible to your audience. For Junior Lab, the appropriate audience is a stereotypical Junior Lab student who has background knowledge and experience similar to your own, but is totally unfamiliar with your experiment.

I. PROBLEM AND RELEVANT THEORY

The report should be type-written in a form that would be suitable for submission as a manuscript for publication in a professional journal such as Physical Review Letters. One helpful resource is the *APS Physical Review Style and Notation Guide* [2]. Another is the *AIP Style Manual* [3]. Figures (created as PDF or PNG files) should be inserted into the text in their natural positions. The body of the summary should include a discussion of the theoretical issues addressed by the experiment. This should be done at a level such that another 8.13 student could follow your development.

One of the most important resources for developing into a strong technical writer is the MIT Writing Center [4]. Students should thoroughly investigate the resources on this site in the first weeks of 8.13. Note that students can receive free consultation — online or in person — on their written reports through this office!

The essence of expository writing is the communication of understanding through a clear and concise presentation of predominately factual material [5, 6]. Most people cannot compose successful expository prose unless they put the need to communicate foremost among their priorities. Two things predominate in generating understanding in the reader:

Organization: The reader must be provided with an overview or outline, know how each fact that he reads fits into that overall picture, and he must be alerted if it is an especially important fact. Furthermore, the facts must be presented in a logical order, so that fact 17 is not important for understanding fact 12.

Uniform depth of presentation: Bearing in mind the preexisting knowledge of the reader, the writer must budget the length of discussion allotted to each topic in proportion to its importance.

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Of course clarity of presentation and elegance of explanation will greatly enhance the ease and pleasure of understanding; still, a murky explanation can be fairly useful if the reader has been told what he is reading about and where it fits into the overall scheme of things — especially if the reader is familiar with the general subject matter under discussion.

The Junior Lab write-up is one of the few opportunities undergraduate physics majors at MIT are given to practice technical writing. Thus, you are urged to concentrate on your overall presentation, not only on the facts themselves. We strongly recommend that you:

1. Base your report on an outline.
2. Begin each paragraph with a topic sentence which expresses the main area of concern and the main conclusion of the paragraph. Put less important material later in the paragraph.

Point 2 is frequently absent in 8.13 reports. Topic sentences are your mechanism for telling the reader what the topic under discussion is and where it fits into the overall picture. You can check your topic sentences by reading them in order, *i.e.* omit all the following sentences in each paragraph. This should give a fair synopsis of your paper.

If you are individually writing up results you obtained with a partner, use “we” and “I” appropriately. Note the following admonition from the *AIP Style Manual* [3, Section III.A.9]:

The old taboo against using the first person in formal prose has long been deplored by the best authorities and ignored by some of the best writers. “We” may be used naturally by two or more authors in referring to themselves; “we” may also be used to refer to a single author and the author’s associates. A single author should also use “we” in the common construction that politely includes the reader: “We have already seen. . . .” But never use “we” as a mere substitute for “I,” as in, for example, “In our opinion. . . ,” which attempts modesty and achieves the reverse; either write “my” or resort to a genuinely impersonal construction.

Use the past tense for your procedure and analysis, the past perfect for preparation and the present for emphasis or conclusions. For example, “Since we had previously measured constructive and destructive interference, we concluded that electrons are waves.”

Some further tips:

- Be sure your figures have comprehensible captions.
- Make a complete estimate of your errors — not just statistical — even if it is crude.

- Trace the origin of formulae you use (*e.g.* Moseley’s law) to well known physics (in this case, to the Bohr atom). Do *not* derive: just indicate what new assumptions are needed.

Please consult the MIT Writing and Communications Center’s web page [4] for further guidance in all aspects of writing, style, and to make appointments with consultants for free advice. They even have an online tutor to which you can submit sections of your paper for critique at any stage of the writing process!

Lastly: Remember to *proofread your paper for spelling and grammar mistakes*. Few things are as offensive to a reviewer as careless writing. Such mistakes will count against you!

