Hydrogen Line

Neutral Hydrogen is the most abundant element in our universe. Most of the matter between the stars in the Milky Way Galaxy and other spiral galaxies occurs in the form of relatively cold neutral hydrogen gas as clouds. These clouds are easily detectable at radio wavelengths because they emit at a wavelength of 21 cm. The map of radiation from this neutral hydrogen can give us a pretty accurate view of different galaxies.

Hydrogen consists of 1 proton and 1 electron, which makes it electrically neutral. The radiation is generated due to a process called 'spin-flip transition'. In simple words, the hydrogen's transition between two levels in its ground state creates this radiation. The electron and the proton in a hydrogen atom have spins, the electron and nuclear-spins respectively, the rotational axes of which are depicted in Figure 1. The state on the left, showing parallel spins, has a slightly higher energy level than the state on the right, showing anti-parallel spins. The exact value of this energy difference is around 5.874 μeV. So with the flip in spin, this energy is radiated as a photon which we aim to detect.

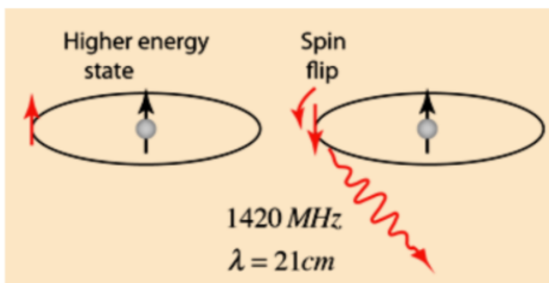

Figure 1.

Using the well-known Planck-Einstein relation, the frequency of emitted photon can be found as, E=hν. Here 'E' is the energy of the emitted photon(=5.874 eV) and 'h' is the Planck's constant. Upon calculation, the corresponding frequency and wavelength values come to be around 1420.406 MHz and 21.106 cm.

The energy difference between the spins can be explained through the hyperfine splitting of the ground state(1S) of the hydrogen atom. In figure 2 we have the hyperfine splitting shown for the same. The upper level is associated with parallel spins and the lower is with antiparallel spins.

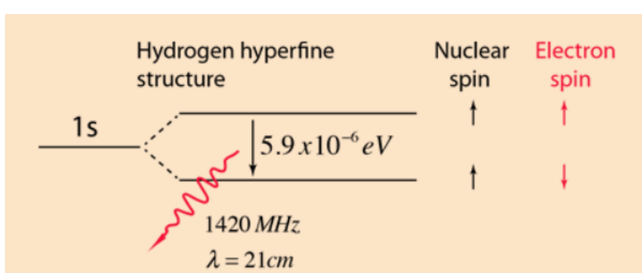

Figure 2.

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The energy difference between these two levels is 5.874 μeV ($\approx$ 5.9 μeV). When we have a transition from the upper-level to the lower a photon corresponding to this energy difference i.e. at 1420.406 MHz is emitted.

But, the radiative lifetime of the 21 cm line is extraordinarily long. We can get the value of the transition probability from Einstein's A-coefficient.

$$A_{UL} \approx (64\boldsymbol{\pi}^4/3hc^3)\ (\boldsymbol{\nu}^3_{UL})\ (\boldsymbol{\mu}^2_B)$$

(1)

In equation 1,

A_{UL} is the Einstein A-coefficient for the transition from level 'U' to level 'L'
h is Planck's constant
c is the speed of light
$\boldsymbol{\nu}_{UL}$ is the frequency of line (≈1420 MHz)
$\boldsymbol{\mu}_B$ is Bohr magneton, the mean dipole moment of the ground state of hydrogen (≈9.27 x 1021 erg/gauss)

Using these, we will get, $A_{UL} \approx 2.85 \times 10^{-15}$ sec^{-1}

The inverse of this value is the radiative lifetime, t ≈ 3.5 x 10^{14} seconds (≈ 11 million years)
This value essentially means that once in 11 million years we will see a transition from the upper level of the hyperfine split to the lower one. So, ideally, it's nearly impossible to see this line.

But, how is it detected in space so easily? The simple reason is we have a very high amount of volume in front of us. Our galaxy itself is spread across around 10 kiloparsecs. So, this builds a very high column density in front of our telescope. So, we can see a huge number of transitions in a very small time scale as well.

References:

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