PHSX815_Project3:

A Weird Way to Solve a Real-Life Problem, Part III

Syd Aarash Maroufian

April 2023

Introduction

In attempt to study population transfer, we introduced interactions between particles as J and the sweeping rate of the external magnetic field as alpha. Here, we take another step forward to make our model, more real-life-like. Our previous model consisted of a number of particles, which could be considered as a chain of particles with different magnetic orders. But here, we suppose that our system consists of multiple chains of particles stacked layer by layer. These arrangement could be interpreted as different layers with opposite magnetic orders, which means that we encounter an antiferromagnetic system. It should be mentioned that our system would be a ferromagnetic material if we consider all layers with similar magnetic orders.

This means that we are able to define a secondary interaction between particles, which defines interlayer interactions. These interactions are defined by J2. Experimental studies show that due to weak van der waals interactions between different layers, J2 could be considered as a ratio of J1. This ratio can vary from 0.1 to 1, which defines the magnetic order strength of our material.

In this study, we have introduced a secondary interaction between particles (J2) in discussed range to study its effect on population transfer. What needs to be mentioned here is that the ratio between J1 and J2 is considered as a function of alpha. This means that the magnetic behavior of the system is a function of alpha, which seems to be a physical impossibility. However, for the sake of study we keep this consideration. In previous studies, we considered a system of three-level systems, where the system's probability of transfer to one of its excited states were studied. But here, we consider a system of two-level system to simulate ferromagnet and antiferromagnets regimes, affected by an external magnetic field.

Fig 1. Chain of 2-level particles

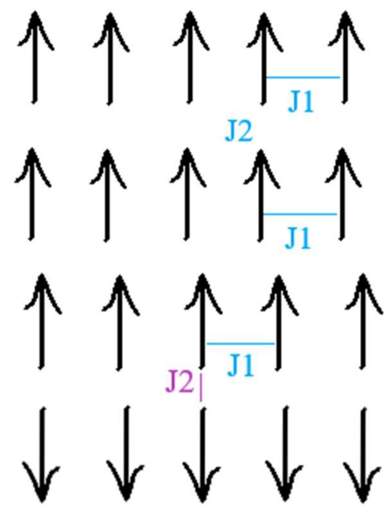

Fig2. (a) Ferromagnet (left) and **(b)** antiferromagnets (right) mediums, studied here. The ratio between J1 and J2 define the strength of the ferromagnetism/antiferromagnetism in our model

Theory

Figure 1 represent the initial chain of particles that we started with, while figure 2-a and 2-b represent the system that we attempt to study now. These figures show magnetic orders of stacked particles (ferromagnet and antiferromagnet regimes).

