High Pressure Paving the Way?

Conventional superconductivity at 190 K at high pressures.
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Recommended with a commentary by Z. Fisk, UC Irvine and J. D. Thompson, Los Alamos National Laboratory

Pressure induced superconductivity at 190K, especially in a chemical associated with the odor of rotten eggs, can be expected to be greeted with some skepticism. However a close look at this interesting work suggests the possibility. Drozdov et al., a well recognized very high pressure group at the Max Planck Institute in Mainz, provide a fairly good case for a transition at 190K to a zero resistance state in a sample of H_2S pressurized in a diamond anvil cell (DAC) to above 150GPa.

The first issue here is do they really have zero resistance? This is of course very difficult to determine with high certainty, especially given the constraints associated with the DAC environment. The resistance measurement is performed in a four lead geometry, with two leads on each of the opposing anvils, the absolute specific resistivity being determined by the van der Pauw method. How close one is to the ideal van der Pauw geometry in this situation is not clear, but it seems likely that some approximation is approached in the DAC used. What is seen is a very rapid drop in resistance below 190K at pressures above 150GPa to a value corresponding to a specific resistivity of $10^{-3}\mu\Omega$-cm, way below any value one would expect for even the highest purity metal at low temperatures. The suspicion that what they might be observing is a metal-insulator transition would seem to be ruled out by the large suppression of the transition temperature in an applied magnetic field of 7T, approximately 10K. Their ability to reversibly cycle through the transition in temperature also appears to rule out their resistance drop originating from a pressure induced chemical decomposition at 190K. Also found is approximately a factor 2 reduction in the observed T_C of D_2S, presented as evidence of the involvement of phonons in the superconductivity. The fact that this suppression is greater than the largest isotope effect one could expect of $1/\sqrt{2}$ in conventional BCS theory suggests that something other than a simple isotope effect is involved and that the claim of conventional superconductivity does not necessarily follow.

It is worth remembering that zero resistance was found in experiments on TTF-TCNQ in the 1970's. In that case a structural phase transition occurred which had the effect of separating part of the fibrous crystal with the voltage pick-up leads from the part of the crystal carrying the current. Presumably here the permutation of current and voltage leads involved in doing the van der Pauw determination of the resistivity would immediately alert one to such a situation. This would also alert one to possible shorting of pick-up leads from mechanical artifacts or chemical attack. However, the details of how the resistivity measurements were carried out are not fully given in the paper. One also sees in their figure 1b showing the comparison between H_2S and D_2S that the resistance of H_2S remains slightly higher at low temperatures than that of D_2S. It is not obvious what to conclude from this. Confirmation of their findings by other experimental groups is in any event the next step towards becoming convinced that we now have a 190K superconductor.

As discussed at length by the authors, it appears likely that H_2S is not the superconducting species but rather some chemical decomposition species, perhaps some other hydrogen sulphide entity, but not H itself, as their Raman data do not detect this. It seems likely that the exact experimental path in pressure and temperature affects the products evolving in the DAC from H_2S, a compound which melts at 191K and boils at 213K at atmospheric pressure. The authors cite theoretical work pointing to various possible high T_c candidate compounds which might form in their experimental situation. Clarifying this clearly awaits x-ray work which will serve as well to make better sense of what is really going on in their DAC.

The exciting possibility of yet higher T_C raised by this report renews one's courage to think, at least in the privacy of their own home, about new directions in superconducting materials. There is no good reason to imagine that some limiting value of T_C has already been achieved, yet nobody really knows where to look for yet higher T_C. The quite surprising results from the studies of elemental superconductivity at high pressure lead to the suspicion that possibly even more remarkable will be the results of pressurizing compounds. One materials observation on the cuprates and pnictides is that these metallic materials both derive from compounds satisfying valence rules rather than the usual dictates of metallic bonding. In the study here, we start with molecular crystals, as does one with elemental oxygen and sulphur for that matter. Perhaps the metallization of such materials has some new twists for us; perhaps the ideas of Little acquire new life? The phase space for experiment seems wide open. One wonders immediately about the other column 6 hydrogen compounds, even H_2O which surely has been looked at to some high pressure, with possibilities that never even meddled with the mind of Kurt Vonnegut.