The issue of induction the superconducting state in selected compressed sulfur and hydrogen systems

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Introduction

The H_5S_2 and H_2S compounds are the two candidates for the low-temperature phase of compressed sulfur-hydrogen system. We have shown that the value of Coulomb pseudopotential (μ^*) for H_5S_2 ($[T_C]_{\exp} = 36$ K and $p = 112$ GPa) is anomalously high. On the other hand, in the case of H_2S it is not necessary to take high value of Coulomb pseudopotential to reproduce the experimental critical temperature relatively well ($\mu^* = 0.15$). In our opinion, H_2S is mainly responsible for the observed superconductivity state in the sulfur-hydrogen system at low temperature. [1]

Formalism

Let us take into account the Eliashberg equations on the imaginary axis ($i = \sqrt{-1}$):

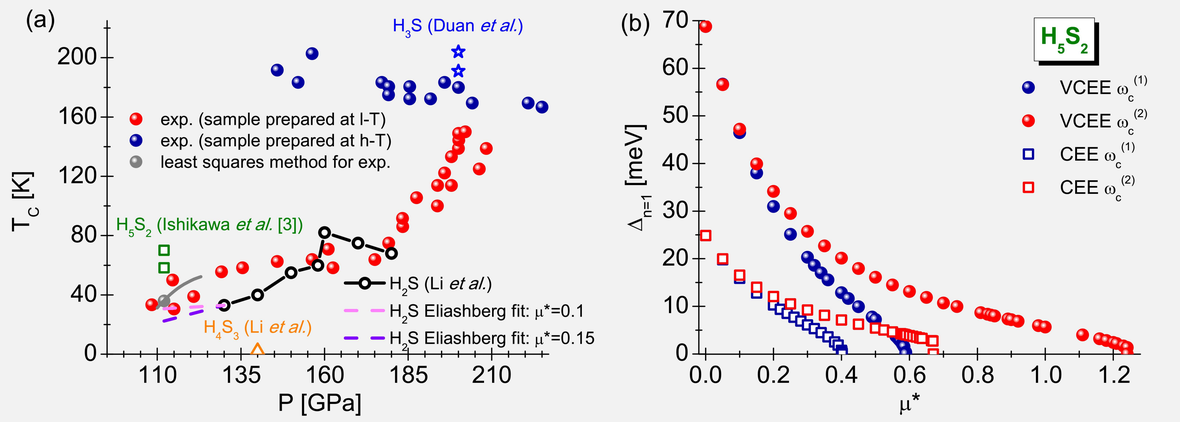
$$\varphi_n = \pi k_B T \sum_{m=-M}^{M} \frac{\lambda_{n,m} - \mu^*_m}{\sqrt{\omega_m^2 Z_m^2 + \varphi_m^2}} \varphi_m - A \frac{\pi^3 (k_B T)^2}{4\varepsilon_F} \sum_{m=-M}^{M} \sum_{m'=-M}^{M} \frac{\lambda_{n,m}\lambda_{n,m'}}{\sqrt{\left(\omega_m^2 Z_m^2 + \varphi_m^2\right)\left(\omega_{m'}^2 Z_{m'}^2 + \varphi_{m'}^2\right)\left(\omega_{-n+m+m'}^2 Z_{-n+m+m'}^2 + \varphi_{-n+m+m'}^2\right)}} \times \left[\varphi_m \varphi_{m'} \varphi_{-n+m+m'} + 2\varphi_m \omega_{m'} Z_{m'} \omega_{-n+m+m'} Z_{-n+m+m'} - \omega_m Z_m \omega_{m'} Z_{m'} \varphi_{-n+m+m'}\right], \quad (1)$$

and

$$Z_n = 1 + \frac{\pi k_B T}{\omega_n} \sum_{m=-M}^{M} \frac{\lambda_{n,m}}{\sqrt{\omega_m^2 Z_m^2 + \varphi_m^2}} \omega_m Z_m - A \frac{\pi^3 (k_B T)^2}{4\varepsilon_F \omega_n} \sum_{m=-M}^{M} \sum_{m'=-M}^{M} \frac{\lambda_{n,m}\lambda_{n,m'}}{\sqrt{\left(\omega_m^2 Z_m^2 + \varphi_m^2\right)\left(\omega_{m'}^2 Z_{m'}^2 + \varphi_{m'}^2\right)\left(\omega_{-n+m+m'}^2 Z_{-n+m+m'}^2 + \varphi_{-n+m+m'}^2\right)}} \times \left[\omega_m Z_m \omega_{m'} Z_{m'} \omega_{-n+m+m'} Z_{-n+m+m'} + 2\omega_m Z_m \varphi_{m'} \varphi_{-n+m+m'} - \varphi_m \varphi_{m'} \omega_{-n+m+m'} Z_{-n+m+m'}\right]. \quad (2)$$

