Oxygen continues to support superconducting life

About two articles per day in the last month on arXiv.org on the subject of Fe-pnictide Superconductors., some of them referred in the text of the commentary below.

Recommended with a Commentary by Zachary Fisk, University of California, Irvine.

It has been a fond hope since the original discovery of cuprate superconductivity that this lightning might strike in other locales, by some ways of thinking that it must. The recent remarkable burst of discoveries in the F-doped ROFeAs (R = rare earth) compounds holds the promise to be just this.

This story begins with Zimmer et al. (J. Alloys Compd. **229** (1995) 238) reporting the discovery of the tetragonal layered ZrCuSiAs-type ROFeP phosphides. This structure consists of slabs of Fe-centered P-tetrahedra alternating with sheets with O tetrahedrally coordinated by rare earth. Superconductivity was first reported by Kamihara et al. (J. Am. Chem. Soc. **128** (2006) 10012) at 3K in LaOFeP. In this paper the effect of F-doping was already noted, approximately doubling T_c. Subsequently LaONiP was also found to be superconducting at 4K by Watanabe et al. (Inorg. Chem. **46** (2007) 7719). The serenity surrounding these findings was severely disturbed by the astonishing report of T_c = 28K in F-doped LaOFeAs by Kamihara et al. (J. Am. Chem. Soc. **130** (2008) 3296). Numerous reports now have pushed T_c with the other rare earths to over 50K, particularly the strong effort from the Chinese Academy of Sciences. Perhaps not surprisingly, Ren et al. now report (cond-mat/0804.2582) that with oxygen deficient $RFeAsO_{1-\delta}$ one can achieve the same high superconducting onset temperature one finds with F-doping.

Simple chemistry suggests that the formula can be written $R^{+3}O^{-2}Fe^{+2}As^{-3}$, consistent with the semi-metallicity observed and the existence of analogs such as RZnSbO (cond-mat/0804.1855). Band structure calculations find (e.g. cond-mat/0803.2740v3;0803.1279v1) strong 2-dimensional features, making not unexpected the observation of a spin-density wave in LaFeAsO below 150K (cond-mat/0804.0796v1). It appears that F-doping drives the Néel temperature down, and that perhaps one way to think about what is going on is a competition between the spin density order and superconductivity. This magnetism living near the border with superconductivity encourages to be sure comparisons with cuprate physics.

It is much to soon to draw any definite conclusions regarding such similarities. Small single crystals have been grown in the original study of the phosphides in the work of Zimmer et al., but we have as yet no single crystal studies on the arsenides. We seem to know nothing as well about the magnetic order which certainly will be there for some of the magnetic rare earths (those with odd number of f-electrons, for example). (CeRuPO single crystals were studied by Krellner et al. (Phys. Rev. B **76** (2007) 104418) and found to be ferromagnetic at 15K.) The specific heat anomaly at T_c for the superconductors is exceedingly small and almost all report are based on Meissner effect and electrical resistivity, but the Meissner reports leave little doubt that bulk superconductivity is being observed.

What is interesting with this set of compounds is the size of the materials phase space: superconductivity is found for the phosphides as well as the arsenides (no report on the antimonides), and for Fe as well as Ni. Given the 40K T_c of MgB_2, maybe we can admit phonons as a possibility, but the spin density wave findings suggest the possibility that magnetism and superconductivity may be feeding at the same trough here. From the materials side, it is fascinating that the chemistry plays in ways similar to the cuprates, with a kind of phase separation at the level of atomic layers supporting a mixed ionic/metallic characteristic. One wonders whether only oxygen can support this form of life.