II. EXPERIMENTAL SKETCH AND SALIENT DETAILS

Here is an example first sentence of an experimental section: The experimental apparatus consists of a specially prepared chemical sample containing $^{13}\text{CHCl}_3$, an NMR spectrometer, and a control computer, as shown in Fig. 1.

This section describes the main components of the apparatus and procedures used. It always makes reference to a figure(s) which contains a block diagram or schematic of the apparatus and perhaps includes the most important signal processing steps. The figure should be referenced as early as possible in this section with the placement of the figure as close to the descriptive text as is possible. It is usually necessary to place additional information within the figures themselves or in their captions for which there is no room in the main body of text. This will help you stay within the four page limit.

II.1. Typesetting Mathematics

One of the great powers of \LaTeX is its ability to typeset all manner of mathematical expressions. While it does take a short while to get used to the syntax, it will soon become second nature. Numbered, single-line equations are the most common type of equation in Junior Lab papers. For example,

$$\chi_+(p) \lesssim [2|\mathbf{p}|(|\mathbf{p}| + p_z)]^{-1/2} \begin{pmatrix} |\mathbf{p}| + p_z \\ px + ip_y \end{pmatrix}. \quad (1)$$

Be sure there is *no empty line* in your \LaTeX source code between `\end{equation}` and the following body text unless you want a new paragraph to start there (and be indented). Also, remember to punctuate your equations according to their usage as parts of sentences.

Mathematics can also be placed directly in the text using $\$$ delimiters: the energy E is related to the mass m via $E = mc^2$, where c is the speed of light. As in

