Global Model of a Fast Ionization Wave in Helium

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I. Uniform Discharges at Elevated Pressures

Low temperature plasma research on discharges at pressures approaching one atmosphere has been steadily increasing over the last few decades, a trend which can be attributed to their suitability for a number of novel applications [1]. The high collisionality and non-equilibrium nature of such discharges pose new experimental and computational challenges. In this work, we focus on the simulation of a fast ionization wave generated in helium at moderate pressures (1-8 Torr) with nanosecond voltage pulses.

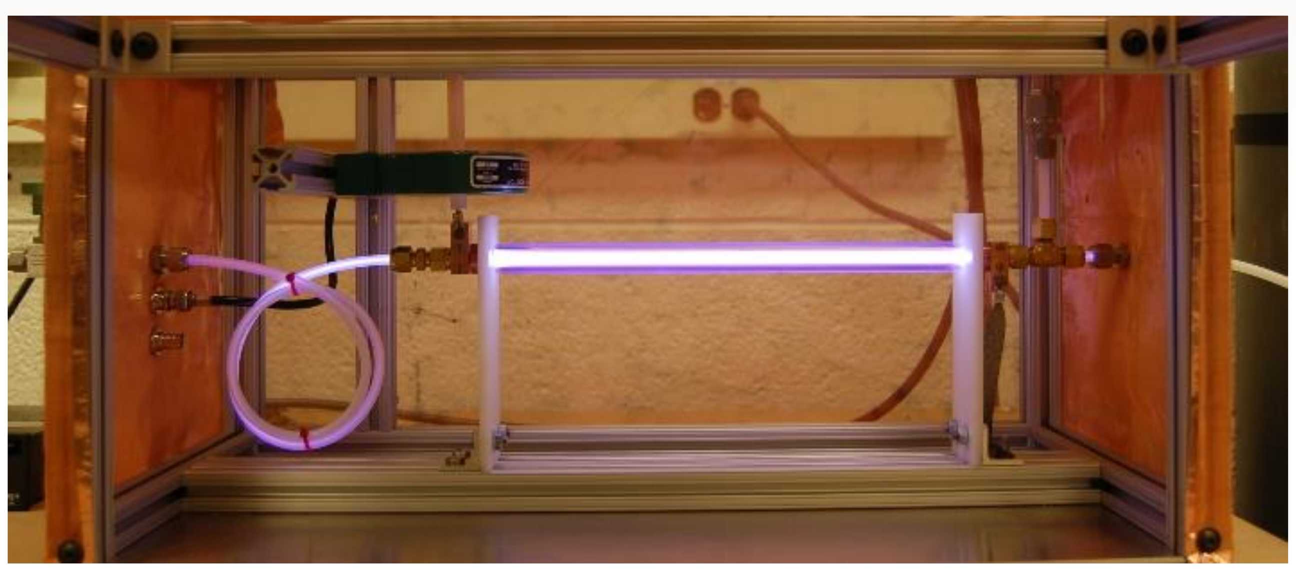

Figure 1 An example of a pulsed nanosecond discharge generated by a 10 ns Gaussian pulse at 10 kV in 20 Torr of helium. The pulse is repeated at several kHz producing a persistent and bright plasma.

II. Modeling Fast Ionization Waves

Unique challenges:

- Non-equilibrium
- Many energetic pathways
- Neutral interactions
- Radiation trapping

Spatial uniformity of the fast ionization wave should allow the use of a global model [2] comprised of coupled continuity equations and an electron energy equation.

Included physics:

- Elastic scattering
- Spontaneous optical transitions (126 transitions, including trapping factors [3,4])
- Electron collision excitiation (380 transitions) [5]
- Atomic excitation transfer (35 transitions) [6,7]

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Figure 2 A comparison of different approaches to calculating the distribution function in response to a 100 Td pulse.

