

## Lecture 20: Local Moments in Metals, Friedel Sum Rule

We ask the question under what condition a given impurity in a metal carries a localized spin. A useful result for the discussion of the effect of an impurity potential on the electronic state is the Friedel sum rule. Assuming spherical symmetry, the electronic wavefunctions are described by the phase shift  $\eta_\ell$  for angular momentum channel  $\ell$ . Friedel's sum rule states that the number of electrons added to the system by the impurity  $Z$  is given by

$$Z = \frac{2}{\pi} \sum_{\ell} (2\ell + 1) \eta_{\ell}(k_F)$$

**Reading:** Ziman, *Theory of Solids*, Chapter 5.5

## Lecture 21: Anderson Model and the Kondo Problem

We next consider the situation where the electronic state introduced by the impurity lies inside the conduction band. The localized state now becomes a resonance due to the hybridization with the conduction electron. This is called the Friedel resonance. Anderson introduced a model where the localized state hybridizes with the conduction electron, but in addition has an energy cost  $U$  for double occupation. The model is solved by the Hartree Fock approximation, leading to a criteria for the formation of a local moment. The interaction of the local moment with the conduction electrons leads to the Kondo problem.

**Reading:** Kittel, *Quantum Theory of Solids*, Chapter 18, p.353.