Contribution ID: **875** Type: **Poster**

Bound eigenstates for Yukawa potential through Matrix representation

Friday, July 6, 2018 8:15 PM (15 minutes)

We study the new numerical method to solve the Schrödinger equation with no analytic solution. As an example, we tried the Yukawa potential, which is popular in most areas of physics, especially, quark-quark interaction in high-energy physics. This method is based on the basic principle in quantum physics that all particle states are represented by the complete set of eigenbases.
In this method, we need to select potential which is similar to the real potential with analytic eigenstates. For the Yukawa potential, the Coulomb potential can be a powerful candidate for this basis potential. We study the validity of the method depending on the Coulomb strength and on the number of eigenbases included in the numerical calculation.
The Coulomb strength is controlled by the coupling constant, which is determined to give the smallest energy eingenvalues when the basis potential is similar to the real potential. When the screening parameter less than around 0.02/a0\, *constant coupling constant for a given screening parameter is enough for eigenenergies with 90% accuracy. However, in the opposite case, the coupling constant need to be changed. When screening parameter is 0.2/a0*, the coupling constant needs to be set as 0.983, 0.947, 0.890 for 1s, 2s and 2p, respectively, to keep the accuracy within 90%.
The number of eingenbases is the dimension of matrix to be treated and it affects the calculation time severely. Therefore we cannot choose as many as we want. We study the minimum number of eigenbases to secure the 90% accuracy and find that at least 1.2 times higher states than the ones we target are necessary. Also the set of eigenbases should start from the lowest state even for the intermediate states, because lower states also play quite a role for higher states.
The method is very efficient in a sense that all bound energies and eigenstates are obtained at the same time. The precision in the numerical calculation should be set smaller than the energy differences between states. Our method is very general and can be adopted for other potential cases.

(* a0 is bour radius)

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Session Classification: POSTER