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Emission spectroscopy of IR laser-induced processes in ultra-dense deuterium D(0): Rotational transitions in D(0) with spin values $s = 2$, 3 and 4

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ABSTRACT

The emission spectrum induced in ultra-dense deuterium D(0) by a 1064 nm pulsed YAG laser with 0.4 J pulses is strongly dependent on the amount of D(0) formed. With D_2 pressure below 10^{-2} mbar at the D(0) generator and no D(0) layer on the metal surface, line spectra can be observed with numerous lines due to metal and gas atoms. When a D(0) layer exists on the generator surface, these lines disappear. A different pattern of emission lines and bands is then found. Several peaks are observed which agree well with the rotational transitions of rotating D-D pairs in D(0) from theory. The peak widths are approximately 20 cm^{-1}. A prominent peak at 760 nm corresponds to spin state $s = 3$ in D(0) from a rotational transition $J = 1 \rightarrow 0$. This gives an experimental D-D distance in this state of 5.052 ± 0.003 pm that is only 0.25% larger than predicted by theory and calculations. The existence of these rotational lines strongly supports the cluster model of D(0) described previously. At a few hundred mbar pressure, a red-emitting apparently self-focused beam is formed by the laser beam. The expected Balmer lines are weak or absent.

1. Introduction

Experimental studies of ultra-dense hydrogen H(0) [1–3] prove that well-defined quantized H-H distances exist in the picometer range. The most commonly observed distance is close to 2.3 pm [4]. A theoretical description of H(0) was published in 2013 [3]. It employs the third level of matter, built on the so called quantum electron radius [5] $r_q = \hbar/2m_ec = 0.1931$ pm (at the Compton scale [6]) for its basic structure, and on the first level of matter through the London penetration depth [5] for its super properties. In this type of description, ordinary matter is the second (intermediate level), built on the Bohr radius $a_0 = 2r_q/\alpha$ where α is the fine structure constant 1/137.04.

The structure of H(0) has mainly been studied by time-of-flight (TOF) and time-of-flight mass spectrometry (TOF-MS). This material consists primarily of long chain clusters $H_{2N}(0)$, with pairs of H forming the clusters, rotating around the vortex of the cluster [7,8]. Also small clusters like $H_4(0)$ exist in the material [9], without any super properties [10] due to the lack of a central axis. The chain clusters can form ordered layers on a metal surface [11]. A quite well-defined transition temperature exists for these layers, from the superfluid state at low temperature to a non-superfluid state consisting only of small clusters like $H_4(0)$ at high temperature above a few hundred K [12]. The scattering of D^+ ions against layers of D(0) was studied [13] and it was shown that the surface was covered entirely by $D_3(0)$ and $D_4(0)$ clusters at a few hundred degrees C. Scattering by $D_3(0)$ and $D_4(0)$ clusters was also observed in gas-phase experiments at higher kinetic energies [14]. The laser-induced ejection (half-collisions) of clusters $H_{2N}(0)$ was also studied in a few publications [1,3,13]. One important process was observed to be rotational excitation of the chain clusters due to their tumbling motion against the surface. This process has basic similarities to the rotational excitation (rotational rainbow) observed for small molecules in molecular-beam surface scattering experiments [15,16].

Optical spectroscopic studies may be used to observe rotational excitations of the $H_{2N}(0)$ clusters due to the very small moments of inertia for the rotational motion caused by the picometer-sized H-H distances. This study is the first giving direct optical spectroscopic evidence of such rotational motion. The interatomic distances derived agree well with theory and calculations, and have a

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precision two orders of magnitude greater than the previous TOF and TOF-MS studies of the chain clusters $H_{2N}(0)$.

2. Theory

Ultra-dense hydrogen H(0) is a quantum material at room temperature. Detailed studies of the structure of D(0) [3,4] and of p(0) [2] have been made. The general form of the clusters forming H(0) is H_{2N}, with the H-H pairs rotating around the main axis of the cluster [17] as shown in Fig. 1. Also smaller clusters with no main axis like $H_4(0)$ exist [9]. The name was changed recently from H(-1) to H(0) [8], since the material is not inverted. Instead of inverted Rydberg matter, it is spin-based Rydberg matter [3] with orbital angular momentum $l = 0$ for the electrons. It is shown to be both superfluid [18,19] and superconductive (Meissner effect [10] observed) at room temperature [7,8]. The Meissner effect means that clusters of H(0) float in the field above the magnet. The measured H-H distances are short, 2.3 pm in the most common spin state $s = 2$ [1,3,4]. The most exact measurement of the normal distance D-D done on clusters of the form D_4 gives 2.15 ± 0.02 pm [9], while theory predicts 2.23 pm [3]. The density of H(0) is close to 10^{29} cm^{-3} or >100 kg cm^{-3} [4,19]. Several spin states with different internuclear distances exist [3]. Several studies have proved the formation of MeV particles from D(0) during laser impact under conditions useful for inertial confinement fusion (ICF) [20–22]. Particle energies up to 50 MeV u^{-1} have been observed [20,23–25]. Most high-MeV particles are neutral at least initially. It is likely that an impinging laser pulse initiates a transition from level $s = 2$ with D-D distance of 2.3 pm, to level $s = 1$ with theoretical distance 0.56 pm [3,26]. At this distance, nuclear reactions are spontaneous and laser-induced nuclear processes are thus relatively easy to start. H(0) is not short-lived but can be retained on a suitable support for days and weeks in a vacuum [19].

