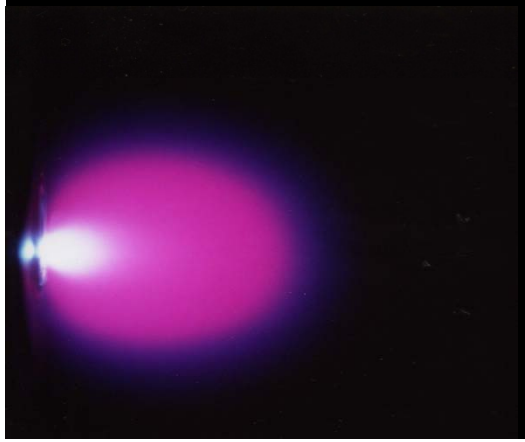
Amal Ibrahim Refaie

Department of Physics
Faculty of Science
Cairo University



Ohio State University (12-26 Oct. 2011)

Topics of Discussion

1. **Atomic Structure Theory for The Calculation of Atomic Properties and the interaction of atoms with electromagnetic field.**

2. **Electron Impact Excitation, Ionization, Recombination and De-excitation Rate Coefficients.**

3. **Experimental Activities.**

4. **Future Work.**

1. Atomic Structure Theory for The Calculation of Atomic Properties and the interaction of atoms with electromagnetic field

Atomic data such as

1. ***Energy levels,***
2. ***Line Strengths,***
3. ***Oscillator strengths,***
4. ***Transition probabilities*: E1, E2, M1, etc..**

are needed in many areas such as for:

Laser produced Plasmas:

which produce ions with different ionization stages and need interpretations and identification of line spectrum.

The determination of plasma conditions:

electron density and plasma temperature, etc.

The development of controlled thermonuclear fusion.

Astrophysics.

In environmental clean-up problems:

where heavy elements are gaining importance.

Atomic Structure Theory

- **The atomic structure theory used for the computation of the atomic properties would be reviewed.**
- **For a multi-electron system, in *non-relativistic* LS coupling calculations, the normal starting point is Shrödinger's equation where the Hamiltonian, in atomic units is given as:**

$$H = \sum_{i=1}^{N} \left(-\frac{1}{2}\nabla_i^2 - \frac{Z}{r_i} \right) + \sum_{i>j}^{N} \frac{1}{r_{ij}}.$$

- **Stationary state of N-electrons is described by a wave function $\Psi(q_1,.....,q_N)$, where $q_i=(r_i, s_i)$ represents the space and spin coordinates of the electron i.**

$$H\,\psi(q_1,\ldots\ldots,q_N) = E\,\psi(q_1,\ldots\ldots,q_N)$$

- **The wave function is assumed continuous w.r.t. the space variables and is a solution to the wave equation.**

The Relativistic Corrections to the Non-relativistic Hamiltonian

- **In the multi-configuration approximation, the wave functions for a state labeled αJM_J are expanded in terms of configuration state functions**

$$\psi(\alpha J M_J) = \sum_{i=1}^{M} c_i \phi(\alpha_i L_i S_i J M_j)$$

- **Where α represents the configuration and the set of quantum numbers required to specify the state.**
- **By using the multi-configuration approximation model one can calculate correlation relativistic corrections (correlation means here interaction between electrons) to the non-relativistic Hamiltonian by considering the Breit-Pauli operator.**

$$H_{BP} = H_{NR} + H_{FS} + H_{RS}$$

H_{NR} is the ordinary non-relativistic many electron Hamiltonian

$$H_{NR} = \sum_{i=1}^{N} \left(-\frac{1}{2}\nabla_i^2 - \frac{Z}{r_i}\right) + \sum_{i>j}^{N} \frac{1}{r_{ij}}.$$

The Relativistic Corrections to the Non-relativistic Hamiltonian

The fine-structure operator H_{FS} consist of three terms

$$H_{FS} = H_{SO} + H_{SOO} + H_{ss}$$

$$H_{SO} = \frac{\alpha^2 Z}{2} \sum_{i=1}^{N} \frac{1}{r_i^3} \ell_i \cdot s_i$$

Spin-Orbit term

$$H_{SOO} = -\frac{\alpha^2}{2} \sum_{i<j}^{N} \frac{r_{ij} \times P_i}{r_{ij}^3} (s_i + 2 s_j)$$

Spin-Other-Orbit term

$$H_{SS} = \alpha^2 \sum_{i<j}^{N} \frac{1}{r_{ij}^3} [s_i s_j - 3 \frac{(s_i . r_{ij})(s_j . r_{ij})}{r_{ij}^2}]$$

Spin-Spin term

The Relativistic Corrections to the Non-relativistic Hamiltonian

H_{RS} is the relativistic shift operator

$$H_{RS} = H_{MC} + H_{D1} + H_{D2} + H_{OO} + H_{SSC}$$

$$H_{MC} = -\frac{1}{\alpha^2}\sum_{i=1}^{N} (\nabla_i^2)^{\dagger} \nabla_i^2$$

Mass Correction term

$$H_{D1} = -\frac{\alpha^2 Z}{8}\sum_{i=1}^{N} \nabla_i^2 \left(\frac{1}{r_i}\right)$$

One– body Darwin terms

$$H_{D2} = \frac{\alpha^2}{4}\sum_{i<j}^{N} \nabla_i^2 \left(\frac{1}{r_i}\right)$$

Two – body Darwin terms

$$H_{OO} = -\frac{\alpha^2}{2}\sum_{i<j}^{N} \left[\frac{P_i . P_j}{r_{ij}} + \frac{r_{ij}\,(r_{ij} . P_i)\,P_j}{r_{ij}^3}\right]$$

Orbit-Orbit term

$$H_{SSC} = -\frac{8\pi\alpha^2}{3}\sum_{i<j}^{N} (s_i . s_j)\,\delta(r_i . r_j)$$

Spin-Spin contact term

Transition Probabilities

- **The weighted oscillator strength for the transition between Ψ and Ψ′ is defined as**

$$g_u f = \frac{2}{3} (\Delta E) S$$

- **The strength of a line is defined as the square of the reduced dipole matrix element**

$$S = \left| \left\langle \psi \left\| \sum_{i=1}^{N} \vec{r}_i \right\| \psi' \right\rangle \right|^2$$

- ***Allowed Electric Dipole Decay Rates (E1):***

  S is related to the transition probability according to

  (j=0,±1, L = 0, ±1, S = 0, parity changes.)

$$A_{u,l} = \frac{64\pi^4 e^2 a_0^2}{3 h g_u} S (\Delta E)^3$$

- **The radiative lifetime τ of an atomic level *k* is related to the sum of transition probabilities to all levels *i* lower in energy than *k*:**

$$\tau_k = \left(\sum_i A_{ki} \right)^{-1}$$

Hartree-Fock Relativistic (HFR)
Cowan (in 1981)
ATOMIC STRUCTURE PACKAGE

1. A relativistic Hartree-Fock program enables the calculation of all atomic data required (energy levels, wavelengths, log gf, transition probabilities and lifetimes), taking into consideration the correlations of the electrons and the relativistic effects included by the Breit- Pauli approximation.

