Ultra-dense hydrogen H(0) as dark matter in the universe: new possibilities for the cosmological red-shift and the cosmic microwave background radiation

Leif Holmlid¹

Received: 26 November 2018 / Accepted: 19 August 2019 / Published online: 29 August 2019
© The Author(s) 2019

Abstract 50 experimental publications exist on ultra-dense hydrogen H(0) from our laboratory. A review of these results was published recently (L. Holmlid and S. Zeiner-Gundersen in Phys. Scr. 74(7), 2019, <https://doi.org/10.1088/1402-4896/ab1276>). The importance of this quantum material in space is accentuated by a few recent publications: The so called extended red emission (ERE) spectra in space agree well (L. Holmlid in Astrophys. J. 866:107, 2018a) with rotational spectra measured from H(0) in the laboratory, supporting the notion that H(0) is a major part of the dark matter in the Universe. The proton solar wind was shown to agree well with the protons ejected by Coulomb explosions in p(0), thus finally providing a convincing detailed energy mechanism for the solar wind protons (L. Holmlid in J. Geophys. Res. 122:7956–7962, 2017c). The very high corona temperature in the Sun is also directly explained (L. Holmlid in J. Geophys. Res. 122:7956–7962, 2017c) as caused by well-studied nuclear reactions in H(0). H(0) is the lowest energy form of hydrogen and H(0) is thus expected to exist everywhere where hydrogen exists in the Universe. The so called cosmological red-shifts have earlier been shown to agree quantitatively with stimulated Raman processes in ordinary Rydberg matter. H(0) easily transforms to ordinary Rydberg matter and can also form the largest length scale of matter, with highly excited electrons just a few K from the ionization limit. Such electronic states provide the small excitations needed in the condensed matter H(0) for a thermal emission at a few K temperature corresponding to the CMB, the so called cosmic microwave background radiation. These excitations can be observed

directly by ordinary Raman spectroscopy (L. Holmlid in J. Raman Spectrosc. 39:1364–1374, 2008b). A purely thermal distribution from H(0) and also from ordinary Rydberg Matter at 2.7 K is the simplest explanation of the CMB. The coupling of electronic and vibrational degrees of freedom observed as in experiments with H(0) gives almost continuous energy excitations which can create a smooth thermal CMB emission spectrum as observed. Thus, both cosmological red-shifts and CMB are now proposed to partially be due to easily studied microscopic processes in ultradense hydrogen H(0) and the other related types of hydrogen matter at the two other length scales. These processes can be repeated at will in any laboratory. These microscopic formation processes are much simpler than the earlier proposed large-scale non-repeatable processes related to Big Bang.

Keywords Ultra-dense hydrogen · Dark matter · Red-shifts · CMB

1 Introduction

Ultra-dense hydrogen H(0) has been extensively studied during the last decade by laser-induced mass spectrometry and neutral kinetic energy spectroscopy (Badiei et al. 2009a,b, 2010a,b,c; Andersson and Holmlid 2009, 2010, 2011, 2012a; Andersson et al. 2011; Holmlid 2011a,b). (Note that a change in nomenclature has been made due to improved theoretical understanding; H(0) was initially named H(−1) for a theoretically supported, inverted form of Rydberg Matter). Laser pulses excite the bonding electrons and induce Coulomb explosions (CE) in the H(0) material (Badiei et al. 2009a,b, 2010a,b,c; Andersson and Holmlid 2009, 2010, 2011, 2012a; Andersson et al. 2011; Holmlid

✉ L. Holmlid
holmlid@chem.gu.se

¹ Atmospheric Science, Department of Chemistry, University of Gothenburg, 412 96 Göteborg, Sweden

Fig. 1 A typical chain cluster of $p(0)$.

2011a,b). The CE process ejects ionic and neutralized fragments with kinetic energy up to 630 eV from spin state $s = 2$, and up to 2.5 keV from spin state $s = 1$ (Andersson and Holmlid 2010). A review of $H(0)$ was recently published (Holmlid and Zeiner-Gundersen 2019). Ultra-dense hydrogen $H(0)$ contains clusters of various forms, with different modes of CE fragmentation. Large clusters are mainly in the form of chains of H–H pairs (see Fig. 1) (Andersson and Holmlid 2011, 2012a). From the CE experiments, the bond distance in $d(0)$ in spin state $s = 2$ is determined to be 2.3 pm, a factor of 100 smaller than in ordinary molecules. This means that the material has very high density, of the order of 10^{29} cm^{-3} (100 kg cm^{-3}). $H(0)$ will absorb electromagnetic radiation only at energies above several hundred eV due to the strong atomic bonding in the keV range, and it is thus not easily observable in absorption in space. However, rotational emission spectra in the visible can be observed (Holmlid 2017a, 2018a). In $H(0)$, it is observed that nuclear processes take place easily (Holmlid and Zeiner-Gundersen 2019), even continuously at a low rate. Experiments showing both spontaneous and laser-induced fusion $d + d$ in $d(0)$ have been described (Badiei et al. 2010c; Andersson and Holmlid 2012b; Holmlid and Olafsson 2015a,b, 2016). The material $p(0)$, ultra-dense protium (Holmlid 2013a), is probably the most common ultra-dense material in the universe. This material has a slightly more complex cluster structure than ultra-dense deuterium $d(0)$. The nuclear processes in $p(0)$ are however similar to those in $d(0)$, giving meson showers containing all types of kaons (Holmlid 2015, 2016, 2017b).

