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Novel Magnetic Phenomena in Oxide Thin Films, Interfaces and Heterostructures

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Oxide films, heterostructures and interfaces present wonderful opportunities for exploring novel magnetic phenomena. The idea of **cationic vacancy induced ferromagnetism** was demonstrated by observing ferromagnetism in $Ta_xTi_{1-x}O_2$(x = 2 - 6%). Using XAS, XPS and XMCD, the magnetism was mainly located at the Ti sites and was shown to arise from Ti vacancies as opposed to Ti^{3+}. The substrate-film interface was crucial for observing the ferromagnetism, as the required concentration of Ti vacancies could only be maintained close to the interface. With electron transport we were able to see with increasing thickness the emerging role of Kondo scattering (mediated by Ti^{3+}) and at larger thickness impurity scattering. The polar $LaAlO_3$/non-polar $SrTiO_3$ interface exhibits a mixture of magnetic phases most likely arising from cationic defects and selective electron occupancy in Ti t_{2g} levels. Using XMCD ferromagnetism was seen at these interfaces even at room temperature. Unlike $LaAlO_3$, polar $LaMnO_3$ is an insulator exhibiting orbital order that has a smaller band gap than $SrTiO_3$. It is a traditional antiferromagnetic material, but when grown on SrTiO3, $LaMnO_3$ exhibits ferromagnetism for film thicknesses exceeding 5 unit cells. This is discussed in terms of electronic reconstruction with polar charge transfer to the $LaMnO_3$ side of the interface and also to the surface of the over layer. Novel magnetic coupling effects are seen in perovskite ferromagnets separated by a polar oxide layer such as $LaAlO_3$ or $NdGaO_3$, whereas non-polar oxides do not show the same effect. The coupling between the ferromagnetic layers oscillates in sign between FM and AFM, depending on the barrier thickness. Such coupling is totally unexpected in the absence of any itinerary electrons, with insulating barriers that are too thick for tunneling. The novel magnetic coupling is shown to be mediated by spin-orbit coupling and also magnetic excitation of defect levels in the polar oxide planes.