2. All the relevant radial integrals have been computed.

3. Then, the radial parameters were fitted in a least square optimizing program fitting the eigen values of the Hamiltonian to the available experimental energy levels. These optimized integrals were used to compute the wavelengths and the transition rates.

Transition probabilities for Si XII (Refaie 2010)

Transition	λ [cal](Å)	Log gf	A [cal] (Sec^{-1})	NIST	[Nahar, TOPbase]
$1s^22p\ ^2P_{1/2} - 1s^23d\ ^2D_{3/2}$	43.95	0.131	1.166E+12	1.15E+12	2.13E+12
$1s^22p\ ^2P_{1/2} - 1s^24d\ ^2D_{3/2}$	32.834	-0.61	3.800E+11	3.81E+11	6.91E+11
$1s^22p\ ^2P_{1/2} - 1s^25d\ ^2D_{3/2}$	29.395	-1.042	1.751E+11	1.77E+11	3.19E+11
$1s^22p\ ^2P_{1/2} - 1s^26d\ ^2D_{3/2}$	27.813	-1.352	9.595E+10	9.55E+10	1.75E+11
$1s^22p\ ^2P_{1/2} - 1s^27d\ ^2D_{3/2}$	26.939	-1.594	5.853E+10	5.82E+10	1.07E+11
$1s^22p\ ^2P_{1/2} - 1s^28d\ ^2D_{3/2}$	26.401	-1.794	3.843E+10	3.82E+10	7.01E+10
$1s^22p\ ^2P_{1/2} - 1s^29d\ ^2D_{3/2}$	26.044	-1.966	2.660E+10	2.65E+10	4.86E+10
$1s^22p\ ^2P_{1/2} - 1s^210d\ ^2D_{3/2}$	25.795	-2.115	1.921E+10		3.51E+10
$1s^22p\ ^2P_{3/2} - 1s^23d\ ^2D_{3/2}$	44.108	-0.57	2.308E+11	2.28E+11	4.24E+11
$1s^22p\ ^2P_{3/2} - 1s^23d\ ^2D_{5/2}$	44.094	0.385	1.386E+12	1.37E+12	2.54E+12
$1s^22p\ ^2P_{3/2} - 1s^24d\ ^2D_{3/2}$	32.922	-1.31	7.540E+10	7.45E+10	1.37E+11
$1s^22p\ ^2P_{3/2} - 1s^24d\ ^2D_{5/2}$	32.919	-0.355	4.525E+11	4.56E+11	8.22E+11
$1s^22p\ ^2P_{3/2} - 1s^25d\ ^2D_{3/2}$	29.466	-1.742	3.478E+10	3.52E+10	6.30E+10
$1s^22p\ ^2P_{3/2} - 1s^25d\ ^2D_{5/2}$	29.464	-0.788	2.087E+11	2.11E+11	3.79E+11
$1s^22p\ ^2P_{3/2} - 1s^26d\ ^2D_{3/2}$	27.876	-2.051	1.906E+10	1.90E+10	3.45E+10
$1s^22p\ ^2P_{3/2} - 1s^26d\ ^2D_{5/2}$	27.876	-1.097	1.144E+11	1.14E+11	2.08E+11
$1s^22p\ ^2P_{3/2} - 1s^27d\ ^2D_{3/2}$	26.998	-2.294	1.163E+10	1.16E+10	2.11E+10
$1s^22p\ ^2P_{3/2} - 1s^27d\ ^2D_{5/2}$	26.998	-1.34	6.977E+10	6.94E+10	1.27E+11
$1s^22p\ ^2P_{3/2} - 1s^28d\ ^2D_{3/2}$	26.458	-2.494	7.635E+09	7.59E+09	1.38E+10
$1s^22p\ ^2P_{3/2} - 1s^28d\ ^2D_{5/2}$	26.457	-1.54	4.582E+10	4.56E+10	8.33E+10
$1s^22p\ ^2P_{3/2} - 1s^29d\ ^2D_{3/2}$	26.099	-2.666	5.278E+09	5.26E+09	9.58E+09
$1s^22p\ ^2P_{3/2} - 1s^29d\ ^2D_{5/2}$	26.099	-1.711	3.173E+10	3.16E+10	5.77E+10
$1s^22p\ ^2P_{3/2} - 1s^210d\ ^2D_{3/2}$	25.849	-2.815	3.818E+09		6.92E+09
$1s^22p\ ^2P_{3/2} - 1s^210d\ ^2D_{5/2}$	25.849	-1.861	2.292E+10		4.17E+10
$1s^23p\ ^2P_{1/2} - 1s^23d\ ^2D_{3/2}$	4766.376	-1.222	4.400E+06	5.00E+06	7.38E+06
$1s^23p\ ^2P_{1/2} - 1s^24d\ ^2D_{3/2}$	126.377	0.066	1.215E+11	1.22E+11	2.22E+11

2. Electron Impact Excitation, Ionization, Recombination and De-excitation Rate Coefficients

1. Rate Coefficients:

- The electronic $|p\rangle \rightarrow |n\rangle$ and $|p\rangle \rightarrow |i\rangle$ transitions in an atom have been considered, where p and n are the (effective) principal quantum numbers of initial and final states $|p\rangle$ and $|n\rangle$, and $|i\rangle$ denotes the ion ground state.
- The following notation is used : E_{pi} and $E_{pn} = E_n - E_p$ are the ionization, excitation (for $E_n > E_p$) and de-excitation ($E_n < E_p$) energies, E_e and E are the incident electron and the energy transfer to the atom, respectively.

a. Ionization rate

The ionization rate coefficient (in cm^3s^{-1}) is given by:

$$K_{ip} = \frac{9.56 \times 10^{-6} (kT_e)^{-1.5} \exp(\varepsilon_{pi})}{\varepsilon_{pi}^{2.33} + 4.38\, \varepsilon_{pi}^{1.72} + 1.32\, \varepsilon_{pi}} \qquad (1)$$

Where ε_{pi} is the transfer energy and is expressed in eV.

b. Recombination rate

The recombination rate coefficient is (in cm^6s^{-1}) given by:

$$K_{ip} = \frac{3.17 \times 10^{-27} (kT_e)^{-3} (g_p / g_i)}{\varepsilon_{pi}^{2.33} + 4.38\, \varepsilon_{pi}^{1.72} + 1.32\, \varepsilon_{pi}} \qquad (2)$$