The organization of this contribution is such that it is firstly aimed at summarizing the published evidence for the closely related phases RM and $H(0)$ in space through the interpretation of several complex sets of observations, especially spectroscopic results with no other known explanations, like ERE (Holmlid 2018b) and DIBs (Holmlid 2004, 2008a, 2011c). Secondly, quantitative evidence is already published on how RM gives cosmological redshifts (Holmlid 2005). This publication may not be so easily accessible, and part of its results is now included here in Appendix. Thirdly, the interpretation of CMB as due to thermal emission from $H(0)$ is discussed, especially concerning the densely spaced energy levels in this condensed material.

It is possible that this interpretation of the CMB is worth a treatment in a separate publication: however, a temperature measurement as the CMB is just one parameter with small information content and it can thus have almost any cause.

2 Theoretical background

2.1 Ultra-dense hydrogen $H(0)$

Ultra-dense hydrogen $H(0)$ is closely related to the lowest form of Rydberg Matter (RM) of the type $H(1)$ (Manykin et al. 1992; Holmlid 1998, 2012). The ultra-dense hydrogen materials will all be named $H(0)$ here, while the different isotopic forms studied will be named $p(0)$, $d(0)$ and $pd(0)$. A review of $H(0)$ was recently published (Holmlid and Zeiner-Gundersen 2019) and the description given in the present study is thus kept brief. The quantum mechanical basis for $d(0)$ was discussed by Winterberg (Winterberg 2010a,b) suggesting the formation of d–d bonding by exchange forces as the crucial factor of its formation. Other more general theoretical descriptions have been published (Holmlid and Zeiner-Gundersen 2019; Holmlid 2013b). $d(0)$ as well as $p(0)$ is observed experimentally to be superfluid at room temperature (Andersson and Holmlid 2011). They are both also proposed to be type-II superconductors at room temperature from the observed Meissner effect (Andersson et al. 2012; Holmlid and Fuelling 2015). Only hydrogen atoms are expected to give an ultra-dense material form, since the inner atomic electrons prevent this formation for all other atoms but possibly for doubly excited He atoms (Holmlid 2004, 2008a, 2011c).

$d(0)$ is the first example studied on Earth of the ultra-dense hydrogen materials that apparently exist in many different objects in space for example in stars and giant planets. $H(0)$ is the lowest energy form of hydrogen, and it will exist everywhere in space where hydrogen exists. Thus, the properties of $H(0)$ are of general importance for our understanding of the Universe (Holmlid 2018b). $H(0)$ has a density up to a thousand times higher than the interior of the Sun, and the particles released in the laboratory by relatively weak laser pulses have kinetic energy of at least 15 MK, similar to the temperature in the Sun (Andersson and Holmlid 2010). Recently, the proton solar wind was shown to agree well with the protons ejected by CE from $p(0)$ (Holmlid 2017c). The most important properties observed for $H(0)$ have not been considered to be possible previously, namely the short bond distances and the strong bonds. The $H(0)$ clusters have dimensions down to a few pm. This is directly verified by rotational spectroscopy in the visible (Holmlid and Zeiner-Gundersen 2019; Holmlid 2017a, 2018a). This means that the $H(0)$ clusters will not scatter electromagnetic radiation with wavelength longer than a few pm, and thus that $H(0)$

clusters will be invisible in absorption in any spectral range with wavelength longer than typical gamma rays. Due to the strong interatomic bonding in H(0) with energy of the order of 1–2 keV, absorptions in the visible or UV ranges are unlikely. No stationary electronic excited states at intermediate energies exist in H(0), but several different spin states have been observed (Holmlid 2017a, 2018a). Rotational transitions exist at many eV energies, as described in two recent publications (Holmlid 2017a, 2018a).

2.2 H(0) formation

Next, we need to consider the energetics of H(0) formation. The d–d and p–p bond energy of the order of 500 eV corresponds to a temperature of approximately 5 MK. Thus, in any dense region in space where the temperature is lower than approximately 1 MK, ultra-dense hydrogen H(0) is the most important form of hydrogen (Holmlid 2018b). This means that even inside many stars will this form of hydrogen be of great importance. The formation of H(0) is spontaneous from higher Rydberg matter (RM) states, for example by H(3) falling down to H(1) (Andersson et al. 2012). H(1) (Badieli and Holmlid 2006) is easily converted to H(0). The facile oscillatory conversion between D(1) and D(0) was even directly observed in real time (Badieli et al. 2010b). This means that the stable state H(0) is easily reached by hydrogen in space at large enough densities or low enough temperatures. Thus, vast amounts of H(0) are proposed to exist in the Universe and this should be the primordial form of hydrogen in space. Of course, if H₂ molecules dominate in some region at present, the formation of H(0) there is slower and more complex, often requiring absorption of H₂ on solid surfaces like carbon or metal oxide surfaces which give dissociative adsorption.