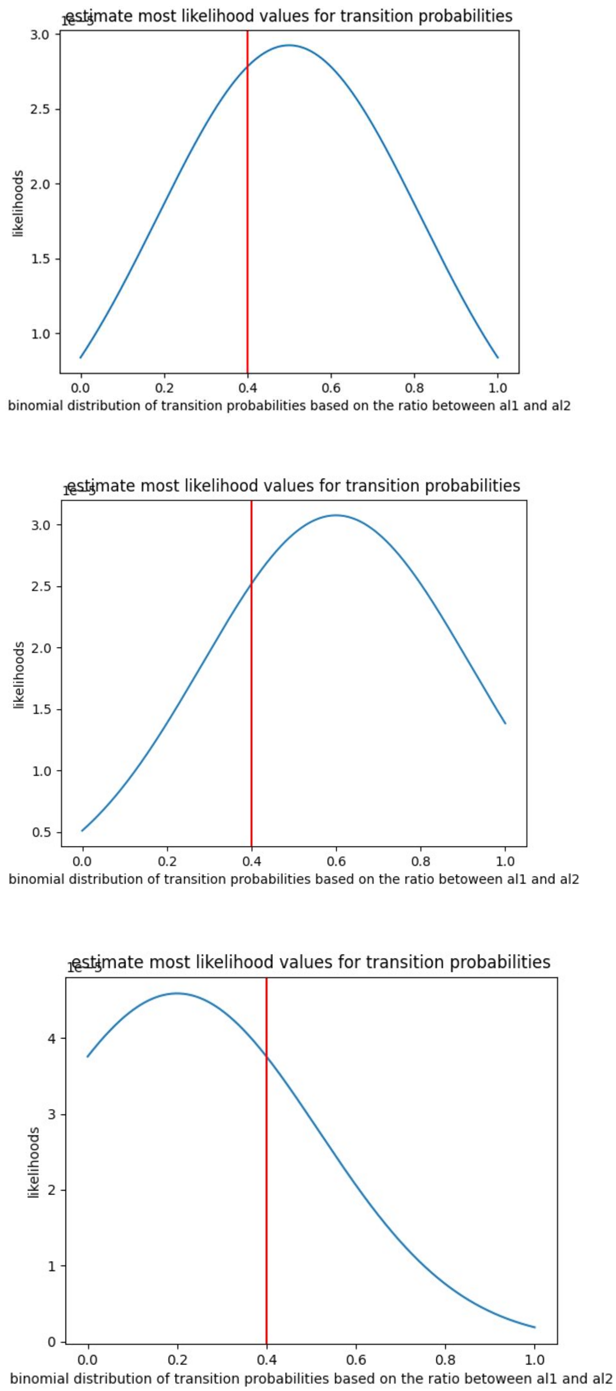

Fig3. Estimate of the likelihood for different values of J1/J2 ratio (blue line), compared to the real value of J1/J2 ratio for weak amtiferromagnetic regimes. As could be seen, different values of alpha leads to different estimates in our model.

As before, an external magnetic field is used to study the population transfer. This study is completed via Landa-Zener model, which you can find in details in projects 1 and 2.

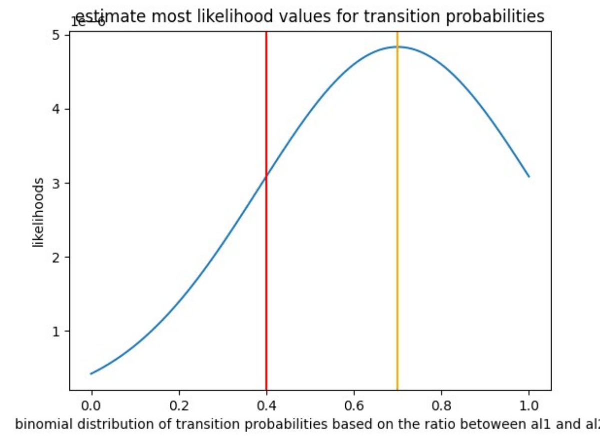

Fig 4. Likelihood of population transfer for strong antiferromagnet systems compared to the real value of J1/J2 ratio for strong antiferromagnets (yellow line)

In previous studies, we generated a random set of numbers to identify the population transfer probabilities for different states using binomial distribution. As we discussed in previous projects, adjusting the value of alpha can shift the final state of the system between ground or a summation of its excited states.

```
realalpha = 2
realratio = 0.3
nexp = 10
alpha = 0.5
J1J2 = 0.4
realratio2 = 0.7
```

Here, we use a binomial distribution function, which is defined using alpha and J to simulate population transfer. In the next step, we identify J2 as a ratio of J1 to simulate interlayer interactions.

```
def experiment(J,alpha,size=nexp):
    return np.random.binomial(J,alpha,size=nexp)

def likelihood(alla12,data):
    return np.prod(norm.pdf(data, loc=J1J2))

def estimate(data):
    return np.mean(data)

dist = experiment(realalpha, realratio,nexp)
```

```
estimatevalues=np.linspace(0,1,1000)
likelihoods = [likelihood(J1J2,dist) for J1

```

In the next step, we identify likelihood of population transfer using population transfer data points and J2. This suggests that for different values of J2 (and respectively J1 and alpha (since J1 and J2 are functions of alpha)), there should be a change in population transfer. We use estimations to find this ratio where the population transfer is maximum.

```
plt.figure()
plt.plot(estimatevalues, likelihoods)
plt.xlabel("binomial distribution of transitio
plt.ylabel("likelihoods")
plt.title("estimate most likelihood values for
plt.axvline(J1J2,color='red')
plt.axvline(realratio2,color='orange')
plt.show()
```

Results

As could be seen in figure 3, at low ratios of J2/J1, we encounter that the system is most likely to be found in the ground state. By increasing the ratio between J2 and J1, the system is most likely to be found in one of its excited states. These results are in good company with previous results, which were accomplished using actual simulations, and not with out-of-nowhere random numbers.

Additionally, as could be seen in figure 3 and 4, estimated values are not as close as we wanted them to be for this experiment. This stems from the fact that we implemented the code with low number of data points and big step size, due to the lack of computational capacities. By increasing step sizes and number of samples (times this experiment was repeated), we could get closer estimates for the ratio.

Conclusion

As proved in projects 1 and 2, this sort of study adds nothing to our understanding of magnetic order of ferromagnet antiferromagnets systems. to come up with some good results, we need to identify the Hamiltonian of the system, using real values for magnetic field, interactions between particles and other variables. This Hamiltonian needs to be solved using time-dependent Schrodinger equation if we are looking for some meaningful data. But as before, it was fun doing it the wrong way.

References

Check previous projects for references ☺