

Identification of New Hydrogen States

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ABSTRACT

Classical physical laws predict that atomic hydrogen may undergo a catalytic reaction with certain species including itself that can accept energy in integer multiples of the potential energy of atomic hydrogen, $m \cdot 27.2 \text{ eV}$ wherein m is an integer. The predicted reaction involves a resonant, nonradiative energy transfer from otherwise stable atomic hydrogen to the catalyst capable of accepting the energy. The product is $H(1/p)$, fractional Rydberg states of atomic hydrogen called “hydrino atoms” wherein $n = \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \dots, \frac{1}{p}$ ($p \leq 137$ is an integer) replaces the well-known parameter $n = \text{integer}$ in the Rydberg equation for hydrogen excited states. Each atomic hydrino state also comprises an electron, a proton, and a photon, but the field contribution from the photon increases the binding rather than decreasing it corresponding to energy desorption rather than absorption. Since the potential energy of atomic hydrogen is 27.2 eV , one or more (m) H atoms can act as a catalyst for a given H by accepting $m \cdot 27.2 \text{ eV}$ from it. Following the nonradiative energy transfer, further energy as characteristic continuum radiation having a short-wavelength cutoff of $m^2 \cdot 13.6 \text{ eV}$ is released as the hydrino transitions to a final stable radius of $1/(1+m)$ that of H . The transition also selectively produces extraordinary high-kinetic energy H . Hydrino transitions were observed experimentally by the predicted catalyst excitation, continuum emission, and hot H . Similar to the case with the 21 cm (1.42 GHz) line of ordinary hydrogen, hydrino atoms were identified by its predicted 642 GHz spin-nuclear hyperfine transition observed by TeraHz absorption spectroscopy of cryogenically cooled H_2 below 35K. Hydrinos react to form molecular hydrino and hydrino hydride ions that are much more stable than the ordinary variants and have characteristic predicted energies, spectra, and NMR shifts. Synthesized and naturally occurring molecular hydrino were observed by electron beam excited ro-vibrational spectral emission and proton NMR. Hydrino hydride ions were observed by proton NMR and XPS. The hydrino continua spectra directly and indirectly match significant celestial observations and the characteristics of hydrino indicate that it is the dark matter.

Key Words: catalysis, EUV continua, hyperfine line, ro-vibrational spectroscopy, NMR, XPS

I. Background

J. R. Rydberg showed that all of the spectral lines of atomic hydrogen were given by a completely empirical relationship:

$$\bar{\nu} = R \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right) \quad (1)$$

where $R = 109,677 \text{ cm}^{-1}$, $n_f = 1, 2, 3, \dots$, $n_i = 2, 3, 4, \dots$ and $n_i > n_f$. Bohr, Schrödinger, and Heisenberg, each developed a theory for atomic hydrogen that gave the energy levels in agreement with Rydberg's equation.

$$E_n = -\frac{e^2}{n^2 8\pi\epsilon_0 a_H} = -\frac{13.598 \text{ eV}}{n^2} \quad (2)$$

$$n = 1, 2, 3, \dots \quad (3)$$

where e is the elementary charge, ϵ_0 is the permittivity of vacuum, and a_H is the radius of the hydrogen atom. The Rydberg equation is a simple integer formula that empirically represents the Rydberg series of spectral lines, the entire hydrogen spectrum given in terms of the differences between all of the principal energy levels of the hydrogen atom. Reproducing this equation was seen as validation of models proposed for the one-electron atom. The Bohr theory was the first success, but failed to physically predict the stability of the $n=1$ state as well as the splitting of the spectral lines in a magnetic field and other atomic observables beyond the Rydberg series of lines. Consequently, Schrödinger proposed that the electron charge as a “cloud” obeyed a three-dimensional wave equation. This model was later modified by Born who proposed a point electron existing everywhere at once weighed statistically so that only an expectation value as a single-valued observable is obtained with measurement that “collapses” the infinity of simultaneous values. This current model is untenable physically; rather, it is purely mathematical and relies on a mathematical definition for the stability of the $n=1$ state [1-13]. Consequently, it is disproved on mathematical inconsistency grounds by the existence of lower-states confirmed by the data presented herein wherein the mathematics does not allow for such states. Moreover, it is even mathematically inconsistent in the excited state quantum numbers. The principal quantum number is defined as the integer radial quantum number minus the integer angular quantum number. But, experimentally the angular or orbital quantum number is multi-valued for any principal quantum number causing the internal inconsistency that the radial quantum number must be multi-valued for a given principal quantum number [14].

In contrast to the current point-particle models that are physically flawed or not based on physics at all, Mills [1-13] solved the structure of the bound electron using classical laws. In closed-form equations containing fundamental constants only, this solution naturally and intuitively predicts all of the hydrogen-atom observables including those not predicted by the

Schrodinger equation nor adequately solved by supplemental theories such as those of Dirac and quantum electrodynamics. Mills subsequently extended the classical solutions to multielectron atoms and essentially all forms of bonding in matter using two basic equations having analytical solutions that match measured parameters of molecules and even their imaged structure to the limit of observation; whereas, quantum mechanics does not (Figures 1 and 2) [2-3], and developed a unification theory based on the classical laws called the Grand Unified Theory of Classical Physics (GUTCP) with results that further match observations for the basic phenomena of physics and chemistry from the scale of the quarks to cosmos.

The structure of the bound atomic electron was solved by first considering one-electron atoms [1-13]. Since the hydrogen atom is stable and nonradiative, the electron has constant energy. Furthermore, it is time dynamic with a corresponding current that serves as a source of electromagnetic radiation during transitions. The wave equation solutions of the radiation fields permit the source currents to be determined as a boundary-value problem. These source currents match the field solutions of the wave equation for two dimensions plus time and the nonradiative $n=1$ state when the nonradiation condition is applied. Then, the mechanics of the electron can be solved from the two-dimensional wave equation plus time in the form of an energy equation wherein it provides for conservation of energy and angular momentum as given in the Electron Mechanics and the Corresponding Classical Wave Equation for the Derivation of the Rotational Parameters of the Electron section of Ref. [1]. Once the nature of the electron is solved, all problems involving electrons can be solved in principle. Thus, in the case of one-electron atoms, the electron radius, binding energy, and other parameters are solved after solving for the nature of the bound electron.

II. Classical Solution of Hydrogen States

For time-varying spherical electromagnetic fields, Jackson [16] gives a generalized expansion in vector spherical waves that are convenient for electromagnetic boundary-value problems possessing spherical symmetry properties and for analyzing multipole radiation from a localized source distribution. The Green function $G(\mathbf{x}', \mathbf{x})$ that is appropriate to the equation

$$(\nabla^2 + k^2)G(\mathbf{x}', \mathbf{x}) = -\delta(\mathbf{x}' - \mathbf{x}) \quad (4)$$

in the infinite domain with the spherical wave expansion for the outgoing wave Green function is

$$G(\mathbf{x}', \mathbf{x}) = \frac{e^{-ik|\mathbf{x}-\mathbf{x}'|}}{4\pi|\mathbf{x}-\mathbf{x}'|} = ik \sum_{\ell=0}^{\infty} j_{\ell}(kr_{<}) h_{\ell}^{(1)}(kr_{>}) \sum_{m=-\ell}^{\ell} Y_{\ell,m}^*(\theta', \phi') Y_{\ell,m}(\theta, \phi) \quad (5)$$

Jackson [16] further gives the general multipole field solution to Maxwell's equations in a source-free region of empty space with the assumption of a time dependence $e^{i\omega_n t}$:

$$\begin{aligned}\mathbf{B} &= \sum_{\ell,m} \left[a_E(\ell,m) f_\ell(kr) \mathbf{X}_{\ell,m} - \frac{i}{k} a_M(\ell,m) \nabla \times g_\ell(kr) \mathbf{X}_{\ell,m} \right] \\ \mathbf{E} &= \sum_{\ell,m} \left[\frac{i}{k} a_E(\ell,m) \nabla \times f_\ell(kr) \mathbf{X}_{\ell,m} + a_M(\ell,m) g_\ell(kr) \mathbf{X}_{\ell,m} \right]\end{aligned}\quad (6)$$

where the cgs units used by Jackson are retained in this section. The radial functions $f_\ell(kr)$ and $g_\ell(kr)$ are of the form:

$$g_\ell(kr) = A_\ell^{(1)} h_\ell^{(1)} + A_\ell^{(2)} h_\ell^{(2)} \quad (7)$$

$\mathbf{X}_{\ell,m}$ is the vector spherical harmonic defined by

$$\mathbf{X}_{\ell,m}(\theta, \phi) = \frac{1}{\sqrt{\ell(\ell+1)}} \mathbf{L} Y_{\ell,m}(\theta, \phi) \quad (8)$$

where

$$\mathbf{L} = \frac{1}{i} (\mathbf{r} \times \nabla) \quad (9)$$

The coefficients $a_E(\ell, m)$ and $a_M(\ell, m)$ of Eq. (6) specify the amounts of electric (ℓ, m) multipole and magnetic (ℓ, m) multipole fields, and are determined by sources and boundary conditions as are the relative proportions in Eq. (7). Jackson gives the result of the electric and magnetic coefficients from the sources as

$$a_E(\ell, m) = \frac{4\pi k^2}{i\sqrt{\ell(\ell+1)}} \int Y_\ell^{m*} \left\{ \rho \frac{\partial}{\partial r} [r j_\ell(kr)] + \frac{ik}{c} (\mathbf{r} \cdot \mathbf{J}) j_\ell(kr) - ik \nabla \cdot (\mathbf{r} \times \mathbf{M}) j_\ell(kr) \right\} d^3x \quad (10)$$

and

$$a_M(\ell, m) = \frac{-4\pi k^2}{\sqrt{\ell(\ell+1)}} \int j_\ell(kr) Y_\ell^{m*} \mathbf{L} \cdot \left(\frac{\mathbf{J}}{c} + \nabla \times \mathbf{M} \right) d^3x \quad (11)$$

respectively, where the distribution of charge $\rho(\mathbf{x}, t)$, current $\mathbf{J}(\mathbf{x}, t)$, and intrinsic magnetization $\mathbf{M}(\mathbf{x}, t)$ are harmonically varying sources: $\rho(\mathbf{x})e^{-i\omega t}$, $\mathbf{J}(\mathbf{x})e^{-i\omega t}$, and $\mathbf{M}(\mathbf{x})e^{-i\omega t}$.

The electron current-density function can be solved as a boundary value problem regarding the time varying corresponding source current $\mathbf{J}(\mathbf{x})e^{-i\omega t}$ that gives rise to the time-varying spherical electromagnetic fields during transitions between states with the further constraint that the electron is nonradiative in a state defined as the $n=1$ state. The potential energy, $V(\mathbf{r})$, is an inverse-radius-squared relationship given by Gauss' law which for a point charge or a two-dimensional spherical shell at a distance r from the nucleus the potential is

$$V(r) = -\frac{e^2}{4\pi\epsilon_0 r} \quad (12)$$

Thus, consideration of conservation of energy would require that the electron radius must be fixed. Addition constraints requiring a two-dimensional source current of fixed radius are matching the delta function of Eq. (4) with no singularity, no time dependence and consequently no radiation, absence of self-interaction (See Appendix II of Ref. [1]), and exact electroneutrality of the hydrogen atom wherein the electric field is given by

$$\mathbf{n} \cdot (\mathbf{E}_1 - \mathbf{E}_2) = \frac{\sigma_s}{\epsilon_0} \quad (13)$$

where $\mathbf{n}$ is the normal unit vector, $\mathbf{E}_1$ and $\mathbf{E}_2$ are the electric field vectors that are discontinuous at the opposite surfaces, σ_s is the discontinuous two-dimensional surface charge density, and $\mathbf{E}_2 = 0$. Then, the solution for the radial electron function, which satisfies the boundary conditions is a delta function in spherical coordinates—a spherical shell [17]

$$f(r) = \frac{1}{r^2} \delta(r - r_n) \quad (14)$$

where r_n is an allowed radius. This function defines the charge density on a spherical shell of a fixed radius (See Figure 3), not yet determined, with the charge motion confined to the two-dimensional spherical surface. The integer subscript n is *determined during photon absorption* as given in the Excited States of the One-Electron Atom (Quantization) section of Ref. [1]. It is shown in this section that the force balance between the electric fields of the electron and proton plus any resonantly absorbed photons gives the result that $r_n = nr_1$ wherein n is an integer in an excited state.

Given time harmonic motion and a radial delta function, the relationship between an allowed radius and the electron wavelength is given by

$$2\pi r_n = \lambda_n \quad (15)$$

Based on conservation of the electron's angular momentum of $\hbar$, the magnitude of the velocity and the angular frequency for *every* point on the surface of the bound electron are

$$v_n = \frac{h}{m_e \lambda_n} = \frac{h}{m_e 2\pi r_n} = \frac{\hbar}{m_e r_n} \quad (16)$$

$$\omega_n = \frac{\hbar}{m_e r_n^2} \quad (17)$$

To further match the required multipole electromagnetic fields between transitions of states, the trial nonradiative source current functions are time and spherical harmonics, each having an exact radius and an exact energy. Then, each allowed electron charge-density (mass-density) function is the product of a radial delta function ($f(r) = \frac{1}{r^2} \delta(r - r_n)$), two angular functions (spherical harmonic functions $Y_\ell^m(\theta, \phi) = P_\ell^m(\cos \theta) e^{im\phi}$), and a time-harmonic function $e^{im\omega_n t}$. The spherical harmonic $Y_0^0(\theta, \phi) = 1$ is also an allowed solution that is in fact required in order

for the electron charge and mass densities to be positive definite and to give rise to the phenomena of electron spin. The real parts of the spherical harmonics vary between -1 and 1 . But the mass of the electron cannot be negative; and the charge cannot be positive. Thus, to insure that the function is positive definite, the form of the angular solution must be a superposition:

$$Y_0^0(\theta, \phi) + Y_\ell^m(\theta, \phi) \quad (18)$$

The current is constant at every point on the surface for the s orbital corresponding to $Y_0^0(\theta, \phi)$.

The quantum numbers of the spherical harmonic currents can be related to the observed electron orbital angular momentum states. The currents corresponding to s, p, d, f, etc. orbitals are

$$\ell = 0$$

$$\rho(r, \theta, \phi, t) = \frac{e}{8\pi r^2} [\delta(r - r_n)] [Y_0^0(\theta, \phi) + Y_\ell^m(\theta, \phi)] \quad (19)$$

$$\ell \neq 0$$

$$\rho(r, \theta, \phi, t) = \frac{e}{4\pi r^2} [\delta(r - r_n)] [Y_0^0(\theta, \phi) + \text{Re}\{Y_\ell^m(\theta, \phi)e^{im\omega_n t}\}] \quad (20)$$

where $Y_\ell^m(\theta, \phi)$ are the spherical harmonic functions that spin about the z-axis with angular frequency ω_n with $Y_0^0(\theta, \phi)$ the constant function and $\text{Re}\{Y_\ell^m(\theta, \phi)e^{im\omega_n t}\} = P_\ell^m(\cos\theta)\cos(m\phi + m\omega_n t)$.

The properties of radiative stability and instability are predicted by Maxwell's equations from the electron source currents. The power density $P(t)$ given by the Poynting power vector is

$$P(t) = \mathbf{E} \times \mathbf{H} \quad (21)$$

For a pure multipole of order (ℓ, m) , the time-averaged power radiated per solid angle $\frac{dP(\ell, m)}{d\Omega}$

given by Jackson [18] is

$$\frac{dP(\ell, m)}{d\Omega} = \frac{c}{8\pi k^2} |a_M(\ell, m)|^2 |\mathbf{X}_{\ell, m}|^2 \quad (22)$$

where $a_M(\ell, m)$ is given by Eq. (11). Since the modulation function $Y_{\ell, m}(\theta, \phi)$ is a traveling charge-density wave that moves time harmonically on the surface of the orbitsphere, spins about the z-axis with frequency ω_n , and modulates at $m\omega_n$ (Eq. (20)), the limits of integration of 0 to 2π of independent spatial variable ϕ can correspondingly be replaced with a change of the spatial variable to azimuthal distance s . As shown in Ref. [1], the magnetic coefficient derived from the three-space integral of the source current evaluated in Eq. (11), can be written as

$$a_M(\ell, m) = \frac{-ek^2}{c\sqrt{\ell(\ell+1)}} \frac{\omega_n}{2\pi} Nj_\ell(kr_n) \Theta \int_0^{vT_n} \cos(ks) ds \quad (23)$$

where s is the distance along a current path with the corresponding limit of integration being the angular displacement of the rotating modulation function during one period T_n at the linear velocity in the $\hat{\phi}$ direction of v , and k is the wavenumber corresponding to the angular frequency. Thus,

$$a_M(\ell, m) = \frac{-ek^2}{c\sqrt{\ell(\ell+1)}} \frac{\omega_n}{2\pi} Nj_\ell(kr_n) \Theta \sin(ks) \quad (24)$$

In the case that k is the lightlike k^0 , then $k = \omega_n / c$, regarding a potentially emitted photon the $\sin(ks)$ term in Eq. (24) vanishes for

$$s = vT_n = R = r_n = \lambda_n \quad (25)$$

Then, the multipole coefficient $a_M(\ell, m)$ and consequently the time-averaged power radiated per solid angle $\frac{dP(\ell, m)}{d\Omega}$ given by Eqs (24) and (22) is zero. *There is no radiation.*

The same nonradiative result follows from Eq. (25) using the Fourier transform of the electron current function (Eq. (20)) and the boundary condition of Haus [19], radiation due to charge motion does not occur in any medium when spacetime harmonics of $\frac{\omega_n}{c} = k$ or

$$\frac{\omega_n}{c} \sqrt{\frac{\epsilon}{\epsilon_0}} = k \text{ for which the Fourier transform of the current-density function is nonzero do not}$$

exist. When this boundary condition is met, there is acceleration without radiation. (Also see Abbott and Griffiths and Goedecke [20-21]). However, in the case that such a state arises as an excited state by photon absorption, it is radiative due to a radial dipole term in its current-density function since it possesses spacetime Fourier transform components synchronous with waves traveling at the speed of light as shown in the Instability of Excited States section of Ref. [1]. *The radiation emitted or absorbed during electron transitions is the multipole radiation given by Eq. (5) as given in the Excited States of the One-Electron Atom (Quantization) section and the Equation of the Photon section of Ref. [1] wherein Mills Eqs. (4.18-4.23) give a macro-spherical wave in the far-field.*

In Chapter 1 of Ref. [1], the uniform current density function $Y_0^0(\theta, \phi)$ (Eqs. (19-20)) that gives rise to the spin of the electron is generated from two current-vector fields (CVFs). Each CVF comprises a continuum of correlated *orthogonal great circle current-density elements (one dimensional "current loops")*. The current pattern comprising each CVF is generated over a half-sphere surface by a set of rotations of two orthogonal great circle current loops that serve as basis elements about each of the $(-\mathbf{i}_x, \mathbf{i}_y, 0\mathbf{i}_z)$ and $\left(-\frac{1}{\sqrt{2}}\mathbf{i}_x, \frac{1}{\sqrt{2}}\mathbf{i}_y, \mathbf{i}_z\right)$ -axis; the span being π radians. Then, the two CVFs are convoluted, and the result is normalized to exactly generate the

continuous uniform electron current density function $Y_0^0(\theta, \phi)$ covering a spherical shell and having the three angular momentum components of $\mathbf{L}_{xy} = +/\!-\frac{\hbar}{4}$ ($+/\!-$ designates both the positive and negative vector directions along an axis in the xy-plane) and $\mathbf{L}_z = \frac{\hbar}{2}$. A representation of the $\left(-\frac{1}{\sqrt{2}}\mathbf{i}_x, \frac{1}{\sqrt{2}}\mathbf{i}_y, \mathbf{i}_z\right)$ -axis view of the total uniform current-density pattern of the $Y_0^0(\phi, \theta)$ orbitsphere with 144 vectors overlaid on the continuous bound-electron current density giving the direction of the current of each great circle element is shown in Figure 4. This superconducting current pattern is confined to two spatial dimensions.