Where g_p and g_i are the statistical weights of level $|p\rangle$ and of the ion ground state $|i\rangle$.

c. Excitation rate

An empirical formula which represents the numerical rate coefficients (in cm^3s^{-1}) for the excitation rate with transfer energy ε_{pn} is:

$$K_{pn} = \frac{1.6\times10^{-7}\,(kT_e)^{0.5}\exp(-\varepsilon_{pn})}{kT_e+\Gamma_{pn}}\times\left[A_{pn}\ln\left(\frac{0.3kT_e}{R}+\Delta_{pn}\right)+B_{pn}\right] \qquad (3)$$

$$\Gamma_{pn} = R\ln\left(1+\frac{p^3kT_e}{R}\right)\left[3+11\left(\frac{s}{p}\right)^2\right]\times\left(6+1.6ns+\frac{0.3}{s^2}+0.8\frac{n^{1.5}}{s^{0.5}}s-0.6\right)^{-1}$$

Where, kT_e is in eV , R is Rydberg energy (in eV).

$$R = 13.595,\quad p = z_{eff}\times\sqrt{R/E_{pi}},\quad n = z_{eff}\times\sqrt{R/E_{ni}},\quad s = |n-p|.$$

$$A_{pn} = \left(2R/E_{pn}\right)f_{pn} \qquad (4)$$

$$\Delta_{pn} = \exp\left(-\frac{B_{pn}}{A_{pn}}\right)+\frac{0.06\,s^2}{np^2}$$

where

$$B_{pn} = \frac{4R^2}{n^3}\left(\frac{1}{E_{pn}^2}+\frac{4E_{pi}}{3E_{pn}}+b_p\frac{E_{pi}^2}{E_{pn}^4}\right)\quad and\quad b_p = \frac{1.4\ln p}{p}-\frac{0.7}{p}-\frac{0.51}{p^2}+\frac{1.16}{p^3}-\frac{0.55}{p^4}$$

d. De-excitation rate

The de-excitation rate is given by:

$$K_{pn} = \frac{1.6 \times 10^{-7} (kT_e)^{0.5} \; g_n / g_p}{kT_e + \Gamma_{np}} \times \left[A_{np} \ln\left(\frac{0.3\, kT_e}{R} + \Delta_{np} \right) + B_{np} \right] \qquad (5)$$

2. Population Densities

Level population can be calculated by solving the steady-state rate equations

$$N_j \left[\sum_{i \prec j} A_{ji} + N_e \left(\sum_{i \succ j} c^{d}_{ji} + \sum_{i \succ j} c^{e}_{ji} \right) \right] = N_e \left(\sum_{i \prec j} N_i c^{e}_{ij} + \sum_{i \succ j} N_i c^{d}_{ij} \right) + \sum_{i \succ j} N_i A_{ij} \qquad (6)$$

where N_j is the population of level j, A_{ji} is the spontaneous decay rate from level j to level i.

"Electron Impact Excitation, Ionization, Recombination and De-excitation Rate Coefficients and Electron Densities Calculations for Lithium-Like Si XII and S XIV"

Objective:

- **To calculate the absolute electron impact excitation, ionization, recombination and de-excitation rate coefficients of about 13 configurations for the doublet state for lithium-like ions Si XII and S XIV.**
- **Oscillator strengths for allowed and forbidden transitions including relativistic effects in Breit-Pauli approximation were calculated by using the Cowan code and also by using the available data in literature. These oscillator strengths are used in the calculations of the rate coefficients.**
- **To calculate the level populations as functions of the electron density and the plasma temperature for the configurations $1s^22s$, $1s^22p$, $1s^23s$, $1s^23p$, $1s^23d$, $1s^24s$, $1s^24p$, $1s^24d$, $1s^24f$, $1s^25s$, $1s^25p$, $1s^25d$ and $1s^25f$ for each ion.**

Results and Discussion:

a. Rate Coefficients

- **The calculations include all forbidden and allowed transitions that are necessary for the calculations. Therefore, in addition to the dipole transitions we have introduced the quadrupole transitions in the calculations.**
- **The rate coefficients are determined for $1s^22s$ ($^2S_{1/2}$), $1s^22p$ ($^2P_{1/2}$), $1s^23s$ ($^2S_{1/2}$-), $1s^23p$($^2P_{1/2}$), $1s^23d$ ($^2D_{3/2}$), $1s^24s$ ($^2S_{1/2}$), $1s^24p$ ($^2P_{1/2}$), $1s^24d$ ($^2D_{3/2}$), $1s^24f$ ($^2F_{5/2}$), $1s^25s$ ($^2S_{1/2}$), $1s^25p$ ($^2P_{1/2}$), $1s^25d$ ($^2D_{3/2}$) and $1s^25f$ ($^2F_{5/2}$) excited atomic states in Si XII and S XIV.**

Ionization rate coefficient vs. temperature for Si XII and S XIV (Refaie 2006)

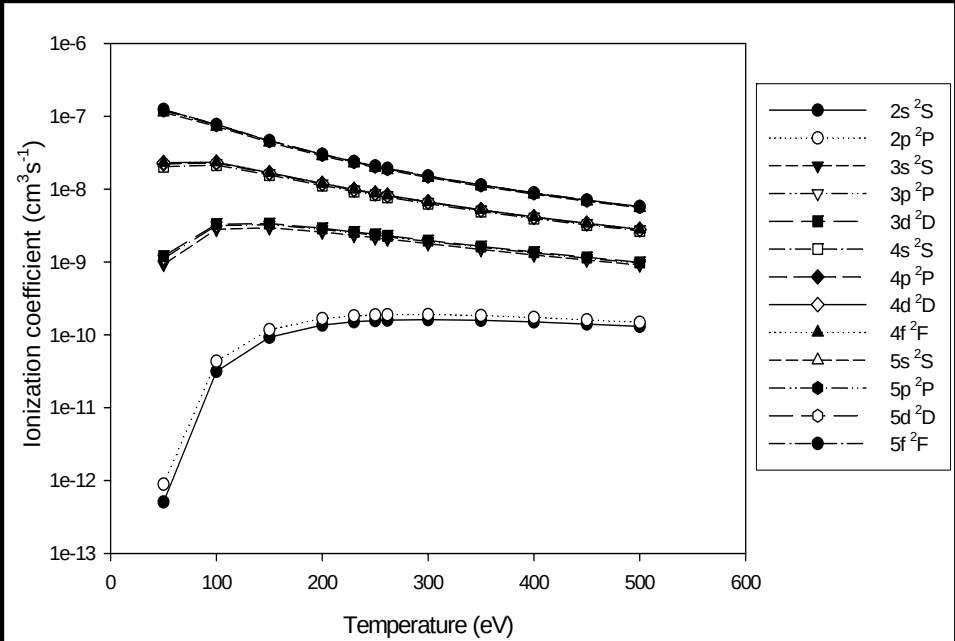


Fig. 1. Ionization rate coefficients for Si XII ion.

