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AUTHOR:
Robin E. Kroon[1]

AFFILIATION:
[1]Department of Physics, University of the Free State, Bloemfontein, South Africa

CORRESPONDENCE TO:
Robin Kroon

EMAIL:
KroonRE@ufs.ac.za

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Sounds like non-ideal Mars atmospheric data

Significance:

Reported experiments on Mars include measurements of the speed of sound and its dependence on the atmospheric conditions. Although the conditions of temperature and pressure vary significantly more than on the surface of Earth, it is nevertheless useful to have typical values for these parameters. We note that such typical values of temperature, pressure and air density should be presented carefully to be consistent with the constraint of the ideal gas law.

While recently setting a problem on the speed of sound waves for an undergraduate physics course, I was inspired by the *Nature* article 'In situ recording of Mars soundscape'[1], which provides an overview of pioneering sound measurements on Mars. This article states that "at Mars pressure, the approximately 95% CO_2 atmosphere can be efficiently modelled as an ideal gas" and provides typical values for the physical variables required to calculate the speed of sound:

> *… sound waves are considered as adiabatic disturbances. It follows that the temperature-derived speed of sound is given by* $c^2=\gamma RT/M$*, with R the molar gas constant (8.314* $\mathrm{J mol^{-1} K^{-1}}$*), M the molar mass of the atmosphere (43.34* $\mathrm{g mol^{-1}}$*), T the temperature in kelvins and* γ *the adiabatic index. Using* $\gamma=9/7$*, the standard value for* CO_2 *— this value is discussed in the main text — we find* $c=238$ $\mathrm{m s^{-1}}$ *at 230* K.

The article follows up with discussion on the relaxation rate of CO_2 molecules and their consequent degrees of freedom under conditions on Mars. This influences the adiabatic index, which, at frequencies above a critical value (where fewer degrees of freedom are active), is better represented by the value of 7/5. As the speed of sound is proportional to the square root of the adiabatic index, this is responsible for two sound speed regimes, having ratio $\sqrt{\frac{7/5}{9/7}}$, which makes them about 4% apart. The article correspondingly reports: "…two distinct values for the speed of sound that are about 10 $\mathrm{m s^{-1}}$ apart below and above 240 Hz…."

It is a coincidence that the same numerical value of 240 applies to three separate parameters of importance in the article, namely:

- Relaxation frequency: "the relaxation frequency is about 240 Hz on Mars"
- Sound speed: "the true sound speed is about 240 $\mathrm{m s^{-1}}$"
- Absolute temperature: "the atmospheric temperatures ranged between 232 K and 240 K"

Despite the interesting complexities based on the adiabatic index, my aim was simply to make use of the 'typical' Mars values of atmospheric conditions provided in the article in order to calculate the speed of sound using the equation $c^2=\gamma P/\rho$ in terms of the pressure P and density ρ, which is an equivalent form to that used by the authors through the ideal gas law $P = nRT/V = \rho RT/M$, where n is the amount of gas molecules and V the corresponding gas volume. The article provided values of the necessary parameters as follows:

- "From the knowledge of Mars atmospheric pressure (about 0.6 kPa)… "
- "Typically, with $\rho=0.02\,\mathrm{kg m^{-3}}$…"

Using these values with $\gamma=9/7$ gives c = 196 m $\mathrm{s^{-1}}$, which is significantly less than the expected approximately 240 $\mathrm{m s^{-1}}$. The alternative adiabatic index $\gamma=7/5$ gives c = 205 m $\mathrm{s^{-1}}$ which, while about 10 m $\mathrm{s^{-1}}$ greater as discussed earlier, is still much too low.

Using the pressure (0.6 kPa) and density ($0.02\,\mathrm{kg m^{-3}}$) values with the ideal gas law $P = \rho RT/M$ allows the corresponding temperature to be calculated, giving T = 156 K, which is at odds with the typical temperature value of about 240 K given. The value adopted for the typical temperature constrains the ratio of the typical pressure to density through the ideal gas law, i.e. $P/\rho = RT/M = 46 \times 10^3$ $\mathrm{m^2\ s^{-2}}$ for a temperature of 240 K. In contrast, the pressure and density values given in the article correspond to $P/\rho = 30 \times 10^3$ $\mathrm{m^2\ s^{-2}}$.

Despite the initial confusion this caused, in retrospect, it seems clear that the authors only provided an order of magnitude estimate of the atmospheric density on Mars ($\rho=0.02\,\mathrm{kg m^{-3}}$) in order to contrast the vastly different acoustic impedance values on Earth and Mars. Nevertheless, they presented the acoustic impedance derived from this value to three significant figures ("Z=4.76 $\mathrm{kg m^{-2} s^{-1}}$ at the surface of Mars"). The constraint $P/\rho = 46 \times 10^3$ $\mathrm{m^2\ s^{-2}}$ (at 240 K), together with the given typical pressure of 0.6 kPa, gives a corresponding typical density of $\rho=0.013\,\mathrm{kg m^{-3}}$, which cannot be reconciled with the given value $\rho=0.02\,\mathrm{kg m^{-3}}$.

Although this does not affect any of the results presented, or detract from the work in general, the article provides a set of typical atmospheric conditions on Mars which is inconsistent with the ideal gas law, and which significantly underestimates the speed of sound waves when calculated using the typical pressure and typical air density values provided. If typical values for the temperature and pressure on Mars are accepted as 240 K and 600 Pa, then the corresponding typical air density should be accepted as $0.013\,\mathrm{kg m^{-3}}$, rather than the significantly different value of $\rho=0.02\,\mathrm{kg m^{-3}}$ given in the paper. Failing to do so will result in inaccurate quantitatively poor estimates of the typical acoustic impedance values. Although the conditions on Mars may vary considerably[2,3] from typical values, it is of importance to present only self-consistent sets of typical values.

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Declarations

I have no competing interests to declare. I have no AI or LLM use to declare.

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