Thus, a bound electron is a constant two-dimensional spherical surface of charge (zero thickness and total charge $= -e$), called an electron orbitsphere that can exist in a bound state at only specified distances from the nucleus determined by an energy minimum for the $n=1$ state and integer multiples of this radius due to the action of resonant photons as shown in the Determination of Orbitsphere Radii section and Excited States of the One-Electron Atom (Quantization) section of Ref. [1], respectively. The bound electron is not a point, but it is point-like (behaves like a point at the origin). The free electron is continuous with the bound electron as it is ionized and is also point-like as shown in the Electron in Free Space section of Ref. [1]. The total function that describes the spinning motion of each electron orbitsphere is composed of two functions. One function, the spin function (see Figure 3 for the charge function and Figure 4 for the current function), is spatially uniform over the orbitsphere, where each point moves on the surface with the same quantized angular and linear velocity, and gives rise to spin angular momentum. It corresponds to the nonradiative $n=1, \ell=0$ state of atomic hydrogen which is well known as an s state or orbital. The other function, the modulation function, can be spatially uniform—in which case there is no orbital angular momentum and the magnetic moment of the electron orbitsphere is one Bohr magneton—or not spatially uniform—in which case there is orbital angular momentum. The modulation function rotates with a quantized angular velocity about a specific (by convention) z-axis. The constant spin function that is modulated by a time and spherical harmonic function as given by Eq. (20) is shown in Figure 5 for several ℓ values. The modulation or traveling charge-density wave that corresponds to an orbital angular momentum in addition to a spin angular momentum are typically referred to as p, d, f, etc. orbitals and correspond to an ℓ quantum number not equal to zero.

It was shown previously [1-13] that classical physics gives closed form solutions for the atom including the stability of the $n=1$ state and the instability of the excited states, the equation of the photon and electron in excited states, the equation of the free electron, and photon which predict the wave particle duality behavior of particles and light. The current and

charge density functions of the electron may be directly physically interpreted. For example, spin angular momentum results from the motion of negatively charged mass moving systematically, and the equation for angular momentum, $\mathbf{r} \times \mathbf{p}$, can be applied directly to the wavefunction (a current density function) that describes the electron. The magnetic moment of a Bohr magneton, Stern Gerlach experiment, g factor, Lamb shift, resonant line width and shape, selection rules, correspondence principle, wave-particle duality, excited states, excited-state lifetimes, reduced mass, rotational energies, and momenta, orbital and spin splitting, spin-orbital coupling, Knight shift, and spin-nuclear coupling are derived in closed form equations based on Maxwell's equations. The agreement between observations and predictions based on closed-form equations with fundamental constants only matches to the limit permitted by the error in the measured fundamental constants.

III. Prediction of Hydrino States

From the success at predicting the vast scope of known phenomena, it can be appreciated that CP is anticipated to predict new, previously unknown phenomena, as well as now solve previously unsolvable mysteries for which old theories were incapable. In addition to the observables on the hydrogen atom that are known, classical laws predict a reaction involving a resonant, nonradiative energy transfer from otherwise stable atomic hydrogen to a catalyst capable of accepting the energy to form hydrogen in lower-energy states than previously thought possible. The excited energy states of atomic hydrogen are given by Eq. (3) for $n > 1$ in Eq. (2). The $n = 1$ state is the “ground” state for “pure” photon transitions (i.e. the $n = 1$ state can absorb a photon and go to an excited electronic state, but it cannot release a photon and go to a lower-energy electronic state). However, an electron transition from the ground state to a lower-energy state may be possible by a resonant nonradiative energy transfer such as multipole coupling or a resonant collision mechanism. Processes such as hydrogen molecular bond formation that occur without photons and that require collisions are common [22]. Also, some commercial phosphors are based on resonant nonradiative energy transfer involving multipole coupling [23]. Specifically, atomic hydrogen may undergo a catalytic reaction with certain atomized elements and ions which singly or multiply ionize at integer multiples of the potential energy of atomic hydrogen, $m \cdot 27.2 \text{ eV}$ wherein m is an integer. The predicted reaction involves a resonant, nonradiative energy transfer from otherwise stable atomic hydrogen to the catalyst capable of accepting the energy. The product is $H(1/p)$, fractional Rydberg states of atomic hydrogen called “hydrino atoms” wherein $n = \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \dots, \frac{1}{p}$ ($p \leq 137$ is an integer) replaces the well-known parameter $n = \text{integer}$ in the Rydberg equation for hydrogen excited states.

The data from a broad spectrum of investigational techniques strongly and consistently indicates that hydrogen can exist in lower-energy states than previously thought possible and support the existence of these states called hydrino, for “small hydrogen,” and the corresponding hydride ions and molecular hydrino. Some of these prior related studies supporting the possibility of a novel reaction of atomic hydrogen, which produces hydrogen in fractional quantum states that are at lower energies than the traditional “ground” ($n=1$) state, include extreme ultraviolet (EUV) spectroscopy, characteristic emission from catalysts and the hydride ion products, lower-energy hydrogen emission, chemically-formed plasmas, Balmer α line broadening, population inversion of H lines, elevated electron temperature, anomalous plasma afterglow duration, power generation, and analysis of novel chemical compounds [24-75]. The basis of each signature can be understood from a more detailed understanding of the mechanism of the hydrino transition given in Secs. IV-VI.

Recently, there has been the announcement of some unexpected astrophysical results that support the existence of hydrinos. In the 1995 Edition of the GUTCP, the prediction [76] that the expansion of the universe was accelerating was made from the same equations that correctly predicted the mass of the top quark before it was measured. To the astonishment of cosmologists, this was confirmed by 2000. Another prediction about the nature of dark matter based on GUTCP may be close to being confirmed. Based on recent evidence, Bournaud et al. [77-78] suggest that dark matter is hydrogen in dense molecular form that somehow behaves differently in terms of being unobservable except by its gravitational effects. Theoretical models predict that dwarfs formed from collisional debris of massive galaxies should be free of nonbaryonic dark matter. So, their gravity should tally with the stars and gas within them. By analyzing the observed gas kinematics of such recycled galaxies, Bournaud et al. [77-78] have measured the gravitational masses of a series of dwarf galaxies lying in a ring around a massive galaxy that has recently experienced a collision. Contrary to the predictions of Cold-Dark-Matter (CDM) theories, their results demonstrate that they contain a massive dark component amounting to about twice the visible matter. This baryonic dark matter is argued to be cold molecular hydrogen, but it is distinguished from ordinary molecular hydrogen in that it is not traced at all by traditional methods, such as emission of CO lines. These results match the predictions of the dark matter being molecular hydrino.

The best evidence yet for the existence of dark matter is its direct observation as a source of massive gravitational mass evidenced by gravitational lensing of background galaxies that do not emit or absorb light as shown in Figure 6 [79]. Hydrogen transitions to hydrinos that comprise the dark matter can be observed celestially and in the laboratory. Characteristic EUV continua of hydrino transitions following radiationless energy transfer with cutoffs at

$\lambda_{\left(H \rightarrow H\left[\frac{a_H}{p=m+1}\right]\right)} = \frac{91.2}{m^2} \text{ nm}$ are observed from hydrogen plasmas in the laboratory (Figure 7) that

match significant celestial observations and further confirm hydrino as the identity of dark matter [24-25]. Hydrinos have been isolated in the laboratory and confirmed by a number of analytical and spectroscopic techniques [24-75].

IV. Catalyst Reaction Mechanism and Products

Classical physics (CP) gives closed-form solutions of the hydrogen atom, the hydride ion, the hydrogen molecular ion, and the hydrogen molecule and predicts corresponding species having fractional principal quantum numbers. The nonradiative state of atomic hydrogen, which is historically called the “ground state” forms the basis of the boundary condition of CP to solve the bound electron. CP predicts a reaction involving a resonant, nonradiative energy transfer from otherwise stable atomic hydrogen to a catalyst capable of accepting the energy to form hydrogen in lower-energy states than previously thought possible called a **hydrino atom** designated as $H\left[\frac{a_H}{p}\right]$ where a_H is the radius of the hydrogen atom. Specifically, CP predicts that atomic

hydrogen may undergo a catalytic reaction with certain atoms, excimers, ions, and diatomic hydrides which provide a reaction with a net enthalpy of an integer multiple of the potential energy of atomic hydrogen, $E_h = 27.2 \text{ eV}$ where E_h is one Hartree. Specific species (e.g. He^+ , Ar^+ , Sr^+ , K , Li , HCl , and NaH) identifiable on the basis of their known electron energy levels are required to be present with atomic hydrogen to catalyze the process. The reaction involves a nonradiative energy transfer of an integer multiple of 27.2 eV from atomic hydrogen to the catalyst followed by $q \cdot 13.6 \text{ eV}$ continuum emission or $q \cdot 13.6 \text{ eV}$ transfer to another H to form extraordinarily hot, excited-state H and a hydrogen atom that is lower in energy than unreacted atomic hydrogen that corresponds to a fractional principal quantum number. That is, in the formula for the principal energy levels of the hydrogen atom given by Eqs. (2-3), fractional quantum numbers:

$$n = 1, \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \dots, \frac{1}{p}; \quad p \leq 137 \text{ is an integer} \quad (26)$$

replace the well known parameter $n = \text{integer}$ in the Rydberg equation for hydrogen excited states. Then, similar to an excited state having the analytical solution of Maxwell’s equations given by Eq. (2.15) of Ref. [1], a hydrino atom also comprises an electron, a proton, and a photon as given by Eq. (5.27) of Ref. [1]. However, the electric field of the latter increases the binding corresponding to desorption of energy rather than decreasing the central field with the absorption of energy as in an excited state, and the resultant photon-electron interaction of the

hydrino is stable rather than radiative

The $n=1$ state of hydrogen and the $n = \frac{1}{\text{integer}}$ states of hydrogen are nonradiative, but

a transition between two nonradiative states, say $n=1$ to $n=1/2$, is possible via a nonradiative energy transfer. Hydrogen is a special case of the stable states given by Eqs. (2) and (26) wherein the corresponding radius of the hydrogen or hydrino atom is given by

$$r = \frac{a_H}{p}, \quad (27)$$

where $p=1,2,3,\dots$. In order to conserve energy, energy must be transferred from the hydrogen atom to the catalyst in units of

$$m \cdot 27.2 \text{ eV}, \quad m=1,2,3,4,\dots \quad (28)$$

and the radius transitions to $\frac{a_H}{m+p}$. The catalyst reactions involve two steps of energy release: a

nonradiative energy transfer to the catalyst followed by additional energy release as the radius decreases to the corresponding stable final state. Thus, the general reaction is given by

$$m \cdot 27.2 \text{ eV} + \text{Cat}^{q+} + H \left[\frac{a_H}{p} \right] \rightarrow \text{Cat}^{(q+r)+} + re^- + H^* \left[\frac{a_H}{(m+p)} \right] + m \cdot 27.2 \text{ eV} \quad (29)$$

$$H^* \left[\frac{a_H}{(m+p)} \right] \rightarrow H \left[\frac{a_H}{(m+p)} \right] + [(p+m)^2 - p^2] \cdot 13.6 \text{ eV} - m \cdot 27.2 \text{ eV} \quad (30)$$

$$\text{Cat}^{(q+r)+} + re^- \rightarrow \text{Cat}^{q+} + m \cdot 27.2 \text{ eV} \quad (31)$$

And, the overall reaction is

$$H \left[\frac{a_H}{p} \right] \rightarrow H \left[\frac{a_H}{(m+p)} \right] + [(p+m)^2 - p^2] \cdot 13.6 \text{ eV} \quad (32)$$

q , r , m , and p are integers. $H^* \left[\frac{a_H}{(m+p)} \right]$ has the radius of the hydrogen atom

(corresponding to $p=1$) and a central field equivalent to $(m+p)$ times that of a proton, and

$H \left[\frac{a_H}{(m+p)} \right]$ is the corresponding stable state with the radius of $\frac{1}{(m+p)}$ that of H . As the

electron undergoes radial acceleration from the radius of the hydrogen atom to a radius of $\frac{1}{(m+p)}$ this distance, energy is released as characteristic light emission or as third-body kinetic

energy. The emission may be in the form of an extreme-ultraviolet continuum radiation having an edge at $[(p+m)^2 - p^2 - 2m] \cdot 13.6 \text{ eV}$ or $\frac{91.2}{[(p+m)^2 - p^2 - 2m]} \text{ nm}$ and extending to longer

wavelengths. In addition to radiation, a resonant kinetic energy transfer to form fast H may occur (See the Dipole-Dipole Coupling section of Ref. [1]). Subsequent excitation of these fast

$H(n=1)$ atoms by collisions with the background H_2 followed by emission of the corresponding $H(n=3)$ fast atoms gives rise to broadened Balmer α emission. A population of extraordinarily high-kinetic-energy hydrogen atoms in certain mixed hydrogen plasma is a well-established phenomenon; however the mechanism has been controversial in that the conventional view that it is due to field acceleration is not supported by the data and critical tests [24, 56-75]. Rather it is shown that the cause is due to the energy released in the formation of hydrinos [24, 56-62]. An additional energetic signature, independently confirmed is the formation of a chemically generated plasma or so-called rt-plasma [29, 36, 47-54] that releases excess power [36, 51].

As given in the Disproportionation of Energy States section of Ref. [1], hydrogen atoms $H(1/p)$ $p=1,2,3,\dots,137$ can undergo further transitions to lower-energy states given by Eqs. (2) and (26) wherein the transition of one atom is catalyzed by a second that resonantly and nonradiatively accepts $m \cdot 27.2 \text{ eV}$ with a concomitant opposite change in its potential energy. The overall general equation for the transition of $H(1/p)$ to $H(1/(p+m))$ induced by a resonance transfer of $m \cdot 27.2 \text{ eV}$ to $H(1/p')$ given by Eq. (5.87) of Ref. [1] is represented by

$$H(1/p') + H(1/p) \rightarrow H + H(1/(p+m)) + [2pm + m^2 - p'^2 + 1] \cdot 13.6 \text{ eV} \quad (33)$$

Hydrogen atoms may serve as a catalyst wherein $m=1$, $m=2$, and $m=3$ for one, two, and three atoms, respectively, acting as a catalyst for another. The rate for the two-atom-catalyst, $2H$, may be high when extraordinarily fast H as reported previously [25, 56-62] collides with a molecule to form the $2H$ wherein two atoms resonantly and nonradiatively accept 54.4 eV from a third hydrogen atom of the collision partners. By the same mechanism, the collision of two hot H_2 provide $3H$ to serve as a catalyst of $3 \cdot 27.2 \text{ eV}$ for the fourth. The EUV continua at 22.8 nm and 10.1 nm, extraordinary ($>100 \text{ eV}$) Balmer α line broadening, highly excited H states, the product gas $H_2(1/4)$, and large energy release is observed consistent with predictions [24-25].

The catalyst product, $H(1/p)$, may also react with an electron to form a hydrino hydride ion $H^-(1/p)$, or two $H(1/p)$ may react to form the corresponding molecular hydrino $H_2(1/p)$. Specifically, the catalyst product, $H(1/p)$, may also react with an electron to form a novel hydride ion $H^-(1/p)$ with a binding energy E_b (Eq. (7.74) of Ref. [1]) derived in the Hydrino Hydride Ion section of Ref. [1]:

$$E_B = \frac{\hbar^2 \sqrt{s(s+1)}}{8\mu_e a_0^2 \left[\frac{1 + \sqrt{s(s+1)}}{p} \right]^2} - \frac{\pi\mu_0 e^2 \hbar^2}{m_e^2} \left(\frac{1}{a_H^3} + \frac{2^2}{a_0^3 \left[\frac{1 + \sqrt{s(s+1)}}{p} \right]^3} \right) \quad (34)$$

where $p = \text{integer} > 1$, $s = 1/2$, $\hbar$ is Planck's constant bar, μ_0 is the permeability of vacuum,

m_e is the mass of the electron, μ_e is the reduced electron mass given by $\mu_e = \frac{m_e m_p}{\frac{m_e}{\sqrt{3}} + m_p}$ where

m_p is the mass of the proton, a_0 is the Bohr radius, and the ionic radius is $r_i = \frac{a_0}{p} (1 + \sqrt{s(s+1)})$

(Eq. (7.73) of Ref. [1]). From Eq. (34), the calculated ionization energy of the hydride ion is 0.75418 eV , and the experimental value given by Lykke [80] is $6082.99 \pm 0.15 \text{ cm}^{-1}$ (0.75418 eV). The binding energies of hydrino hydride ions such as that of $H^-(1/4)$ given by Eq. (34) with $p = 4$ were confirmed by XPS [27-29, 36-39] as shown in Figure 8.

Upfield-shifted NMR peaks are direct evidence of the existence of lower-energy state hydrogen with a reduced radius relative to ordinary hydride ion and having an increase in diamagnetic shielding of the proton. The shift is given by the sum of that of an ordinary hydride ion H^- and a component due to the lower-energy state (Eq. (7.88) of Ref. [1]):

$$\frac{\Delta B_T}{B} = -\mu_0 \frac{e^2}{12m_e a_0 (1 + \sqrt{s(s+1)})} (1 + \alpha 2\pi p) = -(29.9 + 1.37 p) \text{ ppm} \quad (35)$$

where for H^- $p = 0$ and $p = \text{integer} > 1$ for $H^-(1/p)$ and α is the fine structure constant. The predicted peaks were observed by solid and liquid proton or deuterium NMR [25, 27-29, 32, 34-35, 37-39, 41] as shown in Figures 9-12. Upfield shifted peaks were observed in 1H MAS and solution NMR spectra of hydrino compounds produced from reaction mixtures comprising sources of a catalyst and atomic hydrogen during synthesis (Figure 9-11) [32, 34-35, 37-39] and power-producing reactions (Figure 12) [27-29]. The narrower the peak in solid matrix, the less the solid matrix effect shifts and broadens the peak, and the closer the expected agreement between theory and observation. The matrix effect was eliminated by dissolving the hydrino products in liquid solvent obtaining essentially free ions [29]. Using Eq. (35) with $p = 4$ and the experimental absolute resonance shift of TMS, -31.5 ppm , the predicted gas-phase shift of $H^-(1/4)$ is -3.88 ppm that is extraordinarily close to the observed shift of -3.85 ppm . The results were independently confirmed by Rowan University on synthesized hydrino hydride compounds [32] and products of heat producing reactions that were characterized by water flow

calorimetry [34-35]. The presence of hydrinos trapped in alkali halide crystals was further confirmed by Rowan using neutron diffraction [32].