2.3 H(0) stability

The stability of H(0) will be higher than for any other known material. Temperatures above the MK range are required to dissociate this material after it has been formed. Of course, fragmentation due to ionizing photons and fast particles will take place. When the energy density of the radiation field is lower than that corresponding to 1 MK, the ultra-dense hydrogen phase should be stable. The superfluid H(0) phase will quite easily transport energy deposited in one location to other places.

All implications of the large densities of the superfluid and superconductive material H(0) in space are certainly not yet clear. A few conclusions about the effects of H(0) in space were published recently (Holmlid 2018b).

2.4 Star formation in H(0)

H(0) consists of small clusters H_{2N} with pm sizes (Holmlid and Zeiner-Gundersen 2019). The main forces which

may give condensation of such clusters to larger solid or liquid volumes have not yet been studied directly. Winterberg (Winterberg 2010a,b) proposed exchange forces to form larger volumes of D(0), but that was for condensing atoms, not for clusters. Basic forces like dispersion forces and electrostatic forces like dipole interactions (Holmlid 2017a, 2018a) between the clusters will always exist. Such forces vary with distance as r^{-6} , so they may be 10^{12} times stronger for typical distances r of 2 pm in H(0) instead of $2 \text{ \AA} = 200 \text{ pm}$ for typical molecules. However, since the polarizability is several orders of magnitude smaller for H(0) clusters than for ordinary molecules due to their strongly bound electrons, the interaction giving condensation in H(0) is not 10^{12} times stronger; it seems likely that it is 10^3 – 10^6 times stronger than in an H₂ gas. The high energy electrons which exist at the largest length scale of H(0) (Hirsch 2012) are more easily influenced by Coulomb interactions and will give attractive forces between the clusters. These much stronger attractive forces for H(0) will lead to a much faster condensation than in H₂, and the nuclear processes in H(0) (Holmlid and Olafsson 2015a,b, 2016) will start almost immediately in an H(0) cloud. That this will speed up the onset of ordinary p + p fusion reactions seems likely, since the increased temperature given by the nuclear reactions in H(0) should help in starting ordinary fusion reactions. Thus, the rate of star formation may be strongly increased by the condensation and nuclear reaction properties of H(0). This means that also the rate of galaxy formation will be strongly increased. It is suggested that H(0) was the primordial form of hydrogen in space due to its stability up to MK temperatures.

2.5 Three levels of matter

The description used here of matter at three different length scales is based on a publication by J.E. Hirsch (Hirsch 2012), stating on p. 5 “There exists a remarkable parallel in the physics at the three different length scales” $r_q = \hbar/(2mec)$ the ‘quantum electron radius’, $a_0 = \hbar^2/m_e e^2$ the Bohr radius and $2\lambda_L = 137 a_0$ with λ_L the London penetration depth, and with the fine structure constant $\alpha = 1/137$ as the common ratio between these length scales” (Hirsch 2012). Ultra-dense hydrogen H(0) has the length scale r_q while ordinary Rydberg matter has length scale a_0 . Super properties like superconductivity are coupled to the largest length scale which is also similar in its properties to Rydberg matter at large excitation levels (Rydberg-like circular electron orbits, Hirsch 2012). The energy scales are related by the square of the fine structure constant α^2 which gives the energy scale for the largest length scale of 181 μeV (Hirsch 2012). This is equal to 2.1 K, relatively close to the CMB temperature of 2.7 K (see further below). A real thermal contribution from the material H(0) is the most likely factor giving the observed CMB temperature of 2.7 K.

3 Results and discussion

3.1 Ordinary RM in space

From the description of H(0) above, it is concluded that it exists everywhere in space, since it is the lowest energy state of hydrogen and also of matter in general (based on the quantum electron radius r_q). It can easily transform into the lowest excitation level of ordinary hydrogen Rydberg matter named H(1) (Badiei et al. 2010b; Andersson et al. 2012; Holmlid and Fuelling 2015). This gives a mechanism for generating vast amounts of Rydberg matter (RM) in space thus of the form H(RM); such a mechanism has not been apparent previously, even if many spectroscopic results strongly indicated that RM is common in interstellar, interplanetary and even intergalactic space and in the atmospheres of planets and satellites. A short list of published results on this theme is given here:

1. DIBs (diffuse interstellar bands), which are due to absorbing doubly excited atoms especially He within an RM phase (probably in H(1)) in interstellar space. Close to 300 DIB transition wavelengths have been calculated accurately (Holmlid 2004, 2008a, 2011c).
2. Maser lines in space. The optically amplifying entities are clouds of clusters of general RM (Holmlid 2006a), probably mainly H(RM) with excitation level $l = 2, 4, 5, 6$.
3. H(0) as dark matter in the universe, based on the agreement (Holmlid 2018b) of the extended red emission (ERE) spectra with (experimentally observed) rotational emission spectra in H(0) (Holmlid 2017a, 2018a).
4. Faraday rotation in intergalactic space. General RM, probably mainly H(RM) (Badiei and Holmlid 2002a,b).
5. UIB, UIR (unidentified IR bands/emission). General RM, probably mainly H(RM) with experimental confirmation in K(RM) (Holmlid 2000, 2001, 2007).
6. Spectra from comets. General RM with experimental confirmation in K(RM) (Holmlid 2006b).
7. Alkali atmospheres of Mercury and the Moon. Alkali metal RM (Holmlid 2006c).
8. The proton solar wind is due to CE in p(0) in the atmosphere of the Sun (Holmlid 2017c), with verification by time-of-flight studies using laser-induced CE in p(0).
9. Several features from the alkali metal layer in the upper atmosphere of the Earth. Alkali metal RM (Olofson et al. 2010).
10. Homochirality due to circular polarization of light in the alkali metal layer in the upper atmosphere of the Earth. Alkali metal RM (Holmlid 2009).