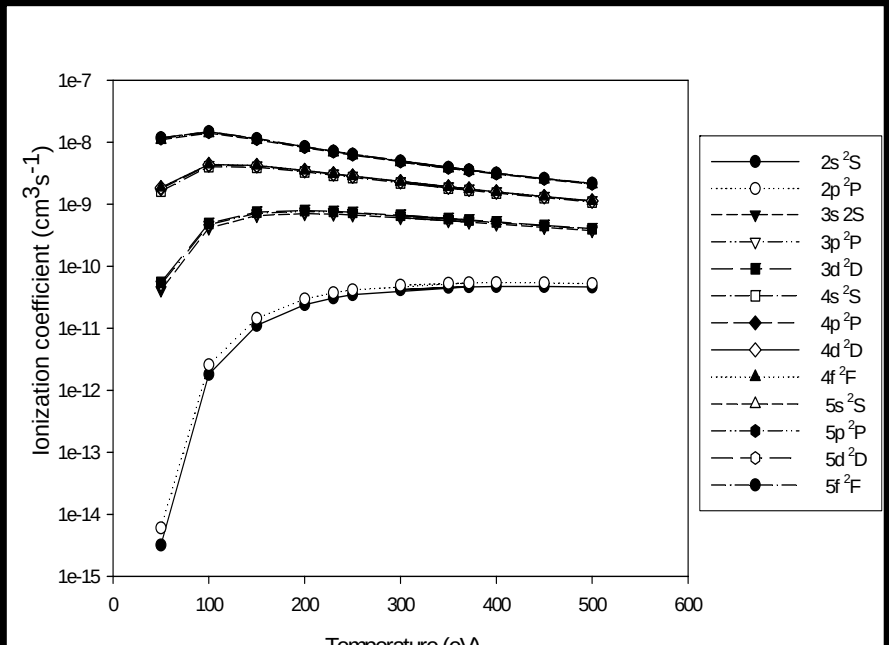
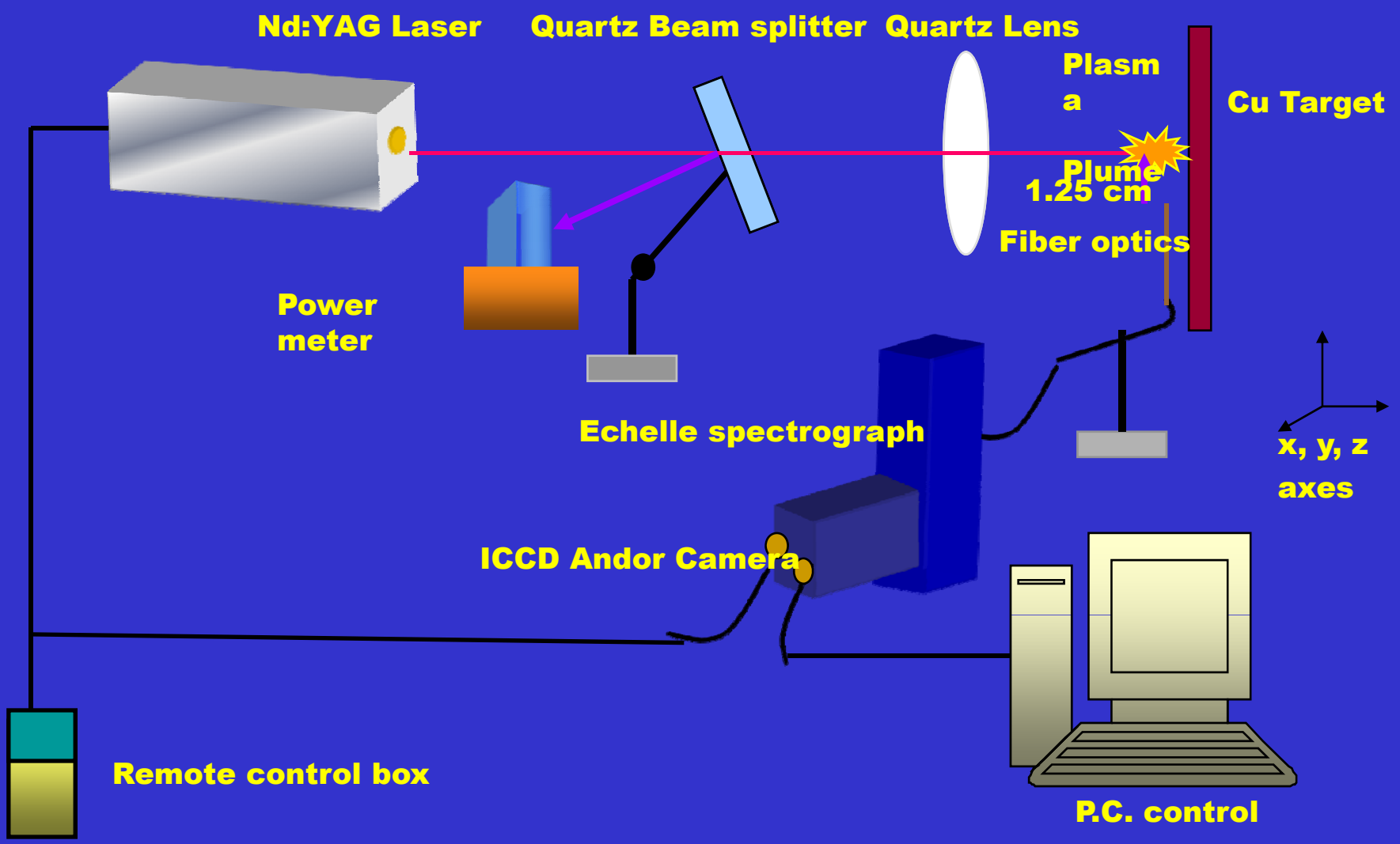


Fig. 2. Ionization rate coefficients for S XIV ion.