$H(1/p)$ may react with a proton and two $H(1/p)$ may react to form $H_2(1/p)^+$ and $H_2(1/p)$, respectively. The hydrogen molecular ion and molecular charge and current density functions, bond distances, and energies were solved in the Nature of the Chemical Bond of Hydrogen-Type Molecules and Molecular Ions section of Ref. [1] from the Laplacian in ellipsoidal coordinates with the constraint of nonradiation.

$$(\eta - \zeta)R_\xi \frac{\partial}{\partial \xi} (R_\xi \frac{\partial \phi}{\partial \xi}) + (\zeta - \xi)R_\eta \frac{\partial}{\partial \eta} (R_\eta \frac{\partial \phi}{\partial \eta}) + (\xi - \eta)R_\zeta \frac{\partial}{\partial \zeta} (R_\zeta \frac{\partial \phi}{\partial \zeta}) = 0 \quad (36)$$

The total energy E_T of the hydrogen molecular ion having a central field of $+pe$ at each focus of the prolate spheroid molecular orbital is (Eqs. (11.192-11.193) of Ref. [1])

$$E_T = -p^2 \left\{ \frac{e^2}{8\pi\epsilon_o a_H} (4 \ln 3 - 1 - 2 \ln 3) \left[1 + p \sqrt{\frac{2\hbar \sqrt{\frac{e^2}{4\pi\epsilon_o (2a_H)^3}}}{m_e c^2}} \right] - \frac{1}{2} \hbar \sqrt{\frac{\frac{pe^2}{4\pi\epsilon_o \left(\frac{2a_H}{p}\right)^3} - \frac{pe^2}{8\pi\epsilon_o \left(\frac{3a_H}{p}\right)^3}}{\mu}} \right\} \quad (37)$$

$$= -p^2 16.13392 \text{ eV} - p^3 0.118755 \text{ eV}$$

where p is an integer, c is the speed of light in vacuum, and μ is the reduced nuclear mass. The total energy of the hydrogen molecule having a central field of $+pe$ at each focus of the prolate spheroid molecular orbital is (Eqs. (11.240-11.241) of Ref. [1])

$$E_T = -p^2 \left\{ \frac{e^2}{8\pi\epsilon_o a_0} \left[\left(2\sqrt{2} - \sqrt{2} + \frac{\sqrt{2}}{2} \right) \ln \frac{\sqrt{2}+1}{\sqrt{2}-1} - \sqrt{2} \right] \left[1 + p \sqrt{\frac{2\hbar \sqrt{\frac{e^2}{4\pi\epsilon_o a_0^3}}}{m_e c^2}} \right] - \frac{1}{2} \hbar \sqrt{\frac{\frac{pe^2}{8\pi\epsilon_o \left(\frac{a_0}{p}\right)^3} - \frac{pe^2}{8\pi\epsilon_o \left(\frac{\left(1+\frac{1}{\sqrt{2}}\right)a_0}{p}\right)^3}}{\mu}} \right\} \quad (38)$$

$$= -p^2 31.351 \text{ eV} - p^3 0.326469 \text{ eV}$$

The bond dissociation energy, E_D , of the hydrogen molecule $H_2(1/p)$ is the difference between the total energy of the corresponding hydrogen atoms and E_T

$$E_D = E(2H(1/p)) - E_T \quad (39)$$

where [81]

$$E(2H(1/p)) = -p^2 27.20 \text{ eV} \quad (40)$$

E_D is given by Eqs. (39-40) and (38):

$$\begin{aligned} E_D &= -p^2 27.20 \text{ eV} - E_T \\ &= -p^2 27.20 \text{ eV} - (-p^2 31.351 \text{ eV} - p^3 0.326469 \text{ eV}) \\ &= p^2 4.151 \text{ eV} + p^3 0.326469 \text{ eV} \end{aligned} \quad (41)$$

The NMR of catalysis-product gas provides a definitive test of the theoretically predicted chemical shift of $H_2(1/4)$. In general, the 1H NMR resonance of $H_2(1/p)$ is predicted to be upfield from that of H_2 due to the fractional radius in elliptic coordinates wherein the electrons are significantly closer to the nuclei. The predicted shift, $\frac{\Delta B_T}{B}$, for $H_2(1/p)$ is given by the sum of that of H_2 and a term that depends on $p = \text{integer} > 1$ for $H_2(1/p)$ (Eq. (11.433) of Ref. [1]):

$$\frac{\Delta B_T}{B} = -\mu_0 \left(4 - \sqrt{2} \ln \frac{\sqrt{2}+1}{\sqrt{2}-1} \right) \frac{e^2}{36a_0 m_e} (1 + \pi \alpha p) \quad (42)$$

$$\frac{\Delta B_T}{B} = -(28.01 + 0.64p) \text{ ppm} \quad (43)$$

where for H_2 $p = 0$. The experimental absolute H_2 gas-phase resonance shift of -28.0 ppm [82-85] is in excellent agreement with the predicted absolute gas-phase shift of -28.01 ppm (Eq. (43)). The predicted NMR peak for the favored product $H_2(1/4)$ at the predicted chemical shift of about 1.25 ppm was observed by solid (Figure 12) and liquid NMR (Figures 10-11 and 13-15) and independently confirmed by Rowan University [32, 34-35]. Gases were cryogenically collected from pulsed plasmas emitting the predicted continuum radiation, power-producing reactions (Figure 14-15) and multiple different plasma sources (11) [25] that also showed fast H including helium-hydrogen, water-vapor-assisted hydrogen, hydrogen, and so-called rt-plasmas involving an incandescently heated mixture of sources of catalyst and hydrogen [47-54]. Liquid NMR samples were prepared by extracting $H_2(1/4)$ into an NMR solvent by adding hydrino compounds and power reaction products to an NMR solvent that was decanted as the sample. Applying the matrix correction obtained by comparing the solution or solid result with the H_2 gas-phase result to the upfield-shifted hydrogen peaks resulted in excellent matches to Eq. (43). Molecular hydrino was also formed and recorded serendipitously. Lu et al. [41] also observed a peak at 1.1 ppm in solid matrix that increased in intensity relative to H_2 at 4.1 ppm with the

duration of in situ heating of $LiH + LiNH_2$ (1.1/1). They were unable to assign the peak labeled unknown in their Figures 8 and 9 that match $H_2(1/4)$.

The identity of dark matter as hydrino and the requirement that it is intragalactic [77-78] implies that $H_2(1/4)$ should be present naturally. Such an unexpected discovery would not be the first time that a common element occurs in new energy states or forms considering carbon is found in fullerene, nanotubes, and graphene in addition to graphitic and diamond form contrary to theory. 1H MAS NMR performed on alkali chlorides showed the $H_2(1/4)$ peak at 1.1 ppm with relative intensities $Na < K < Cs$ as shown in Figure 16.

The vibrational energies, E_{vib} , for the $\nu=0$ to $\nu=1$ transition of hydrogen-type molecules $H_2(1/p)$ are (Eq. (11.223) of Ref. [1])

$$E_{vib} = p^2 0.515902 \text{ eV} \quad (44)$$

where p is an integer and the experimental vibrational energy for the $\nu=0$ to $\nu=1$ transition of H_2 , $E_{H_2(\nu=0 \rightarrow \nu=1)}$, is given by Beutler [86] and Herzberg [87].

The rotational energies, E_{rot} , for the J to $J+1$ transition of hydrogen-type molecules $H_2(1/p)$ are (Eq. (12.74) of Ref. [1])

$$E_{rot} = E_{J+1} - E_J = \frac{\hbar^2}{I} [J+1] = p^2 (J+1) 0.01509 \text{ eV} \quad (45)$$

where p is an integer, I is the moment of inertia, and the experimental rotational energy for the $J=0$ to $J=1$ transition of H_2 is given by Atkins [88]. Ro-vibrational emission of $H_2(1/4)$ was observed on e-beam excited molecules in gases and trapped in solid matrix [29].

The p^2 dependence of the rotational energies results from an inverse p dependence of the internuclear distance and the corresponding impact on the moment of inertia I . The predicted internuclear distance $2c'$ for $H_2(1/p)$ is (Eq. (11.204) of Ref. [1])

$$2c' = \frac{a_o \sqrt{2}}{p} \quad (46)$$

The calculated and experimental parameters of H_2 , D_2 , H_2^+ , and D_2^+ from the Chemical Bond of Hydrogen-Type Molecules section of Ref. [1] are given in Table 1.

Since $H_2(1/4)$ is symmetrical, the otherwise forbidden vibration-rotational emission of $H_2(1/4)$ was induced collisionally by using a 12.5 keV electron gun incident on atmospheric pressure argon. A series of lines were observed that identically matched the spacing and intensity profile of the P branch of $H_2(1/4)$ for the ro-vibrational transitions given Eqs. (44) and (45) with $p=4$, for $\nu=1 \rightarrow \nu=0$ and P(1), P(2), P(3), P(4), and P(5) wherein the slope of the linear curve-fit of the energies of the peaks shown in Figure 17 is 0.25 eV with an intercept of 5.82 eV and a sum of residual errors $r^2 < 10^{-4}$. The linearity is characteristic of rotation, and the

results again match $H_2(1/4)$ [28]. The absence of the R branch is expected since no rotational lines can be populated by thermal excitation due to their excessively high energy.

The same series was previously reported by Murnick et al. as shown in Figure 6 of Ref. [42] and could not be unambiguously assigned by the authors. The series was observed with the same type of e-beam argon plasma with a “contaminant gas” and not observed in krypton and xenon plasmas. The series was further observed in neon gas, but not in helium gas. Although it may be formed during e-beam excitation, the “contaminant” gas that matches $H_2(1/4)$ may occur naturally and may be a component in argon and neon gases. Argon and neon are obtained by fractional distillation of air; whereas, helium is obtained from fractional distillation of natural gas. $H_2(1/4)$ may be a component of air that partitions in liquid argon and liquid neon. This possibility seems to be supported by recent work on hydrogen and deuterium addition that seems to suppress the emission of these lines; however, gas flow seems to decrease the intensity which supports a contribution due to insitu hydrino formation wherein argon and neon serve a source of catalyst [27] or conversion of naturally abundant hydrinos to molecular hydrino.

Natural abundance $H_2(1/4)$ trapped in the lattice of alkali chlorides was also investigated by windowless UV spectroscopy on electron beam excitation of the crystals. The peaks predicted by Eqs. (44) and (45) having an increasing intensity down the column of the Group I elements as predicted were observed (Figure 18) matching the NMR intensity trend (Figure 16). Specifically, the slope matches the predicted rotational energy spacing of 0.241 eV (Eq. (45); $p = 4$) with $J' - J'' = -1$; $J'' = 1, 2, 3, 4, 5, 6$ where J'' is the rotational quantum number of the final state. $H_2(1/4)$ is a free rotator, but is not a free vibrator which is similar to the case of interstitial hydrogen in silicon discussed previously [85-89]. The observed intercept of 5.73 eV is shifted from the predicted $\nu = 1 \rightarrow \nu = 0$ vibrational energy of $H_2(1/4)$ of 8.25 eV (Eq. (44)) by about twice the percentage as that of interstitial H_2 in silicon [80-93] possibly due to an increase in the effective mass from coupling of the molecular vibrational mode with the crystal lattice. These results strongly support naturally abundant hydrinos and prompted the search for the hydrino hyperfine line in hydrogen gas (Sec. VII). In addition, these peaks were increased significantly in intensity with $H_2(1/4)$ trapped in the lattice with the synthesis of hydrino compounds such as KH^*Cl [29].

V. Catalysts

He^+ , Ar^+ , Sr^+ , Li , K , and NaH are predicted to serve as catalysts since they meet the catalyst criterion—a chemical or physical process with an enthalpy change equal to an integer multiple of the potential energy of atomic hydrogen, 27.2 eV. Specifically, a catalytic system is provided by the ionization of t electrons from an atom each to a continuum energy level such

that the sum of the ionization energies of the t electrons is approximately $m \cdot 27.2 \text{ eV}$ where m is an integer. One such catalytic system involves lithium atoms. The first and second ionization energies of lithium are 5.39172 eV and 75.64018 eV , respectively [81]. The double ionization ($t=2$) reaction of Li to Li^{2+} then, has a net enthalpy of reaction of 81.0319 eV , which is equivalent to $3 \cdot 27.2 \text{ eV}$.

$$81.0319 \text{ eV} + Li(m) + H\left[\frac{a_H}{p}\right] \rightarrow Li^{2+} + 2e^- + H\left[\frac{a_H}{(p+3)}\right] + [(p+3)^2 - p^2] \cdot 13.6 \text{ eV} \quad (47)$$

$$Li^{2+} + 2e^- \rightarrow Li(m) + 81.0319 \text{ eV} \quad (48)$$

And, the overall reaction is

$$H\left[\frac{a_H}{p}\right] \rightarrow H\left[\frac{a_H}{(p+3)}\right] + [(p+3)^2 - p^2] \cdot 13.6 \text{ eV} \quad (49)$$

where $m=3$ in Eq. (28). The energy given off during catalysis is much greater than the energy lost to the catalyst. The energy released is large as compared to conventional chemical reactions. For example, when hydrogen and oxygen gases undergo combustion to form water



the known enthalpy of formation of water is $\Delta H_f = -286 \text{ kJ/mole}$ or 1.48 eV per hydrogen atom. By contrast, each ($n=1$) ordinary hydrogen atom undergoing a catalysis step to $n = \frac{1}{2}$ releases a net of 40.8 eV . Moreover, further catalytic transitions may occur: $n = \frac{1}{2} \rightarrow \frac{1}{3}$, $\frac{1}{3} \rightarrow \frac{1}{4}$, $\frac{1}{4} \rightarrow \frac{1}{5}$, and so on. Once catalysis begins, hydrinos autocatalyze further in a process called disproportionation discussed in the Disproportionation of Energy States section of Ref. [1].

Certain molecules may also serve to affect transitions of H to form hydrinos. In general, a compound comprising hydrogen such as MH , where M is an element other than hydrogen, serves as a source of hydrogen and a source of catalyst. A catalytic reaction is provided by the breakage of the $M-H$ bond plus the ionization of t electrons from the atom M each to a continuum energy level such that the sum of the bond energy and ionization energies of the t electrons is approximately $m \cdot 27.2 \text{ eV}$, where m is an integer. One such catalytic system involves sodium hydride. The bond energy of NaH is 1.9245 eV [94], and the first and second ionization energies of Na are 5.13908 eV and 47.2864 eV , respectively [81]. Based on these energies NaH molecule can serve as a catalyst and H source, since the bond energy of NaH plus the double ionization ($t=2$) of Na to Na^{2+} is 54.35 eV ($2 \cdot 27.2 \text{ eV}$). The concerted catalyst reactions are given by

$$54.35 \text{ eV} + \text{NaH} \rightarrow \text{Na}^{2+} + 2e^- + H \left[\frac{a_H}{3} \right] + [3^2 - 1^2] \cdot 13.6 \text{ eV} \quad (51)$$

$$\text{Na}^{2+} + 2e^- + H \rightarrow \text{NaH} + 54.35 \text{ eV} \quad (52)$$

And, the overall reaction is

$$H \rightarrow H \left[\frac{a_H}{3} \right] + [3^2 - 1^2] \cdot 13.6 \text{ eV} \quad (53)$$

With $m = 2$, the product of catalyst NaH is $H(1/3)$ that reacts rapidly to form $H(1/4)$, then molecular hydrino, $H_2(1/4)$, as a preferred state. Specifically, in the case of a high hydrogen atom concentration, the further transition given by Eq. (33) of $H(1/3)$ ($p = 3$) to $H(1/4)$ ($p + m = 4$) with H as the catalyst ($p' = 1$; $m = 1$) can be fast:

$$H(1/3) \xrightarrow{H} H(1/4) + 95.2 \text{ eV} \quad (54)$$

The corresponding molecular hydrino $H_2(1/4)$ and hydrino hydride ion $H^-(1/4)$ are preferred final products [24-25, 27-29, 36-39] consistent with observation since the $p = 4$ quantum state has a multipolarity greater than that of a quadrupole giving $H(1/4)$ a long theoretical lifetime [24-25, 27-29] for further catalysis.

The reaction to form hydrinos and the subsequent product molecule hydrino and hydrino hydride ions is very exothermic, releasing about -50 MJ/mole H_2 consumed compared to the -285 kJ/mole H_2 enthalpy of combustion. To achieve high power, R-Ni having a surface area of about $100 \text{ m}^2/\text{g}$ was surface-coated with trace NaOH and reacted with Na metal to form NaH catalyst. ^1H solution NMR was performed on product gases of NaOH -doped R-Ni 2400 collected in a liquid-helium cryotrap and dissolved in DMF-d7 initially under liquid helium. A large $H_2(1/4)$ peak was observed at 1.2 ppm as shown in Figure 14 confirming that $H_2(1/4)$ was formed as a major product during the liberation of 0.75kJ/g R-Ni from the hydrino reaction. The negative ion ToF-SIMS of R-Ni following heat production showed a very large H^- peak, two other dominant peaks matched the high resolution mass of NaH_3^- and $\text{NaH}_3\text{NaOH}^-$ to 10,000 and were assigned to sodium hydrino hydride and this ion in combination with NaOH , and other unique ions assignable to sodium hydrino hydrides NaH_x^- in combinations with NaOH , NaO , OH^- and O^- were observed as shown in Figure 19.