3.2 Red-shifts by stimulated Raman effects

The very large polarizability of RM due to the high Rydberg levels of its atoms gives rise to a stimulated Raman

effect which shifts the wavelength of light passing through RM without a simultaneous deflection. This gives redshifts or blueshifts of the light depending on the excitation state of the RM. The general theory of stimulated Raman is summarized together with the experimental detection and studies of this effect using tunable diode lasers in the medium infrared range in Refs. (Holmlid 2005, 2004a,b). The most important direct results for the present study are collected in Appendix below, but many general results for example concerning the properties of the shifts are not repeated here since they require the theory of stimulated Raman scattering which is a specialized theory for interactions between quanta and matter far from astrophysics. With H(0) as dark matter, Rydberg matter H(1) and higher excitation levels H(RM) are formed easily, giving dark matter with a large polarizability of its atoms, and red-shifts for distant objects seen through cold RM (Holmlid 2005, 2004a,b). Thus, there is no need for any non-repeatable mechanisms of expansion giving fast receding objects to explain large redshifts, since the stimulated Raman mechanism is much simpler and only involves well-known small-scale physics, which is repeatable and independently testable in any laboratory. The stimulated Raman process is known and extensively studied since the 1960's, but it appears to be quite little known outside laser physics and spectroscopy: thus some basic information on its theory and significance for redshifts in space is repeated in Appendix below.

3.3 Raman shifts at a few K energy

Very small Raman shifts can be observed in RM using an intense IR laser with a tunable cavity and an interferometer as in Holmlid (2008b). Also so called Rabi-flopping features were observed in this study. Rabi-flopping is a type of avoided forbidden transition (Holmlid 2008b). These Raman shifts have an energy of a few K, and were concluded to be due to transitions in the vibrational-electronic structure of the RM clusters. These results were published before H(0) was known to exist and hydrogen gas was not introduced deliberately in the experiments, thus it is not known but unlikely that H(0) (the lowest state of matter) gave these results. It is however likely that the highest level of matter contributed to the detection and size of the shifts in this case in the form of high excitation levels of K(RM), not only low excitation levels of K(RM) as was assumed in that paper. With H(0) as dark matter in the Universe, the transitions between these electronic levels are likely to give a thermal emission background in space with a temperature of a few K, close to the energy levels corresponding to the largest scale of matter as described above and by Hirsch (2012). Of course, the CMB observations strongly indicate matter with a real black-body temperature as the origin of this radiation. It was probably only since no such material was observed

or known to exist a long time ago which made other ideas for the origin of CMB acceptable: however, now when H(0) seems to exist as dark matter almost everywhere in space, H(0) is the prime likely origin for the 2.7 K background emission radiation. One important requirement for such a thermal background emission is that the emitting material can support numerous small excitations so that a quantal structure is not observed in the emission spectrum. Such a quasi-continuous energy distribution exists in ordinary RM and in matter at the largest length scale due to the conduction band electrons. In ultra-dense H(0) another such important factor exists through the coupling of the electrons to the vibrations in this material (Holmlid and Zeiner-Gundersen 2019). This coupling gives the relatively broad bands observed in the rotational emission spectra (Holmlid 2017a, 2018a).

Thus, there is no need for the explanations involving recombination radiation and wavelength changes due to the expansion of the universe which are normally invoked to “explain” the CMB, since a much simpler and robust thermal emission explanation exists. It should be noted that the wavelength expansion from the early Universe is a process that cannot be observed and studied experimentally, and thus it does fulfill the requirements of ordinary science as a verifiable and repeatable process. The processes giving the CMB and redshifts from H(0) of course fulfill all such requirements of being reproducible and repeatable in experiments, in the case of CMB in a really very basic sense as thermal radiation from an observable condensed material existing now, not emitted from matter 14×10^9 years ago with no changes due to absorption after that.

The energy scales for the three levels of matter are related by the square of the fine structure constant α^2 which gives the energy scale for the largest length scale at 181 μeV (Hirsch 2012). This is equal to 2.1 K, smaller than the observed CMB temperature of 2.7 K. This means that there should be a large enough number of transitions together with the coupling to vibrational degrees of freedom in the H(0) material to support a smooth thermal distribution in emission. Here, no argument is given to prove that the temperature of the H(0) dark matter is 2.7 K. Such an argument will mainly depend on the properties of the Universe and not on the properties of H(0), and they are thus outside the scope of the present contribution. Further studies will hopefully be published in this direction.

There is no interaction between the two processes, forming CMB and the redshifts in H(0) dark matter. The amount of dark matter is very large, normally assumed to be much larger than the amount of visible matter and the two processes discussed require just a small number of atoms. The density of H(0) is a few orders of magnitude larger than for ordinary condensed matter like hydrogen ice, so the fraction of H(0) dark matter involved in the two processes is very small.