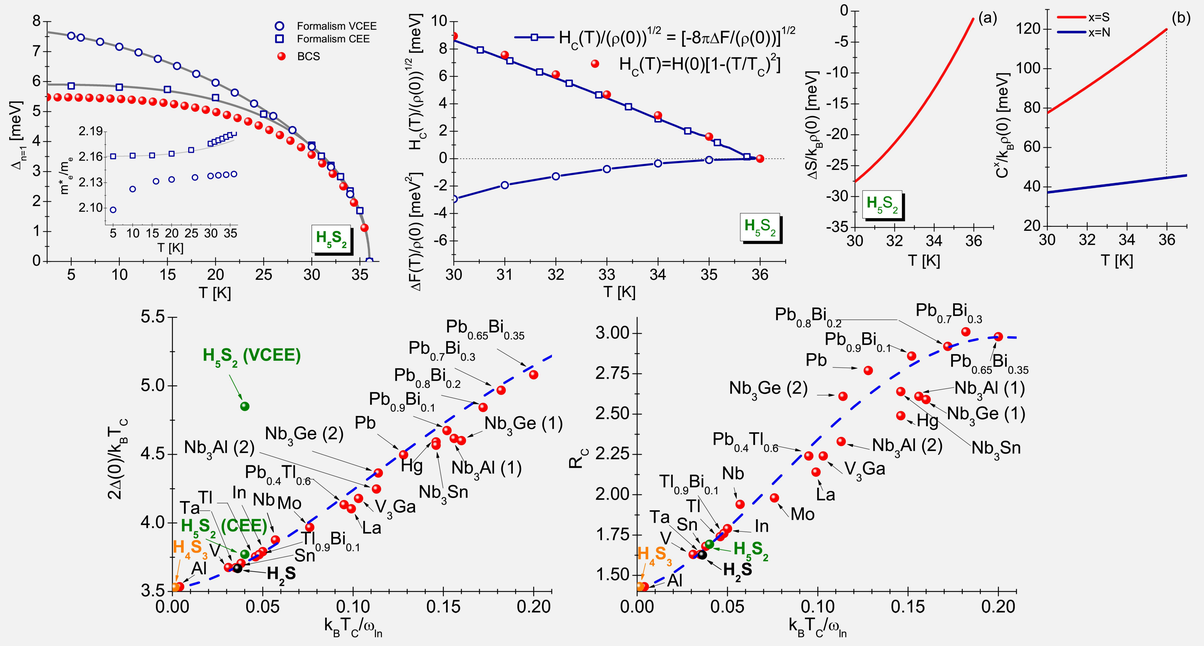
The calculations were carried out in two cases: ($A = 1$) included the lowest-order vertex correction-scheme VCEE, on the other hand ($A = 0$) we get the model without the vertex corrections, the so-called CEE scheme (**C**lassical **E**liashberg **E**quations) [2].

Important Result



In the case of H_5S_2 compound with value of $T_C = 36$ K, we have calculated the pseudopotential parameter. To this end, we used the equation: $[\Delta_{n=1}(\mu^*)]_{T=T_C} = 0$. We obtained the very high value of μ^* in both considered approaches: $\left[\mu^*\left(\omega_c^{(1)}\right)\right]_{VCEE} = 0.589$ and $\left[\mu^*\left(\omega_c^{(1)}\right)\right]_{CEE} = 0.402$, whereby we have chosen the following cut-off frequency: $\omega_c^{(1)} = 3\omega_D$, where $\omega_D = 237.2$ meV [3]. This is the feature of H_5S_2 system, because values of μ^* cannot be reduced by selecting another acceptable cut-off frequency. On the contrary, increasing ω_c leads to the absurdly large increase in the value of Coulomb pseudopotential: $\left[\mu^*\left(\omega_c^{(2)}\right)\right]_{VCEE} = 1.241$ and $\left[\mu^*\left(\omega_c^{(2)}\right)\right]_{CEE} = 0.671$, where $\omega_c^{(2)} = 10\omega_D$.

Results



Conclusion

The superconducting state of H_4S_3 compound is the BCS type, however it cannot be equated with the experimentally measured low-temperature superconducting state in the compressed hydrogen sulfide, since it has a very low critical temperature. Subsequently has been shown that the superconducting state in H_2S compound has thermodynamic parameters with values close to the values determined for H_5S_2 in the CEE scheme and is not the state of BCS type. In our opinion, experimentally was observed the superconducting state in the H_2S compound, which is kinetically protected in the samples prepared at the low temperature. It should be emphasized that in the case of H_2S reproducing the experimental dependence of critical temperature on the pressure does not require anomalously high value of Coulomb pseudopotential.

References

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