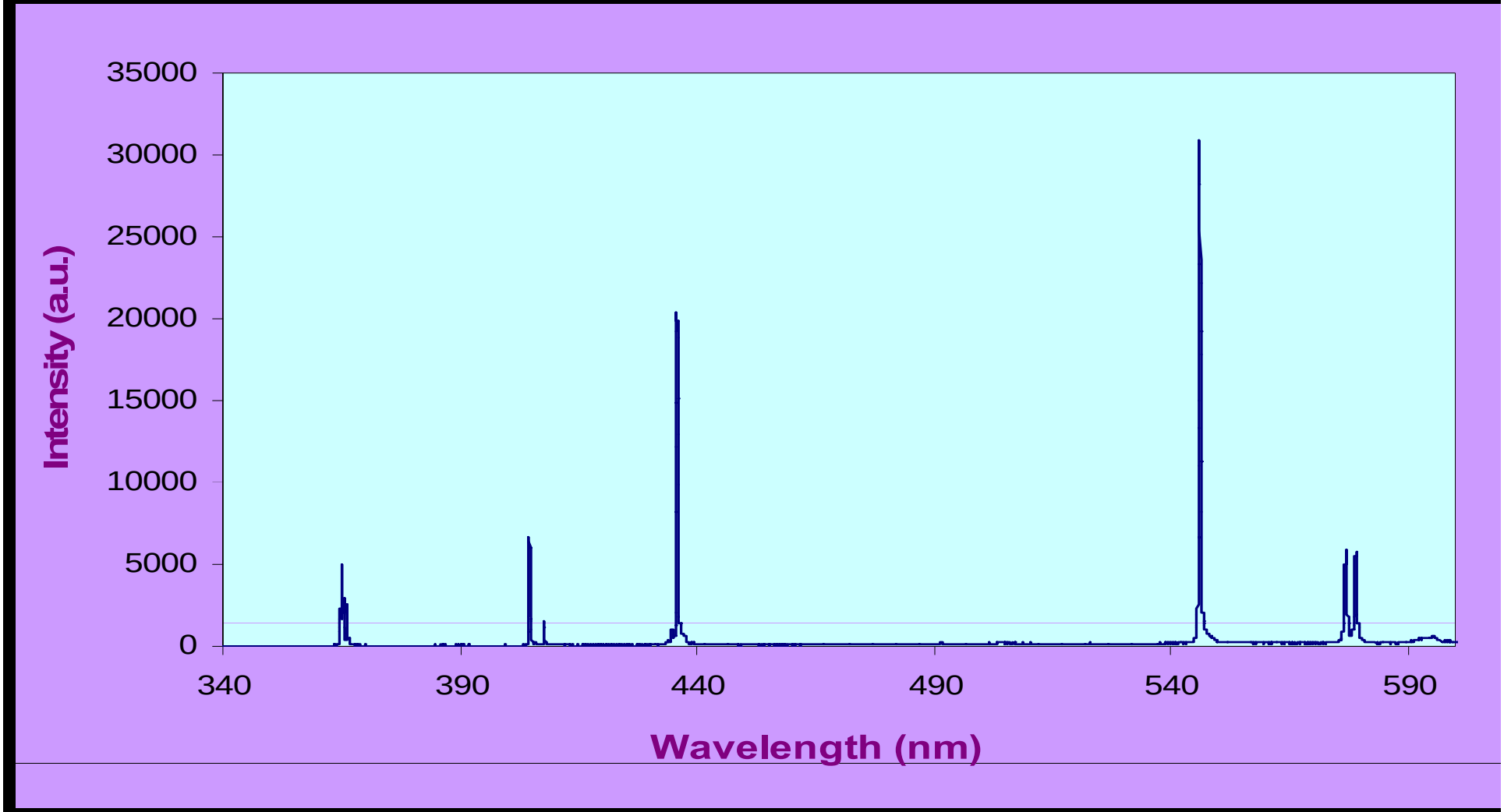
3. Experimental activity

A schematic diagram of the experimental set up is shown. A Q-switched Nd:YAG laser type Brilliant B from Quantel was used at the fundamental wavelength 1064 nm. The energy per pulse 670 mJ was measured at the target surface delivering 6 ns laser pulses with adjustable repetition rate 10 Hz. This corresponds to power density of 5.6×10^{10} W/cm^2 for a laser focal spot radius of ~ 0.25 mm. The laser was focused on the target using 10 cm quartz lens and constant opening gate adjusted at 2 μm .

