A new family of high- T_c compounds——Stepping stones toward understanding unconventional superconductivity

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High-transition temperature (T_c) superconductivity was first discovered in layered copper-based oxides (cuprates) more than two decades ago^[1], but its theoretical interpretation remains controversial^[2,3]. The main question concerning the high- T_c superconductivity phase diagram is the transition between the antiferromagnetic (AF) and superconducting (SC) phases, which is dominated by anomalous properties commonly attributed to a pseudogap^[4,5] in the spectrum. It is believed that the high- T_c mechanism in cuprates cannot be fully understood within the BCS theory^[6] that explains normal superconductivity. Despite much effort, there is no consensus as to the origin of the pseudogap properties, and the high- T_c mechanism remains an open question.

An important issue is whether high-temperature superconductivity is specifically the province of cuprate materials, or can it exist in other families of non-copper oxide compounds as well? If one could find similar phenomena in other compounds, this fresh perspective might allow the current impasse concerning agreement on a high- T_c mechanism to be resolved. Therefore, the recent discovery of superconductivity in layered Fe- and Ni-based transition metal oxypnictides has generated a strong wave of research interest.

The superconductivity was first reported by a Japanese group in Fe-based LaOFeP with a transition temperature of $T_c \sim 4$ K, which increases to 7 K with partial substitution of oxygen by fluorine^[7], and later in Ni-based LaONiP with $T_c \sim 2$ K^[8]. With the replacement of P by As and partial substitution of O by F in the

Fe-based compound ($\text{LaO}_{1-x}\text{F}_x\text{FeAs}$ with $x=0.05-0.12$), a T_c as high as 26 K has been found^[9]. Superconductivity with T_c above 20 K was quickly confirmed by a Chinese group^[10]. Another Chinese group replaced La with Sr and reached a similar transition temperature^[11]. The next breakthrough was made by several Chinese groups when La was replaced by other rare earth elements, including Sm^[12], Ce^[13], Pr^[14], Nd^[15-17], and Gd^[18] leading to even larger values of T_c that are beginning to exceed 50 K at last report, with no clear indication that the end has been reached. There has been by now little doubt that we are witnessing the discovery and elucidation of a new family of non-copper oxide compounds having superconducting transition temperatures that are (at least) higher than for any other known compounds except the copper oxides.

At first glance it is rather surprising that these materials show much superconductivity at all, since iron normally is detrimental to superconductivity because it produces local magnetic moments or long-range ferromagnetic order. Experimental and theoretical considerations suggest that these compounds have an antiferromagnetic spin-density-wave (SDW) instability below a temperature of $\sim 135-150$ K, and that suppression of the SDW by doping or pressure allows a superconductor to emerge at a surprisingly high temperature^[19,20]. Furthermore, a relatively broad agreement that the superconductivity is 2-dimensional in nature is not con-

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sistent with a phonon-mediated BCS mechanism, and occurs under conditions of a relatively low charge-carrier density. Thus the Fe-based system may be in many respects similar to a cuprate. In both cases, there may be an intimate relationship between superconductivity and magnetism, which may imply that the interplay of AF and SC is a common feature of high- T_c compounds.

The theoretical challenge is how to abstract the main physics from such complex systems to build an effective model. For cuprates, the SU(4) model^[21] represents one approach to this challenge, in which both coherent d -wave spin-singlet and spin-triplet pairs are taken into

account. The model is constructed using symmetry principles, but the coherent state method permits the problem to be transformed into a generalized quasiparticle framework. It has been shown that the resulting theory correctly describes the cuprate phase diagram, with a clear picture of the competing order^[22]. And it will be of considerable interest to see whether approaches like that of the SU(4) model, or other models capable of handling multiple competing degrees of freedom in strongly-correlated systems on an equal footing, can explain these new high temperature superconductors and their relationship to the old ones.

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