# Chapter 1: Introduction

Emission spectroscopy was used to infer excited state densities of neutral and singly ionized Argon in the Texas Helimak. The combination of spectra was used to determine a self-consistent value for the electron temperature and density of the plasma using theoretical values from collisional radiative (CR) models for both species, as well as a kinetic description of the neutral Argon gas to estimate the neutral ground state profile. Corrections are also estimated to the electron collisional excitation rates due to a non-maxwellian electron velocity distribution from inelastic collisions.

### 1.1 Background

Atomic emission spectroscopy is a diagnostic tool that can give passive measurements of plasma properties. Transitions between atomic levels emit light of specific wavelengths. When analyzed with a spectrometer, the amount of light at each wavelength can give a measure of how frequently a certain transition is occurring in the plasma. The frequency of the transitions can then be related to plasma parameters though the physics of interactions between other constituents of the plasma.

### 1.2 Motivation

This project began because of seemingly strange results seen from the Texas Helimak [3] between measured spectral intensities from neutral Argon (Ar I), probe measurements of electron temperature and density profiles, and predicted values obtained from a collisional radiative model for neutral Argon developed by Bogaerts et. al. [4]. The usefulness of this model lies in the ability to tie it to the physical quantities of the plasma, but that must be done in a self-consistent manner to be confident in the results. The method of determining neutral density used by Sciamma[5] was used in a scan over a small range of radial positions of the Helimak. However, the variation of the determined z-averaged neutral density was nearly a factor of four, which was much larger than expected. Several approaches were taken to try to eliminate possible causes for inconsistency.

The use of probe measurements of the electron temperature Te and density ne entails several possible issues as it relates to this work. One is that probe data was not available for every shot, and instead had been determined from previous shots that had similar conditions such as the input current of the toroidal field (TF) coils and vertical field (VF) coils, RF power input, and filling pressure. The ideal situation would be to have measurements of ne and Te for every shot they are needed. Another possible issue with the probe data is the uncertainty in the measurement of ne , determined from the ion saturation current, due to their unknown effective area.

There is still some question of how close the electron distribution is to being Maxwellian. At the edge of the plasma, a sheath develops to ensure that the ion and electron current from the plasma are balanced , or . The Bohm criterion states that the ions must enter the sheath at least the sound speed, . If the electron velocity is still nearly thermal, and , then equating the two currents results in . Or, taking the log of both sides results in .

The probes sample the distribution near the floating potential relative to the plasma potential , , which for Argon . The excitation energies of the observed states of neutral Argon are around 11.5eV. For a Te=10eV plasma . The part of the distribution the probe measurements and spectroscopic measurements sample are fairly different, which could lead to some disagreement if the distribution is not Maxwellian.

Finally, the profile of the neutral Argon density is not known a priori. The neutral density was initially estimated from ionization gauge pressure readings, but if the density was not uniform throughout the vacuum chamber, then inferences from the excited states using that pressure reading would not be correct.

### 1.3 Objectives

The overall objective is to obtain self-consistent values of ne, Te, and neutral density (), with measurements of line emission intensity based on the available atomic model [4]. Given a measurement of the absolute line emission intensity from one of the modeled excited states of neutral Argon, the three unknowns ne, Te, and are dependent. Conceptually, this means that three relations are needed to solve them uniquely.

In principle, one could use two separate excited levels of neutral Argon to determine the electron temperature since the ratio of the two levels does not depend on either neutral density or electron density, but does depend on the electron temperature through the excitation rates. However, it was found that the observed lines did not exhibit enough independent behavior to resolve the effect of electron temperature. It is thought that the energies of these levels are too close together to see the temperature dependence over the noise of the observation system.

Instead, a second relation involving ne and Te was obtained by measuring line emissions from the ion Ar II, and using the atomic data for Ar II used by Sciamma [5]. The excitation energies of the observed levels of Ar II are around 19.2eV. This gives an energy separation from the Ar I levels of about 7.7eV, which should be large enough to see the temperature dependence of the excitation rates with the available equipment. If the electron density is approximately equal to the ion density , then the two models could be used to solve for ne and Te, given that could be known.

To determine , it was decided that a kinetic model for a neutral, low density gas would need to be developed and coded for the Helimak’s geometry, boundary conditions, and source profiles. While the kinetic model itself would also depend on ne and Te for inputs to the ionization rates, the combination of the three models should then provide a self-consistent result.

Once these tasks are completed, the ne and Te obtained could be compared to those obtained from the Langmuir probes, and possibly provide a method to calibrate for the systematic error in the density measurements.

A secondary objective was to try to account for the effect of inelastic collisions, which might lead to a non-Maxwellian electron distribution. In an attempt to correct for this in the spectroscopic measurements, a solution was sought to the Fokker-Plank equation using the Landau-Boltzmann collision operator with the addition of inelastic collision and ionization operators. The solution was then used to make a crude correction to electron collision rates without needing to re-calculate the rates that were tabulated using a Maxwellian distribution. These corrections would be used in the models to alter the excitation rates of both Ar I and Ar II as well as the ionization rates used in the kinetic model of .

### 1.4 Organization

The thesis is divided into seven chapters. Chapter 2 describes the Texas Helimak. Chapter 3 describes the equipment used for spectroscopic measurements, calibration methods, data acquisition software, and the processing of the raw data. Chapter 4 explains the collisional radiative models used for Ar I and Ar II and how they would be used to determine ne and Te. Chapter 5 details the kinetic model developed to estimate the neutral density profile in the Helimak. Chapter 6 explains the inclusion of inelastic collisions on the electron distribution. Chapter 7 presents the resulting self-consistent profile of ne and Te that was determined and compares it to that found by Langmuir probes, and suggests future related work.