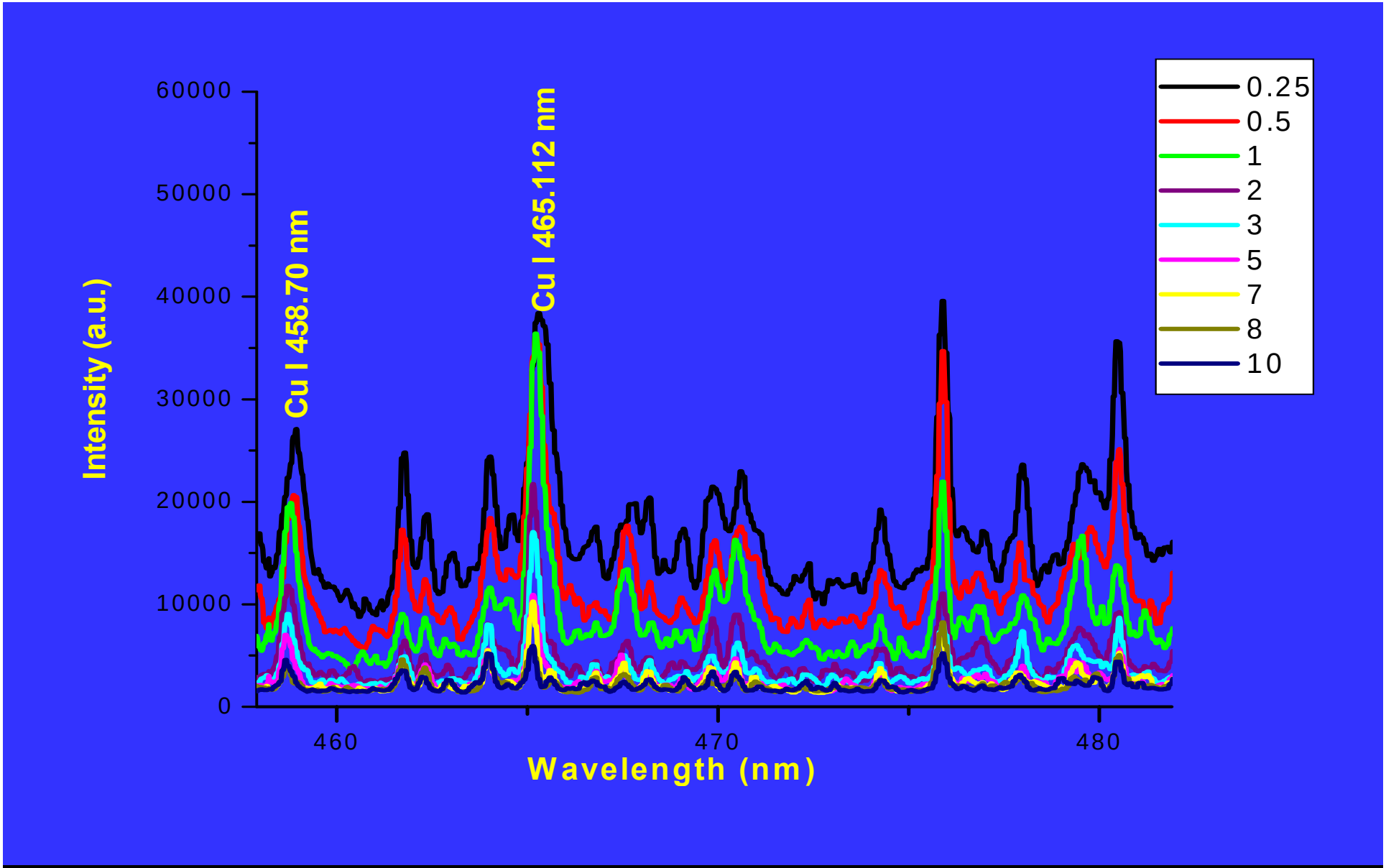
Basic Experimental Arrangement



Experimental Results



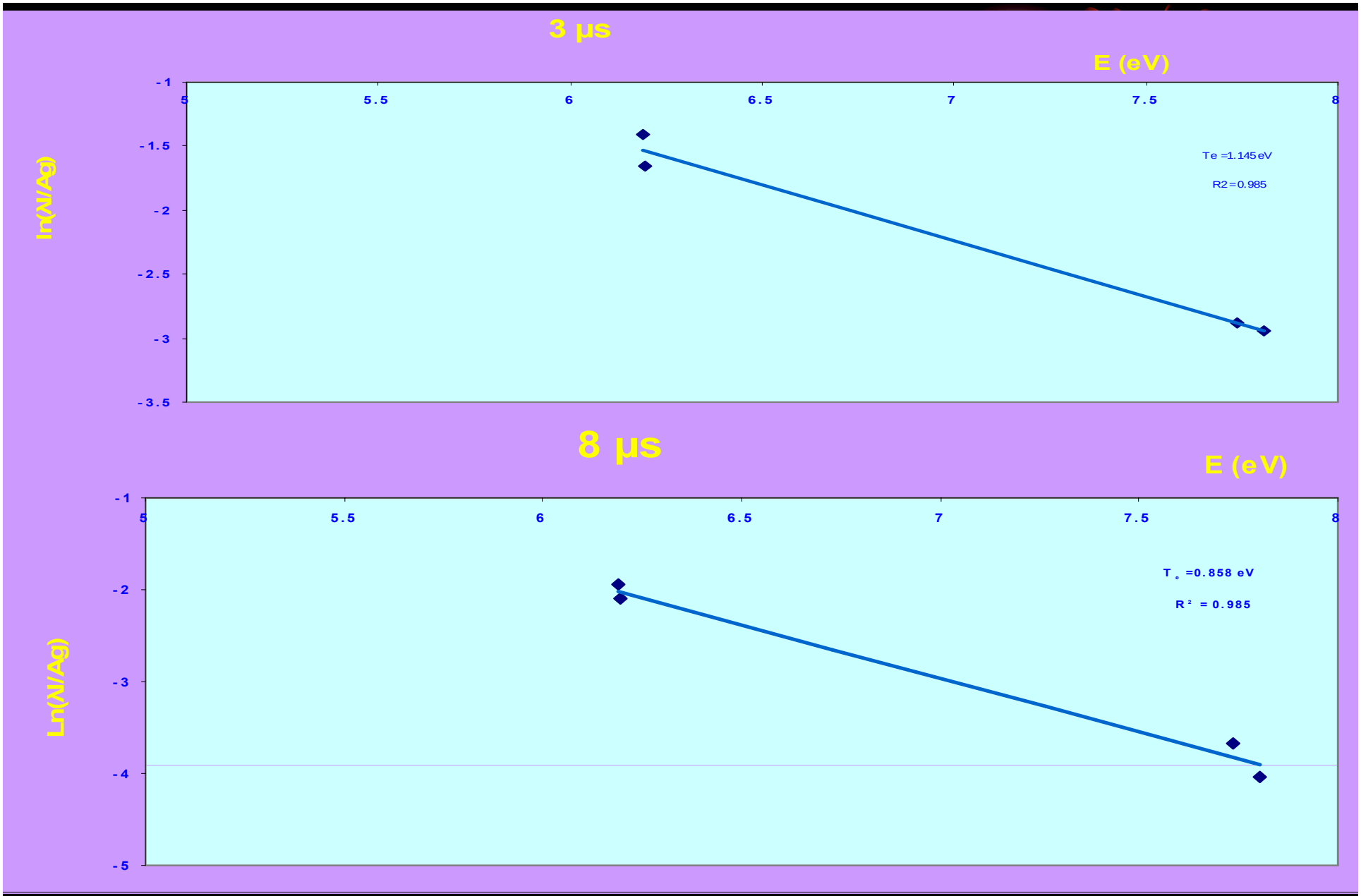
Emission lines of Mercury lamp used for wavelength calibration



