MAGNETIC FIELD SENSITIVE SPECTROSCOPIC LINES AND THEIR PROSPECTS IN ATOMIC AND ASTROPHYSICS

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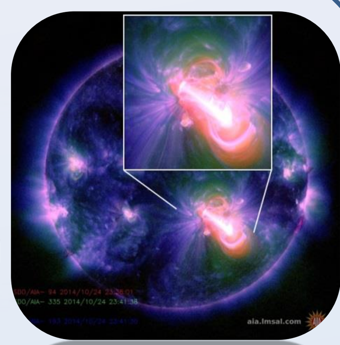
Introduction



Magnetic fields play an important role in determining the properties of plasmas, for example, through driving the energetics and dynamics of enormous solar flares on the surface of the sun. They are also used to restrict huge plasma fluxes in man made fusion device like Tokamak. Measuring the structure of magnetic field in such plasmas is therefore extremely important and useful for understanding and plasma control.
The problem is that there are always many inconvenience or limitations on measuring the magnetic field in high temperature plasmas with traditional methods like Zeeman splitting.

Here we present new possible way to measure the magnetic field in these plasma, which is based on the "magnetic-field induced" radiation that originates from atomic transitions where the lifetime of the upper energy level is sensitive to the local, external magnetic field.

Theory

The main principle is external magnetic field will lead a mixture of near quantum states leading to unexpected transitions to occur, whose strength is depended on the external magnetic field. Measuring strengths of these spectroscopic lines will lead to much information about the local magnetic field structure, but usually these lines' intensities are too weak to make any measurements.

But here we find there is one unique case where even relatively small external magnetic fields can have a striking effect on the ion, leading to resonant magnetic-field induced light. This is due to what is called accidental degeneracy of quantum states. Sometimes the quantum states might end up very close to each other in energy, they are accidentally degenerate, and the perturbation by the external field will be enhanced. If this occurs with a state that without the field has no, or only very weak, electromagnetic transitions to a lower state, a new and distinct feature in the spectrum from the ion will appear – a new strong line. Fortunately nature does present one such case in the iron ion.

Results and Discussion

We studied ions in the Chlorine-like isoelectronic sequence. The energy level structure is show in Fig. 1. The $^4D_{5/2}$ has an allowed, electric-dipole transition to the $^2P_{3/2}$ state in the ground term, which makes it short-lived and gives rise to strong spectral features. The $^4D_{7/2}$ on the other hand, can only decay with a forbidden magnetic quadrupole transition to the same lower state, in the absence of an external field, giving it a lifetime around 1 million times longer. By accident, these two excited states are extremely close in energy in one particular ion, namely Fe^{9+} !
An external magnetic-field will therefore make these two states share their properties and consequently induce a new electric dipole transition $^4D_{7/2} \rightarrow {}^2P_{3/2}$.
We show the calculated results in Fig. 2 how the rate of the normally "forbidden" $^4D_{7/2} \rightarrow {}^2P_{3/2}$ transition varies along the isoelectronic sequence for different magnetic field strengths, revealing a extremely strong resonance effect for iron.
(The fact that this effect is so strong in Fe^{9+} is extraordinary fortunate because of its high abundance in the solar corona. As a matter of fact, the ground state fine structure transition of this ion is used to determine the temperature of the corona and is often referred to as one of the "coronal lines".)

The most urgent act before these two transitions can be used for plasma diagnostics, is therefore to determine the energy difference between the two excited states $^4D_{5/2}$ and $^4D_{7/2}$. Unfortunately, there are currently no direct experimental determinations of this fine structure separation. As we need to overcome two difficulties – firstly we need enough spectral resolution, and secondly we need a light-source with a low density and a magnetic field. (collisions are destroying the population of the upper state before the photon is emitted). In addition to this, observations of the $4D_{7/2} \rightarrow 2P_{3/2}$ line needs a strong enough magnetic field of at least tenths of a Tesla. This leads arguably to only two possible light sources on earth: Tokamaks and Electron Beam Ion Traps , (EBITs).
And although the some spectrometer demonstrates that the required resolving power can be achieved this instrument is not compatible with Tokamaks or EBIT operating parameters and a dedicated instrument is required.
So future works will be focused on the measurements in these manmade plasmas with special designed high resolution spectrometers.

Fig. 1 Energy levels of Chlorine-like ions

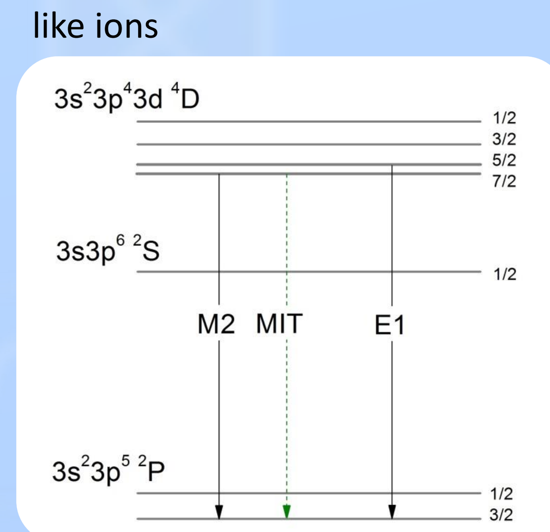


Fig. 2 Rates of the $4D_{7/2} \rightarrow 2P_{3/2}$ transition varies along the isoelectronic sequence