# Physics 430I Long Paper

## 1 Important Information

**Length** $\sim$ 5 typed, double-spaced pages ($\sim$ 1500 words)

**First Draft Due:** January 27, 2005

**Peer Evaluations Due:** February 3, 2005

**Final Draft of Paper Due:** February 10, 2005

## 2 Overview

Prior to beginning this assignment you should have read through page 26 of the Lindley book. This should give you a solid understanding of the basic Stern-Gerlach experiment. Your writing assignment will extend what you have read by delving deeper into variations of the Stern-Gerlach experiment and allowing you to do some exploring on your own.

For this assignment you will conduct a series of experiments using a simulated Stern-Gerlach apparatus (called SPINS) which was originally developed by Daniel V. Schroeder. The Java version, which we will use, was developed by David H. McIntyre. You can find the SPINS applet (which requires a Java-enabled browser) at `http://www.physics.orst.edu/~mcintyre/ph425/spins/spinsapplet.html`. Some instructions on how to use the applet are available at `http://www.physics.orst.edu/~mcintyre/ph425/spins/spinhelp.html`. You should spend some time playing around with the applet, getting to know how it works and what it does, before you attempt to do the experiments listed below. Note that you can do 10,000 runs of the experiment at once by hitting Ctrl-5. This is a good way to build up lots of data quickly.

Your paper should begin with a general introduction to the Stern-Gerlach experiment and the idea of electron spin. For each experiment you should have at least one paragraph which will include the following items:

- a description of the experimental setup (in words),
- a description of the results of the experiment,
- comments on the results and answers to any questions listed in this handout.

You do not need to show any calculations that you perform. You need only give the results (I will be able to tell if you did the calculation correctly). Also, it is unnecessary for you to include diagrams in your paper. You should be able to clearly describe the experimental setup in words. If you feel you must include a diagram then you should ask me for help. Finally, you should end your paper with a concluding paragraph that summarizes your findings and highlights any interesting results that you found.

The main point of these experiments is to illustrate that quantum mechanics forces us to confront two apparent problems:

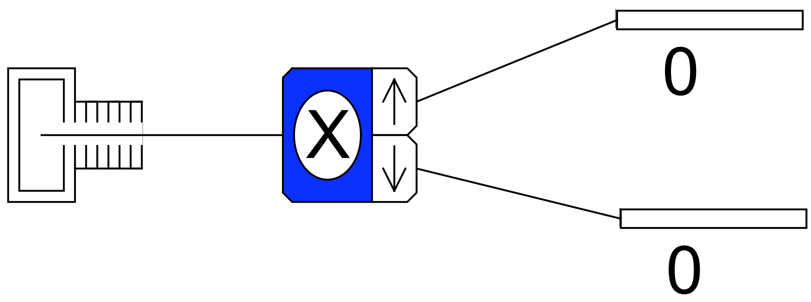
1. measuring the state of a system seems to alter the state of the system, and
2. the quantum state of a system (with respect to some particular measurement) does not seem to be well-defined until the measurement is actually performed.

These two ideas are intimately tied together. The Stern-Gerlach experiment forces us to confront these issues head-on. Later in the semester we will talk about the EPR experiment (which provides a more subtle analysis of item 2 above) and decoherence experiments (which shows just how item 1 works), but the Stern-Gerlach experiment is a good place to start in dealing with both of these issues.

The following section includes diagrams and descriptions of the various experiments that you must perform. Included with each description is a list of specific questions that should be addressed in your discussion of that experiment.