4 Conclusions

It is concluded that the properties of ultra-dense hydrogen H(0) must be taken into account to understand numerous important features in space, since H(0) is the most common form of hydrogen and matter in the Universe. Several of these features like DIBs and UIR have been well studied and described in the literature as due to processes in ordinary Rydberg matter, which is closely related to H(0). It is observed in experiments that H(0) is easily transformed to the lowest Rydberg matter form H(1). Other features in space such as the so-called cosmological redshifts and the so-called cosmological microwave background (CMB) have much simpler explanations within the H(0) framework than outside this framework; for example the H(0) based redshifts have been studied as due to stimulated Raman many years ago in laboratory experiments with spectroscopic methods which can be repeated and tested in any laboratory. It is now suggested that processes in the Universe that are believed to have taken place only once and which are neither possible to repeat nor to study independently should be removed from science and be considered like creation as belonging to the sector of personal belief only.

Acknowledgements Open access funding provided by University of Gothenburg. I acknowledge numerous stimulating discussions on cosmology with my brother Inge Holmlid.

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

Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

Appendix: Redshifts in space from stimulated Raman scattering

Only the most significant information needed to quantitatively understand the stimulated Raman scattering as the origin of cosmological redshifts is included here. For a more complete treatment, see Refs. (Holmlid 2005, 2004a,b) and the fundamental theoretical descriptions cited there. In what follows, the term light is used for simplicity in many places where the term electromagnetic radiation is more generally valid.

An important process for the interaction between light and Rydberg Matter (RM) is the stimulated electronic Raman scattering of the Stokes or anti-Stokes type (SERS, ASERS) (White 1992). Anti-Stokes Raman scattering and similar processes in RM have been observed in different

types of experiments, even at low light intensities. See further references in Holmlid (2005). For cold ground-state RM, Stokes scattering should be observed instead. There is no phase matching condition for this type of process (White 1992), and the Raman-scattered light proceeds in the same direction as the incident light.

It is necessary to estimate the magnitude of the stimulated Raman effect in the case of an RM material. For this, we use the ordinary classical steady-state gain factor originally derived for molecular vibrational transitions (cited in Holmlid 2005, 2004a,b). The formulas are given for the Stokes scattering, which is the case of interest for astrophysical processes. The equations are identical in form for the anti-Stokes and Stokes cases. The incident light frequency is ω_L and the generated Stokes wave has a frequency ω_S . The difference $\omega_E = \omega_L - \omega_S$ is the resulting electronic excitation in the RM material. For the Stokes wave, the steady-state gain factor G_{ss} at its maximum is given by Yariv (1989)

$$G_{ss} = \frac{N_d k_s}{8m\epsilon\gamma c} \left(\frac{\partial \alpha}{\partial q} \right)_0^2 |E_L|^2 \quad (1)$$

In this expression, N_d is the density of the dipoles created by the incident light wave, here chosen to correspond to the number of electrons in the RM;

k_s is the wavenumber for the Stokes wave;

m is the mass of the driven oscillator, in this case, one electron mass;

$\epsilon = \epsilon_r \epsilon_0$ is the permittivity of the medium, with ϵ_r close to unity,

γ is the coupling constant for the electronic excitation in the intermediate state to other degrees of freedom;

$\partial \alpha / \partial q$ is the variation of the polarizability with the coordinate describing the excited motion, here the electronic motion; and

E_L is the electric field strength of the incident light.

The excitation levels in Rydberg matter observed from the so-called unidentified infrared bands (Holmlid 2000) have the most probable value close to n (or l) = 80. A comparison with the parameter values appropriate for the laboratory studies of cold RM (Holmlid 2005, 2004a,b), shows that the density N_d is several orders of magnitude smaller in space than in the laboratory experiments. On the other hand, for visible light, the wave number k_s is approximately 50 times larger than for the experimental IR studies used to quantify the stimulated Raman effect in Refs. (Holmlid 2005, 2004a,b).

Equation (3) in Holmlid (2005) shows that a shift due to the stimulated Raman effect exists if the product $G_{ss}x$ is

larger than unity. With Eq. (1) used for G_{ss} and with reasonable values also used for estimation of this factor as in Ref. (Holmlid 2005), it is possible to find a condition on the electric field strength of the light field. The distance covered by light in space is denoted by l . Then the inequality

$$\frac{k_s}{8m\epsilon\gamma c} \left(\frac{\partial \alpha}{\partial q} \right)_0^2 \geq \frac{\Delta \bar{\nu}}{N_d l |E_L|^2} \quad (2)$$