Regeneration-capable heterogeneous catalysts systems including one that could be thermally regenerated at the power-reaction operating temperature comprising sources of catalyst and hydrogen and other components to facilitate the hydrino reactions by certain exchange chemistries such as hydride-halide exchange were measured by absolute water flow calorimetry, and the hydrino products were characterized by ^1H NMR, ToF-SIMS, and XPS [27-29]. For example, the ^1H solution NMR recorded following DMF-d7 solvent extraction of the products of the heterogeneous catalyst systems are shown in Figures 12 and 15 with the $H_2(1/4)$ peak

identified at about 1.23 ppm and $H^- (1/4)$ peak at about -3.84 ppm. Typical parameters measured by absolute water-flow calorimetry were 2-5 times energy gain relative to regeneration chemistry, 7 W cm^{-3} , and 300-400 kJ/mole oxidant. Product regeneration in the temperature range of 550-750°C showed that the cell operation temperature was sufficient to maintain the regeneration temperature of cells in the corresponding phase of the power-regeneration cycle wherein the forward and reverse reaction times were comparable. The results indicate that continuous generation of power liberated by forming hydrinos is commercially feasible using simplistic and efficient systems that concurrently maintain regeneration as part of the thermal energy balance [95-96]. The calorimetry and regeneration results were confirmed by Rowan University [30-31, 33-35].

VI. Plasma Reactions

Helium ions can serve as a catalyst because the second ionization energy of helium is 54.417 eV , which is equivalent to $2 \cdot 27.2 \text{ eV}$. In this case, 54.417 eV is transferred nonradiatively from atomic hydrogen to He^+ which is resonantly ionized. The electron decays to the $n=1/3$ state with the further release of 54.417 eV as given in Eq. (56). The catalysis reaction is

$$54.417 \text{ eV} + He^+ + H[a_H] \rightarrow He^{2+} + e^- + H^* \left[\frac{a_H}{3} \right] + 54.4 \text{ eV} \quad (55)$$

$$H^* \left[\frac{a_H}{3} \right] \rightarrow H \left[\frac{a_H}{3} \right] + 54.4 \text{ eV} \quad (56)$$

$$He^{2+} + e^- \rightarrow He^+ + 54.417 \text{ eV} \quad (57)$$

And, the overall reaction is

$$H[a_H] \rightarrow H \left[\frac{a_H}{3} \right] + 54.4 \text{ eV} + 54.4 \text{ eV} \quad (58)$$

wherein $H^* \left[\frac{a_H}{3} \right]$ has the radius of the hydrogen atom and a central field equivalent to 3 times that of a proton and $H \left[\frac{a_H}{3} \right]$ is the corresponding stable state with the radius of 1/3 that of H.

As the electron undergoes radial acceleration from the radius of the hydrogen atom to a radius of 1/3 this distance, energy is released as characteristic light emission or as third-body kinetic energy. Characteristic continuum emission starting at 22.8 nm (54.4 eV) and continuing to longer wavelengths was observed as predicted for this transition reaction as the energetic hydrino intermediate decays. The emission has been observed by EUV spectroscopy recorded on pulsed discharges of helium with hydrogen [25]. Alternatively, a resonant kinetic energy transfer to

form fast H may occur consistent with the observation of extraordinary Balmer α line broadening corresponding to high-kinetic energy H [24-25, 56-62].

Hydrogen and hydrinos may serve as catalysts. As given in the Disproportionation of Energy States section of Ref. [1] hydrogen atoms $H(1/p)$ $p=1,2,3,\dots,137$ can undergo transitions to lower-energy states given by Eqs. (2) and (26) wherein the transition of one atom is catalyzed by a second that resonantly and nonradiatively accepts $m \cdot 27.2 \text{ eV}$ with a concomitant opposite change in its potential energy. The overall general equation for the transition of $H(1/p)$ to $H(1/(m+p))$ induced by a resonance transfer of $m \cdot 27.2 \text{ eV}$ to $H(1/p')$ is represented by Eq. (33). Thus, hydrogen atoms may serve as a catalyst wherein $m=1$, $m=2$, and $m=3$ for one, two, and three atoms, respectively, acting as a catalyst for another. The rate for the two- or three-atom-catalyst case would be appreciable only when the H density is high. But, high H densities are not uncommon. A high hydrogen atom concentration permissive of $2H$ or $3H$ serving as the energy acceptor for a third or fourth may be achieved under several circumstances such as on the surface of the Sun and stars due to the temperature and gravity driven density, on metal surfaces that support multiple monolayers, and in highly dissociated plasmas, especially pinched hydrogen plasmas. Additionally, a three-body H interaction is easily achieved when two H atoms arise with the collision of a hot H with H_2 . This event can commonly occur in plasmas having a large population of extraordinarily fast H as reported previously [25, 56-62]. This is evidenced by the unusual intensity of atomic H emission. In such cases, energy transfer can occur from a hydrogen atom to two others within sufficient proximity, being typically a few angstroms as given in the Dipole-Dipole Coupling section of Ref. [1]. Then, the reaction between three hydrogen atoms whereby two atoms resonantly and nonradiatively accept 54.4 eV from the third hydrogen atom such that $2H$ serves as the catalyst is given by

$$54.4 \text{ eV} + 2H + H \rightarrow 2H_{fast}^+ + 2e^- + H^* \left[\frac{a_H}{3} \right] + 54.4 \text{ eV} \quad (59)$$

$$H^* \left[\frac{a_H}{3} \right] \rightarrow H \left[\frac{a_H}{3} \right] + 54.4 \text{ eV} \quad (60)$$

$$2H_{fast}^+ + 2e^- \rightarrow 2H + 54.4 \text{ eV} \quad (61)$$

And, the overall reaction is

$$H \rightarrow H \left[\frac{a_H}{3} \right] + [3^2 - 1^2] \cdot 13.6 \text{ eV} \quad (62)$$

Since the $H^* \left[\frac{a_H}{3} \right]$ intermediate of Eq. (59) is equivalent to that of Eq. (55), the continuum emission is predicted to be the same as that with He^+ as the catalyst. The energy transfer to two H causes pumping of the catalyst excited states, and fast H is produced directly as given by

Eqs. (59-62) and by resonant kinetic energy transfer as in the case of He^+ as the catalyst. With increasingly lower-energy states formed over time as the reaction progresses according to the mechanism of Eqs. (59-62) and (33), very large kinetic energies are predicted throughout the cell observed by broadened Balmer lines emitted during recombination of the hot protons to form excited-state H. Only isotropic non-directional broadening of hydrogen atomic lines is predicted with an increase in fast H with time. These features have been confirmed experimentally [25, 56-62], especially regarding closed hydrogen plasmas or water vapor plasmas that become predominantly H plasmas in time [25, 56-58] as shown in Figure 20. The 22.8 nm continuum radiation, pumping of H excited states, and fast H were also observed with hydrogen plasmas wherein $2H$ served as the catalyst [24-25].

The predicted product of both of the helium ion and $2H$ catalyst reactions given by Eqs. (55-58) and Eqs. (59-62), respectively, is $H(1/3)$. In the case of a high hydrogen atom concentration, the further transition given by Eq. (33) of $H(1/3)$ ($p=3$) to $H(1/4)$ ($p+m=4$) with H as the catalyst ($p'=1$; $m=1$) can be fast as given by Eq. (54). A secondary continuum band is predicted arising from the subsequently rapid transition of the He^+ catalysis product $\left[\frac{a_H}{3}\right]$ (Eqs. (55-58)) to the $\left[\frac{a_H}{4}\right]$ state wherein atomic hydrogen accepts 27.2 eV from $\left[\frac{a_H}{3}\right]$. This 30.4 nm continuum was observed, as well. Similarly, when Ar^+ served as the catalyst, its predicted 91.2 nm and 45.6 nm continua were observed. The predicted fast H was observed as well. Additionally, the predicted product $H_2(1/4)$ was isolated from both He^+ and $2H$ catalyst reactions and identified by NMR (Figure 13) at its predicted chemical shift given by Eq. (43).

In another H -atom catalyst reaction involving a direct transition to $\left[\frac{a_H}{4}\right]$ state, two hot H_2 molecules collide and dissociate such that three H atoms serve as a catalyst of $3 \cdot 27.2$ eV for the fourth. Then, the reaction between four hydrogen atoms whereby three atoms resonantly and nonradiatively accept 81.6 eV from the fourth hydrogen atom such that $3H$ serves as the catalyst is given by

$$81.6 \text{ eV} + 3H + H \rightarrow 3H_{fast}^+ + 3e^- + H * \left[\frac{a_H}{4}\right] + 81.6 \text{ eV} \quad (63)$$

$$H * \left[\frac{a_H}{4}\right] \rightarrow H \left[\frac{a_H}{4}\right] + 122.4 \text{ eV} \quad (64)$$

$$3H_{fast}^+ + 3e^- \rightarrow 3H + 81.6 \text{ eV} \quad (65)$$

And, the overall reaction is

$$H \rightarrow H \left[\frac{a_H}{4} \right] + [4^2 - 1^2] \cdot 13.6 \text{ eV} \quad (66)$$

The extreme-ultraviolet continuum radiation band due to the $H^* \left[\frac{a_H}{4} \right]$ intermediate of Eq. (63) is predicted to have short wavelength cutoff at 122.4 eV (10.1 nm) and extend to longer wavelengths. This continuum band was confirmed experimentally [24] as shown in Figure 7, and the high-energy hydrogen continuum radiation was independently replicated [26]. The same spectrum was observed with deuterium replacing hydrogen as expected. Considering the low energy of 2.6 J per pulse, the observed radiation energy up to 122.4 eV, and control experiments, no conventional explanation was found to be plausible including electrode metal emission, Bremsstrahlung radiation, ion recombination, molecular or molecular ion band radiation and instrument artifacts involving radicals and energetic ions reacting at the CCD and H₂ re-radiation at the detector. In general, the transition of H to $H \left[\frac{a_H}{p=m+1} \right]$ due by the acceptance of $m \cdot 27.2 \text{ eV}$ gives a continuum band with a short wavelength cutoff and energy $E_{\left(H \rightarrow H \left[\frac{a_H}{p=m+1} \right] \right)}$

given by

$$E_{\left(H \rightarrow H \left[\frac{a_H}{p=m+1} \right] \right)} = m^2 \cdot 13.6 \text{ eV} \quad (67)$$

$$\lambda_{\left(H \rightarrow H \left[\frac{a_H}{p=m+1} \right] \right)} = \frac{91.2}{m^2} \text{ nm} \quad (68)$$

and extending to longer wavelengths than the corresponding cutoff. Considering the 91.2 nm continuum shown in Figures 17 and 31 of Ref. [40] and the results shown in Figures 3-8 of Ref. [24], hydrogen may emit the series of 10.1 nm, 22.8 nm, and 91.2 nm continua.

The continua spectra directly and indirectly match significant celestial observations. Hydrogen self-catalysis and disproportionation may be reactions occurring ubiquitously in celestial objects and interstellar medium comprising atomic hydrogen. Stars are sources of atomic hydrogen and hydridos as stellar wind for interstellar reactions wherein very dense stellar atomic hydrogen and singly ionized helium, He^+ , serve as catalysts in stars. Hydrogen continua from transitions to form hydridos matches the emission from white dwarfs, provides a possible mechanism of linking the temperature and density conditions of the different discrete layers of the coronal/chromospheric sources, and provides a source of the diffuse ubiquitous EUV cosmic background with a 10.1 nm continuum matching the observed intense 11.0-16.0 nm band in addition to resolving the identity of the radiation source behind the observation that diffuse H α emission is ubiquitous throughout the Galaxy and widespread sources of flux shortward of

912 $\text{\AA}$ are required. Moreover, the product hydrinos provides resolution to the identity of dark matter [24-25].

VII. Spin-Nuclear Coupling (Hyperfine Structure)

The radius of the hydrogen or hydrino atom is increased or decreased very slightly due to the Lorentz force on the electron due to the magnetic field of the proton and its orientation relative to the electron's angular momentum vector. The additional small centripetal magnetic force is the relativistic corrected Lorentz force, $\mathbf{F}_{mag}$, given by Eq. (2.187) of Ref. [1]:

$$\mathbf{F}_{mag} = \pm \frac{pe\alpha c}{2} \frac{\mu_0}{r^3} \mu_p \sqrt{\frac{3}{4}} \quad (69)$$

wherein the central field of a hydrino atom is $+pe$. The outward centrifugal force on the electron is balanced by the electric force and the magnetic forces given by Eq. (6.20) of Ref. [1]:

$$\frac{m_e v^2}{r} = \frac{\hbar^2}{m_e r^3} = \frac{pe^2}{4\pi\epsilon_0 r^2} - \frac{\hbar^2}{m_p r^3} \pm \frac{pe\alpha c}{2} \frac{\mu_0}{r^3} \mu_p \sqrt{\frac{3}{4}} \quad (70)$$

$$r = \frac{a_H}{p} \pm \frac{2\pi\alpha}{ec} \frac{\mu_p}{\mu_B} \sqrt{\frac{3}{4}} \quad (71)$$

where μ_p is the proton magnetic moment, a_H is the radius of the hydrogen atom, the plus sign corresponds to parallel alignment of the magnetic moments of the electron and proton, and the minus sign corresponds to antiparallel alignment.

The magnetic energy $\Delta E_{magdipole}$ to flip the orientation of the proton's magnetic moment, μ_p , from antiparallel to parallel to the direction of the magnetic flux $\mathbf{B}_s$ of the electron (180° rotation of the magnetic moment vector) given by Eq. (6.23) of Ref. [1] is given by

$$\Delta E_{magdipole} = -\frac{p\mu_0 e\hbar}{2m_e} \mu_p \sqrt{\frac{3}{4}} \left(\frac{1}{r_+^3} + \frac{1}{r_-^3} \right) = -p\mu_0 \mu_B \mu_p \sqrt{\frac{3}{4}} \left(\frac{1}{r_+^3} + \frac{1}{r_-^3} \right) \quad (72)$$

where μ_B is the Bohr magneton.

The change in the electric energy $\Delta E_{ele}^{S/N}$ of the electron due to the slight shift of the radius due to the spin-nuclear interaction is given by the difference between the electric energies associated with the two possible orientations of the magnetic moment of the electron with respect to the magnetic moment of the proton, parallel versus antiparallel given by the substitution of the corresponding radius given by Eq. (71) into Eq. (6.24) of Ref [1]:

$$\Delta E_{ele}^{S/N} = \frac{-pe^2}{8\pi\epsilon_0} \left[\frac{1}{r_+} - \frac{1}{r_-} \right] \quad (73)$$

In addition, the interaction of the magnetic moments of the electron and proton increases the magnetic energy of the electron given by Eq. (6.25) or Ref. [1]. The change in the magnetic energy $\Delta E_{mag}^{S/N}$ of the electron due to the slight shift of the radius of the electron due to the spin-

nuclear interaction is given by

$$\begin{aligned}\Delta E_{mag}^{S/N} &= -\left(1 + \left(\frac{2}{3}\right)^2 + \alpha \left(\cos \frac{\pi}{3}\right)^2\right) \frac{\pi \mu_o e^2 \hbar^2}{m_e^2} \left(\frac{1}{r_+^3} - \frac{1}{r_-^3}\right) \\ &= -\left(1 + \left(\frac{2}{3}\right)^2 + \frac{\alpha}{4}\right) 4\pi \mu_o \mu_B^2 \left(\frac{1}{r_+^3} - \frac{1}{r_-^3}\right)\end{aligned}\quad (74)$$

The total energy of the transition from antiparallel to parallel alignment $\Delta E_{total}^{S/N}$ is given as the sum of Eqs. (72-74):

$$\begin{aligned}\Delta E_{total}^{S/N} &= \Delta E_{magdipole} + \Delta E_{ele}^{S/N} + \Delta E_{mag}^{S/N} \\ &= -p \mu_0 \mu_B \mu_P \sqrt{\frac{3}{4} \left(\frac{1}{r_+^3} + \frac{1}{r_-^3}\right)} - \frac{pe^2}{8\pi\epsilon_o} \left[\frac{1}{r_+} - \frac{1}{r_-}\right] - \left(1 + \left(\frac{2}{3}\right)^2 + \frac{\alpha}{4}\right) 4\pi \mu_o \mu_B^2 \left(\frac{1}{r_+^3} - \frac{1}{r_-^3}\right)\end{aligned}\quad (75)$$

where r_+ and r_- are given by Eq. (71). The energy is expressed in terms of wavelength using the Planck relationship:

$$\lambda = \frac{hc}{\Delta E_{total}^{S/N}} \quad (76)$$

The calculated hyperfine structure for H given by substitution of $p=1$ into Eqs. (75) and (76) is 21.10610 cm^{-1} . The experimental value from the hydrogen maser is 21.10611 cm^{-1} [97]. The 21 cm line is important in astronomy for the determination of the presence of hydrogen. There is remarkable agreement between the calculated and experimental values of the hyperfine structure that is only limited by the accuracy of the fundamental constants in Eqs. (71-75).

Considering the evidence such as that given in Sec. VI that hydrinos are formed by self catalysis, molecular hydrogen generation occurs via atomic H formation, $H(1/4)$ is a preferred stable state, and the activation energy to form $H_2(1/4)$ may be higher than ambient thermal energies, the $H(1/4)$ hyperfine structure transition was investigated in hydrogen gas. From Eq. (75), the hyperfine state of $H(1/4)$ with the proton and electron spins parallel differs in energy $E_{u\ell}$ from the state with them antiparallel by

$$E_{u\ell} = \Delta E_{total}^{S/N} = 42.52 \times 10^{-23} \text{ J} \quad (0.002654 \text{ eV}) \quad (77)$$

Using Eq. (76), the corresponding wavenumber is

$$\lambda^{-1} = 21.4052 \text{ cm}^{-1} \quad (78)$$

The antiparallel lower energy state has a total spin of $S=0$; so, its degeneracy is $g_\ell = 2S+1=1$. The upper state has a total spin of $S=1$; so, its degeneracy is $g_u = 2S+1=3$. The energy difference between the states corresponds to a temperature $T_{u\ell}$ of

$$T_{u\ell} = E_{u\ell} / k = 30.797 \text{ K} \quad (79)$$

The level population n is given by the Boltzmann factor and the degeneracy:

$$\frac{n_u}{n_\ell} = \frac{g_u}{g_\ell} e^{-E_{u\ell}/kT} = \frac{3}{1} e^{-30.797 \text{ K}/T} \quad (80)$$

Then the population in the lower state is

$$\frac{n_T}{n_\ell} - 1 = 3e^{-30.797 \text{ K}/T} \quad (81)$$

$$n_\ell = \frac{n_T}{3e^{-30.797 \text{ K}/T} + 1} \quad (82)$$

wherein $n_\ell + n_u = n_T$ and n_T is the total population. Consider the population ratio change with lowering the temperature from slightly above $T_{u\ell}$ at 36 K to slightly below at 25.5 K. Using Eqs.

