Road to Room Temperature Superconductivity: Hydrides and Other Systems

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June 18, 2017 (HP126, STH49). The goal of attaining room temperature superconductivity (this dream was born shortly after the discovery of superconductivity in 1911) has become perfectly realistic. There are several directions paths pursuing this search. The most promising family of materials is that of compounds containing hydrogen and heavy ions (hydrides). The record value of T_c=203 K (!) has been observed for sulfur hydride under high pressure [1, 2], see the review [3]. The high-T_c state for these hydrides was predicted in [4, 5]. The H-S system can form different structures and the stability of each depends on the external pressure. The highest T_c has been found for the cubic structure (Fig.1a). The superconducting state with such a high T_c is caused by strong electron-phonon coupling enabled by the presence of high-frequency optical H-modes. However, the usual description of the phonon mechanism (see, e.g., [6-8]) is not applicable here because the phonon spectrum is uniquely broad (up to 200 meV) and its structure is quite complicated (Fig. 1b).

It is possible to develop a generalized approach [9], whereby the system is characterized by two characteristic phonon frequencies $\tilde{\Omega}_{opt.}$ and $\tilde{\Omega}_{ac.}$ and, correspondingly, by two coupling constants, $\lambda_{opt.}$ and $\lambda_{ac.}$ The following analytical expression can be derived:

$$T_c = \left[1 + 2\frac{\lambda_{ac.}}{\lambda_{opt.} - \mu^*}\frac{1}{1+\left(\pi T_c^0/\tilde{\Omega}_{ac.}\right)^2}\right]T_c^0 .$$

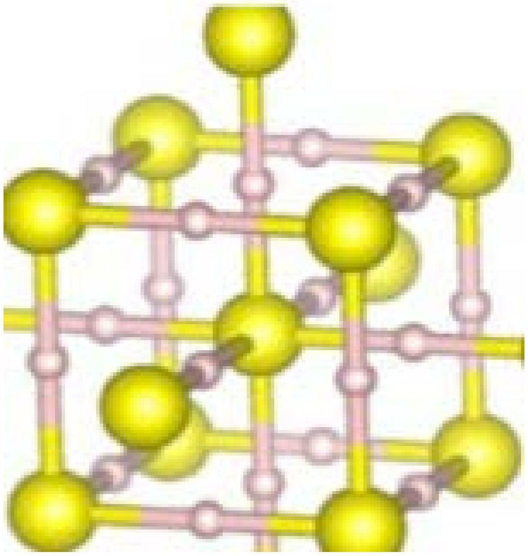
Here T_c^0 is the value of the critical temperature caused by the interaction with only the optical phonons (it can be described by [8]). The values of the parameters turn out to be as follows: $\tilde{\Omega}_{opt.}$ = 1700 K, $\tilde{\Omega}_{ac.}$ = 450 K, $\lambda_{opt.}$ =1.5, and $\lambda_{ac.}$= 0.5. We obtain $T_c \approx$ 215 K, in quite good agreement with the experimental data [1,2]. Moreover, $T_c^0 \approx$170K and $\Delta T_c^{ac} \approx 45K$. It is interesting that for the lower pressure phase (P≈100-120 GPa) with a lower T_c ≈120 K the value of the total coupling constant $\lambda_T=\lambda_{opt.}+\lambda_{ac}$ is approximately the same as for the high-T_c phase ($\lambda_T \approx 2$), but $\lambda_{opt.} \approx \lambda_{ac} \approx 1$. Therefore, the drastic increase in T_c from 120K to 200K is caused by a "redistribution" of the interaction strength [9]. The transition into the high-T_c phase is first-order [9, 10].

Hydrides may reach even higher values of T_c, up to room temperature. For example, higher critical temperatures are predicted for $CaCl_6$, T_c≈240 K [9 ,11], for YH_6, T_c≈255 K [12].

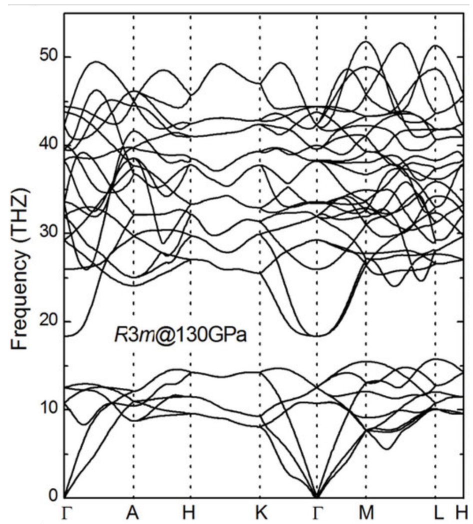
High T_c also can be observed for selected metallic nanoclusters [13]. The effect has been observed for Al_{66} clusters [14],whose T_c≈120K is much higher than that of bulk aluminum's T_c ≈1.1K. The quest is to build nanocluster-based Josephson tunneling networks, which would be capable of transmitting a macroscopic supercurrent much stronger than in bulk networks [15].

More than fifty years ago, W. A. Little introduced the electronic mechanism of superconductivity [16]. Recently, a manifestation of this mechanism was finally observed experimentally [17] with the use of two carbon nanotubes. According to [17], future modifications of the system may create the superconducting state at room temperature.

One can fully expect room temperature superconductivity to be observed in the near future.



(a)



(b)

Fig. 1. (a) The high-T_c (≈200 K) phase is cubic [5]. (b) Phonon spectrum for the high-T_c (≈200 K) phase. It contains two groups: (1) acoustic modes (up to ~70 meV, motion of the S ions) and (2) optical modes (up to ~200 meV, dominated by the motion of the H ions.

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