Neutral gas modelling

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BOUT++ Workshop 16th September 2014

UNIVERSITY of York

Outline

- Neutral gas and plasma turbulence
- Neutral gas physics: Cross-sections and mean free paths
- Typical length-scales
- Approaches used in BOUT++
- Discussion

Neutrals and plasma turbulence (1/2)

- 2D transport codes include molecular and atomic physics
  $\rightarrow$ Essential for e.g. divertor physics, detachment
- 3D turbulence codes have typically assumed fully ionised, single ion species plasma

Strong motivations for including neutral gas physics in 3D code:

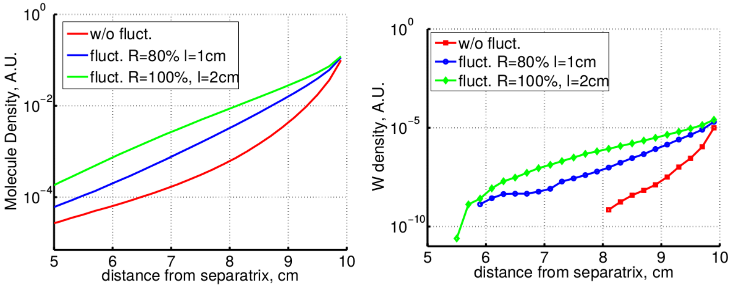
1. **Effect of neutrals on turbulence**
   - Sources and sinks of density and momentum
   - Damping from ion-neutral interactions
   - Electron-neutral interaction may have more complex effect on drift-wave stability

2. Effect of turbulence on neutrals

- Ion-neutral cross-sections are strongly nonlinear:

$$\overline{n\,\langle\sigma v\rangle} \neq \overline{n}\overline{\langle\sigma v\rangle}$$

- Neutral gas profiles affected by fluctuations



2D ITER simulations with and without synthetic fluctuations[1]

Caused by hardening of CX neutral spectrum

[1] S.Mekkaoui

Neutral gas processes

Several processes involved:

- Charge Exchange (CX) $H + H^+ \rightarrow H^+ + H$
- Ionisation (electron impact) $H + e^- \rightarrow 2e^- + H^+$
  Also produces radiation through excitation
- Recombination has several pathways:
  - Radiative recombination: $e^- + H^+ \rightarrow H + h\nu$
  - Three-body recombination: $e^- + e^- + H^+ e^- + H$
  - Negative-ion mediated recombination (MAR):

$$\begin{aligned} e^- + H_2 &\rightarrow H_2^- \rightarrow H + H^- \\ H^+ + H^- &\rightarrow H + H \end{aligned}$$

  - Ion-conversion mediated recombination (MAR):

$$\begin{aligned} H^+ + H_2 &\rightarrow H + H_2^+ \\ e^- + H_2^+ &\rightarrow H + H \end{aligned}$$

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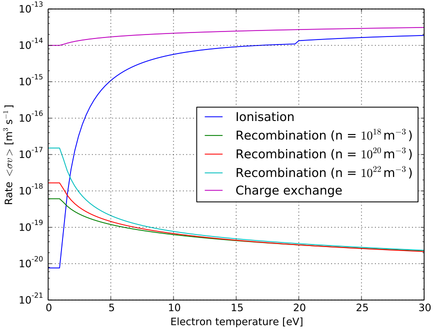
[1] EIRENE: http://www.eirene.de/

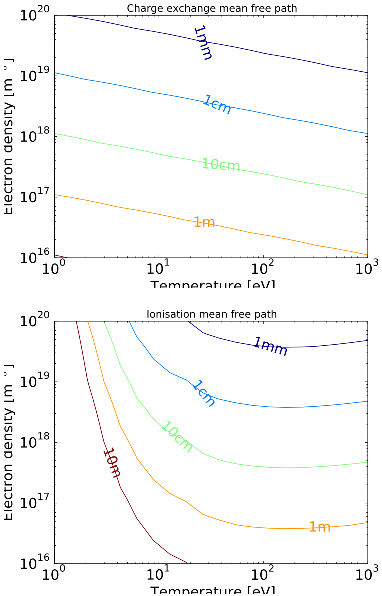
[2] KN1D: http://www.psfc.mit.edu/~labombard/KN1D_Source_Info.html

- Analytic forms used for ionisation, recombination, and charge exchange cross sections[2]



[1] Thanks to Eva Havlickova, CCFE

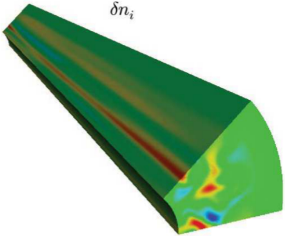
- Mean free paths shown for a 300K (0.025eV) neutral gas atom using a crude analytical model for cross-sections
- Often a 3.5 eV "Frank-Condon" energy is assumed instead
- Charge exchange results in a population of fast neutrals, which can have much longer m.f.p.

