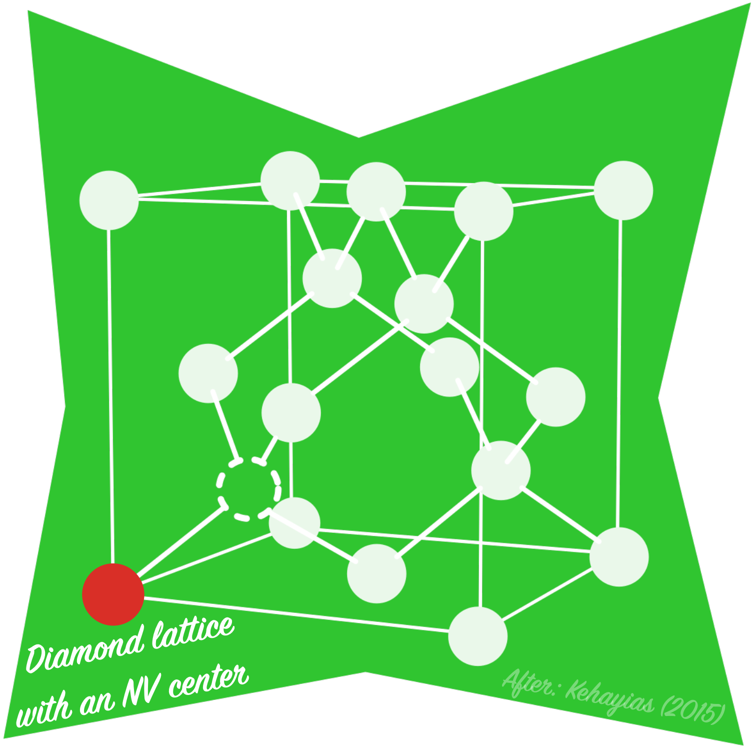
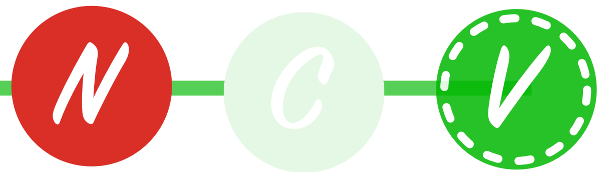

The Nitrogen
NO VACANCY
By Julius de Hond
Center

What's an NV center?

Nitrogen-vacancy (NV) centers occur in (artificially grown) diamonds when a nitrogen impurity takes up the spot of a carbon atom in the lattice. Additionally, an empty space gets created next to the nitrogen atom; this combination is the NV center.

NV centers are a quantum system with coherence properties that persist up to room temperature. Despite them being embedded in a lattice, they behave like an isolated spin system in a lot of respects, and they have strong optical transitions in the visible spectrum. Combined, these properties make them ideal for use in quantum sensing and quantum communication applications.

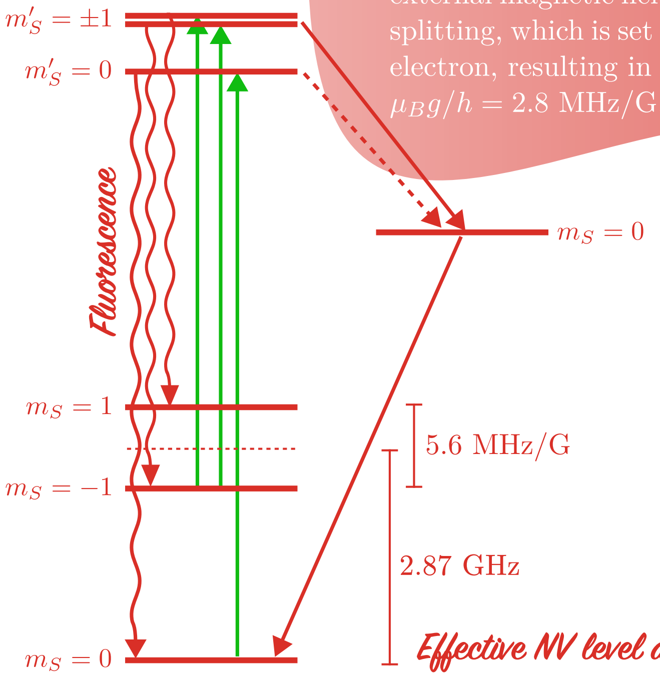




Electronic Properties

The ground state of the NV center is a spin triplet ($S = 1$), where the interaction with the nuclear spin of the nitrogen atom lifts the degeneracy. Due to this interaction ($\propto S_z^2$ and which is called the 'zero-field splitting'), the $m_S = 0$ state is the lowest-lying one, while the $|m_S| = 1$ states are shifted up by 2.87 GHz. The degeneracy between the ± 1 levels can be lifted with an external magnetic field via the usual Zeeman splitting, which is set by the g factor of a free electron, resulting in a magnetic moment of $\mu_B g/h = 2.8$ MHz/G.

NV centers have a broad absorption spectrum, absorbing most wavelengths south of 638 nm where the 'zero-phonon line' sits (so named because at lower wavelengths excess energy gets carried off by phonons). The excited state is also a triplet, and it has two relevant decay paths. One goes through a non-radiating, metastable intermediate singlet state, but the $m'_S = 0$ state is only weakly coupled to this. Instead it prefers decaying straight back down to the ground state, emitting a red photon at 638 nm. As a result, the $m'_S = 0$ state radiates more strongly than the $|m'_S| = 1$ states. The difference in fluorescence strength can be used to read out the NV center's state. The level couplings also allow for some degree of state preparation through optical pumping: when driving the optical transition, the NV center preferentially decays into the $m_S = 0$ state, creating an imbalance.



Effective NV level diagram

Sensing with NV centers

The simplest sensing application of NV centers is to measure the external field using the Zeeman splitting between two ground-state sublevels. By exposing an NV center to green light while scanning on a microwave field, a spectrum can be measured.

If the microwave field is resonant with the $m_S = 0 \rightarrow 1$ transition, for instance, the population that has been pumped into $m_S = 0$ gets depleted, causing a dip in the fluorescence. This phenomenon is called optically-detected magnetic resonance (ODMR), and by precisely measuring the microwave frequencies where dips occur it's possible to measure the magnetic field of the environment.


The Nitrogen
NO VACANCY
Center