Physics with neutrons 2

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Exercise sheet 10
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Exercise 10.1

Nature of the Magnetic Order in the charge-ordered cuprate La1:48Nd0:4Sr0:12CuO4.
Substitution of Nd for La in $La_{1-x}Sr_xCuO_4$ stabilizes a low-temperature tetragonal structure, which permits the formation of a spin-charge-ordered phase with suppressed superconducting transition temperature T_c. Cu^2+ ions are linked by oxygen forming a perfect square lattice layer in the crystallographic ab-plane.
The result of the neutron diffraction experiment is shown in Fig. 1 (*PRL 98, 197003 (2007)*). The detected three series of quartet peaks can be described by two magnetic domains shown in Fig. 2.

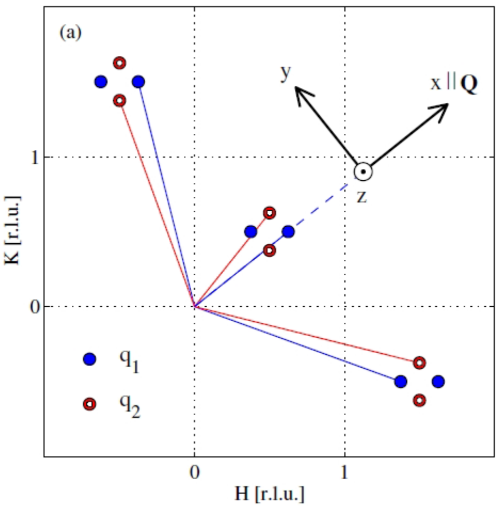


Figure 1: Reciprocal space of the square CuO_2. The circles indicate the positions of magnetic peaks. The peaks marked by blue and read were measured by $(H, 0)$ and $(0, K)$ scans, respectively.

1. Find which domain (A and B) leads to the reflections shown by red and blue circles in Fig. 1. The peaks in the first zone are situated away from the antiferromagnetic point (0.50.5). What is the incommensurability? *(Hint: define the magnetic unit cell for both domains and define the corresponding magnetic ordering vectors).*
2. Find the expression for the structure factor for given magnetic orders.
3. Explain the variation of the intensity shown in Fig. 3 based on the structure factor and polarization factors.

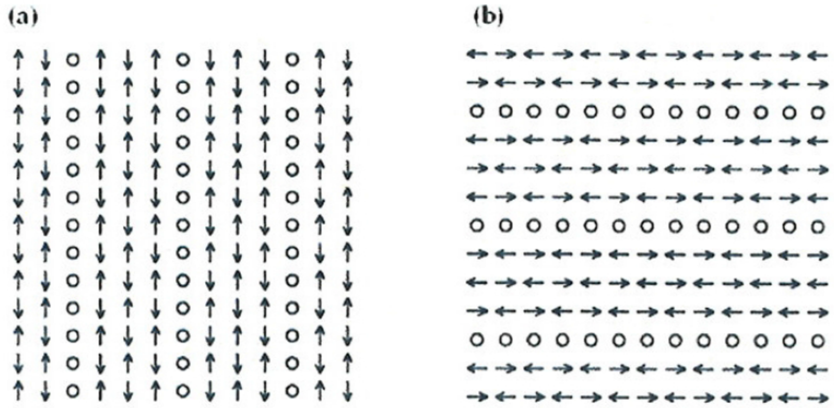


Figure 2: Two magnetic domains of $La_{1-x}Sr_xCuO_4$. We assume that both domains are equally populated.