should be valid for the SERS effect to exist. In this inequality, the space-related quantities are collected at the right hand side. The difference $\omega_L - \omega_S$ was replaced by $c\Delta\bar{\nu}$, where $\Delta\bar{\nu}$ is in wavenumbers. Assuming conservatively that γ is as large as the upper experimental limit found, 10^3 s^{-1} , we find that the left-hand side is equal to $2 \times 10^{-12} \text{ m}^3 \text{ V}^{-2}$, with the other parameter values estimated as previously (Holmlid 2005). With the experimental values from the study of the cold RM described in Holmlid (2004b), $\Delta\bar{\nu} = 0.02 \text{ cm}^{-1}$, $N_d = 10^{17} \text{ m}^{-3}$, $l = 0.25 \text{ m}$, and $E_L = 90 \text{ V m}^{-1}$, the right-hand side becomes $1 \times 10^{-20} \text{ m}^3 \text{ V}^{-2}$. This is many orders of magnitude smaller than the left-hand side, as required by Eq. (2). Because some of the quantities are anyway somewhat uncertain, we may assume that the right-hand side of Eq. (2) in space should be as small as this value found in the experiments. (This is a very conservative estimate.) Then $\Delta \approx 10^4 \text{ cm}^{-1}$ (the typical total summed SERS shift in observations in space), $N_d = 10^6 \text{ m}^{-3}$ (Holmlid 2005), and $l = 8 \times 10^8 \text{ pc} = 2.5 \times 10^{25} \text{ m}$ may be used, giving $E_L = 3 \times 10^{-3} \text{ V m}^{-1}$. The distance l used is smaller than the radius of the observable universe by about a factor of 10. This gives a light intensity of $2 \times 10^{-8} \text{ W m}^{-2}$ as the minimum intensity required to make the stimulated Raman process work, corresponding to the intensity of light from the Sun at our nearest star α Centauri. This is a very conservative estimate, based on the experimental results. If we instead use the condition that the right-hand side in Eq. (2) should only be smaller than the estimated value $2 \times 10^{-12} \text{ m}^3 \text{ V}^{-2}$ of the left-hand side, the required light intensity may even be a factor of 10^9 smaller, thus larger than $2 \times 10^{-17} \text{ W m}^{-2}$ corresponding to the field strength $E_L = 10^{-7} \text{ V m}^{-1}$. This is the same as the intensity of light from the Sun at the distance $4 \times 10^4 \text{ pc}$, i.e., on the other side of our galaxy. Thus, a redshift due to SERS exists even at very large distances from the source. For redshifts from distant galaxies and similar objects, the incident light intensity E_L is much larger than for the Sun for a large distance along the light beam, so the right-hand side of Eq. (2) becomes smaller and the inequality is more easily fulfilled.

It is further concluded that the density of H(0) was much larger in space during earlier epochs of the Universe since much less material was condensed into galaxies. This increases the SERS effect for distant galaxies, for which redshifts of a cosmological origin were assumed to exist.