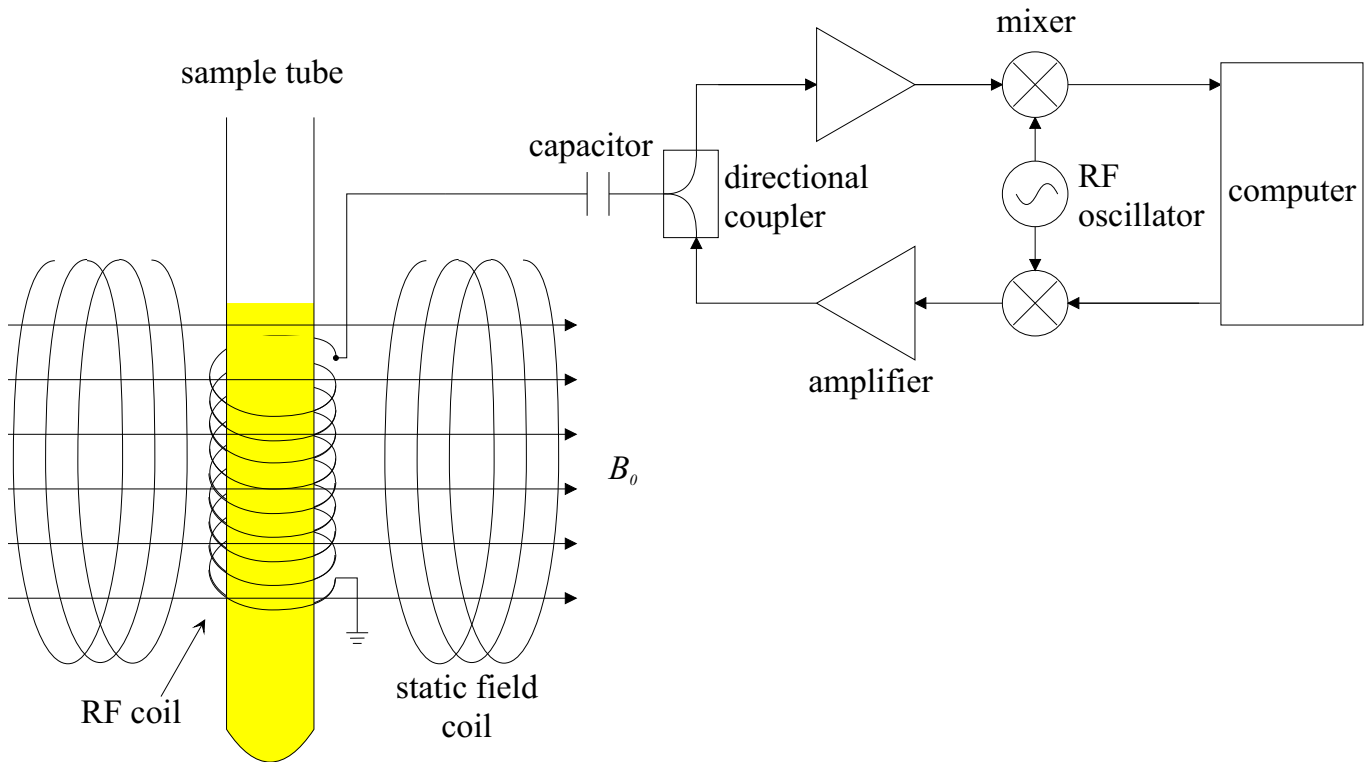


FIG. 1. This is a schematic of the main apparatus. Use the caption space to elaborate on specific issues, complications, or operating procedures. This is especially valuable given the limited amount of space in the main body of text. The size of this graphic was set by the `width` command option. The aspect ratio defaults to 1.0 if the height is not also set. Note, this figure spans two columns, instead of just one. This effect was accomplished using the `figure*` environment instead of just `figure`. Use this effect *sparingly*: single-column figures should suffice in most circumstances. Adapted from [7, 8].

the previous sentence, you should use this construction not just for whole equations in running text, but also for referring to individual variables by name: otherwise the variables will be set in different typefaces when appearing in text versus equations.

Infrequently, you may wish to typeset long equations which span more than one line of a two-column page. A good solution is to split up the equation into multiple lines and label all lines with a single equation number, as in Equation (2). See the \LaTeX source to see how this is done using the `multline` environment.

$$\begin{aligned} \sum |M_g^{\text{viol}}|^2 &= g_S^{2n-4} (Q^2) N^{n-2} (N^2 - 1) \\ &\times \left(\sum_{i < j} \right) \sum_{\text{perm}} \frac{1}{S_{12}} \frac{1}{S_{12}} \sum_{\tau} c_{\tau}^f. \end{aligned} \quad (2)$$

Since \LaTeX does not know mathematical grammar, you have to tell it the appropriate place to split the input using the `\` sequence. Here is an example of not simply splitting a long equation across lines, but also having multiple equations for which the equality signs should

align on the page. It uses the `align` environment:

$$\begin{aligned} \vec{\psi}_1 &= |\psi_1\rangle \\ &\equiv c_0|0\rangle + c_1|1\rangle \chi^2 \end{aligned} \quad (3)$$

$$\approx \prod \sum \left[\frac{y_i - f(x_i)}{\sigma_i} \right]^2 |\psi_1\rangle$$

$$Q(z) \sim \lim_{\mu \rightarrow \infty} p(x; \mu) \geq \frac{1}{\sqrt{2\pi\mu}} e^{-(x-\mu)^2/2\mu} P(x) \quad (4)$$

$$\alpha(\delta) \ll \int_{-\infty}^x p(x') dx' a \times b \pm c \quad (5)$$

$$\aleph \Rightarrow \nabla \hbar. \quad (6)$$

There are in fact several useful environments² for splitting equations across multiple lines, but if you do not want to memorize them all, then just use the `align` environment. You may encounter older \LaTeX code which instead uses the `eqnarray` environment for this purpose. Use of the `eqnarray` environment is deprecated and should be avoided.

² For example, Equation (3) gathers several typeset lines as one logical equation using the `split` environment inside the `align` environment.

Finally, it is often useful to group related equations to denote their relationship, *e.g.* in a derivation. Enclosing single line and multiline equations in `\begin{subequations}` and `\end{subequations}` will produce a set of equations that are “numbered” with letters, as shown in Equations (7a) and (7b) below:

$$f(u)^n = \left\{ abc123def + \alpha\beta\gamma\delta - 123456\alpha\beta \frac{1 \sum_b^a}{A^2} \right\} / 42, \quad (7a)$$

$$\mathcal{M} = ig_Z^2 (4E_1 E_2)^{1/2} (l_i^2)^{-1} (g_{\sigma_2}^e)^2 \chi_{-\sigma_2}(p_2) \times [\epsilon_i]_{\sigma_1} \chi_{\sigma_1}(p_1). \quad (7b)$$

II.2. Plagiarism: Don’t Do It

It is worth mentioning here some thoughts on ethics and writing in science.