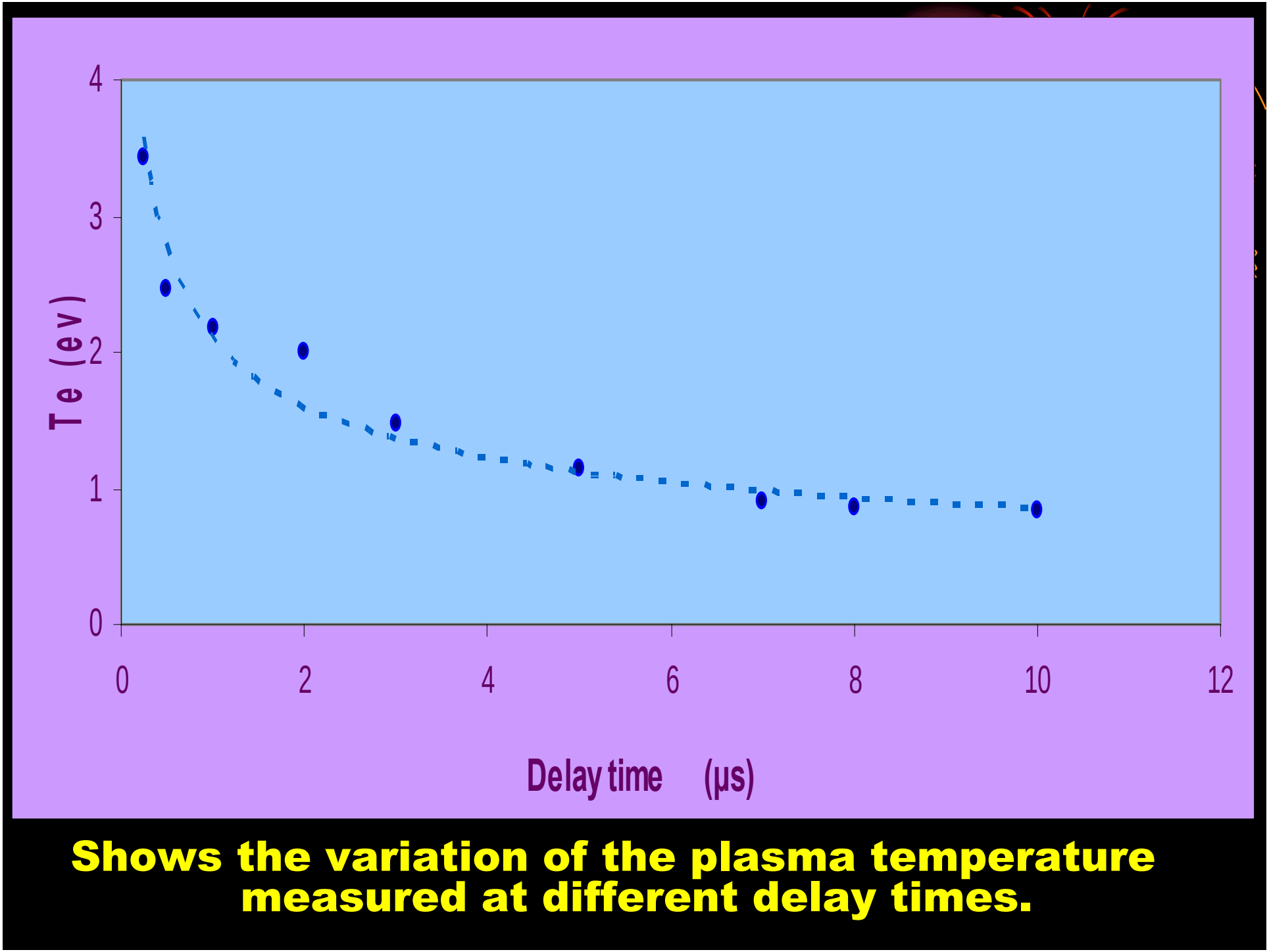
Temporal evolution of the spectra in the wavelength ranges of 457.9-481.9 nm. The delay times are: (1) 0.25 μs (2) 0.5 μs (3) 1 μs (4) 2 μs (5) 3 μs (6) 5 μs (7) 7 μs (8) 8 μs and (9) 10 μs.

Spectroscopic data of Cu I lines used for estimating T_e

Transition	λ (nm)	E_m (eV)	E_n (eV)	g_m	g_n	A_{mn} ($10^8 s^{-1}$)
^4F-^4D	458.70	5.10	7.81	8	6	0.32
^4F-^4D	465.112	5.07	7.74	10	8	0.38
^2P-^2D	515.55	3.79	6.19	2	4	0.60
^2P-^2D	521.324	3.82	6.19	4	6	0.75



Boltzmann plot of emission spectra of Cu I transitions at 458.70, 465.112, 515.324 and 521.82 nm in air.



Shows the variation of the plasma temperature measured at different delay times.

Density Determination from The Line Width

The full half width $\Delta\lambda_{1/2}$ of a Stark broadened line is related to the electron density by

$$\Delta\lambda_{1/2}\left(A^{\circ}\right) = 2w\left(\frac{n_e}{10^{16}}\right) + 3.5A\left(\frac{n_e}{10^{16}}\right)^{1/4}\left[1 - \frac{3}{4}N_D^{-1/3}\right]w\left(\frac{n_e}{10^{16}}\right)$$

w **is the electron impact parameter,**

A **is the number of particles in the Debye sphere an**

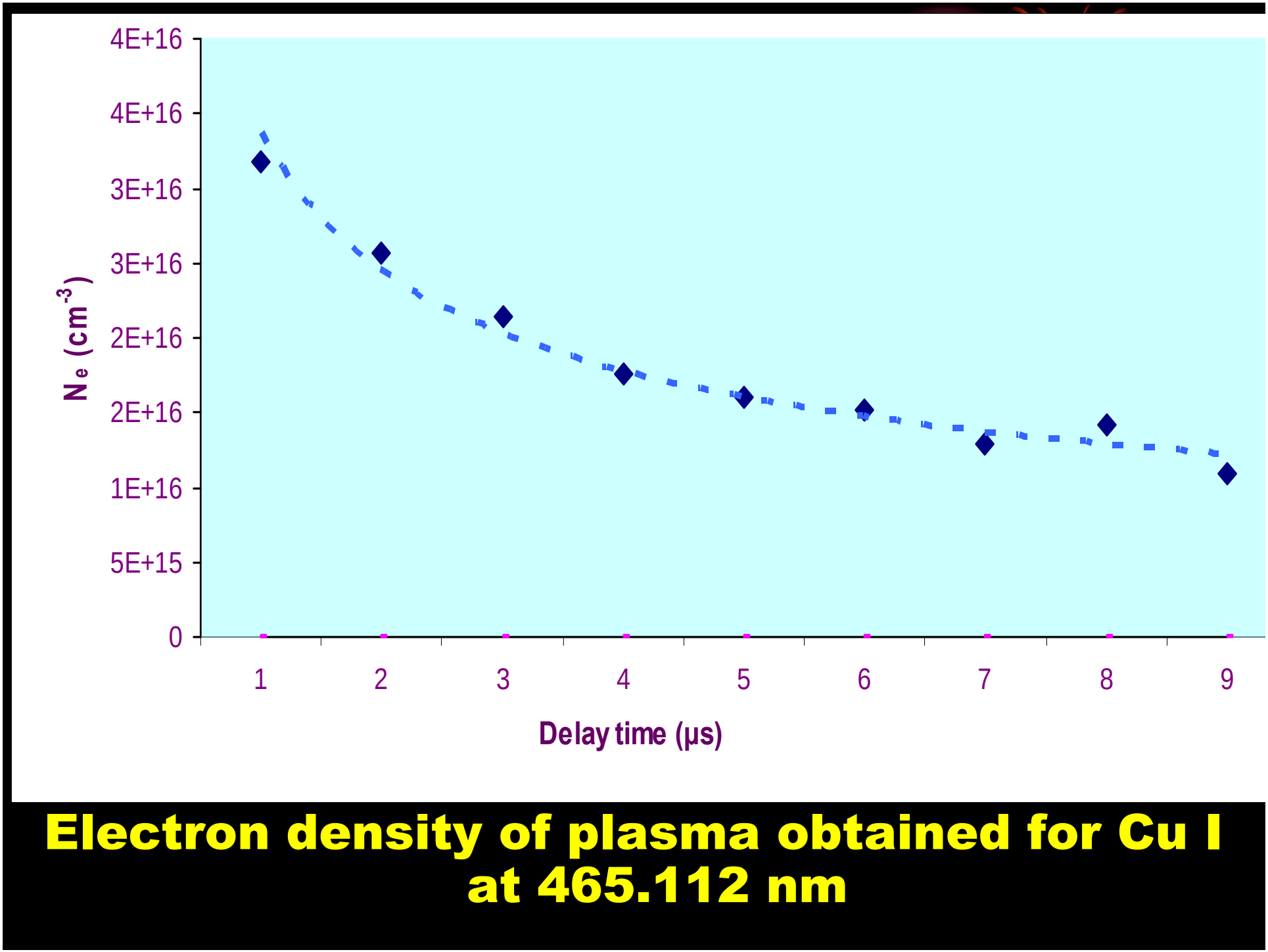
N_D **is the ionic –impact broadening parameter.**

