Thomson Scattering Plasma Diagnostic

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Introduction

Thomson Scattering (TS) is an active spectroscopy technique where a laser with a monochromatic light is fired into a plasma and the scattered light is collected and analysed. It measures plasma electron temperature, T_e, and its density, n_e.

- It allows reliably to study plasma structures of magnetic confinement devices.
- We distinguish Incoherent and Coherent Thomson Plasma Diagnostics.
- Accurate measurements of electron temperature and density using these diagnostics were performed on JET and MAST and scheduled on ITER.

Theory

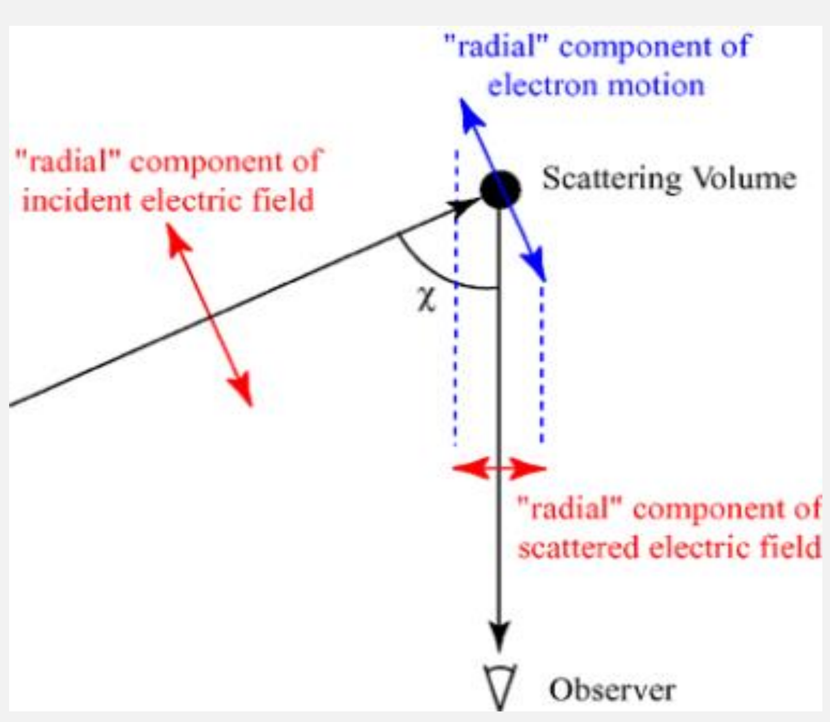
The Incoherent Thomson Scattering is based on two principles – the Doppler Effect and the Doppler broadening of monochromatic light.

- The Doppler effect (or Doppler shift) is the change in frequency f_0 of a wave for an observer moving relative to its source.

$$\Delta f = f - f_0 = \frac{\Delta v}{c} f_0$$

- The Doppler broadening of is a widening spectrum line. As result of this the monochromatic laser line will be widened.
- We consider electrons as single and independent particles, and the plasma does not demonstrate collective behaviour.

This figure explains why scattering of light happens. The laser light with "radial" component of electric field interacts with electrons in the Scattering volume, and the observer sees only a "radial" component of the scattered electric field.



The measurement technique

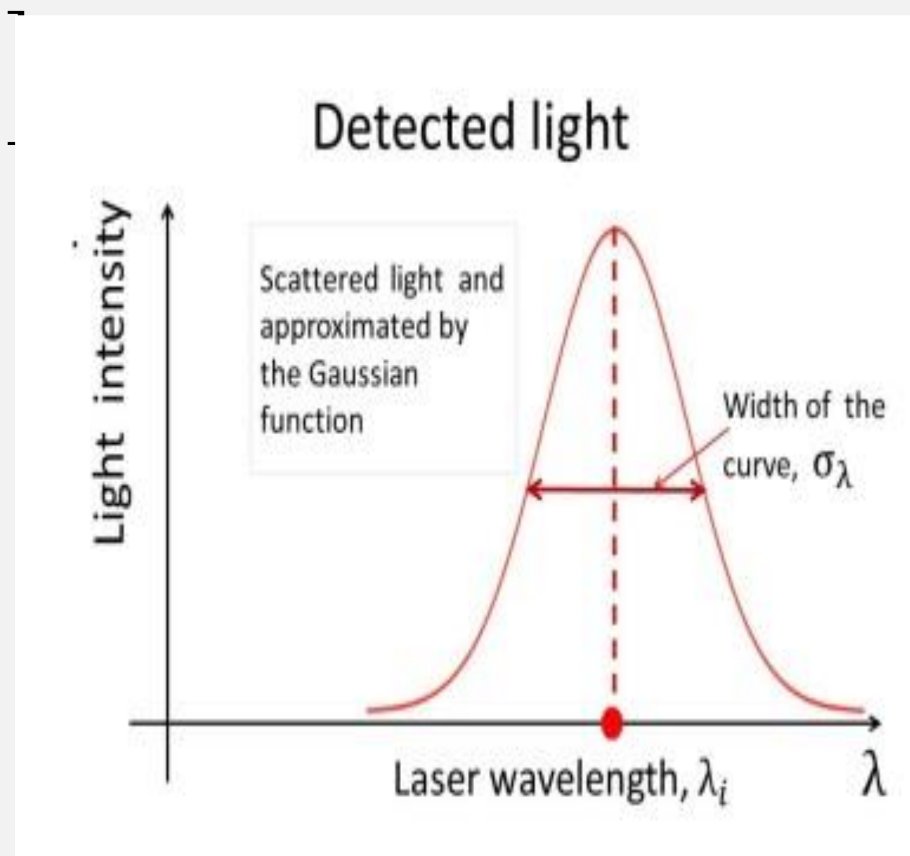
As long as thermal electron velocities have the Maxweilian distribution, wavelength of the scattered photons will have the same distribution and its shape can be approximated by the Gaussian function.