When you read the report of a physics experiment in a reputable journal (*e.g.* Physical Review Letters) you can generally assume it represents an honest effort by the authors to describe exactly what they observed. You may doubt the interpretation or the theory they create to explain the results. But at least you trust that if you repeat the manipulations as described, you will get essentially the same experimental results.

Nature is the ultimate enforcer of truth in science. If subsequent work proves a published measurement is wrong by substantially more than the estimated error limits, a reputation shrinks. If fraud is discovered, a career may be ruined. So most professional scientists are very careful about the records they maintain and the results and errors they publish.

In keeping with the spirit of trust in science, Junior Lab instructors will assume that what you record in your lab book and report in your written and oral presentations is exactly what you have observed.

Fabrication or falsification of data, using the results of another person’s work without acknowledgement, or copying from the internet or “living group bibles” are intellectual crimes as serious as plagiarism, and possible causes for dismissal from the Institute.

The acknowledgement of other people’s data also applies to the use of other people’s rhetoric. The appropriate way to incorporate an idea which you have learned from a textbook or other reference is to study the point until you understand it and then put the text aside and state the idea in your own words.

One often sees, in a scientific journal, phrases such as “Following Bevington and Melissinos [7, 9] . . .” This means that the author is following the ideas or logic of these authors and not their exact words.

If you do choose to quote material, it is not sufficient just to include the original source among the list of references at the end of your paper. If a few sentences or more are imported from another source, that section should be

indented on both sides or enclosed in quotes, and attribution must be given immediately in the form of a reference note. [7]

If you have any question at all about attribution of sources, please see your section instructor. Further information about how to avoid plagiarism is available from the MIT Writing Center at <http://goo.gl/7PwXJe>.

III. DATA PRESENTATION AND ERROR ANALYSIS

Graphics, such as Fig. 2, should be well thought out and crafted to maximize their information content while retaining clarity of expression.

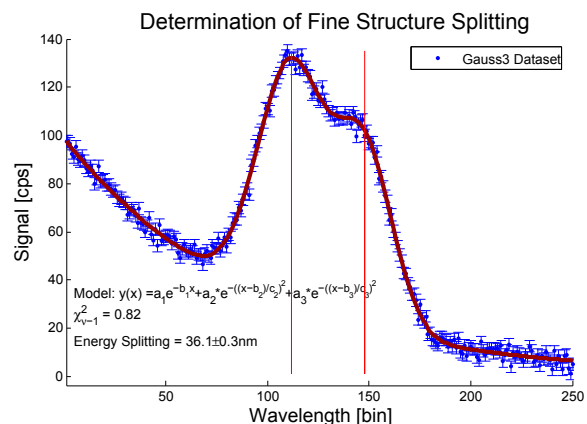


FIG. 2. Sample figure describing a set of data, fit procedures and results, created using the Junior Lab MATLAB template script at <http://web.mit.edu/8.13/matlab/fittemplate11.m>. Use the caption space to provide more details about the fitting procedure, results, or implications if you do not have sufficient room in the main body of text.

All papers should have at least one graphic showing an assemblage of raw data, sometimes placed as an appendix as in Fig. 4. Often these primary data are analyzed in a specific way that needs to be clearly communicated to the reader. In many physics experiments, the peak positions in an energy spectrum may be required. A graphic demonstrating a typical fit result, functional model, and reduced χ^2 is shown in Fig. 2. Finally, there should be one graphic which summarizes the experimental data, and which conveys the primary finding(s) of the laboratory exercise (*e.g.* the Geiger-Nuttall relationship in Fig. 3, Moseley’s law, the rotation curve of the Milky Way, the Compton scattering energies *vs.* angle, *etc.*). You may find that you need more, but these three should be a minimum. Finally, it can be useful in *some* circumstances to have a table of results, see Table I.