(79) and (82), the factor increase in the number of lower states is

$$\frac{n_{\ell 25.5 \text{ K}}}{n_{\ell 36 \text{ K}}} = \frac{3e^{-30.797 \text{ K}/36 \text{ K}} + 1}{3e^{-30.797 \text{ K}/25.5 \text{ K}} + 1} = 1.20 \quad (83)$$

The dependence of the absorption coefficient on the temperature-dependent state populations is considered next. Consider the attenuation coefficient κ_ν for the 21 cm line of ordinary H given by [98]

$$\kappa_\nu = \frac{3}{8\pi} n_\ell A_{u\ell} \lambda_{u\ell}^2 \phi_\nu (1 - e^{-E_{u\ell}/kT}) = \frac{3}{8\pi} n_\ell A_{u\ell} \lambda_{u\ell}^2 \frac{1}{\sqrt{2\pi}} \frac{\lambda_{u\ell}}{\sigma_\nu} e^{-v^2/2\sigma_\nu^2} (1 - e^{-E_{u\ell}/kT}) \quad (84)$$

wherein σ_ν is the velocity dispersion and $A_{u\ell}$ is the Einstein A coefficient. Applying the same formula to the 21.4 cm⁻¹ line (Eq. (84)) and using the result of Eq. (83) gives the factor increase in the κ_ν due to a temperature change of 36 K to 25.5 K:

$$\begin{aligned} \frac{\kappa_{\nu 25.5 \text{ K}}}{\kappa_{\nu 36 \text{ K}}} &= \frac{n_{\ell 25.5 \text{ K}}}{n_{\ell 36 \text{ K}}} \frac{(1 - e^{-30.797/25.5})}{(1 - e^{-30.797/36})} \frac{\sigma_{\nu 36 \text{ K}}}{\sigma_{\nu 25.5 \text{ K}}} e^{(v^2/2\sigma_{\nu 36 \text{ K}}^2 - v^2/2\sigma_{\nu 25.5 \text{ K}}^2)} \\ &= 1.46 \frac{\sigma_{\nu 36 \text{ K}}}{\sigma_{\nu 25.5 \text{ K}}} e^{(v^2/2\sigma_{\nu 36 \text{ K}}^2 - v^2/2\sigma_{\nu 25.5 \text{ K}}^2)} \end{aligned} \quad (85)$$

In addition to population changes and velocity dispersion (Eq. (85)), another potentially dominant factor in the absorption is the effect of pressure broadening. Collisions or interactions of $H(1/4)$ with the background H_2 can decrease the hyperfine excitation and also broaden the profile width in intentionally highly collisional molecular hydrogen such that the peak is decreased relative to the background H_2 translational absorption band. Simplicistically, the collisionally induced interactions depend on the collisional frequency per unit volume $Z_{H(1/4)-H_2}$ given by [99]

$$Z_{H(1/4)-H_2} = \pi (r_{H(1/4)} + r_{H_2})^2 \left[\frac{8RT}{\pi} \left(\frac{1}{M_{H(1/4)}} + \frac{1}{M_{H_2}} \right) \right]^{1/2} C_{H(1/4)} C_{H_2} \quad (86)$$

where $r_{H(1/4)}$, $M_{H(1/4)}$, and $C_{H(1/4)}$ are the interaction radius, the mass, and number density of $H(1/4)$ and r_{H_2} , M_{H_2} , and C_{H_2} are the interaction radius, the mass, and number density of H_2 .

Thus, a factor of three decrease in density with a temperature change from 36 K to 25.5 K could cause a factor of 10 increase in the observed absorption (Eq. (86)). Thus, under dense, cryo-temperature conditions, a considerable increase in the attenuation (absorption) coefficient may be expected for the situation of lowered temperature and density at 25.5 K versus 36 K.

Using a long path length (60 m), multi-reflection absorption cell coupled to a Fourier transform interferometer, Wishnow et al. [43-46] recorded the H_2 spectrum at a spectral resolution of 0.24 cm^{-1} over the wavenumber, temperature, and pressure ranges of 20-320 cm^{-1} , 21-38 K, and 1-3 atmospheres, respectively. The density of the gas expressed in amagat units, the ratio of the gas density to that of an ideal gas at STP was about in the range of about 10 to 40 amagat. The pressure was maintained such that liquefaction was avoided requiring a lower density as the temperature was lowered. This can be appreciated from the relationship between the vapor pressure of liquid H_2 and temperature wherein the vapor pressure is 1204.0 kPa at 32.5 K compared to only 364.3 kPa at 25.5 K [100]. The submillimeter absorption spectra of normal H_2 at 36 K and at 25.5 K are shown Figures 21A and B, respectively. The corresponding data processed into an absorption-coefficient-dependent line shape function $G(\sigma)$ [43] is shown in Figures 22 A and B, respectively. The sharp line at 89.2 cm^{-1} is the R(0) line of HD that increased in intensity at the lower temperature. Similarly, a line at 21.4 cm^{-1} is observed at 25.5 K, but is absent at 36 K. The wavenumber of the line is a match to the predicted 21.4 cm^{-1} $H(1/4)$ hyperfine line. In addition to a density effect, the dependence of the observation of the line on the reduction of the temperature from 36 K to 25.5 K also matches that predicted based on $T_{ul} = 30.797\text{ K}$ (Eq. (79)) consistent with the correlation between the presence of the 21.4 cm^{-1} peak and the substantial increase in intensity of the 89.2 cm^{-1} R(0) line of HD. Work is in progress to specifically test the observation of the 21.4 cm^{-1} line and its assignment to the hyperfine transition of $H(1/4)$.

VIII. Conclusion

Continuum radiation, the characteristic spectral signature of transitions of atomic H to form hydrinos, and the existence of hydrinos in atomic, molecular, and hydride form that are products of catalysis reactions as well as occurring naturally were confirmed by multiple complementary methods. The energetics of the hydrino reaction were manifest by extraordinary fast H, chemically catalyzed plasma formation, and power. Serendipitously, characteristic signatures of hydrino were observed by other researchers such as fast H due to the energetics of the hydrino reaction observed by isotropically Doppler broadened Balmer lines, an upfield shifted peak due to $H_2(1/4)$ observed by solid 1H NMR, ro-vibrational lines of $H_2(1/4)$ observed by e-beam emission spectroscopy, and a 21.4 cm^{-1} line due to the hyperfine transition

of $H(1/4)$ observed by submillimeter cryogenic H_2 absorption spectroscopy. Many of the results such as the hydrogen high-energy continuum radiation [26], plasma formation [52], fast H [56, 60], power [30-31, 33-36] and hydrino products [32] were independently confirmed. In the latter case, Rowan University confirmed hydrino hydride and molecular hydrino in synthesized hydrino hydride compounds and products of heat producing reactions that were characterized by water flow calorimetry. The presence of hydrinos trapped in alkali halide crystals was further confirmed by Rowan using neutron diffraction.

For example, using H as a self-catalyst, EUV continua at 91.2 nm, 22.8 nm and 10.1 nm, extraordinary (>50 eV) Balmer α line broadening, highly excited catalyst states, and the product gas $H_2(1/4)$ were observed as predicted [24-25]. In the latter case, gases from the pulsed-plasma cells showing continuum radiation were collected and dissolved in $CDCl_3$. Molecular hydrino $H_2(1/4)$ was observed by solution NMR at the predicted chemical shift of 1.25 ppm on these as well as gases collected from power reaction products and multiple plasma sources including helium-hydrogen, water-vapor-assisted hydrogen, hydrogen, and so-called rt-plasmas involving an incandescently heated mixture of strontium, argon, and hydrogen [25]. These results are in good agreement with prior results on synthetic reactions to form hydrino compounds comprising hydrinos. The 1H MAS NMR value of 1.1 ppm observed for $H_2(1/4)$ in solid MH^*X (M=alkali, H^* is hydrino hydride, and X=halide) corresponded to the solution value of 1.2 ppm and that of gases from plasma cells having a catalyst. The corresponding hydrino hydride ion $H^-(1/4)$ was observed from solid compounds at the predicted shift of -3.86 ppm in solution NMR and its ionization energy was confirmed at the predicted energy of 11 eV by X-ray photoelectron spectroscopy [27-29, 36-39]. $H_2(1/4)$ and $H^-(1/4)$ were also confirmed as the products of hydrino catalytic systems that released multiples of the maximum energy possible based on known chemistries; moreover, reactant systems were developed and shown to be thermally regenerative that are competitive as a new power source [27-29].

It was confirmed that hydrinos occur naturally. Synthesized and naturally occurring molecular hydrino were observed by electron beam excited ro-vibrational spectral emission and proton NMR. $H_2(1/4)$ was observed as a constituent of argon and neon gas as a series of lines that identically matched the spacing and intensity profile of the P branch of $H_2(1/4)$ for the ro-vibrational transition $\nu=1 \rightarrow \nu=0$. By the same method $H_2(1/4)$ was observed to be embedded in alkali chloride crystals in natural abundance and as a catalysis product. 1H MAS NMR performed on alkali chlorides showed the $H_2(1/4)$ peak at 1.1 ppm with relative intensities $Na < K < Cs$ as expected based on the lattice spacing to accommodate the gas molecules. Similar to the case with the 21 cm (1.42 GHz) line of ordinary hydrogen, naturally abundant hydrino atoms were identified by its predicted 642 GHz spin-nuclear hyperfine

transition observed by TeraHz absorption spectroscopy of cryogenically cooled H₂ below 35K.

The continua spectra and characteristics of hydrinos directly and indirectly match significant celestial observations. Naturally occurring hydrinos, their forbidden electronic and ro-vibrational transitions consistent with a dark spectrum, the overwhelming abundance of hydrogen in the universe, the greater abundance of dark matter, the existence of intergalactic dark matter with the constraint that it is a form of hydrogen [77-78] leads to the conclusion that hydrino is the most likely identity of dark matter. The assignment is supported by naturally occurring hydrino observed by the authors and serendipitously by others in compounds, argon and neon gas, and hydrogen gas via solid NMR [41], e-beam excitation spectroscopy [42], and submillimeter absorption spectroscopy [43-46]. Other signatures of energetic reactions such as extraordinary fast H have also been observed serendipitously [63-75].

The recent experimental confirmation of the predictions for transitions of atomic hydrogen to form hydrinos, such as power production and characterization of hydrino reaction products, as well as pumped catalyst states, fast H, characteristic continuum radiation, and the hydrino products [24-75] have profound implications theoretically, scientifically, and technologically in that they (1) confirm GUTCP in the prediction of hydrinos, (2) directly disprove atomic theories such as the Schrödinger and Dirac equation theories based on the definition of $n=1$ as the ground state, the defined state below which it is impossible to go, as expected based on many physical failings and preexisting mathematical inconsistencies [1-13], (3) offer resolution to many otherwise inexplicable celestial observations with (a) the identity of dark matter being hydrinos, (b) the hydrino-transition radiation being the radiation source heating the WHIM and behind the observation that diffuse H α emission is ubiquitous throughout the Galaxy requiring widespread sources of flux shortward of 912 Å, and (c) the energy and radiation from the hydrino transitions being the source of extraordinary temperatures and power regarding the solar corona problem [24-25], and (4) directly demonstrate a new field of hydrogen chemistry and a powerful new energy source [27-36, 95-96].

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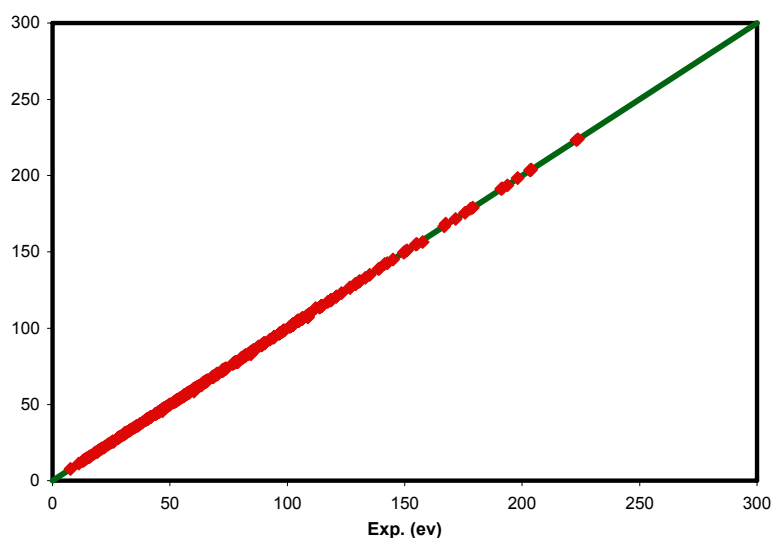
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Table 1. The Maxwellian closed-form calculated and experimental parameters of H_2 , D_2 , H_2^+ and D_2^+ [1].

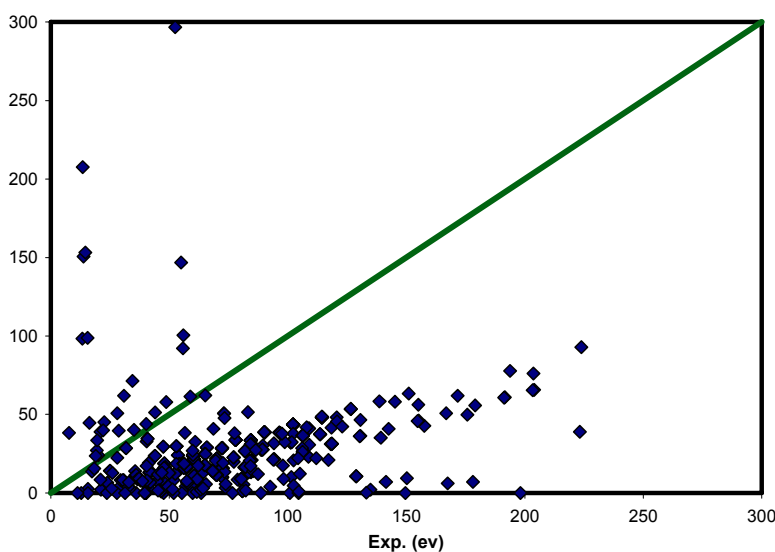
Parameter	Calculated	Experimental
H_2 Bond Energy	4.478 eV	4.478 eV
D_2 Bond Energy	4.556 eV	4.556 eV
H_2^+ Bond Energy	2.654 eV	2.651 eV
D_2^+ Bond Energy	2.696 eV	2.691 eV
H_2 Total Energy	31.677 eV	31.675 eV
D_2 Total Energy	31.760 eV	31.760 eV
H_2 Ionization Energy	15.425 eV	15.426 eV
D_2 Ionization Energy	15.463 eV	15.466 eV
H_2^+ Ionization Energy	16.253 eV	16.250 eV
D_2^+ Ionization Energy	16.299 eV	16.294 eV
H_2^+ Magnetic Moment	$9.274 \times 10^{-24} JT^{-1} (\mu_B)$	$9.274 \times 10^{-24} JT^{-1} (\mu_B)$
Absolute H_2 Gas-Phase NMR Shift	-28.0 ppm	-28.0 ppm
H_2 Internuclear Distance ^a	0.748 Å $\sqrt{2}a_o$	0.741 Å
D_2 Internuclear Distance ^a	0.748 Å $\sqrt{2}a_o$	0.741 Å
H_2^+ Internuclear Distance	1.058 Å $2a_o$	1.06 Å
D_2^+ Internuclear Distance ^a	1.058 Å $2a_o$	1.0559 Å
H_2 Vibrational Energy	0.517 eV	0.516 eV
D_2 Vibrational Energy	0.371 eV	0.371 eV
H_2 $\omega_e x_e$	$120.4 cm^{-1}$	$121.33 cm^{-1}$
D_2 $\omega_e x_e$	$60.93 cm^{-1}$	$61.82 cm^{-1}$
H_2^+ Vibrational Energy	0.270 eV	0.271 eV
D_2^+ Vibrational Energy	0.193 eV	0.196 eV
H_2 J=1 to J=0 Rotational Energy ^a	0.0148 eV	0.01509 eV
D_2 J=1 to J=0 Rotational Energy ^a	0.00741 eV	0.00755 eV
H_2^+ J=1 to J=0 Rotational Energy	0.00740 eV	0.00739 eV
D_2^+ J=1 to J=0 Rotational Energy ^a	0.00370 eV	0.003723 eV

^a Not corrected for the slight reduction in internuclear distance due to $\bar{E}_{osc}$.

Figure 1. The total bond energies of exact classical solutions of 415 molecules generated by Millsian 1.0 and those from a modern quantum mechanics-based program, Spartan's pre-computed database using 6-31G* basis set at the Hartree-Fock level of theory, were compared to experimental values. (A) The Millsian results were consistently within an average relative deviation of about 0.1% of the experimentally values. (B) In contrast, the 6-31G* results deviated over a wide range of relative error, typically being >30-150% with a large percentage of catastrophic failures, depending on functional group type and basis set.



(A)



(B)

Figure 2. Atomic force microscopy image of pentacene by Gross et al. [15] and the superimposed analytical classical solution that matches the physical structure. The polycyclic aromatic hydrocarbon pentacene was imaged by atomic force microscopy using a single CO molecule as the probe. The resulting breakthrough in resolution revealed that in contrast to the fuzzy images touted by quantum theoreticians as proof of the cloud model of the electron, the images showed localized bonding molecular orbitals and atomic orbitals in agreement with the classical solution.

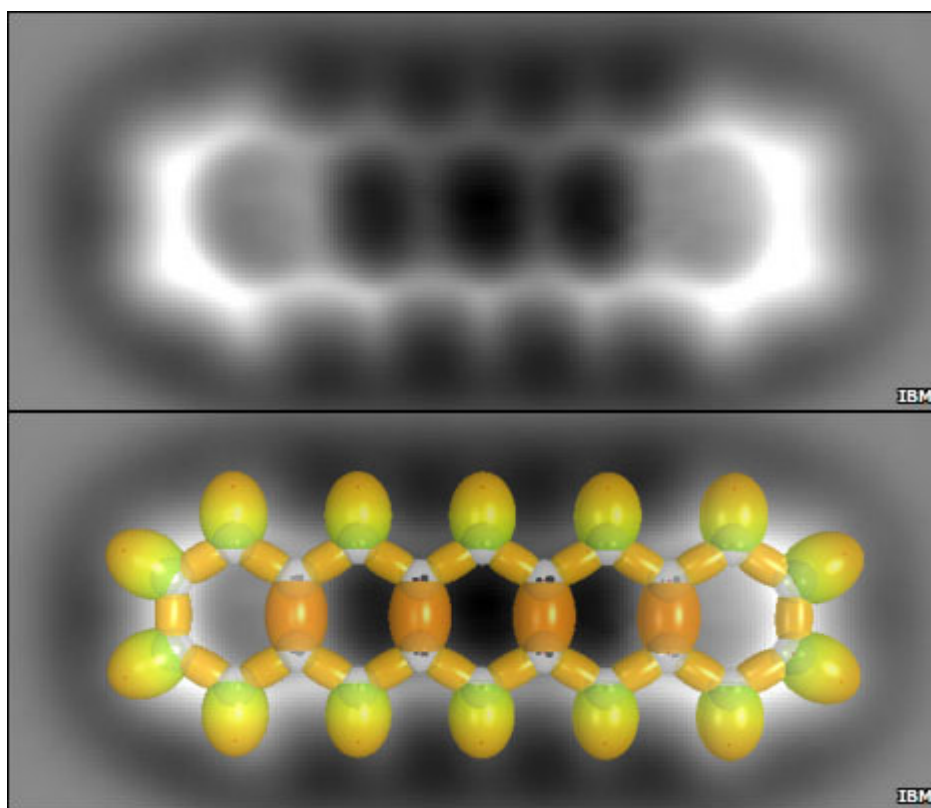


Figure 3. A bound electron is a constant two-dimensional spherical surface of charge (zero thickness, total charge = $\theta = \pi$, and total mass = m_e), called an *electron orbitsphere*. The corresponding uniform current-density function having intrinsic angular momentum components of $\mathbf{L}_{xy} = \frac{\hbar}{4}$ and $\mathbf{L}_z = \frac{\hbar}{2}$ following Larmor excitation give rise to the phenomenon of electron spin.