The first term gives the contribution from electron broadening, and the second term is the ion broadening correction.

Density Determination from The Line Width

The contribution is almost entirely due to electron impact, and therefore the half width of the Stark-broadened transition can be estimated by

$$\Delta\lambda_{1/2} = 2w\left(\frac{N_e}{10^{16}}\right)$$



Electron density of plasma obtained for Cu I at 465.112 nm

Transition probabilities for Cu II (Refaie et al. 2008)

Transition Levels		λ (nm)	A_{ji} (sec^{-1})	
Lower	Upper		This Work(Theo.)	Exp. Work
$3d^9\ 5p\ ^3D_1$	$3d^9\ 5d\ ^3P_0$	698.6521	5.950E+06	4.757E+06
$3d^9\ 5p\ ^3F_2$	$3d^9\ 5d\ ^3F_3$	699.6543	1.359E+06	1.315E+06
$3d^9\ 5p\ ^3F_2$	$3d^9\ 5d\ ^3D_3$	705.3523	1.977E+05	1.892E+05
$3d^9\ 5p\ ^3P_0$	$3d^9\ 5d\ ^3S_1$	708.3776	4.420E+05	2.987E+05
$3d^9\ 5p\ ^1F_3$	$3d^9\ 5d\ ^3F_4$	712.6817	6.117E+05	9.096E+04
$3d^9\ 5p\ ^3F_2$	$3d^9\ 5d\ ^3P_1$	712.703	1.280E+06	1.205E+06
$3d^9\ 5p\ ^1F_3$	$3d^9\ 5d\ ^3F_3$	713.1743	3.735E+04	1.612E+05
$3d^9\ 5s\ ^3D_3$	$3d^9\ 5p\ ^3D_2$	715.7757	1.753E+06	6.257E+05
$3d^9\ 5p\ ^1P_1$	$3d^9\ 5d\ ^3P_1$	718.9454	7.113E+06	5.253E+06
$3d^9\ 5p\ ^1F_3$	$3d^9\ 5d\ ^3D_3$	719.0955	1.940E+06	1.889E+05
$3d^9\ 5p\ ^1P_1$	$3d^9\ 5d\ ^3P_2$	719.9323	2.420E+04	1.575E+04
$3d^9\ 5p\ ^3D_1$	$3d^9\ 5d\ ^3D_2$	726.0784	2.332E+04	1.932E+04
$3d^9\ 5p\ ^1F_3$	$3d^9\ 5d\ ^3P_2$	727.7455	9.498E+05	1.122E+05
$3d^9\ 5s\ ^3D_2$	$3d^9\ 5p\ ^3D_2$	732.6006	5.206E+07	2.276E+07
$3d^9\ 5p\ ^1D_2$	$3d^9\ 5d\ ^3D_2$	739.6151	1.269E+05	2.387E+05
$3d^9\ 5s\ ^3D_3$	$3d^9\ 5p\ ^3D_3$	739.9875	5.202E+07	2.763E+07
$3d^9\ 5s\ ^3D_1$	$3d^9\ 5p\ ^1D_2$	742.0567	9.970E+06	5.059E+06
$3d^9\ 5p\ ^1P_1$	$3d^9\ 5d\ ^3S_1$	742.2328	2.671E+05	1.364E+05
$3d^9\ 5p\ ^3D_1$	$3d^9\ 5d\ ^3P_1$	742.2771	6.463E+04	2.997E+04
$3d^9\ 5p\ ^1D_2$	$3d^9\ 5d\ ^3D_3$	748.1555	1.067E+05	1.765E+05
$3d^9\ 5s\ ^3D_1$	$3d^9\ 5p\ ^3D_1$	756.2017	4.720E+07	3.995E+07
$3d^9\ 5p\ ^1D_2$	$3d^9\ 5d\ ^3P_1$	756.4305	1.019E+05	7.434E+04

4. Future Work

- **To calculate the interaction between charged particles (electrons and ions) and external and self-generated electric and magnetic fields.**

This work is a three-dimensional, fully relativistic, that has successfully been applied to a number of problems, ranging from *laser-plasma interaction* and *inertial fusion* to *plasma shell collisions in astrophysical scenarios*.

- The emergence of the high- energy density (HED) experimental facilities realized that a new class of laboratory astrophysics could be pursued.

- The new HED facilities allow matter to be placed in extreme states of temperature, density and velocity.

- Measurements of these conditions and their evolution, when diagnose, allow theoretical models computer simulation codes to be tested under the extreme conditions relevant to HED regimes of astrophysics.

- **Examples include measurements of:**
  (i) opacities
  (ii) the phase, conductivity and equation of state
  (iii) ionization states of radiatively pumped photoionized plasma

- **Several areas of astrophysics could be described - supernovae, supernova remnants, gamma-ray bursts and giant planets.**
  e. g., experiments addressing the dynamics of supernova remnants have demonstrated that the blast waves can be produced in laboratory experiments .

- **These experiments illustrated the need for 3D simulations.**

- What will be established in the future is the global effect of radiative cooling as a strong shock traverses a medium.

- Simulations of these high Mach number interactions show both the complexity and the need for coupled radiative, nonlinear hydrodynamics for shock-induced star formation.

- In addition to hydrodynamics phenomena there exist a broad range of collision effects which are responsible for cosmic ray generation in supernova remnants.

- HED facilities might contribute to simulations of such phenomena.

Conclusion

1. Atomic Physics provides the fundamental parameters for Physics and Astronomy.

2. Atomic Spectroscopy is the key to understanding the physical and chemical conditions in physical and astronomical objects.

3. A detailed ab initio study on radiative and collisional atomic processes is needed in physical and astrophysical plasmas.


Thank You