If you reuse graphics from your paper in oral presentation slides, make sure to increase the size of all the fonts

so that they remain legible from 20 feet away!

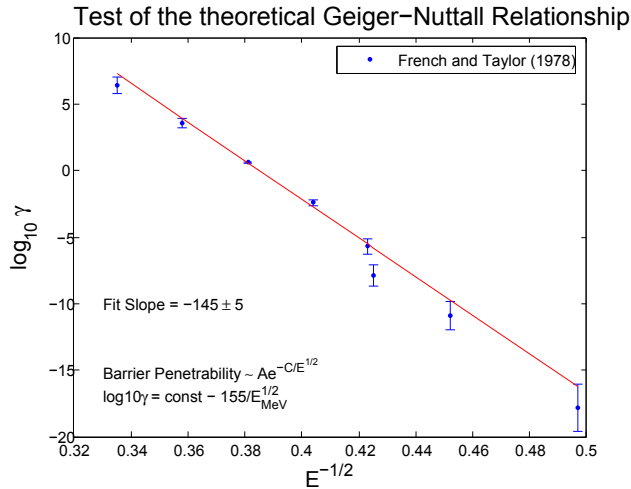


FIG. 3. Sample figure showing overall physical relationship you set out to test, created using the same script as Fig. 2.

Try to avoid the temptation to inundate the reader with too many graphics. It is worth spending some time thinking of how best to present information rather than just creating graph after graph of uninformative data. All figures and tables must be properly captioned. As always, material and ideas drawn from the work of others must be properly cited.

TABLE I. An example table with footnotes. Note that several entries share the same footnote. Always use a preceding zero in the data you record in tables. *Always display units!* Inspect the \LaTeX source for this table to see exactly how it is done.

	r_c (Å)	r_0 (Å)	κr_0		r_c (Å)	r_0 (Å)	κr_0
Cu	0.800	14.10	2.550	Sn ^a	0.680	1.870	3.700
Ag	0.990	15.90	2.710	Pb ^a	0.450	1.930	3.760
Tl	0.480	18.90	3.550				

^a Here is the first footnote mark, from Ref. [9].

If circumstances in an experiment are such that you cannot get your own data (*e.g.* broken equipment, bad weather), you may use another students' data *provided you acknowledge it and have received your instructor's explicit permission.*

IV. CONCLUSIONS

The conclusion section is *not* simply a summary of your measurement results, but rather a commentary on the scientific meaning of those results. Remember to report your results with appropriate significant digits, units, and uncertainties, *e.g.* $Q = (2.12 \pm 0.06) \text{ kg}\cdot\text{s}^{-1}$. It is often useful to express the quality of your result by measuring how many standard deviations it lies from expected values. Do *not* apologize or make excuses for your data.

Bibliographies are very important in Junior Lab papers, so some remarks are in order. Beyond the requisite citation of source material, they provide evidence of your investigations beyond the narrow scope of the lab manual, something explicitly required of all Junior Lab students! Good bibliographies are doubly important in the real world where they are very (often the most) important sources of information for researchers entering the field. Bibliographic entries are made within a separate `.bib` file which gets attached during process of building a final PDF document. See this document's `sample-paper.bib` file for details on several types of bibliographic entries and their required and optional fields.

ACKNOWLEDGMENTS

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- [1] “The Writing Process,” <http://cmsw.mit.edu/writing-and-communication-center/resources/writers/writing-process/> (2014).
- [2] A. Waldron, P. Judd, and V. Miller, *Physical Review Style and Notation Guide*, American Physical Society (2011).
- [3] *AIP Style Manual*, American Institute of Physics, 4th ed. (1990).
- [4] “MIT Writing Center,” <http://cmsw.mit.edu/writing-and-communication-center/> (2014).
- [5] L. C. Perelman, J. Paradis, and E. Barrett, *The Mayfield Handbook of Technical and Scientific Writing* (Mayfield, 1998).
- [6] D. Pritchard, “Junior lab written report notes,” (1990).
- [7] A. Melissinos, *Experiments in Modern Physics* (Academic Press, 1966).
- [8] A. Melissinos and J. Napolitano, “Experiments in modern physics,” (Academic Press, 2003) Chap. 5, pp. 179–184, 2nd ed.
- [9] P. Bevington and D. Robinson, *Data Reduction and Error Analysis for the Physical Sciences* (McGraw-Hill, 2003).