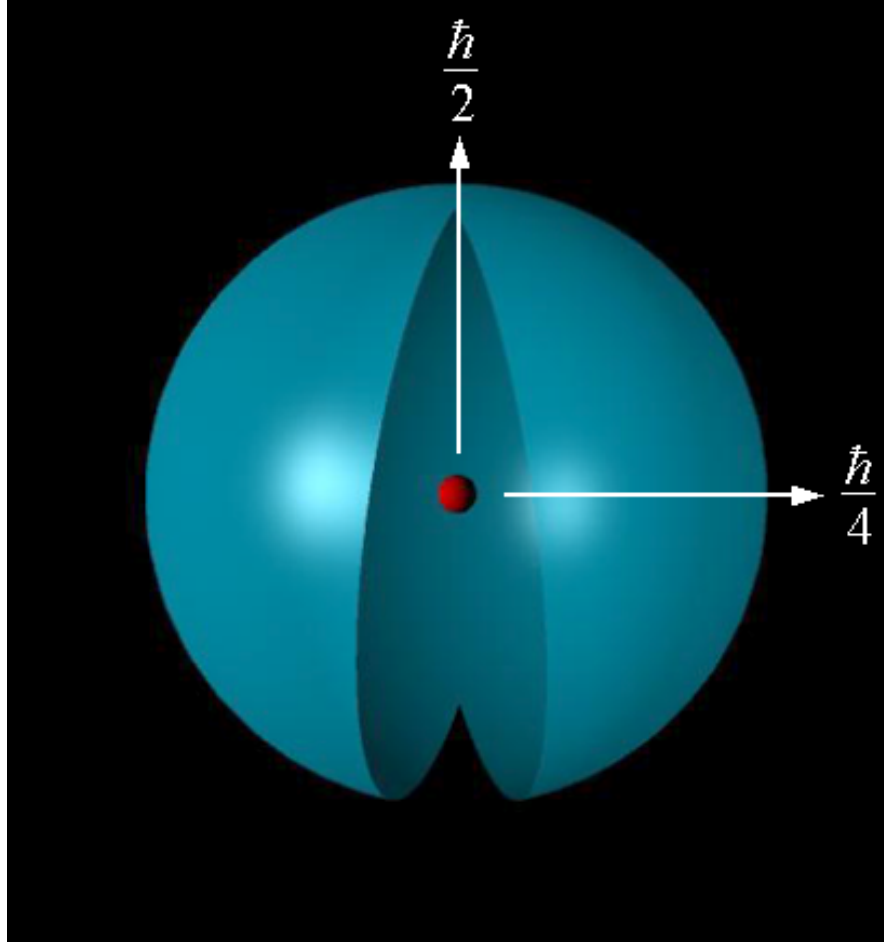


Figure 4. The bound electron exists as a spherical two-dimensional supercurrent (electron *orbitsphere*), an extended distribution of charge and current completely surrounding the nucleus. Unlike a spinning sphere, there is a complex pattern of motion on its surface (indicated by vectors) that generates two orthogonal components of angular momentum (Figure 3) that give rise to the phenomenon of electron spin. A representation of the $\left(-\frac{1}{\sqrt{2}}\mathbf{i}_x, \frac{1}{\sqrt{2}}\mathbf{i}_y, \mathbf{i}_z\right)$ -axis view of the total uniform current-density pattern of the $Y_0^0(\phi, \theta)$ orbitsphere with 144 vectors overlaid on the continuous bound-electron current density giving the direction of the current of each great circle element (nucleus not to scale) is shown.

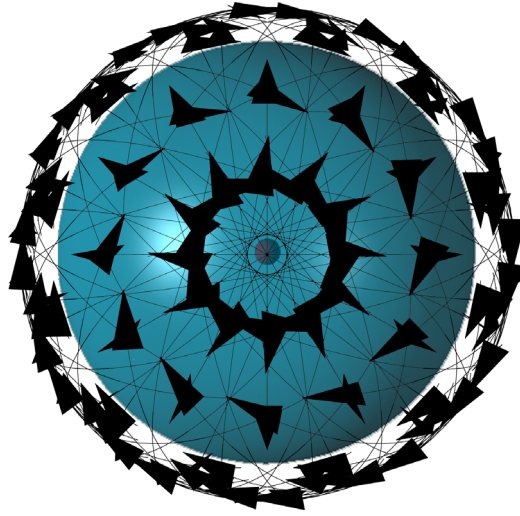


Figure 5. The orbital function modulates the constant (spin) function, (shown for $t = 0$; three-dimensional view).

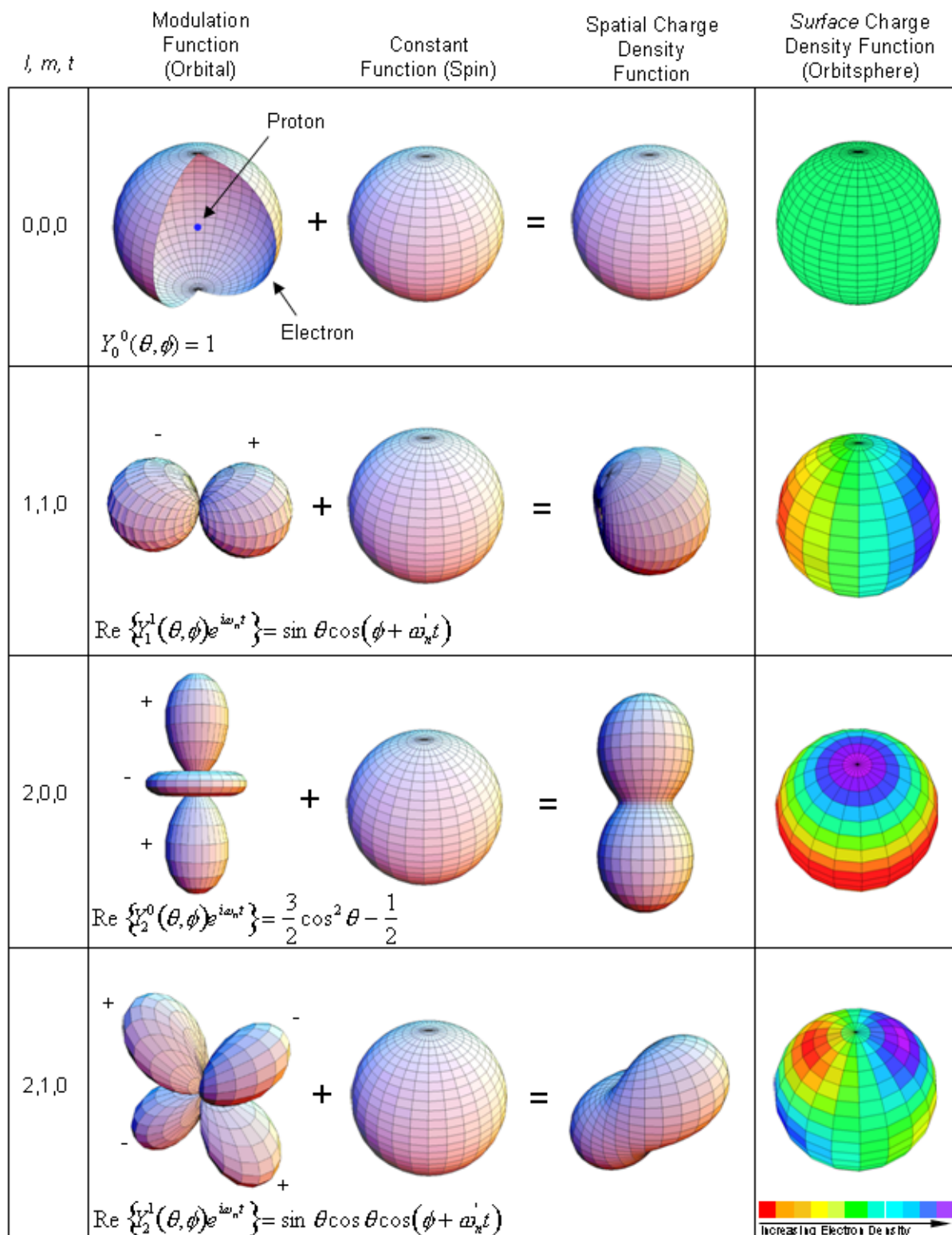


Figure 6. Dark matter ring in galaxy cluster. This Hubble Space Telescope composite image shows a ghostly “ring” of dark matter in the galaxy cluster Cl 0024+17. The ring is one of the strongest pieces of evidence to date for the existence of dark matter, a prior unknown substance that pervades the universe. Courtesy of NASA, M.J. Jee and H. Ford (Johns Hopkins University).



Figure 7. Emission spectra (3-46 nm) of electron-beam-initiated, high-voltage pulsed discharges in hydrogen (solid) and helium (dashed) with W electrodes recorded by the EUV grazing incidence spectrometer using the 600 lines/mm grating and 1000 superpositions showing two continuum bands having short wavelength cutoffs at 22.8 nm and 10.1 nm. The predicted continua from the transitions $H^*\left[\frac{a_H}{3}\right] \rightarrow H\left[\frac{a_H}{3}\right] + 54.4 \text{ eV}$ and $H^*\left[\frac{a_H}{4}\right] \rightarrow H\left[\frac{a_H}{4}\right] + 122.4 \text{ eV}$ were observed for hydrogen only.

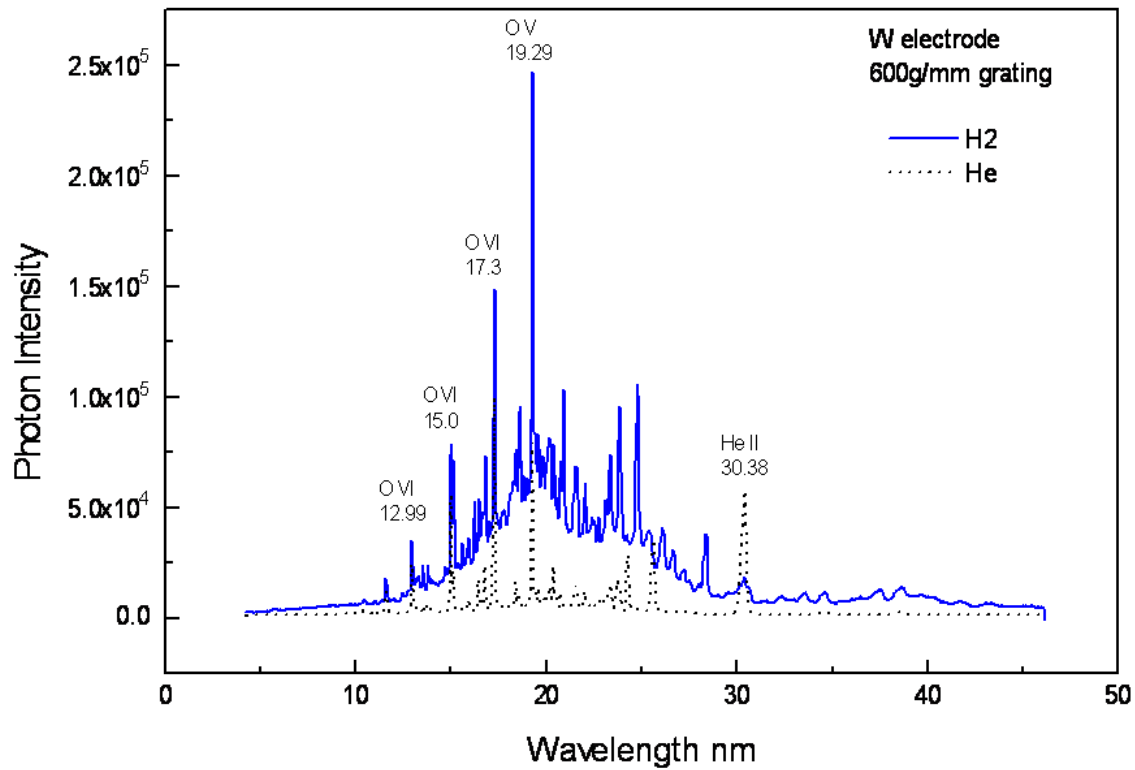
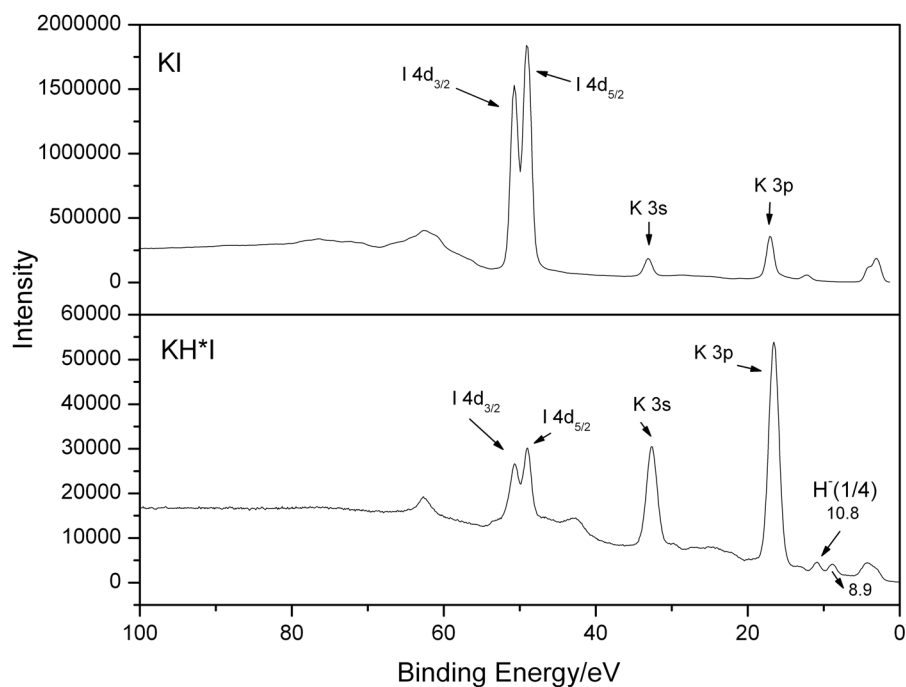


Figure 8. The 0-100 eV binding energy region of a high resolution XPS spectrum of KH^*I and the control KI (top). The XPS spectrum of KH^*I differs from that of KI by having additional peaks at 9.5 eV and 12.3 eV that could not be assigned to known elements and do not correspond to any other primary element peak. The peaks match $H^-(1/4)$ in two different chemical environments.



Figures 9A-C. ^1H or ^2H MAS NMR spectra relative to external TMS. (A) KH^*Cl showing a very sharp -4.46 ppm upfield-shifted peak corresponding to an environment of $\text{H}^-(1/4)$ that is essentially that of a free ion. (B) KD^*Cl showing a sharp -4.54 ppm upfield-shifted peak corresponding to the deuterated hydride ion $\text{D}^-(1/4)$. (C) KH^*I showing a broad -2.31 ppm upfield-shifted $\text{H}^-(1/4)$ peak that was broadened and downfield shifted relative to that of KH^*Cl due to the solid matrix effect of KI . Both ^1H spectra also had a ~ 1.13 ppm peak assigned to $\text{H}_2(1/4)$.

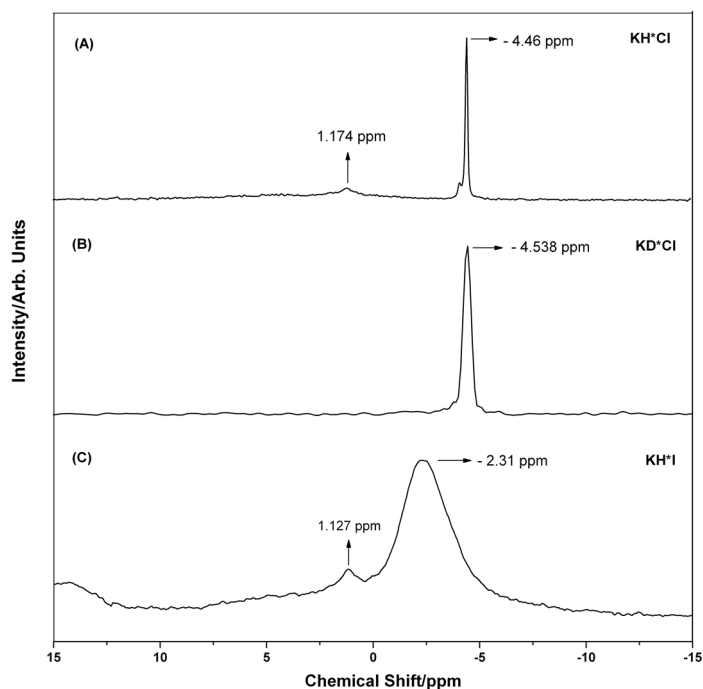


Figure 10. ^1H solution NMR of KH^*Cl dissolved in DMF-d_7 showing isolated $\text{H}_2(1/4)$ and $\text{H}^-(1/4)$ at 1.2 ppm and -3.85 ppm, respectively, wherein the absence of any solid matrix effect or the possibility of alternative assignments such as U-centered H or F centers in solid matrix confirm the solid NMR assignment of the 1.13 ppm and -4.4 ppm peaks shown in Figure 9A to $\text{H}_2(1/4)$ and , respectively.

