The Rydberg excitons are unique structures, a bridge joining macroscopic and quantum world. Let's start from the very bottom of the scale's size, from one of the smallest fundamental particles - the electron. In semiconductors, most of the electrons are highly confined and strongly binding to their atoms. The valence electrons, populating the outer atomic orbitals, can be freed by providing them with the sufficient amount of the energy in the form of a light quanta - a photon. Even then, the newly deteched electron is not totally free. The atom it has left now has a single, missing negative elementary charge. This empty space is called a hole, and it can be described as a sort of positively charged particle. The opposite charges are attracting each other; the electron establishes a stable orbit around the positive center. As a matter of fact, we get something resembling the hydrogen atom, but much bigger. The exciton is created. The orbits are quantized with the principal number n, e. g. they have discrete numbers $n = 1,2,3...$ and corresponding radius proportional to n^2. For very high $n >> 1$, we obtain the so-called Rydberg excitons. Electrons on those high energy levels are weakly connected to the atoms and react strongly to the external electric and magnetic fields. Moreover, these orbits are gigantic - on the order of micrometres, many times larger than the wavelength of light that creates them. A single exciton spans hundreds of atoms across - we are talking about a quantum structure that is comparable to the diameter of spider silk strand! This is the key property making the Rydberg excitons so interesting - they give us an unprecedented opportunity to observe quantum mechanical phenomena on macroscopic scales, bringing together two completely different worlds.

In our project we intend to study theoretically various aspects of light-matter interaction in media containing Rydberg excitons. We will take advantage of their unique properties - sensitivity to external fields, long range interactions between excitons, closely spaced energy levels and their long lifetimes.

One of the interesting phenomena that can occur in a medium containing Rydberg Excitons is Franz - Keldysh effect: the external electric field modifies the absorption coefficient of the semiconductor. We are going to study this effect in Cu_2O crystal.

Strong, long-range interactions between excitons lead to the nonlinear effects: the propagation of electromagnetic wave in the medium becomes dependent on its amplitude and multiple external factors such as temperature. In our project we will concentrate on the optical properties stemming from intra- and interband transitions.

The exceptionally large size of the exciton means that it is „aware" of its surroundings. In particular, if we try to constrain its mobility, for example by confining it inside a nanowire, then the properties of exciton will change considerably. As opposed to typical quantum nanostructures (dots, wells, wires) which, as the name suggests, have dimensions on the order of nanometres, we can operate on a much bigger scale. This makes them more convenient to study and easier to manufacture.

The electromagnetically induced transparency (EIT) is a spectacular quantum effect that allows one to slow down the light, or even to stop completlly and store it in the form of medium excitations. Light storage is a key functionality of quantum memories - a foundation of a full quantum computer. However, there is one significant obstacle - up till now the traditional EIT media are mostly gaseous, not very suitable for miniaturized components. The long „ladder" of energy levels available with Rydberg excitons allows one to choose convenient states for realization of EIT in crystal, for example in Cu_2O. We will investigate the influence of nonlinear effects on this process in order to find the optimal conditions for storing the light, taking advantage of long lifetimes of Rydberg excitons.

Among many available energy levels, there are highly excited ones, which are located closely together. The transition between them is accompanied with emission of microwave photon. By choosing appropriate transitions, we will investigate the possibility of constructing a maser, e. g. a microwave laser. The high sensitivity of Rydberg excitons to the external field is highly desirable here - even a small number of them is sufficient to initiate stimulated emission, creating high intensity, coherent beam of light.