References

- Andersson, P.U., Holmlid, L.: Ultra-dense deuterium: a possible nuclear fuel for inertial confinement fusion (ICF). *Phys. Lett. A* **373**, 3067–3070 (2009)
- Andersson, P.U., Holmlid, L.: Deuteron energy of 15 MK in a surface phase of ultra-dense deuterium without plasma formation: temperature of the interior of the Sun. *Phys. Lett. A* **374**, 2856–2860 (2010). <https://doi.org/10.1016/j.physleta.2010.03.009>
- Andersson, P.U., Holmlid, L.: Superfluid ultra-dense deuterium D(−1) at room temperature. *Phys. Lett. A* **375**, 1344–1347 (2011). <https://doi.org/10.1016/j.physleta.2011.01.035>
- Andersson, P.U., Holmlid, L.: Fast atoms and negative chain cluster fragments from laser-induced Coulomb explosions in a superfluid film of ultra-dense deuterium D(−1). *Phys. Scr.* **86**, 045601 (2012a). <https://doi.org/10.1088/0031-8949/86/04/045601>
- Andersson, P.U., Holmlid, L.: Fusion generated fast particles by laser impact on ultra-dense deuterium: rapid variation with laser intensity. *J. Fusion Energy* **31**, 249–256 (2012b). <https://doi.org/10.1007/s10894-011-9468-2>
- Andersson, P.U., Holmlid, L., Fuelling, S.R.: Search for superconductivity in ultra-dense deuterium D(−1) at room temperature: depletion of D(−1) at field strength >0.05 T. *J. Supercond. Nov. Magn.* **25**, 873–882 (2012). <https://doi.org/10.1007/s10948-011-1371-6>
- Andersson, P.U., Lönn, B., Holmlid, L.: Efficient source for the production of ultra-dense deuterium D(−1) for laser-induced fusion (ICF). *Rev. Sci. Instrum.* **82**, 013503 (2011). <https://doi.org/10.1063/1.3514985>
- Badiei, S., Holmlid, L.: Rydberg Matter in space—low density condensed dark matter. *Mon. Not. R. Astron. Soc.* **333**, 360–364 (2002a)
- Badiei, S., Holmlid, L.: Magnetic field in the intracluster medium: Rydberg matter with almost free electrons. *Mon. Not. R. Astron. Soc.* **335**, L94–L98 (2002b)
- Badiei, S., Holmlid, L.: Experimental studies of fast fragments of H Rydberg matter. *J. Phys. B, At. Mol. Opt. Phys.* **39**, 4191–4212 (2006)
- Badiei, S., Andersson, P.U., Holmlid, L.: Fusion reactions in high-density hydrogen: a fast route to small-scale fusion? *Int. J. Hydrog. Energy* **34**, 487–495 (2009a)
- Badiei, S., Andersson, P.U., Holmlid, L.: High-energy Coulomb explosions in ultra-dense deuterium: time-of-flight mass spectrometry with variable energy and flight length. *Int. J. Mass Spectrom.* **282**, 70–76 (2009b). <https://doi.org/10.1016/j.ijms.2009.02.014>
- Badiei, S., Andersson, P.U., Holmlid, L.: Laser-induced variable pulse-power TOF-MS and neutral time-of-flight studies of ultra-dense deuterium. *Phys. Scr.* **81**, 045601 (2010a). <https://doi.org/10.1088/0031-8949/81/04/045601>
- Badiei, S., Andersson, P.U., Holmlid, L.: Production of ultra-dense deuterium, a compact future fusion fuel. *Appl. Phys. Lett.* **96**, 124103 (2010b). <https://doi.org/10.1063/1.3371718>
- Badiei, S., Andersson, P.U., Holmlid, L.: Laser-driven nuclear fusion D+D in ultra-dense deuterium: MeV particles formed without ignition. *Laser Part. Beams* **28**, 313–317 (2010c). <https://doi.org/10.1017/S0263034610000236>
- Hirsch, J.E.: The origin of the Meissner effect in new and old superconductors. *Phys. Scr.* **85**, 035704 (2012). <https://doi.org/10.1088/0031-8949/85/03/035704>
- Holmlid, L.: Classical energy calculations with electron correlation of condensed excited states—Rydberg Matter. *Chem. Phys.* **237**, 11–19 (1998)
- Holmlid, L.: A novel model for the interpretation of the unidentified infrared (UIR) bands from interstellar space: deexcitation of Rydberg Matter. *Astron. Astrophys.* **358**, 276–286 (2000)
- Holmlid, L.: Observation of the unidentified infrared (UIR) bands in the laboratory: anti-Stokes stimulated Raman spectroscopy of a Rydberg Matter surface boundary layer. *Astrophys. J.* **548**, L249–L252 (2001)
- Holmlid, L.: Rydberg Matter as the diffuse interstellar band (DIB) carriers in interstellar space: the model and accurate calculations of band centers. *Phys. Chem. Chem. Phys.* **6**, 2048–2058 (2004)
- Holmlid, L.: Quantized redshifts of galaxies: stimulated Raman scattering in cold intergalactic Rydberg Matter. *Astrophys. Space Sci.* **291**, 99–111 (2004a)
- Holmlid, L.: Detection of frequency red shifts and blue shifts for single-mode IR laser radiation in Rydberg matter. *Appl. Phys. B* **79**, 871–877 (2004b)
- Holmlid, L.: Redshifts in space caused by stimulated Raman scattering in cold intergalactic Rydberg Matter with experimental verification. *J. Exp. Theor. Phys.* **100**, 637–644 (2005). *Zh. Eksp. Teor. Fiz.* **100**, 723–731 (2005)
- Holmlid, L.: Amplification by stimulated emission in Rydberg Matter clusters as the source of intense maser lines in interstellar space. *Astrophys. Space Sci.* **305**, 91–98 (2006a)
- Holmlid, L.: Rydberg Matter as the dust atmosphere in comets: spectroscopic and polarization signatures. *Icarus* **180**, 555–564 (2006b)
- Holmlid, L.: The alkali metal atmospheres on the Moon and Mercury: explaining the stable exospheres by heavy Rydberg Matter clusters. *Planet. Space Sci.* **54**, 101–112 (2006c)
- Holmlid, L.: Electronic transitions in Rydberg Matter as the source of the unidentified infrared bands (UIR) observed in interstellar space. *arXiv.org* 2007-10-17. [arXiv:0710.3293](https://arxiv.org/abs/0710.3293)
- Holmlid, L.: The diffuse interstellar band carriers in interstellar space: all intense bands calculated from He doubly excited states embedded in Rydberg Matter. *Mon. Not. R. Astron. Soc.* **384**, 764–774 (2008a)
- Holmlid, L.: Vibrational transitions in Rydberg Matter clusters from stimulated Raman and Rabi-flopping phase-delay in the infrared. *J. Raman Spectrosc.* **39**, 1364–1374 (2008b)
- Holmlid, L.: Light in condensed matter in the upper atmosphere as the origin of homochirality: circularly polarized light from Rydberg Matter. *Astrobiology* **9**, 535–542 (2009). <https://doi.org/10.1089/ast.2008.0309>
- Holmlid, L.: Large ion clusters H_N^+ of Rydberg Matter: stacks of planar clusters H_7 . *Int. J. Mass Spectrom.* **300**, 50–58 (2011a). <https://doi.org/10.1016/j.ijms.2010.12.008>
- Holmlid, L.: High-charge Coulomb explosions of clusters in ultra-dense deuterium D(−1). *Int. J. Mass Spectrom.* **304**, 51–56 (2011b). <https://doi.org/10.1016/j.ijms.2011.04.001>
- Holmlid, L.: Diffuse interstellar bands (DIB): co-planar doubly excited He and metal atoms embedded in Rydberg Matter. *Astrophys. Space Sci.* **336**, 391–412 (2011c). <https://doi.org/10.1007/s10509-011-0795-6>
- Holmlid, L.: Experimental studies and observations of clusters of Rydberg matter and its extreme forms. *J. Clust. Sci.* **23**, 5–34 (2012). <https://doi.org/10.1007/s10876-011-0417-z>
- Holmlid, L.: Laser-mass spectrometry study of ultra-dense protium p(−1) with variable time-of-flight energy and flight length. *Int. J. Mass Spectrom.* **351**, 61–68 (2013a). <https://doi.org/10.1016/j.ijms.2013.04.006>
- Holmlid, L.: Excitation levels in ultra-dense hydrogen p(−1) and d(−1) clusters: structure of spin-based Rydberg Matter. *Int. J. Mass Spectrom.* **352**, 1–8 (2013b). <https://doi.org/10.1016/j.ijms.2013.08.003>
- Holmlid, L.: Nuclear particle decay in a multi-MeV beam ejected by pulsed-laser impact on ultra-dense hydrogen H(0). *Int. J. Mod. Phys. E* **24**, 1550080 (2015). <https://doi.org/10.1142/S0218301315500809>
- Holmlid, L.: Leptons from decay of mesons in the laser-induced particle pulse from ultra-dense protium p(0). *Int. J. Mod. Phys. E* **25**, 1650085 (2016). <https://doi.org/10.1142/S0218301316500853>

