Tritium Diagnostics by Balmer-alpha Emission

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Abstract

Spectral line emission from tritium in a plasma may be distinguished from deuterium emission by a small isotope shift. A diagnostic system to measure tritium Balmer-alpha emission from the plasma edge has been installed on TFTR. This system has been used in deuterium plasmas, and the deuterium alpha line profile used as a basis to predict the spectrum at differing tritium concentrations in future D-T runs. The tritium and deuterium lines are partially blended, however, analysis of the predicted D-T spectra by a line fitting program produced estimates of the tritium density that closely matched those input to the spectra, providing confidence that the tritium density can be reliably measured. The spectrum maps the tritium velocity distribution at the plasma edge and will be important for studies of tritium edge physics.

I. INTRODUCTION

Magnetically confined fusion stands at the threshold of producing significant fusion power by the introduction of the radioactive fuel, tritium, into the plasma. First discharges in deuterium-tritium fuelled mixtures have been reported from JET[1] and tritium experiments in TFTR are planned for late 1993.[2] The fusion reaction rate is a maximum for equal densities of tritium and deuterium, however methods to measure directly the tritium concentration in the plasma are rare. On TFTR, a diagnostic system has been installed to measure optical emission from the 6560Å n=3 - m=2 Balmer-alpha transition in neutral tritium (Tα), generated at the plasma edge. This emission, together with emission from deuterium alpha (Dα), and hydrogen alpha (Hα), occurs in the scrapeoff region when molecular hydrogen isotopes, recycled from the wall, undergo various electron impact dissociation reactions.[3] Additional contributions to Tα, Dα, and Hα arise from charge-exchange neutrals and fast reflected particles. These lines are close in wavelength and will be partially blended. This paper reports on initial measurements of the Hα, Dα line profile in TFTR and predictions, based on the experimental results, of the Hα, Dα, Tα spectrum expected when tritium is added to the plasma. The predicted Hα, Dα, Tα spectra was analysed to determine the feasibility of tritium density measurements from the Balmer-alpha spectra.

Measurements of Hα and Dα emission have long been used in studies of the plasma edge.[4-5678] On TFTR a modular, fiberoptic coupled spectroscopic diagnostic (dubbed HAIFA[9]) is used to monitor the combined Dα, Hα emission yielding information on core recycling rates, ion and neutral particle limiter fluxes and conditions in the plasma scrapeoff layer.[10] This region is critically important since it permits the creation of "supershots"[11] and affects the heat and particle flux to the first wall, thereby controlling the tritium inventory accumulating in the machine. Hydrogen recycling from limiter or divertor targets plays a critical role in many aspects of plasma physics and engineering. The Dα, Hα spectral line profile maps the velocity distribution of the atoms in the scrapeoff layer. Previous measurements of the Dα, Hα line profile on TEXTOR[12] revealed evidence for emission from fast ions that were neutralized and reflected at the limiter surface. This data was used to assess the existing database for hydrogen reflection and penetration into plasmas,[13] important in modelling both current and future machines.

II. EXPERIMENTAL SETUP

The wavelengths of the Hα/Dα/Tα emission lines are separated by a small isotope shift arising from differences in the reduced mass and are at 6562.8Å, 6561.04Å and 6560.45Å respectively. Note that the Dα - Tα separation (1/3 that of Dα - Hα) is comparable to the linewidth so it is not clear *a priori* that Tα can be measured independently. The fine structure splitting of 0.1Å is not

resolved. A high resolution interferometer was installed to measure the spectrum on TFTR. The system is an upgrade of HAIFA,[9] an array of telescopes coupled by fiberoptics to a remote system of interference filters and detectors that is used for monitoring Hα, Dα and visible bremsstrahlung emission. The bandpass of the filters is 10Å so the existing system measures the sum of the emission from the hydrogen isotopes. To resolve the individual spectral lines, the light emerging from the filter in a dedicated HAIFA channel was input to a Fabry Perot interferometer (Burleigh Model TL38). The setup is shown in figure 1. The free spectral range of the Fabry Perot was 7Å and plate reflectivity 92% yielding a resolution of 0.2Å.