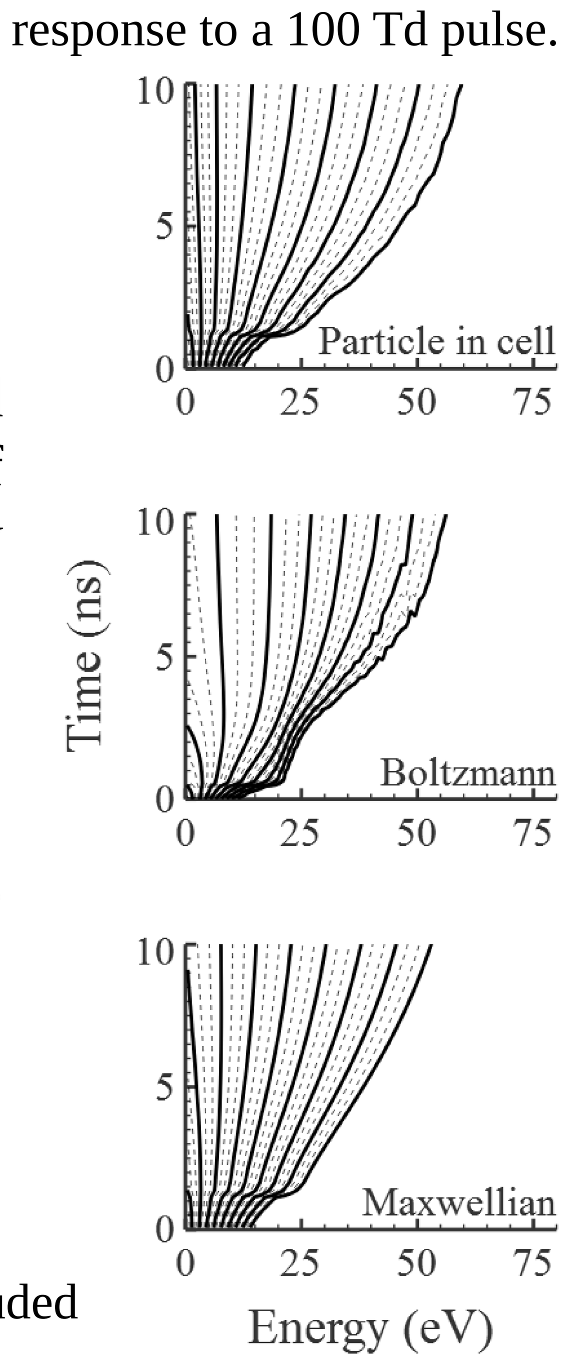

Table 1 A listing of the atomic states of helium that are included in the model as well as their energies [8].

State	Energy (eV)	State	Energy (eV)	State	Energy (eV)	State	Energy (eV)
1^1S	0.0000	3^3S	22.7185	3^1P	23.0870	4^1D	23.7363
2^3S	19.8196	3^1s	22.9203	4^3S	23.5940	4^3F^o	23.7370
2^1S	20.6158	3^3P^o	23.0071	4^1S	23.6736	4^1F^o	23.7370
2^3P^o	20.9641	3^3D	23.0737	4^3P^o	23.7079	4^1P^o	23.7421
2^1P^o	21.2180	3^1D	23.0741	4^3D	23.7361		

III. Model Domain

The simulation parameters were chosen to match a fast ionization wave experiment previously described in [9]. The discharge was initiated by a 6.4 kV pulse, 25 ns in width, and repeated at a rate of 1.0 kHz. The same experiment's metastable densities were used to seed the model.

