The long-sought goal of room-temperature superconductivity has reportedly been realized recently in a carbonaceous sulfur hydride under high pressure.\(^1\) Snider et al.\(^1\) report sharp drops in resistance as a function of temperature at temperatures that decrease when a magnetic field is applied, and sharp jumps in a.c. magnetic susceptibility at similar temperatures. However, here we point out that the extremely narrow widths of the transitions in the absence of a magnetic field, and the fact that the widths do not change with the applied magnetic field, suggest that the observed phenomena are not associated with superconductivity. This calls into question the existence of superconductivity in this hydride.

Snider et al.\(^1\) claimed that the material, hereafter denoted CSH (for carbonaceous sulfur hydride), is a weakly type II superconductor with a Ginzburg–Landau (GL) parameter \(\kappa = \lambda(T)/\xi(T) = 1.5\), in which \(\lambda\) and \(\xi\) are the London penetration depth, coherence length and temperature, respectively. A type I or weakly type II superconductor will exclude applied magnetic fields from its interior, hence the width of the superconducting transition would not be affected by the field. Snider et al.\(^1\) extracted from the experimental data an upper critical field \(H_{c2}(T=0) = 61.8\) T. This determines the coherence length \(\xi_0\) from the GL formula

\[
H_{c2} = \frac{\Phi_0}{2\pi\xi_0^2}
\]

as \(\xi_0 = 2.3\) nm, with \(\Phi_0 = 2.07 \times 10^{-7}\) G cm\(^2\) the flux quantum. They then extracted \(\lambda(0)\) from the formula

\[
\lambda(0) = \frac{\Phi_0}{2\sqrt{2}\pi H_{c2}(0)\xi_0}
\]

assuming \(H_{c2}(0) = 61.8\) T. However, 61.8 T is the upper critical field \(H_{c2}(T=0)\) and is not the much smaller thermodynamic critical field \(H_c(0)\) that appears in equation (2). \(\lambda(0)\) cannot be extracted from the experimental results presented in Snider et al.\(^1\), therefore both its numerical value and its temperature dependence in extended data figure 3b, c of Snider et al.\(^1\) are not derived from data, nor is the value \(\kappa = \lambda(T)/\xi(T) = 1.5\) that they claim\(^1\).

We can estimate the Fermi velocity \(v_f\) from the relation \(\xi_0 = \hbar v_f/(\pi \Delta(0))\), in which \(\Delta(0)\) is the superconducting energy gap, and the penetration depth from \(\lambda(0) = \sqrt{m^* c^2/(4\pi m_e^2)}\), in which \(m^*\) is the superfluid density, \(m^*\) the effective mass of the charge carriers, \(c\) the speed of light and \(e\) the electron charge. With \(\Delta(0) = 42\) meV inferred from the measured critical temperature \(T_c\), we obtain \(\lambda(0) = 56\) nm assuming \(m^* = 2m_e\) (R. P. Dias, personal communication), which is much larger than the value of \(\lambda(0) = 3.8\) nm estimated by Snider et al.\(^1\). Disorder increases the value of this estimate further\(^2\), thus increasing the GL ratio. We therefore argue that \(\kappa = \lambda/\xi = 50\) is likely to be a lower bound for this material. This should broaden the resistive transition in a magnetic field, as explained below.

For comparison, for yttrium barium copper oxide (YBCO) superconductors typical values are \(\xi = 1.8\) nm and \(\lambda = 180\) nm, hence \(\kappa = 100\); for MgB\(_2\), \(\xi = 5\) nm and \(\lambda = 140\) nm, hence \(\kappa = 28\). Thus, all these materials have a GL parameter \(\kappa > 1\), therefore they are strongly type II superconductors.

The curves of resistance versus temperature in figure 1 of Snider et al.\(^1\) show transition widths smaller than 1 K in the absence of an applied magnetic field, corresponding to fractional widths smaller than 0.5%. These are notably sharp transitions, rarely seen in any superconductor except for exceptionally pure single-crystal samples of type I superconductors. Assuming that the sample analysed in Snider et al.\(^1\) is both single-crystal-like and in the dirty limit, as suggested\(^1\), we point out that disorder broadens superconducting transitions in both conventional and unconventional superconductors, particularly for higher transition temperatures. Furthermore, Snider et al.\(^1\) indicate that pressure gradients in the system account for the observed differences in transition temperatures when measured by resistivity and susceptibility. The presence of pressure gradients should also broaden the resistive transition. However, the transitions shown in figure 1 of Snider et al.\(^1\) are exceptionally sharp.

This anomalous behaviour becomes clearer still in figure 2 of Snider et al.\(^1\), where a magnetic field is applied. In type II superconductors the resistive transition will necessarily broaden in a magnetic field: the magnetic field penetrates the material in the form of vortices that carry one flux quantum each, and a circulating current causes motion of the vortices that dissipates energy, hence the resistivity is non-zero. This is a universal phenomenon for all type II superconductors, and it becomes more pronounced the higher the temperature and more strongly type II the material is. However, there is no indication in figure 2b of Snider et al.\(^1\) of any broadening of the resistive transition when a magnetic field is applied.