The Fabry Perot repetitively scans the wavelength region. The minimum time to acquire a spectrum is 20msec (corresponding to 5 interference orders scanned in 100msec). For the data presented here a slower scan speed (2 orders/ 500 msec) was used to increase the signal/noise. The light was detected by a photomultiplier, amplified and digitized at 2Khz. To maintain high resolution the drift in alignment of the interferometer plates must be less than 50Å. Since access to the interferometer was not possible during machine operations, the interferometer was housed in a chamber in which the temperature was held constant to within 1°C. In addition, an active stabilization system used an attenuated helium-neon laser beam that was input to the interferometer in the same fiber optic used for the plasma light. For the period 0-7 seconds during a plasma shot, this beam was blocked; at other times the signal from the laser was used in an electronic controller which maintained optimal Fabry Perot cavity separation. Since the line profile is scanned in time there is some potential for time dependent fluctuations in the edge density to modulate the line profile. A second HAIFA channel with a 10Å bandpass interference filter recorded the combined Hα+Dα+Tα signal and was available to normalize the line profile where necessary.

Both telescopes viewed a region on the TFTR inner limiter 5cm in diameter, 55cm below the midplane. In this location the magnetic field strength was typically 6.5 - 6.8 Tesla in a direction 4° below horizontal. The Zeeman effect splits the Hα,Dα,Tα lines into an unshifted π component, polarized parallel to the field direction, and two σ components displaced by ±1.3Å and polarized perpendicular to the field. The Zeeman splitting has been used to measure the local magnetic field and hence the location of the emission region.[14] In the present experiment a polarizing filter was placed in front of the telescope lens and oriented to transmit only the unshifted π component.

III. RESULTS FROM DEUTERIUM, HYDROGEN PLASMAS

The system was operational during the 10/92 - 11/92 run period and figure 2 shows a Hα, Dα line profile taken during neutral beam injection at 3.7 seconds on shot 69019. This was a 'supershot'[11] conditioned by the injection of 2 lithium pellets at 2 sec. The profile was taken in a single scan and

it was not necessary to normalize it with the data from the reference channel. An instrumental profile was taken immediately after the discharge using the helium-neon laser light and a dedicated linefitting program (SV.FOFFE) was used to analyze the data by the method of least squares. First, the instrumental profile was fit by a combination of 2 Gaussians with a 1st order polynomial background and then this was deconvolved from the observed Hα, Dα profile. The resulting profile was analyzed by performing an unweighted least-squares fit to 4 Gaussian line profiles (2 for H and 2 for D), broadly corresponding to the contributions from 'cold' dissociation products and 'warm' charge-exchange atoms.[7] The actual line profile is Doppler broadened and non-Maxwellian but could be well fit by the combination of 2 Gaussians per isotope. The resulting Gaussians for deuterium had temperatures of 1 eV and 24 eV with the broad 24 eV Gaussian slightly displaced to shorter wavelengths by 0.25 Å. This displacement is attributed to the contribution of ions neutralized and reflected from the wall which have an anisotropic velocity distribution. From the fitting parameters the density ratio H / (H + D) in the scrapeoff region was determined to be 12% (±3%). More significant for the planned Tα measurements is the intensity of the line wings that determines the degree of blending of the Dα and Tα lines.

IV. TRITIUM ALPHA LINE PROFILE MODELLING

The measured Hα, Dα spectral line profiles were used to provide a prediction of the spectrum expected when tritium is introduced into TFTR. No measurements of the Tα line profile in a high temperature plasma have been made to date, however it it possible to make reasonable predictions of the expected profile based on the Dα results. The kinetic energies of the excited tritium produced from dissociation and charge exchange are expected to be the broadly the same as deuterium. There are some differences in the deuterium and tritium particle reflection coefficients in the database used in the DEGAS[15] code that will affect that part of the line profile arising from ions reflected and neutralized at the wall. These will be investigated when the experimental tritium line profile becomes available. For the present purposes the major difference in the profile arises from the higher reduced mass that displaces the line center and decreases the Doppler width by a factor of $\sqrt{(3/2)}$ compared to deuterium.

A "synthetic" tritium spectrum was constructed from the right hand side of the Dα profile by manipulating the data elements with a spreadsheet program. After mirror reflection to generate a symmetrical profile, the line width was reduced by a factor 0.71 by deleting approximately every 5th data element. The profile was then shifted in wavelength by the isotope shift, multiplied by a scaling factor corresponding to various tritium densities and added to the original data. The resulting H, D, T predicted spectra are shown in Fig. 3. The Tα and Dα line peaks are seen to be separated while the line wings are blended.