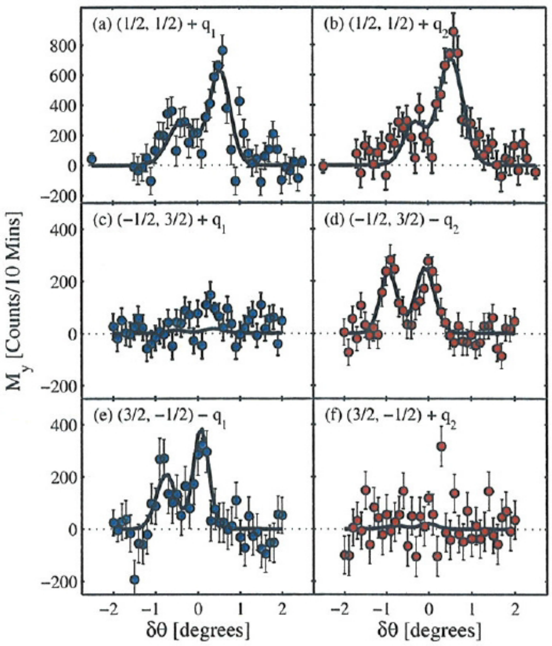
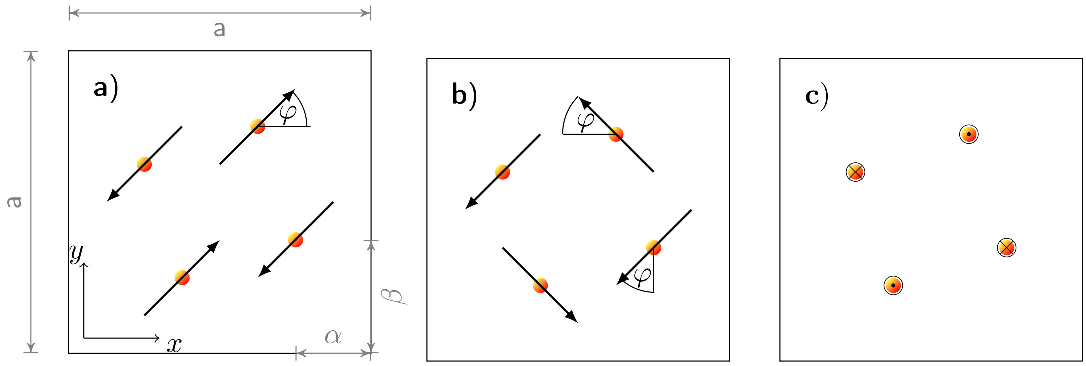


Figure 3: Q-scans measured through the six peak positions indicated by blue and red circles in Fig. 1

EXERCISE 10.2

Consider a two-dimensional tetragonal system with four spins per unit cell but without nuclear scattering in the following situations ($k = 1$):

- Situation depicted in **a**.
- Domain A as in **a** and domain B $\varphi_B = \varphi_A + 90°$ with a relative population of α and $1 - \alpha$, respectively.
- Situation depicted in **b**.
- Situation depicted in **c**.



1. Calculate the magnetic Bragg scattering intensity for any given h and $k4$ with unpolarized neutrons, i.e. compute $|\mathbf{F}_{M\perp}(h\ k\ 0)|^2$ for situations 1-4.
   Is it possible to distinguish the four cases using unpolarized neutrons?
2. Compute the magnetic Bragg peak intensity in situations 1-4 for uniaxially polarized neutrons, i.e. calculate the spin-flip $\frac{d^2\sigma^{\pm\mp}}{d\Omega dE}$ and the non-spin-flip cross section $\frac{d^2\sigma^{\pm\pm}}{d\Omega dE}$. Consider a polarization $\mathbf{P}$ parallel to the scattering vector $\mathbf{q}$.
3. Repeat the previous calculation with a polarization $\mathbf{P}$ perpendicular to the scattering vector $\mathbf{q}$, but still in the $(h, k, 0)$ plane.
4. Same task as before, but now with a polarization $\mathbf{P}$ perpendicular to the $(h, k, 0)$ plane.

Is it possible to distinguish the four cases by measuring only a single magnetic Bragg reflection and applying uniaxial polarization analysis? Or is it necessary to measure several reflections (in the plane) for a distinction of the different spin structures?