- Holmlid, L.: Emission spectroscopy of IR laser-induced processes in ultra-dense deuterium D(0): rotational transitions with spin values $s = 2, 3$ and 4. *J. Mol. Struct.* **1130**, 829–836 (2017a). <https://doi.org/10.1016/j.molstruc.2016.10.091>
- Holmlid, L.: Mesons from laser-induced processes in ultra-dense hydrogen H(0). *PLoS ONE* **12**, e0169895 (2017b). <https://doi.org/10.1371/journal.pone.0169895>
- Holmlid, L.: The solar wind proton ejection mechanism: experiments with ultra-dense hydrogen agree with observed velocity distributions. *J. Geophys. Res.* **122**, 7956–7962 (2017c). <https://doi.org/10.1002/2017JA024498>
- Holmlid, L.: Rotational emission spectroscopy in ultra-dense hydrogen p(0) and p_xD_y(0): groups p_N, pD₂, p₂D and (pD)_N. *J. Mol. Struct.* **1173**, 567–573 (2018a). <https://doi.org/10.1016/j.molstruc.2018.06.116>
- Holmlid, L.: Ultra-dense hydrogen H(0) as stable dark matter in the Universe: ERE (extended red emissions) spectra agree with rotational transitions in H(0). *Astrophys. J.* **866**, 107 (2018b). <https://doi.org/10.3847/1538-4357/aad4a1>
- Holmlid, L., Fuelling, S.R.: Meissner effect in ultra-dense protium p($l = 0, s = 2$) at room temperature: superconductivity in large clusters of spin-based matter. *J. Clust. Sci.* **26**, 1153–1170 (2015). <https://doi.org/10.1007/s10876-014-0804-3>
- Holmlid, L., Olafsson, S.: Spontaneous ejection of high-energy particles from ultra-dense deuterium D(0). *Int. J. Hydrog. Energy* **40**, 10559–10567 (2015a). <https://doi.org/10.1016/j.ijhydene.2015.06.116>
- Holmlid, L., Olafsson, S.: Muon detection studied by pulse-height energy analysis: novel converter arrangements. *Rev. Sci. Instrum.* **86**, 083306 (2015b). <https://doi.org/10.1063/1.4928109>
- Holmlid, L., Olafsson, S.: Charged particle energy spectra from laser-induced processes: nuclear fusion in ultra-dense deuterium D(0). *Int. J. Hydrog. Energy* **41**, 1080–1088 (2016). <https://doi.org/10.1016/j.ijhydene.2015.10.072>
- Holmlid, L., Zeiner-Gundersen, S.: Ultradense protium p(0) and deuterium D(0) and their relation to ordinary Rydberg matter: a review. *Phys. Scr.* **74**(7) (2019). <https://doi.org/10.1088/1402-4896/ab1276>
- Manykin, É.A., Ozhovan, M.I., Poluéktov, P.P.: Condensed states of excited cesium atoms. *Sov. Phys. JETP* **75**, 440 (1992)
- Olofson, F., Andersson, P.U., Holmlid, L.: Rydberg Matter clusters of alkali metal atoms: the link between meteoritic matter, polar mesosphere summer echoes (PMSE), sporadic sodium layers, polar mesospheric clouds (PMCs, NLCs), and ion chemistry in the mesosphere. *arXiv.org* 2010-02-08. [arXiv:1002.1570](https://arxiv.org/abs/1002.1570)
- White, J.C.: In: Mollenauer, L.F., White, J.C., Pollock, C.R. (eds.) *Tunable Lasers*, 2nd edn. Topics in Applied Physics, vol. 59. Springer, Berlin (1992)
- Winterberg, F.: Ultradense deuterium. *J. Fusion Energy* **29**, 317 (2010a)
- Winterberg, F.: Ultra-dense deuterium and cold fusion claims. *Phys. Lett. A* **374**, 2766 (2010b)
- Yariv, A.: *Quantum Electronics*, 3rd edn. Wiley, New York (1989)