Figure 1 shows the typical broadening seen in high-temperature conventional and unconventional superconductors. MgB\(_2\), like the hydrides\(^3\), is universally believed to be a conventional superconductor. Its upper critical field is approximately \(H_{c2}(O) = 16\) T. For an applied field \(H = 2.5\) T, hence \(H/H_{c2}(O) = 0.15\), the transition is broadened over a range \(\Delta T_c = 2.5\) K, for critical temperature \(T_c = 30\) K. Therefore, for MgB\(_2\)

\[
\frac{\Delta T_c}{T_c} (H/H_{c2}(O) = 0.15) = 8.3\%.
\]

By contrast, consider the resistive transition shown in figure 2b of Snider et al.\(^1\) for an applied magnetic field of 9 T. With \(H_{c2}(O) = 61.8\) T,
Matters arising

Fig. 1 | Resistive transition in a magnetic field for MgB₂ and YBCO. Left, polycrystalline MgB₂, reprinted from ref. 1. Physica C 385, Canfield, P. C., Bud’ko, S. L. and Finnemore, D. K., An overview of the basic physical properties of MgB₂, 1–7, Copyright 2003, with permission from Elsevier. Right, YBCO single crystal, reprinted from ref. 12. Physica C 153–155, Iye, Y. et al, The anisotropic superconductivity of RBa₂Cu₃O₇₋ₓ (R: Y, Gd and Ho) single crystals, 26–31, Copyright 1988, with permission from Elsevier.

this corresponds also to \( H/H_c(0) = 0.15 \). The broadening of this transition is \( \Delta T_c = 0.4 \text{K} \), for \( T_c = 265 \text{K} \). Hence

\[
\frac{\Delta T_c}{T_c} \left( H/H_c = 0.15 \right) = 0.15%.
\]

Therefore, the broadening of the resistive transition in CSH is at least a factor of 50 smaller than expected. We say ‘at least’ because we argued earlier that this material should be more strongly type II than is MgB₂, and in addition, the transition is at a much higher temperature.

Figure 2 contrasts the broadening in MgB₂ and in YBCO with the exceptionally small broadening in CSH.1

The transition between normal and superconducting states in type II conventional superconductors and the resulting transport properties are well understood3–5: flux-flow resistivity arises from the motion of vortices in the mixed phase, broadening the transition. At the high temperatures at which the transition apparently occurs in CSH, thermal activation of vortices should be pronounced and the role of pinning centres reduced, increasing the broadening. Broadening of the resistive transition is also quite well understood for the cuprates, in which some novel physics and additional dissipation mechanisms may exist.6 In both conventional7 and unconventional8–12 superconductors, broadening of the resistive transition in a magnetic field is an inescapable consequence of the physics of superconductors that have coherence lengths substantially shorter than the London penetration depth, independent of the mechanism that gives rise to the superconductivity.

Our arguments apply to type II superconductors not only in the clean limit, but also in the presence of disorder. For example, ref. 16 shows that the irradiation of MgB₂ thin films—which creates disorder—broadens the resistive transitions both in the absence and even more so in the presence of an applied magnetic field.

We also argue that the extreme sharpness of the transitions seen in the magnetic susceptibility data of Snider et al.1— for example the curve for \( P = 166 \text{GPa in figure 2a}, \) in which the susceptibility decrease occurs over a temperature range \( \Delta T = 0.3 \text{K} \)—is extremely anomalous. Typical a.c. susceptibility data for materials that become superconducting under pressure show much larger widths—see, for example, ref. 13.

We therefore consider an alternative origin of the apparent superconducting transitions seen in this hydride under high pressure. A possible explanation is that metallic conduction paths were suddenly established where previously there were none. The material is inhomogeneous and is likely to be composed of metallic and non-metallic regions, and at some given pressure and temperature a metallic path may be established, suddenly decreasing the resistance. The transition can be extremely sharp in that case, with the lower-temperature state having much lower electrical resistance than the higher-temperature state. However, it would not be a superconducting state.

In conclusion, the exceptional sharpness of the transitions shown in Snider et al.1—both in the absence and particularly in the presence of applied magnetic fields—challenges the claim of the observation of room-temperature superconductivity in these hydrides.

Acknowledgements We acknowledge clarifying correspondence with the authors of ref. 1.

F.M. was supported in part by the Natural Sciences and Engineering Research Council of Canada (NSERC) and by an MIF from the Province of Alberta.

Author contributions J.E.H. and F.M. contributed equally to all aspects of the preparation of this work.

Competing interests The authors declare no competing interests.

Additional information Correspondence and requests for materials should be addressed to J.E.H. or F.M. Reprints and permissions information is available at http://www.nature.com/reprints.

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

© The Author(s), under exclusive licence to Springer Nature Limited 2021