These profiles were used as a test case to determine the accuracy of the linefit program in assessing the tritium level. The linefit program was used to fit the modified data with 2 Gaussians being allocated to each isotope (a total of 6 Gaussians) with a first order polynomial background. While the amplitudes of all the Gaussians were free, the total number of free parameters in the fit was reduced from 20 to 8 by linking the wavelengths and widths of the T and H profiles to the D profile according to their known relation to the D parameters. The tritium / deuterium density ratios were calculated from the fitting parameters and the result compared to the input scaling factor. Preliminary results showed good agreement even for the lowest density case (see Fig. 4).

A second method was used to create a tritium profile. Here the Gaussian fitting parameters derived from the deuterium spectrum were modified to correspond to tritium, and a 2 Gaussian tritium profile generated. This was combined with the deuterium and hydrogen Gaussians and reconvolved with the instrumental profile. These resulting spectral profiles were consistent with those above.

The experimental spectral profile reflects the velocity distribution of hydrogen isotopes in the edge region. This parameter is also contained in recycling codes such as DEGAS that are used in divertor/edge studies of future machines, e.g., ITER. We plan to make a detailed comparison of the experimental profiles to the code predictions. This study will be a valuable benchmark of the code and lead to information on the physics of the edge region. We are also planning to improve the resolution and sensitivity of the experimental system to facilitate measurements at higher scan rates and lower light levels.

In summary we have installed a high resolution spectrometer and measured the Hα, Dα, line profile on TFTR. The profile has been used to predict that expected when tritium is added to the machine. The Hα, Dα and Tα lines emitted from the plasma edge will be partially blended, however analysis with line fitting software gives us confidence that it will be possible to measure reliably the tritium / deuterium density ratio and to investigate tritium edge physics.

Acknowledgment

Figure Captions

Figure 1. Experimental setup.

Figure 2. Hα, Dα spectrum recorded in a single scan during neutral beam injection in shot 69019. The direction of scan is such that the wavelength decreases with increasing time.

Figure 3. Predicted profiles of Hα, Dα, and Tα at differing ratios of tritium to deuterium density. The tritium peak for T/D = 0.71 is more prominent than deuterium even though its density is lower, due to its narrower linewidth.