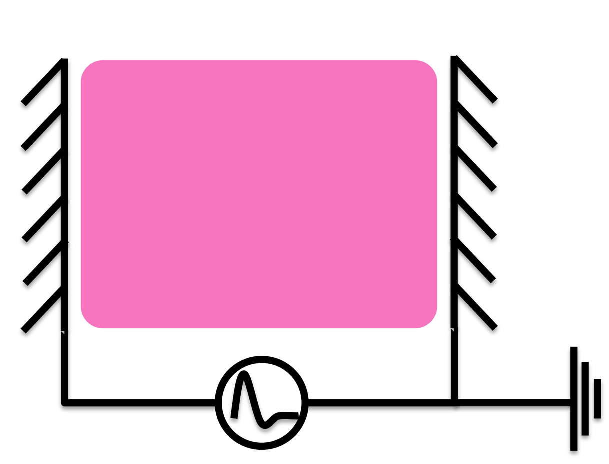

Figure 3 Sketch of the global model simulation domain

IV. Predicting Fields, Temperatures, Densities, and Emissions

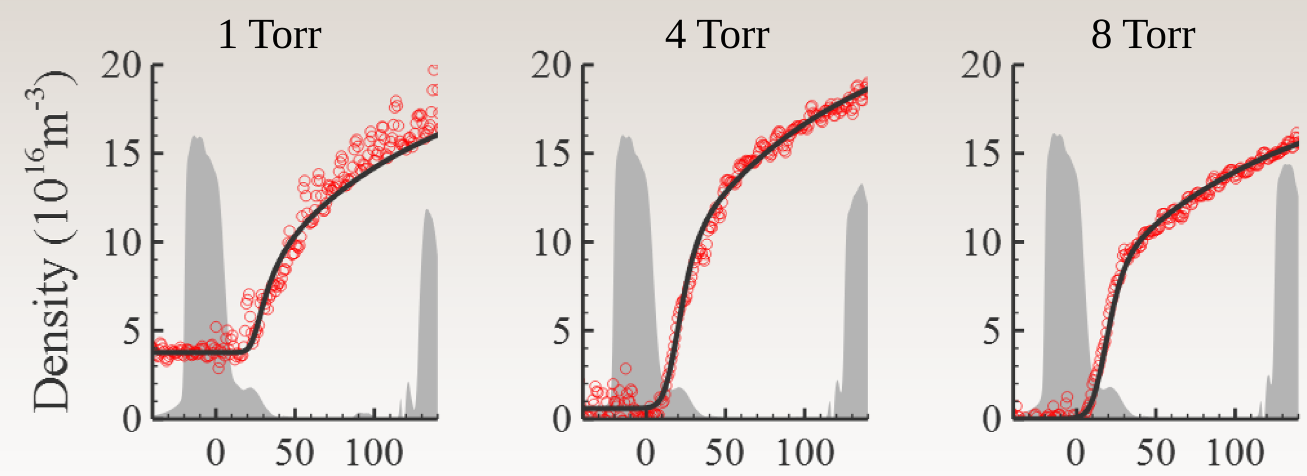

Figure 4 Predicted 2^3S densities (solid line) compared to measured metastable densities [9] with measured voltage pulse in gray..

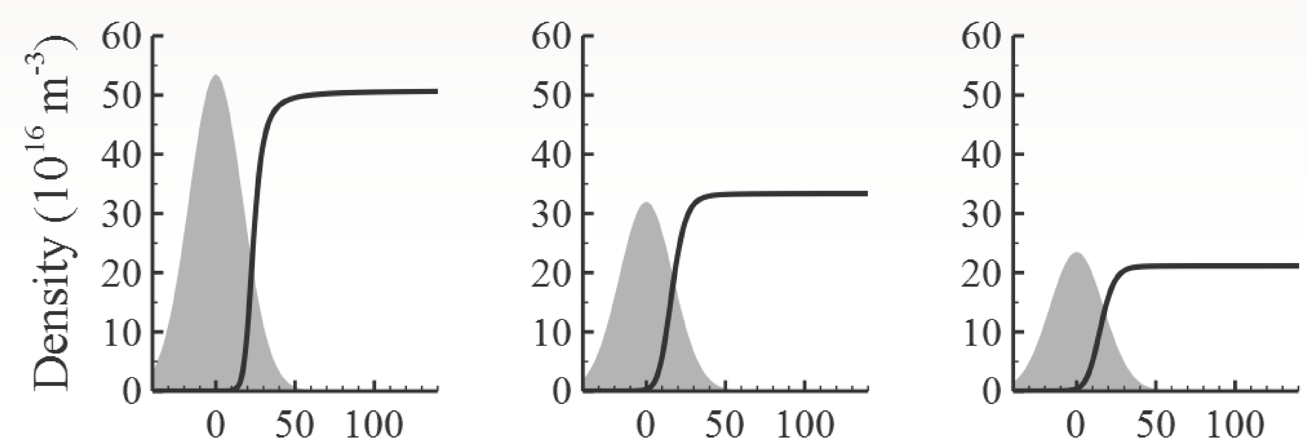

Figure 5 Resulting predictions of electron densities in fast ionization wave, simulated electric field in gray.