- By measuring the width of the Gaussian function, we can find the velocity distribution of electrons and calculate the electron temperature.
- The electron density is proportional to the total amount of scattered photons.

$$\frac{dP_s}{d\lambda_s}(\vec{R}, \lambda_s) \sim \exp\left[-\frac{1}{2}\left(\frac{\lambda_s - \lambda_i}{\sigma_\lambda}\right)^2\right]$$

$$T_e = \frac{m_e c^2 \sigma_\lambda{}^2}{4 k_b \lambda_i{}^2 \sin^2(\chi/2)},$$

Where
m_e is the mass of electron,
σ_λ is the width of the scattered spectrum (the Gaussian function)
χ is angle between the laser and the scattered light,
k_b is the Boltzmann constant,
λ_i is the laser wavelength .



Coherent Thomson Scattering

The Incoherent Thomson Scattering technique has a limitation and is restricted by a criteria $\alpha = \frac{1}{\Delta k\, \lambda_D} >> 1$, which is called the Scattering parameter.

- Electrons cannot be treated as single independent particles any longer.
- Collective plasma behaviour should be considered.
- The shape of detected light cannot be approximated by the Gaussian curve.
- We should use a new model, called Coherent Thomson Scattering, which should satisfy the criteria $\alpha = \frac{1}{\Delta k\, \lambda_D} \leq 1$
- The spectrum of the detected light will depend on of the dynamic structure function S(k,ω), structure of which is very complicated.

History and first experiments

The technique is named for J. J. Thomson, which was presented in 1907. However it was not tested until lasers with monochromatic light became available.

- First measurements of electron plasma temperature were made on Soviet tokomak T-3 and the results were published in "Nature" in November 1969.
- However, it was a rough estimation of an average plasma temperature.
- Nowadays more accurate measurements of plasma temperature and density are required.

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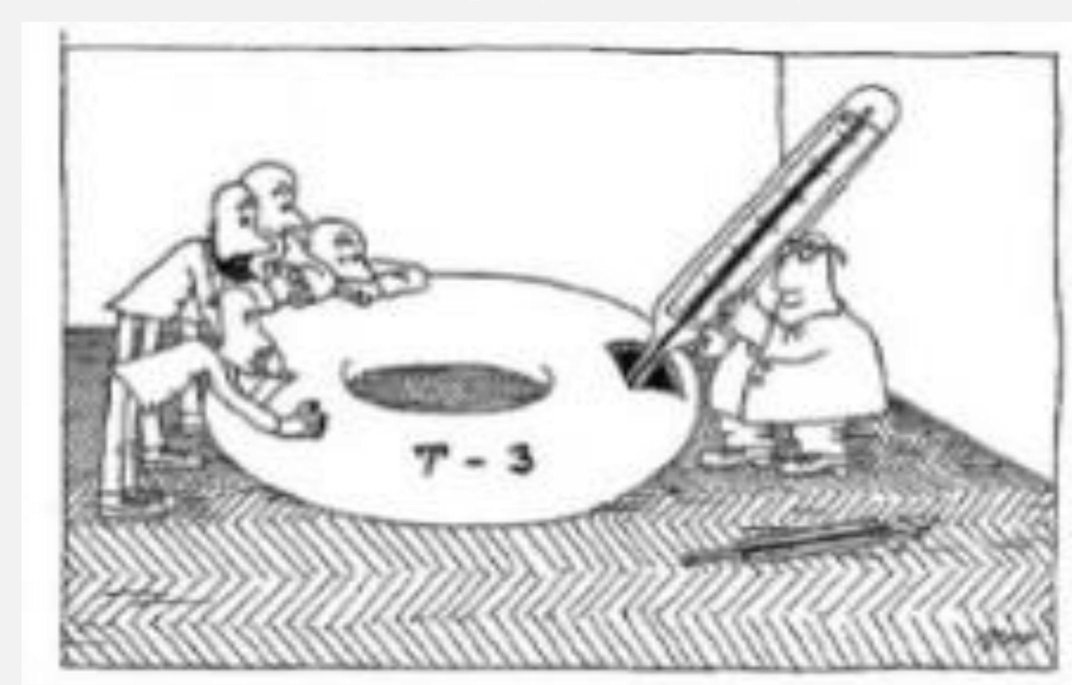
(This figure shows the physicists working hard to make measurements of a tokomak electron plasma temperature for the first time.)



Achievements and future plans

Thomson Scattering Plasma Diagnostics were performed on JET, MAST and Scheduled to be used on ITER. Three main system TVTS system, Nd:YAG TS and LIDAR (Laser Detecting and Arranging) were developed.

- Ruby and Nd (glass) lasers are used.
- Lasers operate with wavelengths of 1064, 532 and 694.4 nm
- Powers of the laser pulses are few Joules.
- High temporal and spatial resolution of 5 – 7 cm were achieved.
- Errors for electron temperature and density measurements were to 3 – 5%.
- Such accurate measurements greatly helped to understand the structure of magnetic confinement plasma and improve its efficiency.

References

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