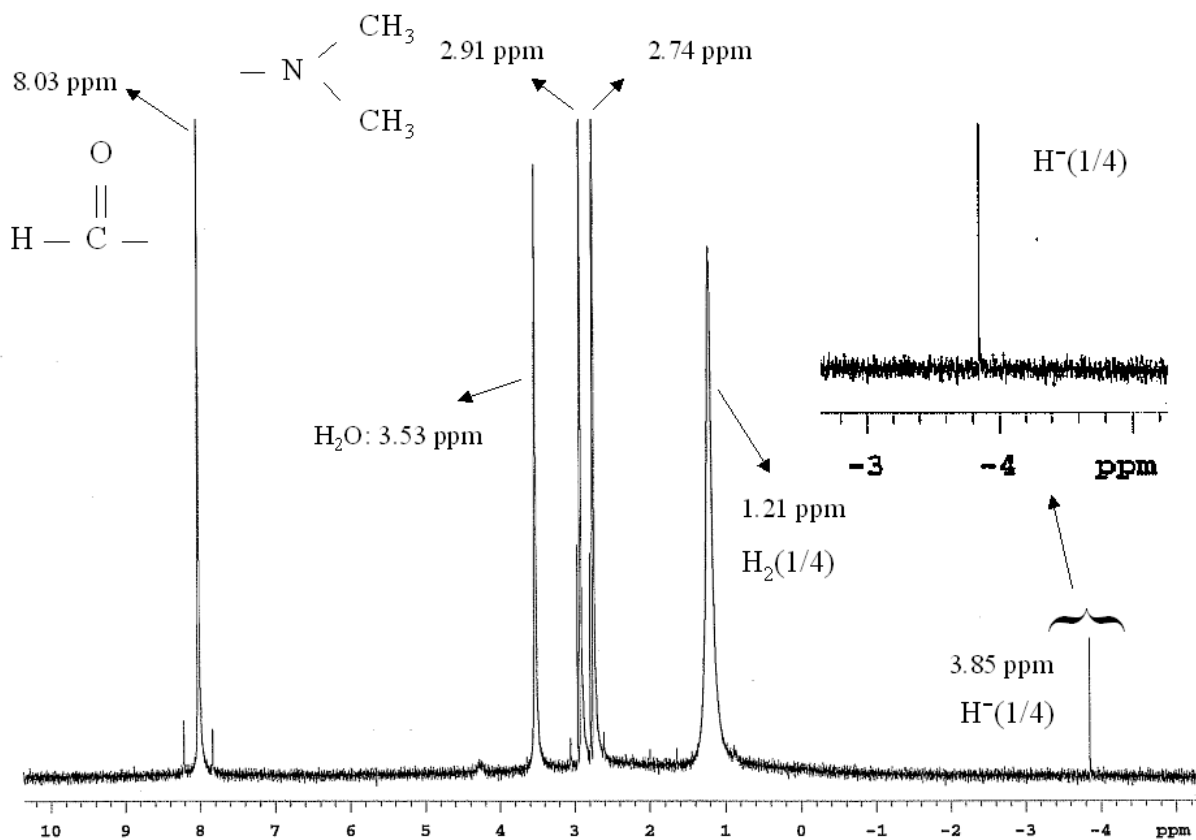


Figure 11. ^1H solution NMR of KH^*I dissolved to saturation in DMF-d_7 that showed increasing intensities and slight downfield shifts of the $\text{H}_2(1/4)$ and $\text{H}^-(1/4)$ peaks to 1.28 ppm and -3.79 ppm, respectively, as the concentration of KH^*I increased. The concentration-dependent solution matrix effect confirmed the solid matrix effect corresponding to the NMR assignment of $\text{H}_2(1/4)$ and $\text{H}^-(1/4)$ to the peaks at 1.13 ppm and -2.31 ppm shown in Figure 9C.

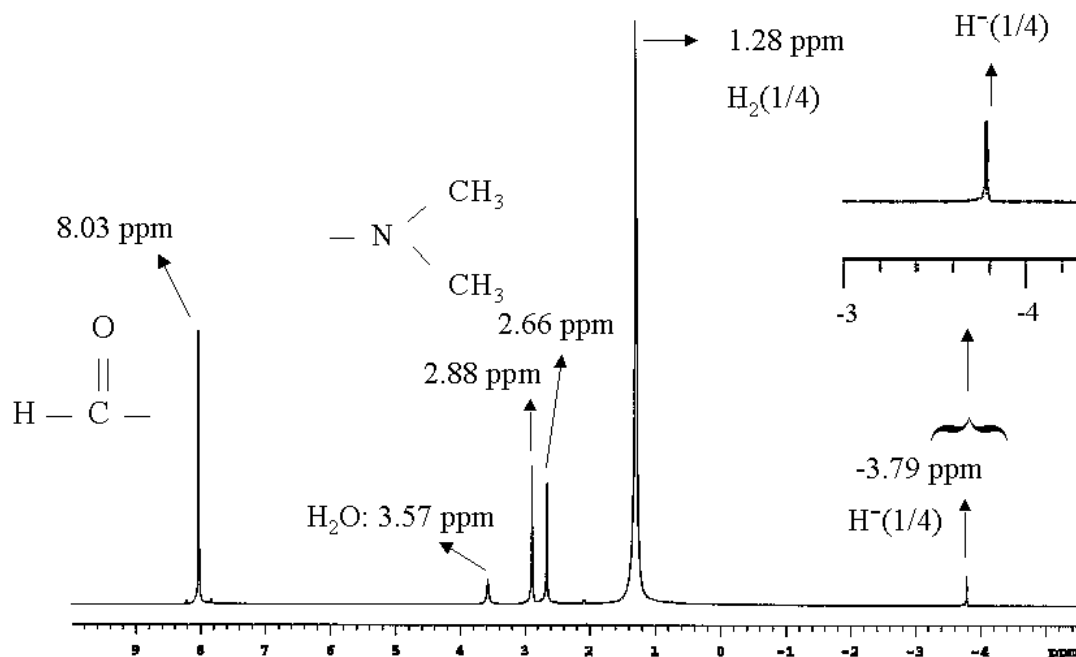


Figure 12. ^1H solution NMR following DMF- d_7 solvent extraction of the product of the reaction mixture comprising 1g $\text{NaH}(s)$ + 1g MgH_2 mixed with 4g activated carbon and pressurized with 0.0094 moles of SF_6 showed the $\text{H}^-(1/4)$ peak at -3.84 ppm. The other peaks in the spectrum are due to DMF (labeled), trace H_2O at 3.62 ppm, and background hydrocarbon peaks from the AC.

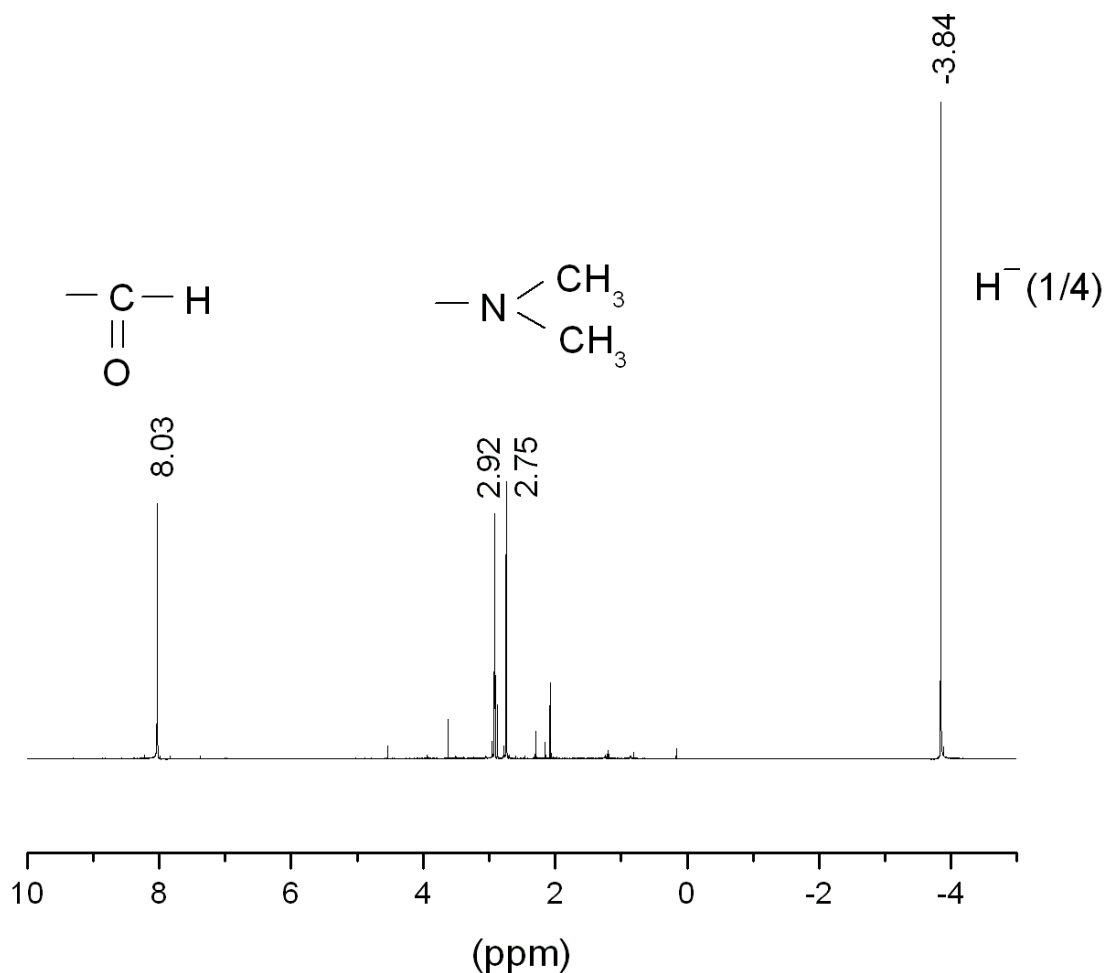


Figure 13. ^1H NMR (0 ppm to 8 ppm) relative to tetramethylsilane (TMS) of water-vapor RF plasma gases collected at 4K and dissolved in CDCl_3 showing the major peaks, the solvent peak at 7.26 ppm, the H_2 peak at 4.62 ppm, and the broad H_2O peak at 1.54 ppm. The singlet peak upfield of H_2 at 1.25 ppm was the only peak in the spectrum that could not be assigned to common species. It matched the theoretical position of $\text{H}_2(1/4)$.

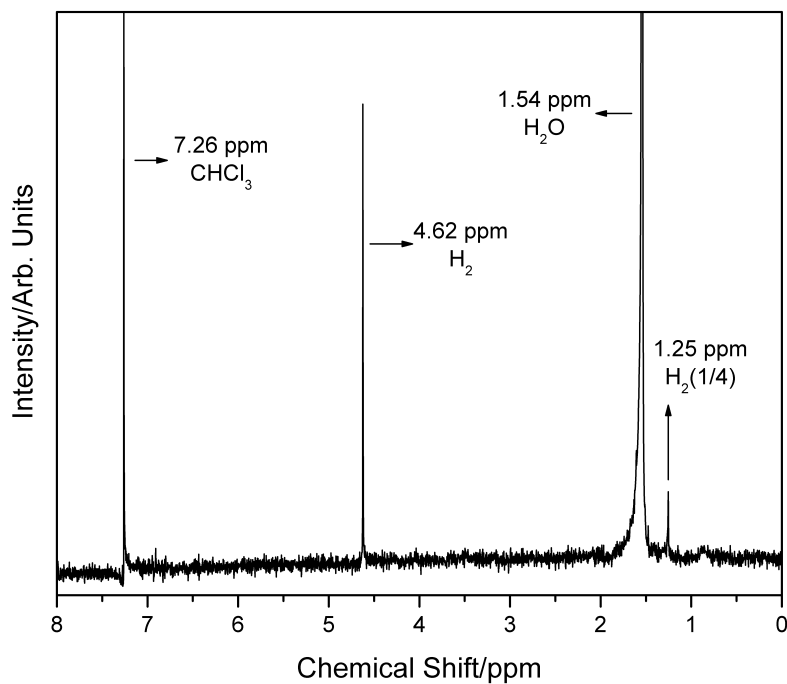


Figure 14. ^1H solution NMR of NaOH -doped R-Ni 2400 product gases collected and dissolved in DMF-d_7 initially under liquid helium showing the $\text{H}_2(1/4)$ at 1.2 ppm.

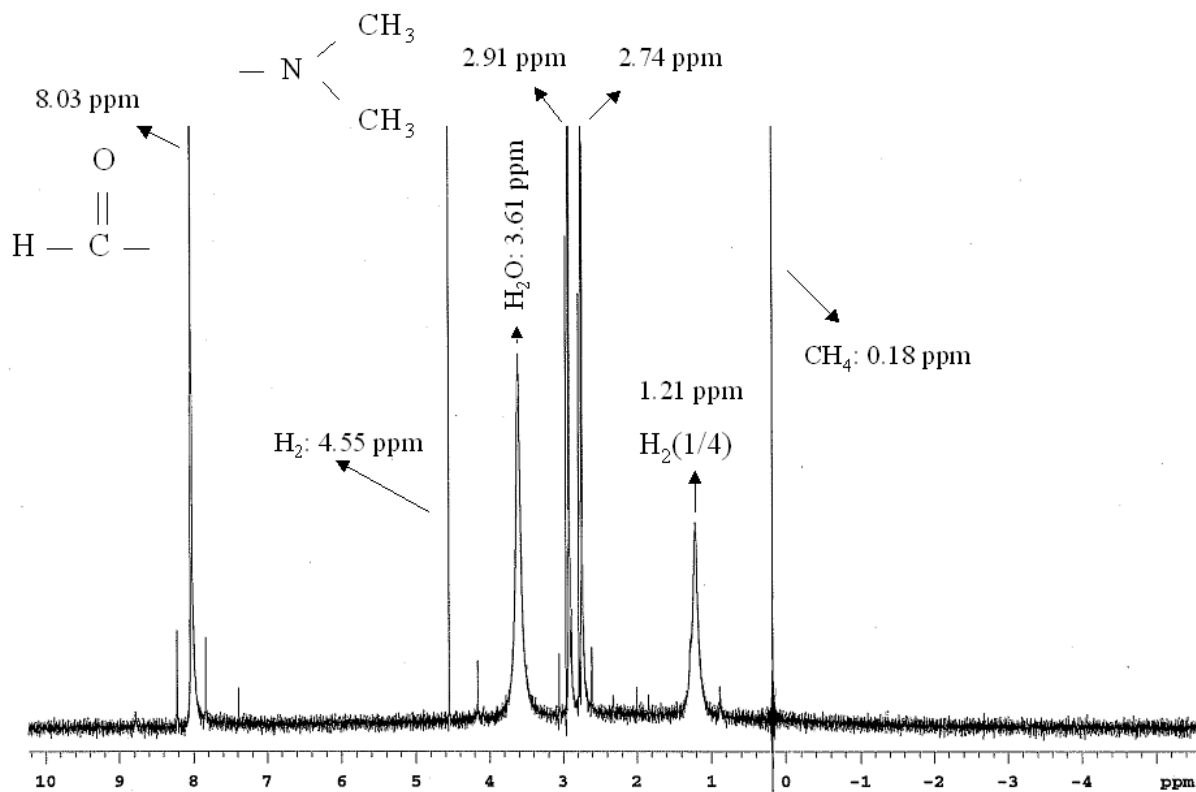


Figure 15. ^1H solution NMR following DMF-d₇ solvent extraction of the product of the reaction mixture comprising 1.66g $\text{KH}(s)$ + 1g Mg powder + 4g AC + 3.92g EuBr_3 that showed the $\text{H}_2(1/4)$ peak at 1.23 ppm.

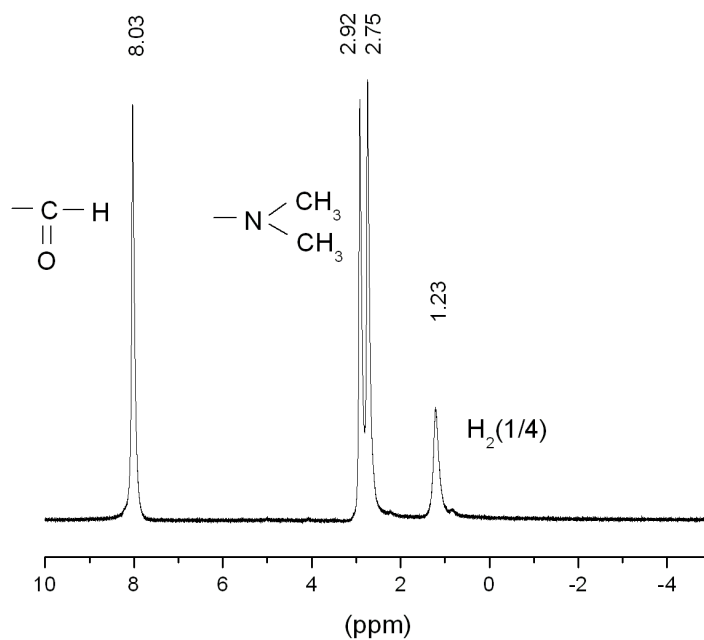


Figure 16. The ^1H MAS NMR spectra relative to external TMS of NaCl , KCl , and CsCl showing the expected trend of increasing intensity of $H_2(1/4)$ at 1.1 ppm relative to the H_2 at 4.3 ppm down the column of the Group I elements.

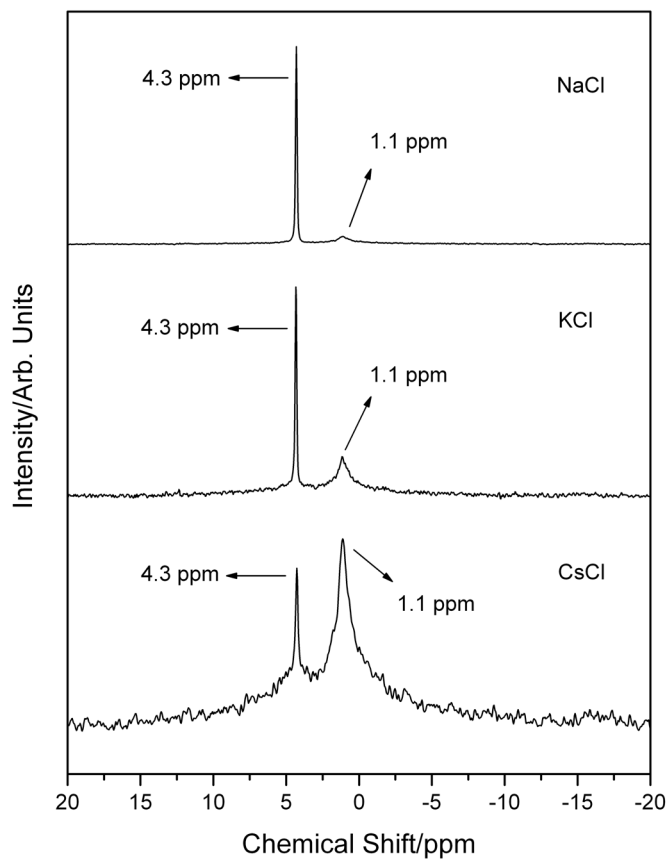


Figure 17. The 100-560 nm spectrum of 750 Torr, 12.5 keV-electron-beam-maintained plasma of argon containing about 1% hydrogen determined by mass spectroscopy. The slope of the linear curve fit of the series of peaks in the 150-180 nm region is 0.24 eV with an intercept of 8.24 eV which matches Eqs. (44) and (45) very well for $p = 4$. Single peaks of the evenly spaced lines observed in the 220-300 nm region that matched the spacing and intensity profile of the P branch of $H_2(1/4)$ were observed to the 3rd order.