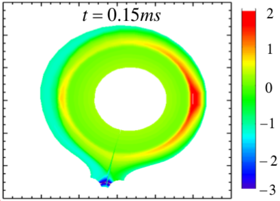


BOUT++ neutral models

Three approaches being followed to neutral modelling

1. Simple drag model for CX in LAPD[1]
2. Fluid modelling[2]
   - Valid for short mean-free-path interactions
   - Conputationally lower cost than Montecarlo methods
3. Montecarlo modelling
   - Can be applied when m.f.p is long
   - Much more expensive computationally, but parallelises very well
   - Coupling to EIRENE
   - Currently testing in linear geometry[3]



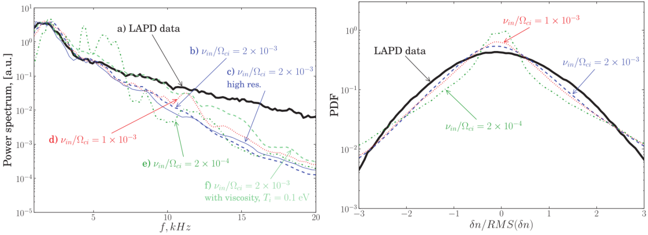


[1] P.Popovich, M.V.Umansky, T.A.Carter and B.Friedman arXiv:1005.2418 (2010)
[2] Z.H.Wang, X.Q.Xu, T.Y.Xia, T.D.Rognlien Nucl. Fusion 2013
[3] S.Mekkaoui et al. PSI conference 2014

Simple model

- Sensitivity of turbulence to neutral gas studied in LAPD simulations[1]
- Treat charge-exchange as a sink of vorticity with ion-neutral collision rate $\nu_{in} \sim 10^{-3}\Omega_{ci}$

$$\partial_t \omega = \ldots - \nu_{in}\omega$$



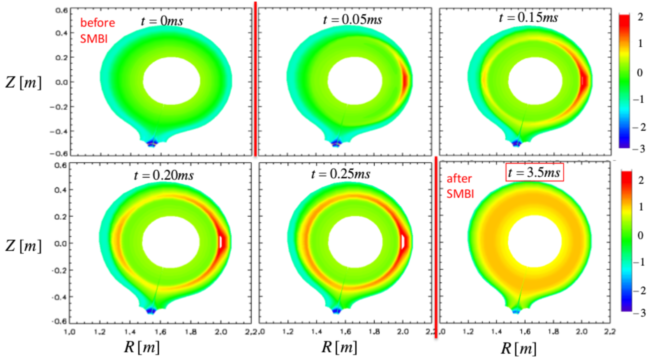
[1] P.Popovich, M.V.Umansky, T.A.Carter and B.Friedman arXiv:1005.2418 (2010)

Fluid neutral model

Fluid model developed[1] which takes into account dissociation and ionisation:

$$H_2 \rightarrow 2H^0 \rightarrow 2H^+ + 2e$$

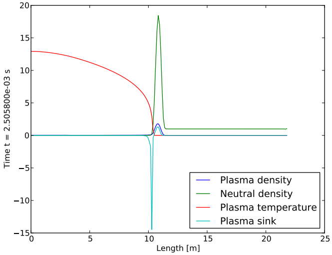
and charge-e Currently models neutrals along a 1D beam (SMBI). Provides a source of density for fuelling



[1]Z.H.Wang, X.Q.Xu, T.Y.Xia, T.D.Rognlien Nucl. Fusion 2013

Ongoing work with neutral fluid models

- 1D modelling of detachment fronts
  - At high density (low divertor temperature), volume recombination can detach plasma from the target plates
  - Ionisation-recombination front can move upstream
  - Stability and control of this front is essential



Ongoing work with neutral fluid models

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  - At high density (low divertor temperature), volume recombination can detach plasma from the target plates
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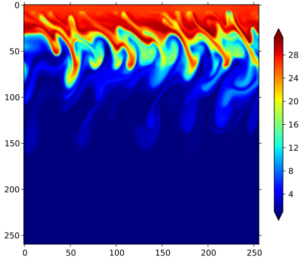
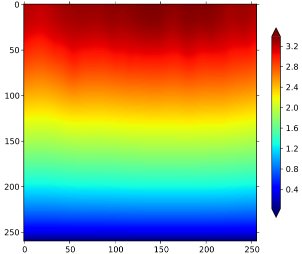
  - Stability and control of this front is essential
- 2D modelling of plasma turbulence - neutral gas interactions
  - Diffusive model for neutral gas
  - So far low power cases $\rightarrow$ small variation in density

Plasma temperature [eV]



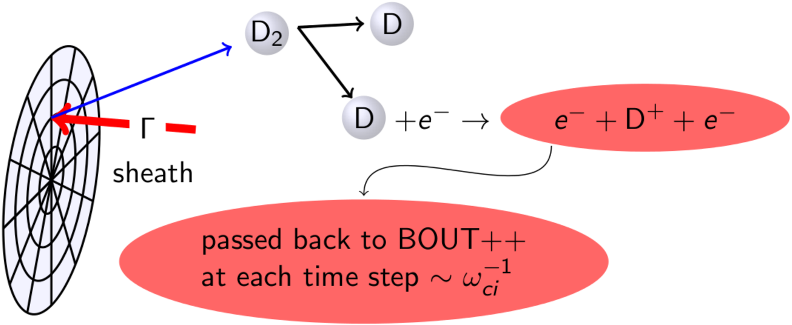
Neutral temperature [eV]



BOUT++ / EIRENE coupling

Work ongoing to couple BOUT++ to EIRENE

- Starting in linear geometry (LAPD, PSI-2, Magnum-PSI)
- Technical coupling completed. Both codes run in parallel (MPI), passing data in memory
- Initial turbulence simulations beginning
  $\rightarrow$ Some issues related to initialisation transients



Summary

- Simple models used in BOUT++ to study broad trends
- Fluid models can be run for long times relatively cheaply
- A kinetic treatment is probably needed
  - Need to capture changes in neutral energy spectrum
  - Mean-free-paths can be comparable to turbulent scales
- Ongoing work with BOUT++ and EIRENE[3]

[3] S.Mekkaoui, EFDA fellowship 2014. Poster at PSI 2014