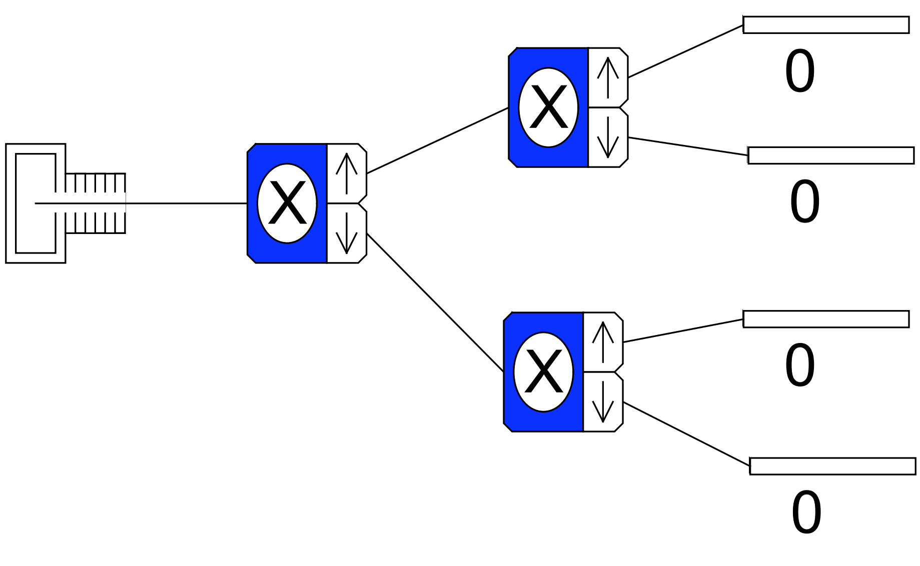
## 3 Experiments

**Experiment 1:** Make sure the **Initialize** menu is set to Random. This means the electrons coming out of the electron gun are in a random admixture of different quantum states. Then perform the experiment shown below.



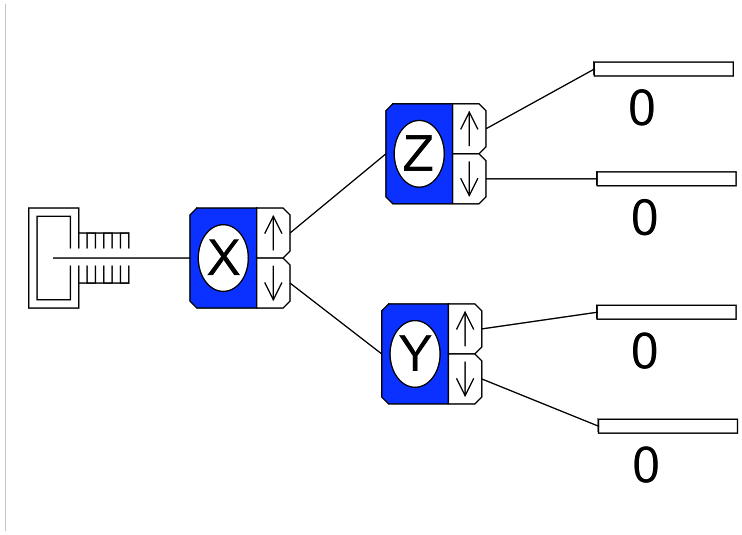

- Can the results of this experiment be explained while maintaining the idea that each electron exists in a definite spin state? In other words, if you want to think of each electron as being definitely "up" or "down" (with respect to the $x$-axis) can you still explain the results of this experiment?
- Change the analyzer so that it measures spin along the $y$-axis and redo the experiment. Comment on your results.