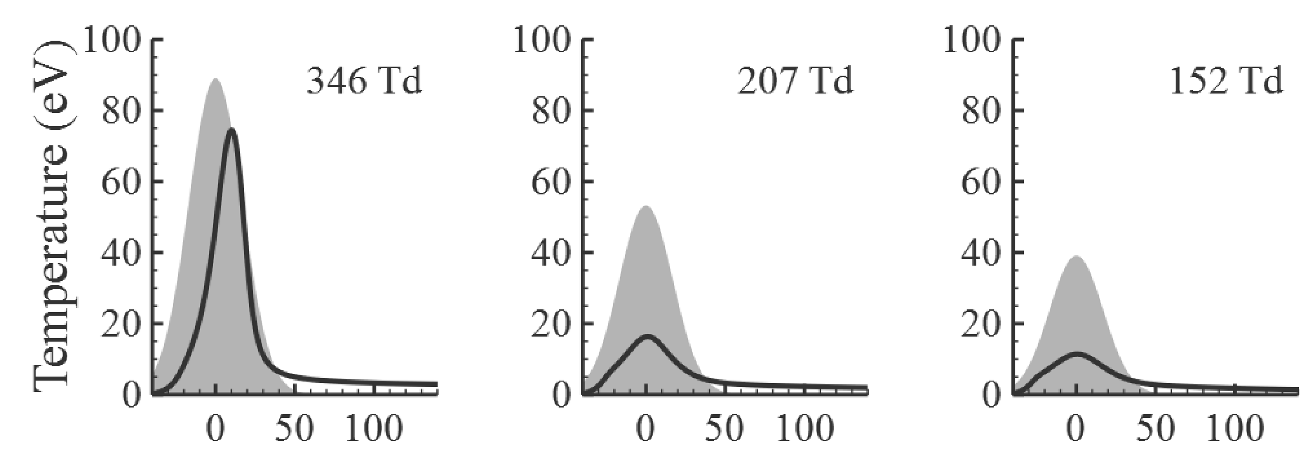

Figure 6 Predictions of electron temperatures (solid line) and the peak electric fields for each case. Simulated electric field in gray.

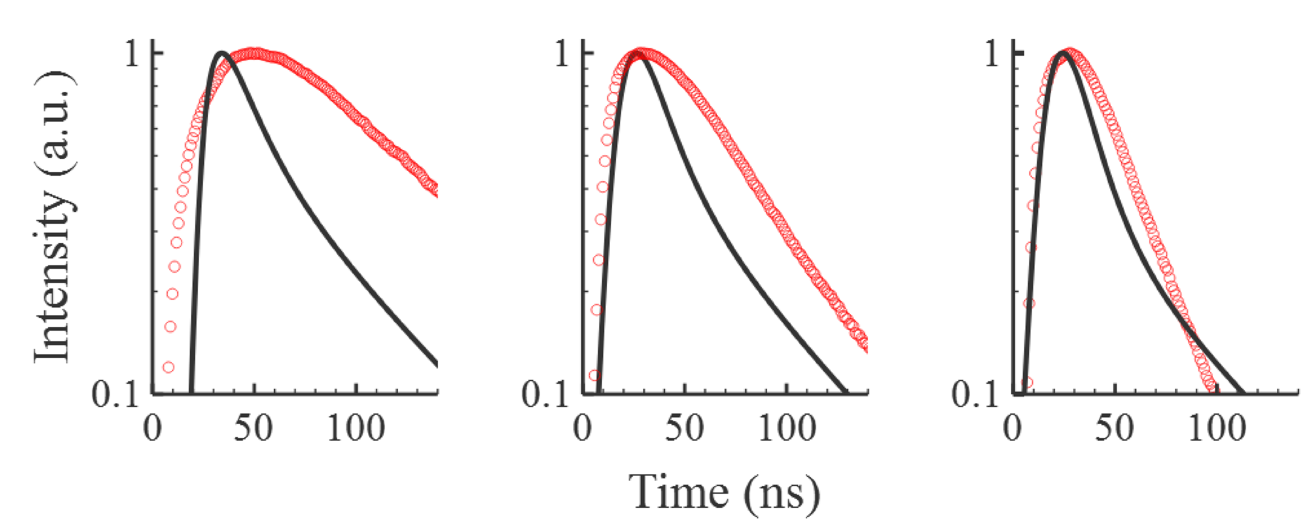

Figure 7 Simulated (solid line) and measured (red circles) emissions from the 3^1D-2^1P^o transition.

Using the global model we are able to predict the nanosecond-timescale dynamics of the fast ionization wave.

- Successfully matches the population dynamics of the metastable state
- Suggests monotonic decrease in electron density with pressure
- Fast heating and cooling of electrons
- High fields consistent with previous estimates [10]
- Longer than expected emissions suggest persistent energy source, possibly from wall charging.

V. Conclusions

Leveraging the uniformity of the fast ionization wave, a global model was developed. The resulting simulations showed excellent agreement with experimental measurements of helium metastable states and predict trends in electron densities and temperatures. Discrepancies in light emissions suggest a relatively long-lived source of energy believed to be related to persistent electric fields.

VI. References

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