Appendix A: L^AT_EX on Windows

For students who would like to use a Windows platform, M_IK_TE_X (pronounced *mik-tek*) is a freely available implementation of T_EX and related programs available from www.miktex.org. Note that M_IK_TE_X itself runs from a command line prompt and is not terribly convenient unless you are comfortable with the Windows shell. Luckily, M_IK_TE_X comes packaged with the T_EXWORKS editing environment as a front end to L^AT_EX. Many beginners find T_EXWORKS easier and more intuitive to use than the alternative of a generic text editor and command line compilation. Advanced users may prefer a more powerful editor like EMACS or VI instead of a L^AT_EX-specific editor like T_EXWORKS.

Note that due to some “bad” distributions of L^AT_EX floating around the internet, some Windows users may need to update their L^AT_EX installation to the latest version of REV_TE_X-4.1 and the required natbib package. Alternatively, they can use the older REV_TE_X-4 by changing the `\documentclass` declaration at the beginning of the source file. You will know if you need to do this if you attempt to compile this sample document and receive errors about bad bibliography entries.

Once you have installed the above software, you will need to download the source files listed in the next section and put them on your Windows machine in order to “rebuild” this document from scratch.

Appendix B: L^AT_EX on Athena

For students wishing to utilize MIT’s Athena environment, the process to create your documents is quite simple. You can use the following commands verbatim or tweak them to suit your own organizational system.

In your home directory on Athena, create a convenient directory structure for all of your Junior Lab work by typing:

```
> mkdir ~/8.13
> mkdir ~/8.13/papers
> mkdir ~/8.13/papers/template
> cd ~/8.13/papers/template
```

Once this (or similar) directory structure has been created, copy all of the files needed to compile the template from the Junior Lab locker into your own Athena account by typing:

```
> cp /mit/8.13/www/Samplepaper/sample-zipped/* .
```

The final period above places the copied files into the current directory so make sure you are in the correct directory! You can see where you are by typing:

```
> pwd
```

The following files should now be in your current directory:

```
sample-paper.tex
sample-paper.bib
sample-paper.pdf
sample-fig1.pdf
sample-fig2.pdf
sample-fig3.pdf
typical-fit-plot.pdf
frenchtaylor.pdf
lgrind.sty
```

Additional files may also have been copied but do not worry: these get regenerated when you build your PDF document.

Now build the file (omitting the `.tex` suffix in the following steps):

```
> pdflatex sample-paper
> bibtex sample-paper
> pdflatex sample-paper
> pdflatex sample-paper
```

The repeated calls to `pdflatex` are necessary to resolve any nested references in the final PDF file. The `bibtex` call reads in the bibliography file `sample-paper.bib` allowing citation references to be resolved.

Remember to “ispell -t filename.tex” to perform a L^AT_EX-safe spell check before handing in your paper!

Appendix C: Graphics Utilities

Students should become proficient with a simple vector based drawing program such as INKSCAPE. Every written summary should include one or two simple schematics, based on your initial hand sketches from your lab notebook

It is easy to convert images from one format to another, *e.g.* a scanned JPEG or bitmap image into a PDF file for inclusion into a written summary. A useful utility, available on some Unix machines, is `IMCONVERT`. Typing `imconvert` without any arguments will show you the accepted file types. Other useful conversion utilities include `PS2PDF`, `EPS2PDF`, and a variety of similar programs.

MATLAB is perhaps the most common tool used by Junior Lab students for data analysis and representation. MATLAB figures can incorporate L^AT_EX symbols in their titles, axes labels, and text labels. Figures can be saved directly into PDF or PNG format, obviating the need for any further format conversion.