**Experiment 2:** Make sure the **Initialize** menu is set to Random and then conduct the experiment shown below.



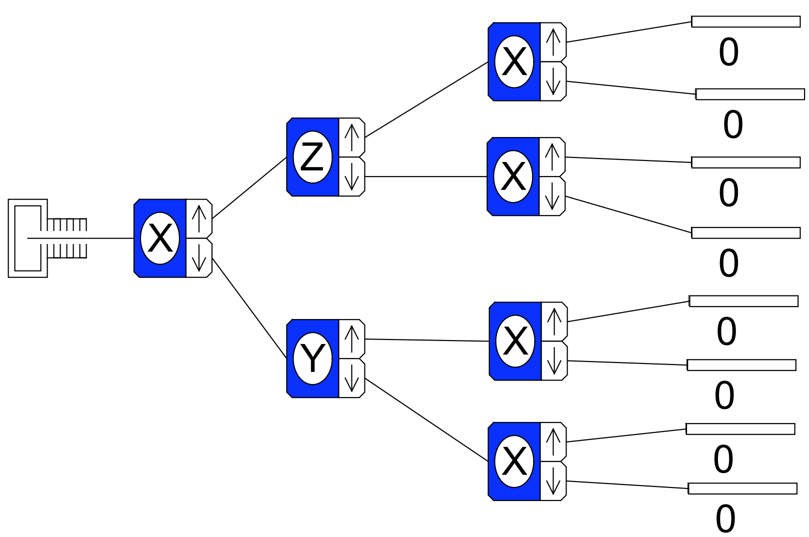

- Do the results of this experiment make sense if we think of each electron as existing in a well-defined spin state with respect to the $x$-axis?
- What does this experiment tell you about the spin (with respect to the $x$-axis) of electrons coming out of a Stern-Gerlach analyzer?

**Experiment 3:** With the **Initialize** menu set to Random, conduct the experiment shown below.




- Can the results of this experiment be explained while maintaining the idea that each electron exists in a definite spin state with respect to each of the axes? In other words, if you think of each electron as being definitely "up" or "down" (or "left" or "right", whatever you want to call it) with respect to each axis can you still explain the results of this experiment?
- If an electron has a well-defined spin along the $x$-axis, can it also have a well-defined spin along the $y$ or $z$ axes?

**Experiment 4:** With the **Initialize** menu set to Random, conduct the experiment shown below.




- Can the results of this experiment be explained while maintaining the idea that each electron exists in a definite spin state with respect to each of the axes? In other words, if you think of each electron as being definitely "up" or "down" (or "left" or "right", whatever you want to call it) with respect to each axis can you still explain the results of this experiment?
- What is the effect of putting a non-$x$ analyzer between two $x$-axis analyzers?

**Experiment 5:** Set the **Initialize** menu set to Unknown 1. This means the electrons coming out of the electron gun will be in a single (but as yet unknown) quantum state. Our goal is to analyze that state in terms of spin along each of the three coordinate axes. For example, the electrons may be in a state given by $\psi = a\chi_+^{(x)} + b\chi_-^{(x)}$ where $\chi_+^{(x)}$ is the state of an electron with spin "up" (with respect to the $x$-axis) and $\chi_-^{(x)}$ is the state of an electron with spin "down" (with respect to the $x$-axis). We will let $a$ and $b$ be real numbers, although in general they can be complex. In this case the probability for the electron to be measured with spin "up" would be $a^2$ and the probability for it to be measured with spin "down" would be $b^2$.

- What restrictions exist on the values of $a$ and $b$?
- Redo Experiment 1, but this time using Unknown 1 as the initial state. Determine the values of $a$ and $b$ for this state (there are four possible sets of values, but you need only find one set).
- Now repeat the experiment, again using Unknown 1 as the initial state, but this time set the analyzer to measure spin along the $y$-axis. Determine the values of $a$ and $b$ for which the initial state can be represented as $\psi = a\chi_+^{(y)} + b\chi_-^{(y)}$.
- Do the experiment again, this time measuring spin along the $z$-axis. Again, find the values of $a$ and $b$ such that the initial state is represented as $\psi = a\chi_+^{(z)} + b\chi_-^{(z)}$.
- What do these results tell you about the relationship between spin states measured along different coordinate axes? For example, how is the state $\chi_+^{(z)}$ related to the states $\chi_+^{(x)}$ and $\chi_-^{(x)}$? If an electron has a well-defined spin (either "up" or "down") with respect to one axis, can it also have a well-defined spin with respect to the other axes?
- Do your results for this experiment fit with the results you have seen in Experiments 3 and 4?

**Experiment 6:** Use the same procedure as in Experiment 5 to determine the state of one of the other Unknown initial conditions (Unknown 2, 3, or 4). Represent the state you choose to analyze in terms of spin states with respect to the $x$, $y$, and $z$ axes (so you will have three different pairs of values for $a$ and $b$, one for each axis).

**Experiment 7:** Conduct a new experiment that is different from any of the experiments described above. You can do whatever you want, but try to make it interesting. Explain your results and how they fit in with the results of the previous 7 experiments. Analyze the experiment in as much detail as you can.

# 4 That's it . . .

Let me know if you need help with any of this. I encourage you to try out the SPINS software right away. That way, if you run into any problems you will have time to come ask me for help. Good luck!