Collective Excitations in Transition Metal Oxides: Unresolved Problems and Novel Properties

Let us start with the following, seemingly unrelated problem – imagine that we have a jelly powder and by adding water (and waiting) a jelly is formed. Next, we put such a jelly on top of the table. When we look at it, probably the most interesting features are as follows: Firstly, that out of the powder a *kind of* a solid object is formed, with completely different properties than the powder. Secondly, when very lightly kicked with a finger, the jelly can start shaking back and forth. Finally, when, e.g. using a knife, we make a small hole somewhere in the jelly, some of the properties of this system change. For example, when we now gently kick the jelly, depending on the shape of the hole (e.g. when it is really deep and large enough), the oscillations of the jelly will change and also the hole made in the jelly can be affected by such a kick. While this is a rather obvious situation, the mathematical modelling of this situation, which can predict the magnitude and shape of the jelly / hole oscillations in the presence of a hole in the jelly, is not that straightforward.

It turns out that the project that we wish to conduct is surprisingly similar to the above described problem. One just needs to: (i) take electrons (instead of a jelly powder); (ii) mix electrons with the particular ions forming a strongly correlated compound with localised electrons (instead of mixing the jelly powder with the water); (iii) use an x-ray probe to gently kick the crystal and probe its collective excitations (instead of kicking the jelly with a finger); (iv) add a hole in the crystal by using e.g. the chemical substitution which leads to the removal / addition of charge to the crystal and observe the changes in its excitations (instead of creating a hole in a jelly with a knife and observing the oscillations).

More precisely, we will mostly be occupied with the problem of excitations related to the spin and orbital degrees of freedom of an electron in a large class of compounds called transition metal oxides. We will study the interaction between these two different kinds of excitations with each other and with the charge being additionally added / removed from the crystal. The main object of our research actually concerns the mathematical modelling of the behaviour of such a system that can later be checked against the experiments. This way we should be able to understand such a complex and difficult system in an unambiguous way.

The above problem is interesting also due to its interesting applications. It turns out that some of the transition metal oxides have spectacular but still not fully understood properties, such as e.g. the high temperature superconductivity. Therefore, a better understanding of their complex physics may help in unravelling novel properties of these materials.