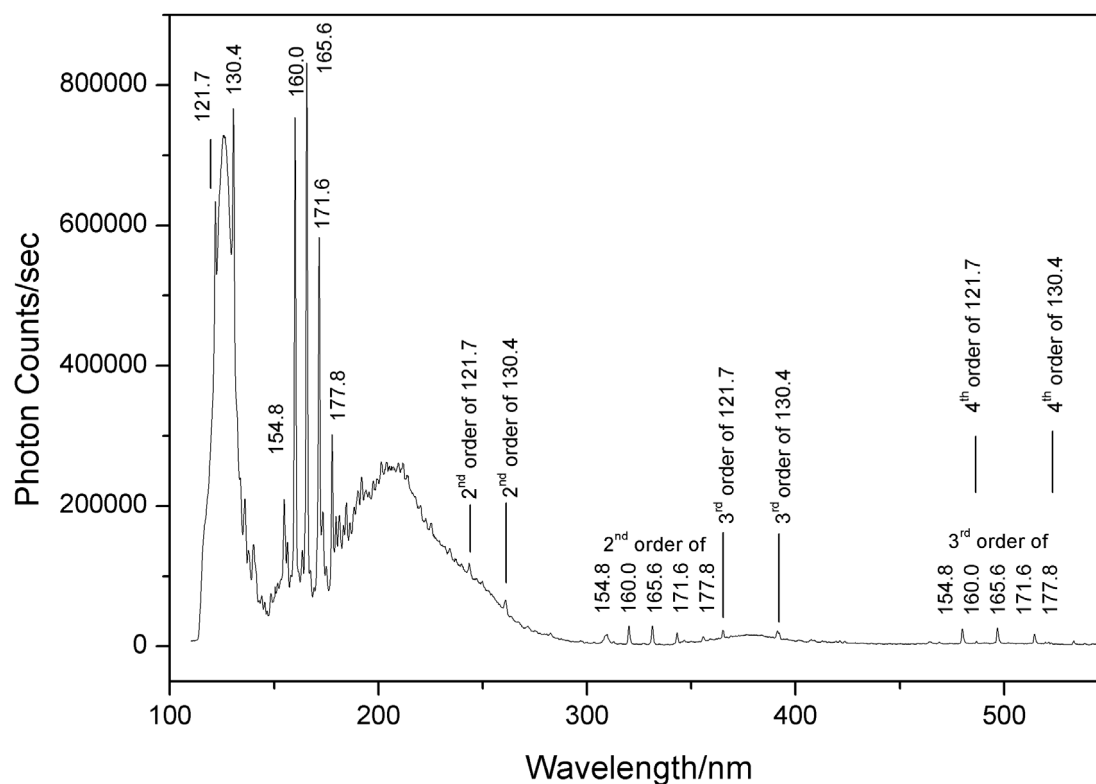


Figure 18. The 180-350 nm spectra of electron-beam excited NaCl , KCl , and CsCl crystals having trapped $H_2(1/4)$. For each, a series of evenly spaced lines was observed in the 220-300 nm region that matched the spacing and intensity profile of the P branch of $H_2(1/4)$. The expected trend of increasing intensity of $H_2(1/4)$ down the column of the Group I elements was observed that matched the intensity trend of the $H_2(1/4)$ NMR peak at 1.1 ppm relative to the H_2 peak at 4.3 ppm (Figure 16). The band shifted to longer wavelength down the column of the Group I elements due to the vibrational matrix interaction.

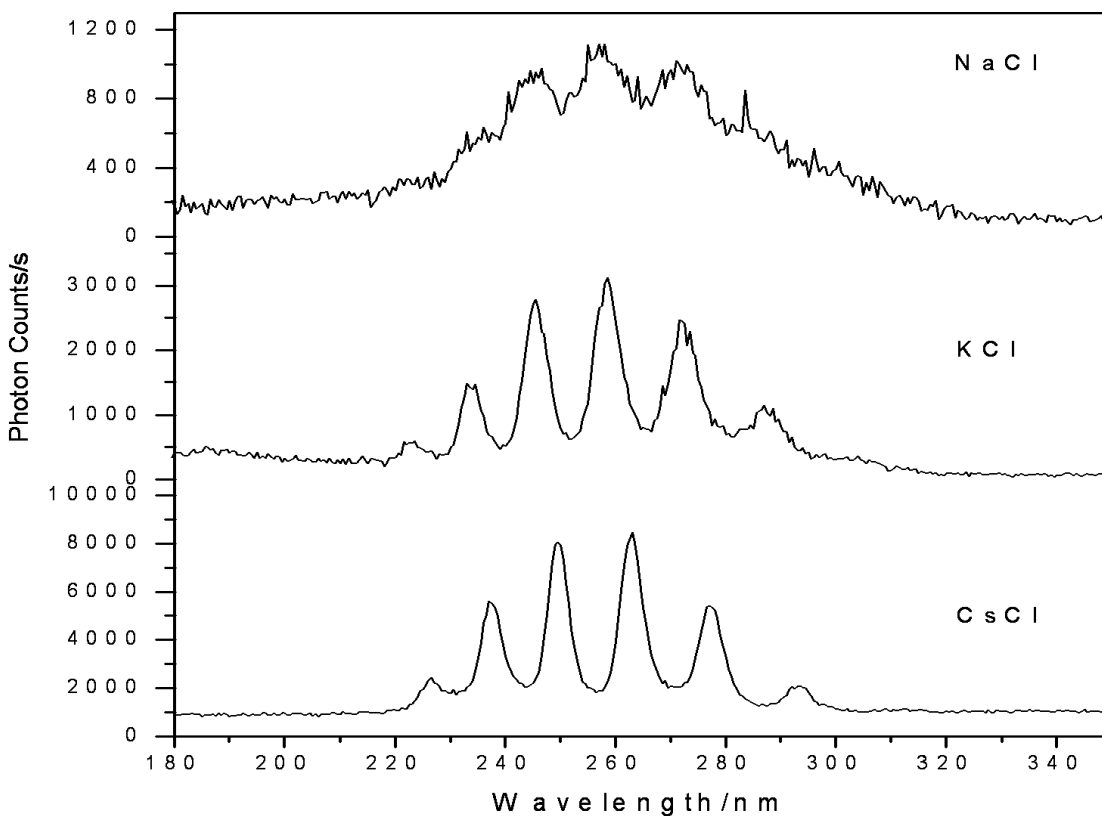
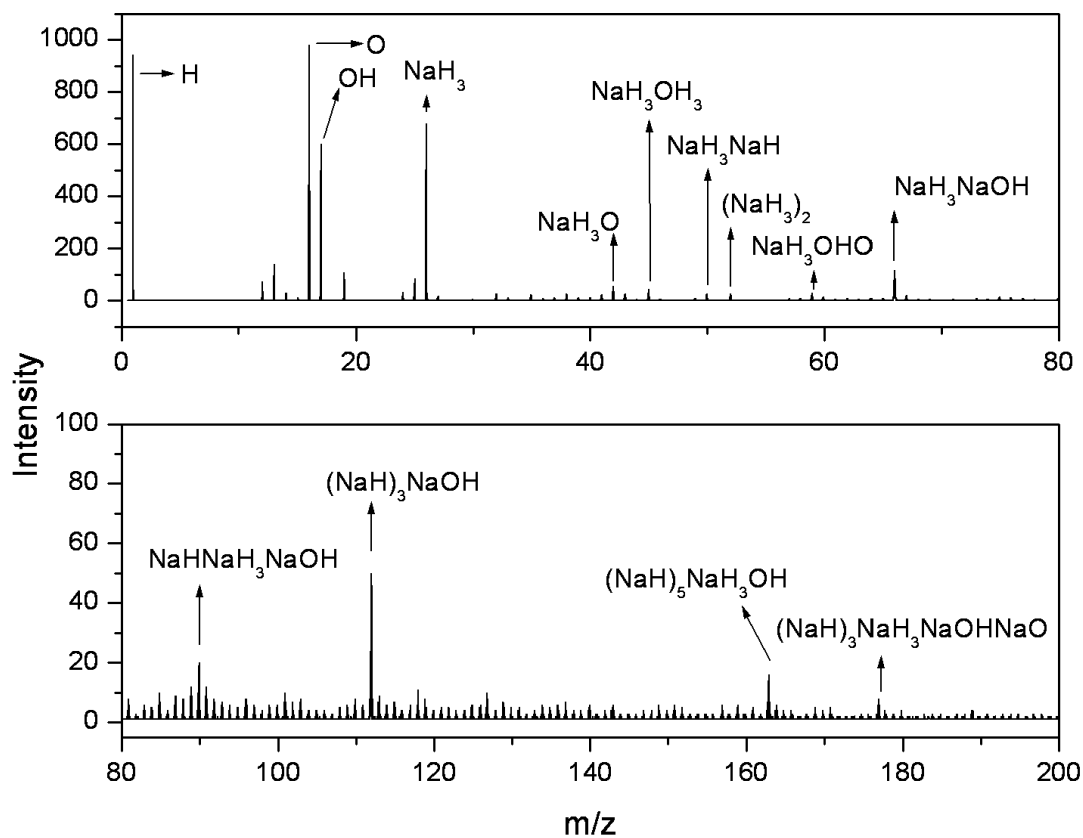
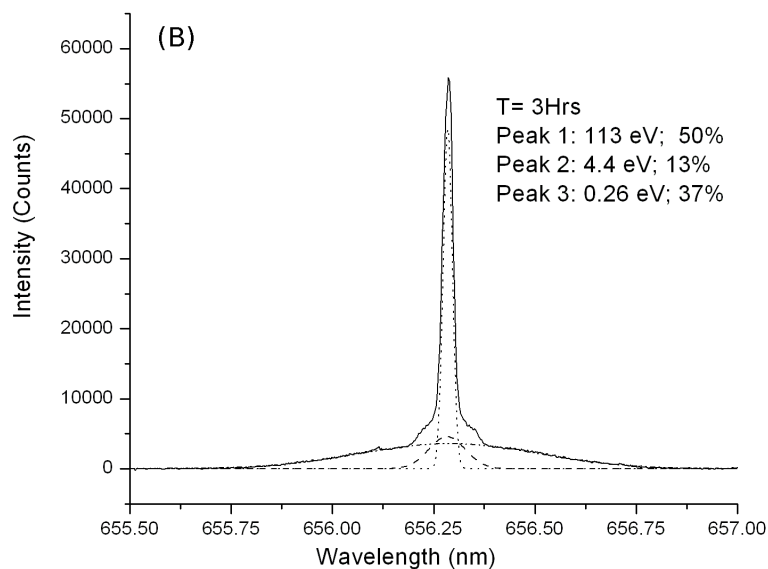
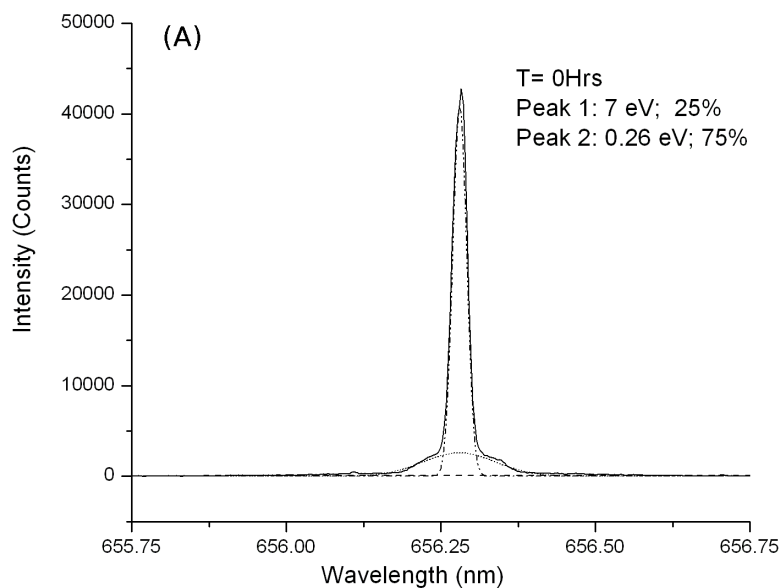


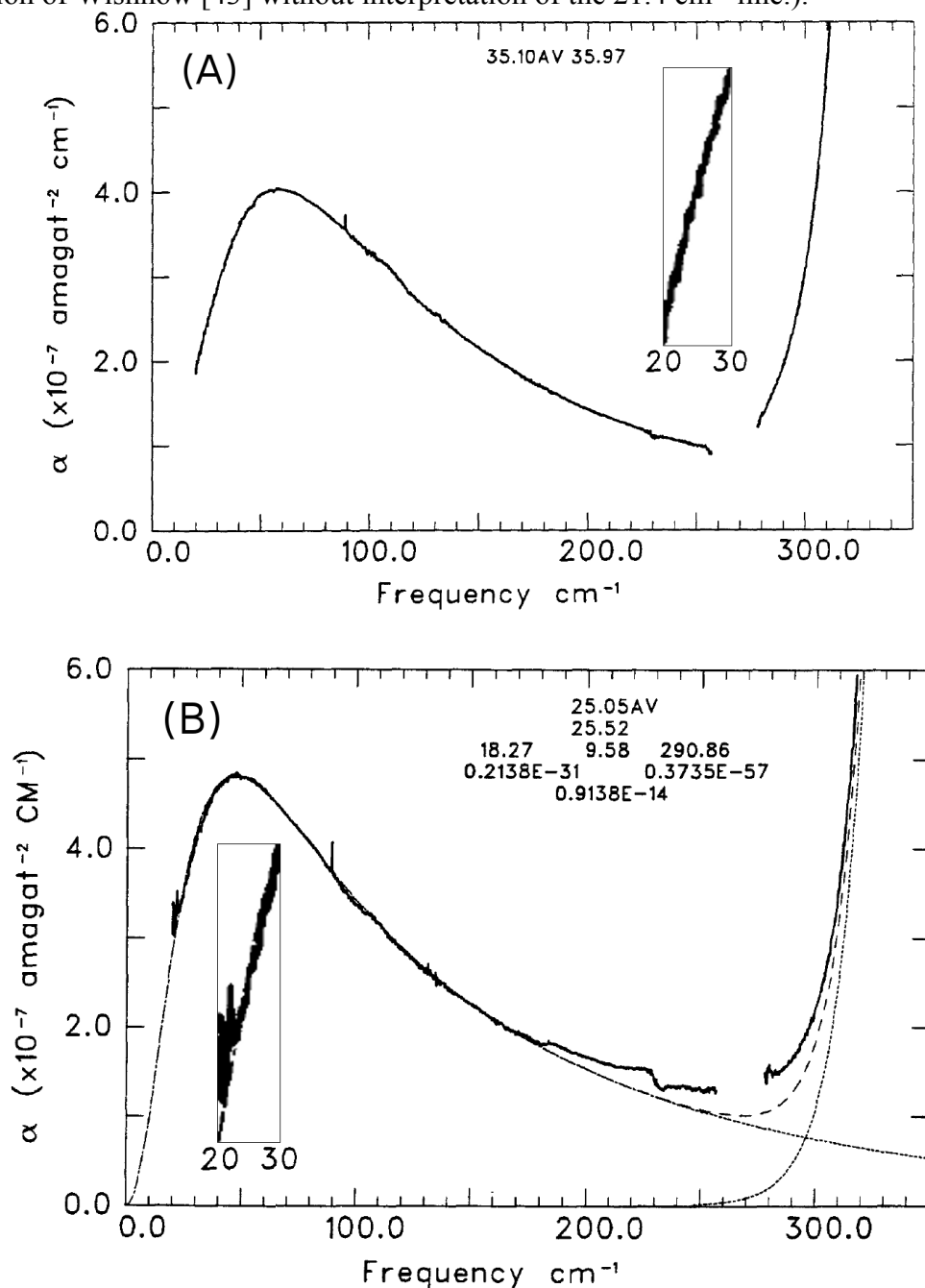
Figure 19. The negative ToF-SIMS spectrum ($m/e = 0 - 200$) of R-Ni reacted over a 48 hour period at 50°C . A dominant hydride, NaH_3^- and $\text{NaH}_3\text{NaOH}^-$ assigned to sodium hydrino hydride and this ion in combination with NaOH , as well as other unique ions assignable to sodium hydrino hydrides NaH_x^- in combinations with NaOH , NaO , OH^- and O^- were observed.



Figures 20A-B. The temporal evolution of Balmer α line profile width recorded on hydrogen plasmas at 100 mTorr and an rf coupled power of 200 Watt over a three-hour plasma duration. (A) Initial populations showing only warm and cold hydrogen. (B) The emission profile showing the fast H population after 3 hours of maintaining the hydrogen plasma without flow. A fast population of H atoms with energies greater than 100 eV was observed later in time; whereas, only mildly warm H atoms with energies of 7 eV were observed in the beginning of the experiment.



Figures 21A-B. The 20-320 cm^{-1} submillimeter cryogenic absorption spectra of normal H_2 (Added insert: expansion 20-30 cm^{-1} region). A. Spectrum recorded at 36 K. The sharp line at 89.2 cm^{-1} is the R(0) line of HD. B. Spectrum recorded at 25.2 K. The R(0) line of HD increased in intensity at the lower temperature. Additionally, a 21.4 cm^{-1} line was observed at 25.5 K that was absent at 36 K. The wavenumber of the line is a match to the predicted 21.4 cm^{-1} $^1H(1/4)$ hyperfine line. The dependence of the observation of the line on the reduction of the temperature from 36 K to 25.5 K also matches that predicted based on $T_{ul} = 30.797 \text{ K}$ (Eq. (79)). (Permission of Wishnow [43] without interpretation of the 21.4 cm^{-1} line.).



Figures 22A-B. The absorption-coefficient-dependent line shape function $G(\sigma)$ determined from the corresponding 20-320 cm^{-1} submillimeter cryogenic absorption spectra of normal H_2 (Added insert: expansion 20-30 cm^{-1} region). A. Spectrum recorded at 36 K. The sharp line at 89.2 cm^{-1} is the R(0) line of HD. B. Spectrum recorded at 25.2 K with an insert showing the 21.4 cm^{-1} region in higher detail. The R(0) line of HD increased in intensity at the lower temperature. Additionally, a 21.4 cm^{-1} line was observed at 25.5 K that was absent at 36 K. The wavenumber of the line is a match to the predicted 21.4 cm^{-1} $H(1/4)$ hyperfine line. The dependence of the observation of the line on the reduction of the temperature from 36 K to 25.5 K also matches that predicted based on $T_{uc} = 30.797 \text{ K}$ (Eq. (79)). (Permission of Wishnow [43] without interpretation of the 21.4 cm^{-1} line.).