Figure 4. The deviations from the straight line represent the difference between the T/D density ratio calculated from the line fitting parameters and tritium scaling factor used to create the line profile.
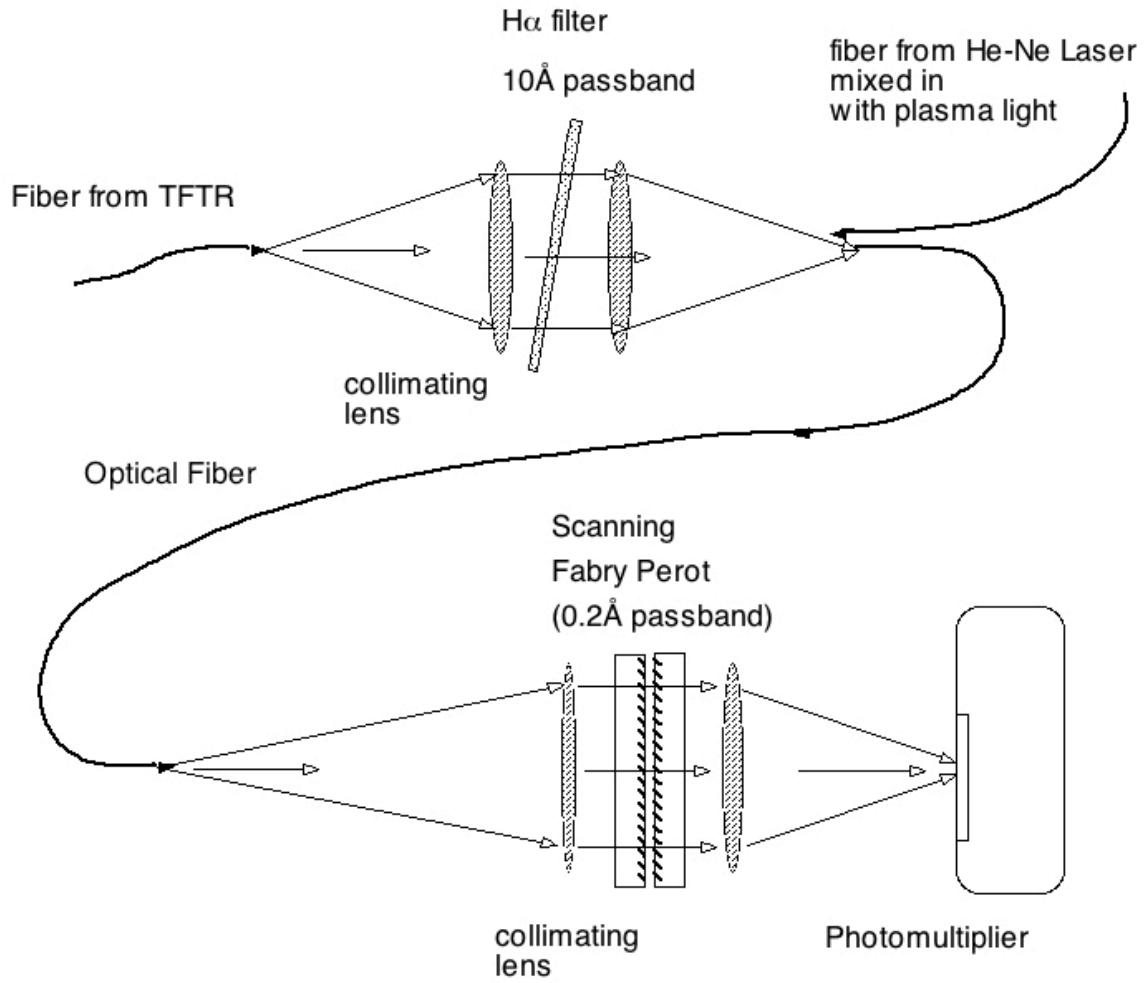
Hα filter

10Å passband

fiber from He-Ne Laser
mixed in
with plasma light

Fiber from TFTR

collimating
lens

Optical Fiber

Scanning
Fabry Perot
(0.2Å passband)

