Image-charge mechanism for negative-U behavior in $LaAlO_3/SrTiO_3$ quantum dots

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Since the discovery of superconductivity in transition-metal oxide interfaces such as $LaAlO_3/SrTiO_3$ (LAO/STO) and $LaAlO_3/KTaO_3$ (LAO/KTO) [1], the microscopic mechanism responsible for electron pairing in these low carrier-density systems has remained an open problem [2,3]. Despite a variety of theoretical scenarios, including pairing mediated by ferroelectric fluctuations, coupling to ferroelectric domains, and electron–phonon interactions, none provides a unified explanation of the full range of experimental observations in the superconducting state.

New insights into this issue may emerge from recent studies of oxide-based quantum dots (QDs). Experiments on electrostatically defined LAO/STO QDs have reported unusual Coulomb blockade behavior with a tendency for even electron occupancy, consistent with attractive electron–electron interactios and described in terms of the negative-U Anderson model [4]. The microscopic origin of this behavior, however, remains unresolved. Its clarification would not only constrain possible mechanisms of negative-U in quantum dots but also provide important insight into superconductivity in LAO/STO interfaces.

In this presentation, we show that attractive interactions in LAO/STO QDs can naturally arise from image charge induced by the strongly field-dependent paraelectric response of $SrTiO_3$ and the associated spatial variation of the dielectric constant across the interface. Within a configuration-interaction framework combined with a self-consistent treatment of the electrostatic environment, we demonstrate that the competition between Coulomb repulsion and image-charge-mediated attraction can drive a transition into a negative-U regime. Our results suggest that electrostatic environment effects inherent to $SrTiO_3$ may play an important role in pairing phenomena in oxide two-dimensional electron gases.

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References

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