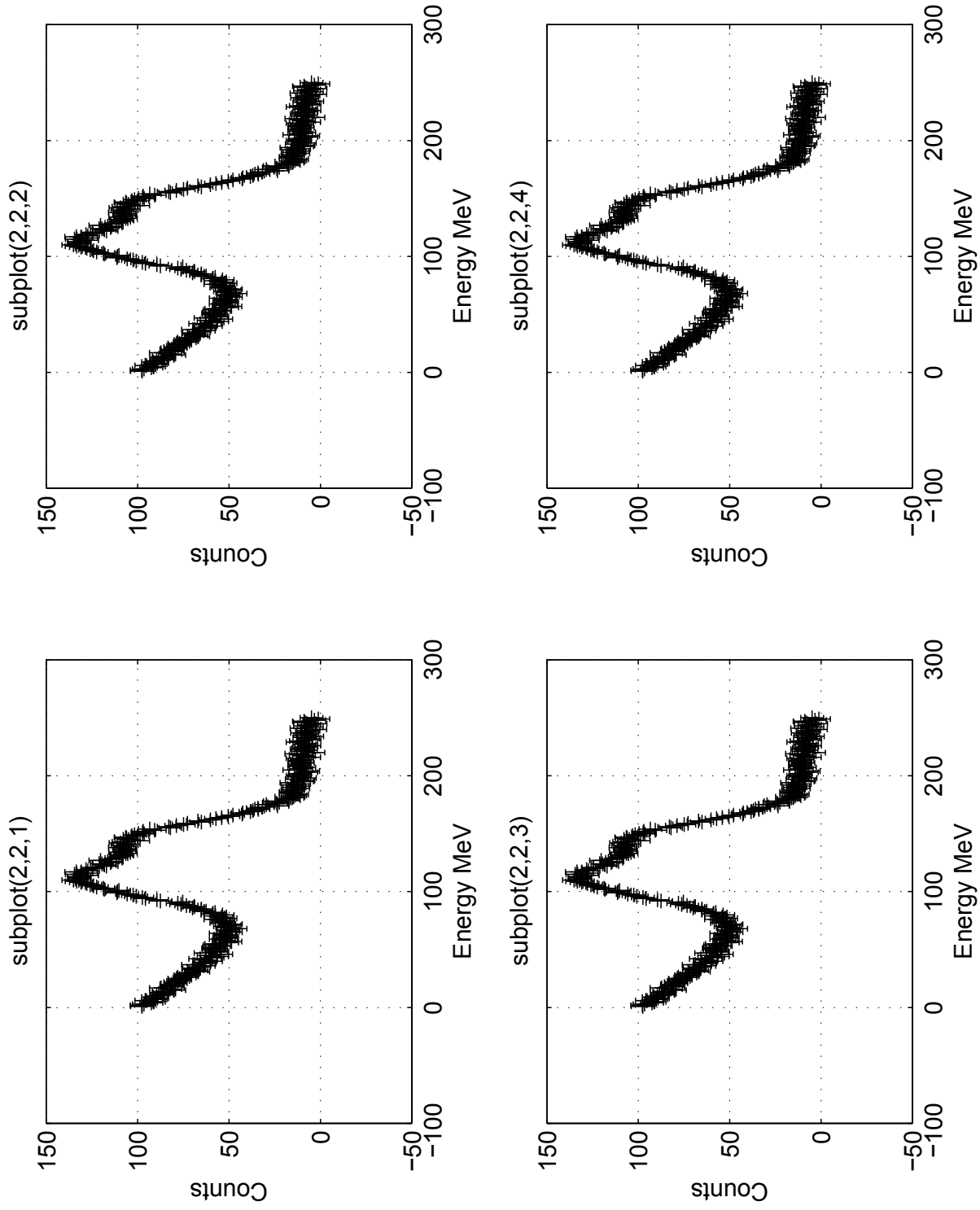


FIG. 4. For very large plots where important detail might be lost if too compressed, it may be convenient to use the turnpage environment for displaying in landscape mode, *e.g.* any experiment where a data set is acquired at several angular positions (21 cm, e/m , Rutherford), or is time varying (alpha decay or pulsed NMR). These full page graphics are usually best kept in appendices so as not to impede the flow of the paper. Note that large tables can also be presented in this landscape environment if desired

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