TECHNICAL COMMENT

HIGH-PRESSURE PHYSICS

Comment on "Observation of the Wigner-Huntington transition to metallic hydrogen"

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Dias and Silvera (Research Article, 17 February 2017, p. 715) report on the observation of the Wigner-Huntington transition to metallic hydrogen at 495 gigapascals at 5.5 and 83 kelvin. Here, we show that the claim of metallic behavior is not supported by the presented data, which are scarce, contradictory, and do not prove the presence of hydrogen in the high-pressure cavity.

A recent paper of Dias and Silvera (*1*) reports on production of metallic hydrogen in a diamond anvil cell (DAC) at 495 GPa at 5.5 and 83 K, with potential implications for "energy and rocketry." Here, we argue that the presented (very scarce) results are contradictory to the presented experimental description, making their claims unsupported experimentally. Moreover, the proposed implications are highly speculative, making this paper very confusing for a broad audience (*2*). Elucidating the claims and the related implications is important for building a coherent picture that is currently emerging as the result of theoretical calculations at various levels and experimental investigations employing static and dynamic compression techniques [e.g., (*3*–*7*)]. We have no doubt that hydrogen metallizes at high pressures, but this does not make all claims about reaching this state immediately valid. The scientific community would like to learn at what conditions hydrogen metallizes, what is the nature of the conducting state (*8*), and its properties (e.g., superconductivity). Here, we argue that the presented data do not provide reliable information on this.

The high-pressure physics community has great interest in the experimental evidence of the metallic hydrogen phase claimed by Dias and Silvera (*1*). The pressure in their experiment is not measured using current community standards. Dias and Silvera present no continuity in the infrared-Raman data, the Raman spectrum at the claimed pressure of 495 GPa does not characterize hydrogen, and it is not of sufficient quality to unambiguously assign a Raman signal from the stressed anvil, as has been reported in other works (*5*, *7*). The linear loading curves that Dias and Silvera present are likely unreliable as a tool for estimating pressure at the extreme conditions of the experiments due to diamond cupping and other high-pressure effects [e.g., (*9*)]. Therefore, we doubt that Dias and Silvera were anywhere close to the claimed pressure.

Dias and Silvera also reported reflectivity measurements of their "Wigner-Huntington" state of hydrogen. They use the diamond absorption correction of (*10*) to offset the unknown absorption of their diamonds at high pressure (Fig. 1). However, the correction has been applied erroneously as, according to Vohra (*10*), at 405 nm (3.06 eV) [see also figure S4 in (*1*)], the optical density of the diamond anvil should be ~6 (extrapolated to 495 GPa), leaving almost no light to pass through (Fig. 1). This contradicts the observations in (*1*) of about 50% of raw reflectivity at 405 nm, suggesting that their signal is spurious (not from the sample) and/or that they have not reached the claimed pressure.

In summary, we refute the claim of Dias and Silvera that they "have produced atomic [metallic hydrogen] in the laboratory at high pressure and low temperature." Rather, they reported an artifact of their measurements at the unknown (likely at much lower than claimed) pressures, and their observations have nothing to do with the properties of metallic hydrogen, which will be a topic for research to come. Their experiments must be repeated using the procedures accepted by the high-pressure physics community (as outlined above) and/or reproduced in other laboratories to become trustworthy.

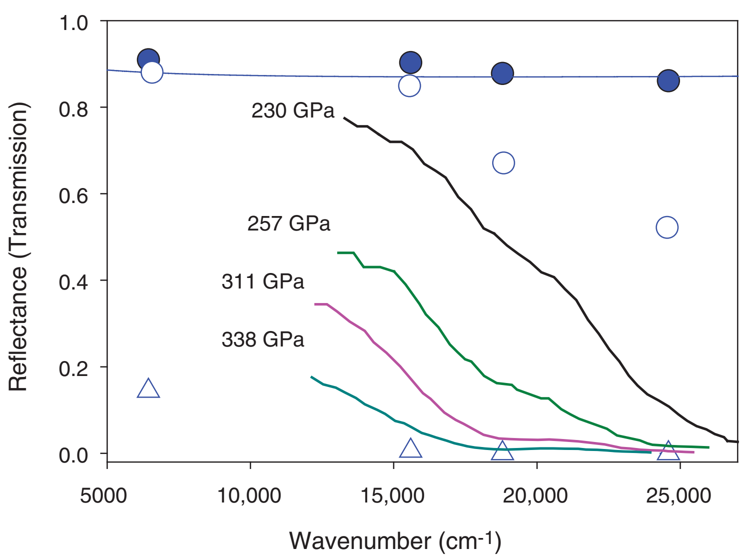

Fig. 1. Reflectance of hydrogen. Reflectance of hydrogen at 495 GPa, as determined by Dias and Silvera (*1*) (filled circles, corrected; open circles, uncorrected), in comparison with the diamond transmittance from Vohra (*10*) at 230, 257, 311, and 338 GPa [broadly consistent with the results of Goncharov *et al*. (*11*)] used to correct the data for the diamond absorption at high pressures. The proper correction (estimated from Vohra's data extrapolated to 495 GPa) suggests that the uncorrected results should be much lower than reported in (*1*); these are shown as open triangles. These estimates strongly suggest that the reflected signal presented by Dias and Silvera was spurious and/or that pressures were much lower than claimed, below 230 GPa.

Dias and Silvera reported visual observations of a very shiny material in the DAC cavity. Without specifying what could cause such observations, they did not rely on continuous monitoring of the presence of hydrogen by tracking a specific physical property of hydrogen in the cavity at these conditions [e.g., (*5*, *7*)], so their observation may not necessarily be related to a change in hydrogen properties.

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REFERENCES AND NOTES

1. R. P. Dias, I. F. Silvera, *Science* **355**, 715–718 (2017).
2. V. V. Brazhkin, A. G. Lyapin, *Nat. Mater.* **3**, 497–500 (2004).
3. M. D. Knudson *et al*., *Science* **348**, 1455–1460 (2015).

4. J. M. McMahon, M. A. Morales, C. Pierleoni, D. M. Ceperley, *Rev. Mod. Phys.* **84**, 1607–1653 (2012).
5. M. I. Eremets, I. A. Troyan, A. P. Drozdov, Low temperature phase diagram of hydrogen at pressures up to 380 GPa. A possible metallic phase at 360 GPa and 200 K. arXiv:1601.04479 [cond-mat.mtrl-sci] (18 January 2016).
6. J. Chen *et al*., *Nat. Commun.* **4**, 2064 (2013).
7. P. Dalladay-Simpson, R. T. Howie, E. Gregoryanz, *Nature* **529**, 63–67 (2016).
8. E. Babaev, A. Sudbø, N. W. Ashcroft, *Nature* **431**, 666–668 (2004).
9. R. J. Hemley *et al*., *Science* **276**, 1242–1245 (1997).
10. Y. K. Vohra, Isotopically pure diamond anvil for ultrahigh pressure research, in Proceedings of the XIII AIRAPT International Conference on High Pressure Science and Technology (Bangalore, India, 1991).
11. A. F. Goncharov, E. Gregoryanz, R. J. Hemley, H. Mao, *Proc. Natl. Acad. Sci. U.S.A.* **98**, 14234–14237 (2001).

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