Gaseous Electronics and Plasmas

- Gaseous electronics: the field of low temperature, non-equilibrium plasmas
- Gaseous electronics is the study of partially-ionized gases (or vapors) existing under non-equilibrium conditions
- Where does plasma exist?
e.g. https://www.sciencemag.org/content/342/6164/1343.abstract
1. Introduction

Plasmas consist of:

- neutral species (e.g. rare gases, \( \text{N}_2 \), \( \text{O}_2 \), etc.)
- Positive and negative ions (\( \text{N}_2^+ \), \( \text{O}^- \), \( \text{O}_2^+ \), etc.)
- Electrons
- Radicals (e.g. \( \text{CH}_2 \) from \( \text{CH}_4 \))

Quasi-neutrality in a plasma:

\[
\sum N_i^+ \cdot Z_i \approx \sum N_i^- \cdot Z_i
\]

- \( N_i \): number density (\( \text{cm}^{-3} \)), \( Z_i \): magnitude of charge
In typical low temperature plasma system, a small NET positive charge exists.:
\[
\frac{N^+ - N^-}{N^+ + N^-} \approx 10^{-5} - 10^{-6}
\]

Another important characteristic of the plasma we will study is that they are only partially (or weakly) ionized:
\[
\frac{N^+}{\text{neural density } (N)} \approx 10^{-2} - 10^{-6}
\]

e.g. fluorescent lamp
N (argon density) $\sim 10^{16}$ cm$^{-3}$
\[
\text{electron density } (n_e) \sim 10^{10} \text{ cm}^{-3}
\]

Vast majority of collisions in the plasma involve at least one neutral species.

1. Introduction
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Containers or “Walls”:
All terrestrial plasmas are confined within a vessel

Wall reactions can have a critical bearing on plasma characteristics.

Typically,
We say a plasma is “non equilibrium” when each class of species has its own temperature:

\[ T_e \gg T_i \geq T_{\text{gas}} \]

- electrons
- ions
- neutrals

1. Introduction

![Graph showing temperature (K) vs. pressure](image)
Note: temperature is used as a “shorthand” to represent an entire energy distribution.

$T_e \sim 2-5$ eV, i.e. $T_e \sim 20,000 - 50,000$ K (300K ~ 1/40eV, 1eV ~ 12000K)
$T_i \sim 0.1$ Ev ~ 1000 K, $T_{\text{gas}} \sim 300$-500 K (25 - 50 meV)

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Types of plasmas

Plasma is estimated to make up ~99% of the universe.
Interstellar and planetary plasmas are a course unto themselves.

This course will focus on laboratory or, more specifically, “technological” plasmas. These are non-fusion plasmas
1. Introduction

Classes by application:

Lasers

• A. Continuous wave (CW):
  He-Ne, CO\textsubscript{2}, Ar\textsuperscript{+}
  pressure of few Torr where 1 atm $\sim$ 760 Torr and 1 Torr = $3.21 \times 10^{16}$ cm\textsuperscript{-3}

• B. Pulsed
  Cu, excimer, N\textsubscript{2}, H\textsubscript{2}

Light sources (incoherent)

• A. Fluorescent
  Ar/Hg $\sim$ 93/7, $P \sim$ 1 Torr, 10s – 100s of mA- cm\textsuperscript{-2}, $n_e \sim 10^{10} – 10^{11}$ cm\textsuperscript{-3}

• B. Metal-halide or Na vapor lamps
  HgI\textsubscript{2}, ScI\textsubscript{3}, DyI\textsubscript{3}, etc. Pressure beyond 1 atm.

Plasma material processing

• Plasma etching, plasma deposition, sputter deposition, surface modification