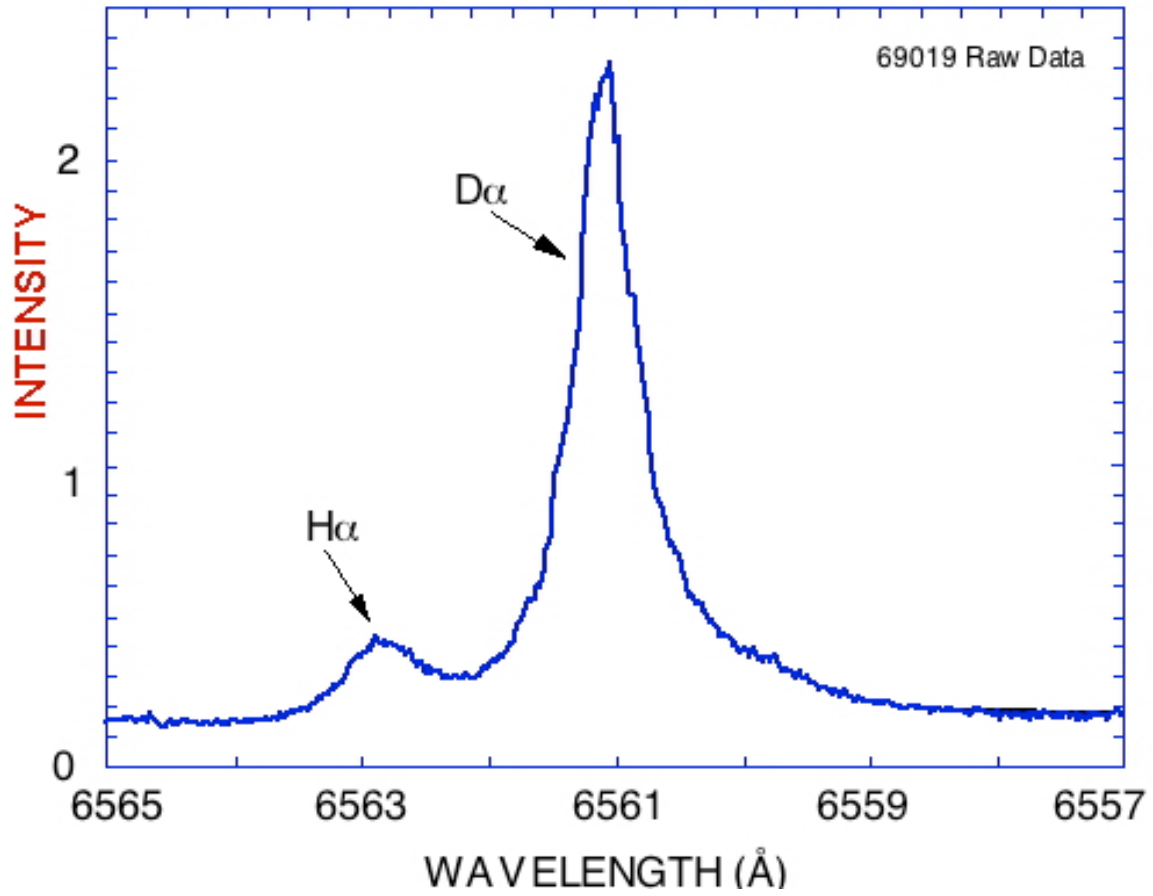collimating
lens

Photomultiplier

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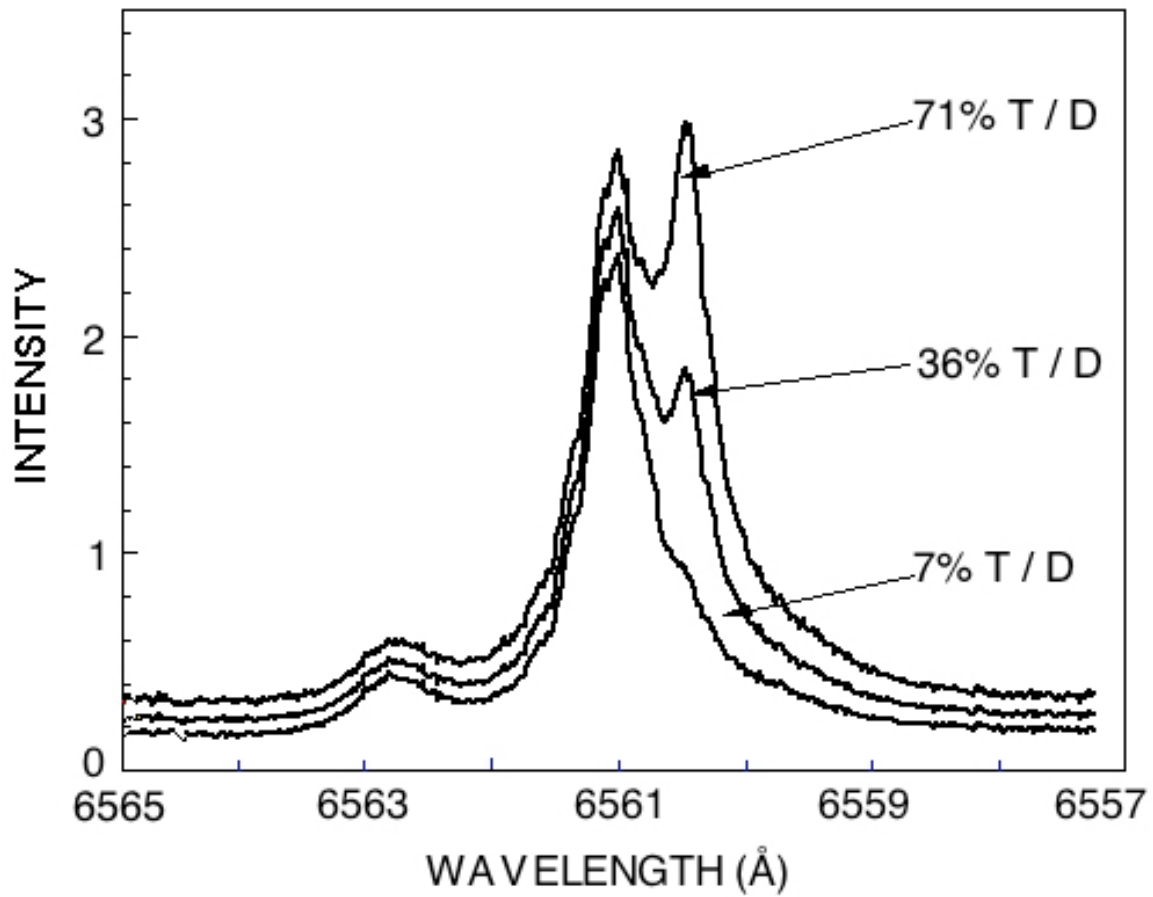
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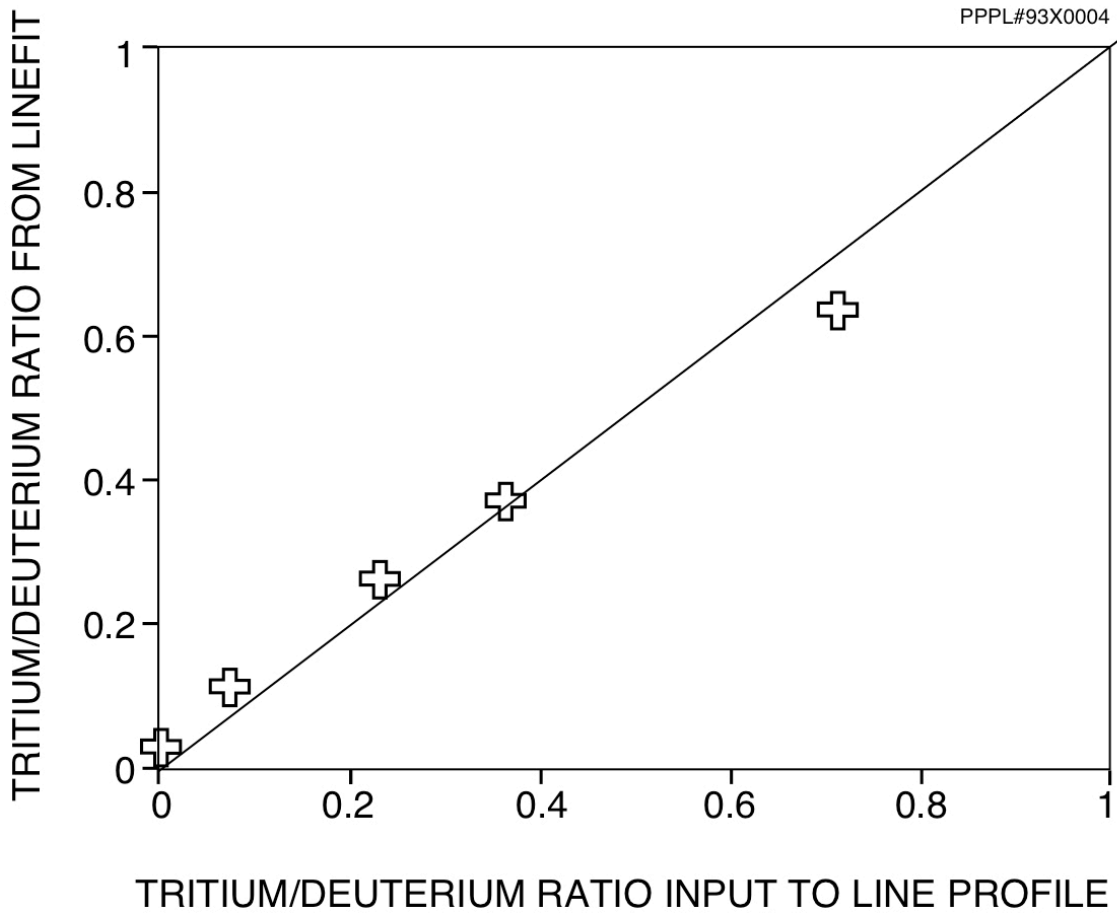
Figure. 4 The deviations from the straight line represent the difference between the T/D density ratio calculated from the line fitting parameters and tritium scaling factor used to create the line profile.

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