Ordinary Rydberg matter (orbital angular momentum l based Rydberg matter) has $l > 0$ for its binding electrons [17]. Ultra-dense hydrogen instead has $l = 0$ and $s > 0$ (1, 2, 3, …), i.e. the spin quantum number for the bonding electrons. Thus, the electrons which give the ultra-dense matter structure have only a spin motion and no orbital motion. This electron spin motion may be interpreted as a motion of the charge with orbit radius $r_q = \hbar/2m_ec = 0.1931$ p.m. and with the velocity of light c ('zitterbewegung') [5]. This spin motion is centered on the D atoms and may give a planar structure for the D-D pairs as in the case of the planar clusters for ordinary Rydberg matter [17]. This means that the interatomic distance in ordinary Rydberg matter which is $d = 2.9\, l^2\, a_0$ is replaced by $d = 2.9\, s^2\, r_q$ for the ultra-dense matter. The Bohr radius is indicated as a_0. This distance formula was shown to be correct for H(0) by direct measurements [3]. Here, 2.9 is a constant called the dimensional ratio determined numerically for ordinary Rydberg matter [27] and confirmed experimentally for ordinary Rydberg matter by radio frequency spectroscopy [28,29].

The D-D pairs in the D_{2N} clusters can rotate around the axis of the cluster. This motion can be excited by collisions and is used to interpret an effect in the time-of-flight spectra from D(0) and p(0) [1,3,13]. There, the initial length of the H_{2N} chain clusters on the surface influences the final kinetic energy of the cluster fragment (due to kinetic energy release KER in the laser-induced Coulomb explosions). To explain the experimental effect with lower translational kinetic energy than expected from theory, a rotational excitation of the separate pairs in the clusters was assumed to take place at ejection from the surface [13]. Due to the short bond distances in the pm range, the rotational quanta are in the eV energy range and above [13] and may thus be observable by visible emission spectrometry. The general equations for rotational transitions are used to calculate the transition energies and wavelengths, using

$$\Delta E_{rot} = \frac{\hbar^2}{I}(J+1)$$

with the moment of inertia $I = \mu$ u d^2 for a diatomic pair of nuclei D-D in given spin state s. The reduced mass is μ and the mass unit is u.

3. Experimental

The vacuum chamber used is pumped by a forevacuum pump to a base pressure of 2×10^{-3} mbar. It is a short cylinder with diameter 100 mm, as shown in Fig. 2. In the H(0) generator part, several potassium doped iron oxide catalyst samples [30–32] form D(0) from deuterium gas (99.8% purity). Some of the ultra-dense material formed stays on the generator upper surface, where the laser interacts with it. The gas pressure in the chamber is up to 0.6 mbar (uncorrected Pirani gauge reading) with constant pumping and up to 500 mbar with gas filling.

The laser used was a Nd:YAG laser with pulse energy <0.4 J at 1064 nm and pulse length 7 ns. The pulse repetition rate was 10 Hz. The laser beam was focused with an $f = 40$ mm lens at a point approximately 1 cm above the generator surface. This means a laser intensity of $<4 \times 10^{13}$ W cm^{-2} for a Gaussian beam outside the surface with D(0). The light from the interaction is taken out

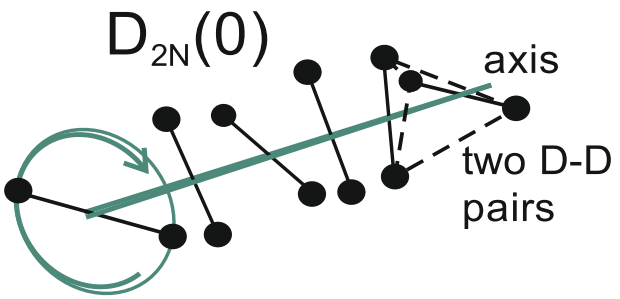

Fig. 1. Rotational motion in the D(0) clusters of one D-D pair. Two D-D pairs which may be coupled are shown.

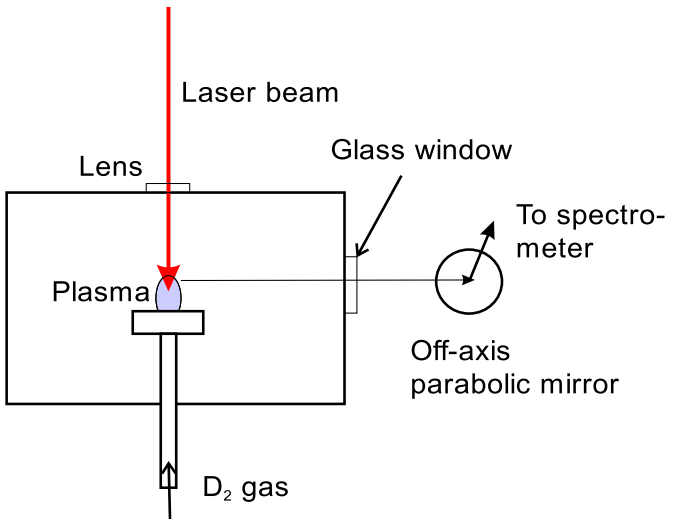

Fig. 2. Principle of the apparatus used, vertical cut. The laser is focused 1 cm above the target. Diameter of chamber is 10 cm.

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