Beam Interaction with gas filled RF Cavities

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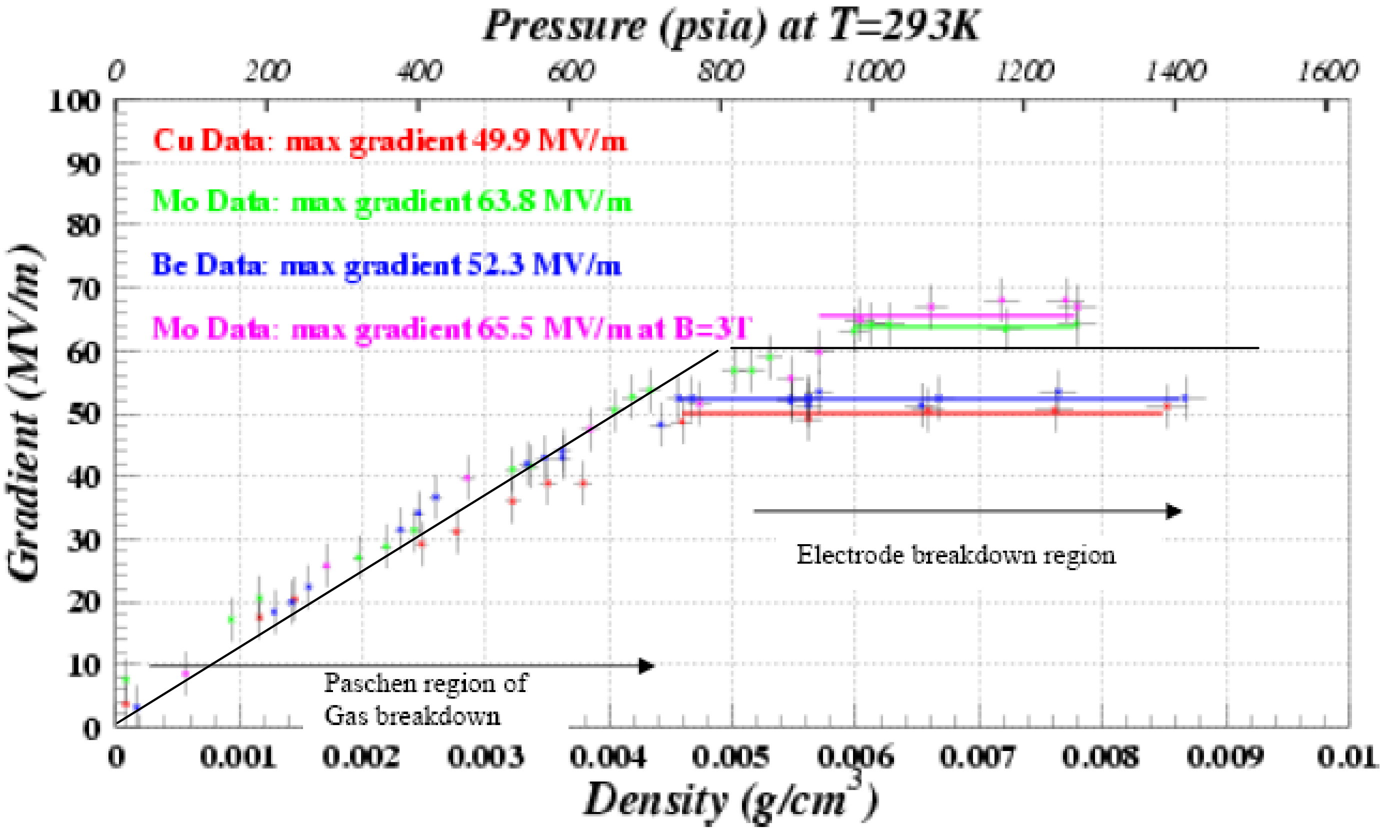
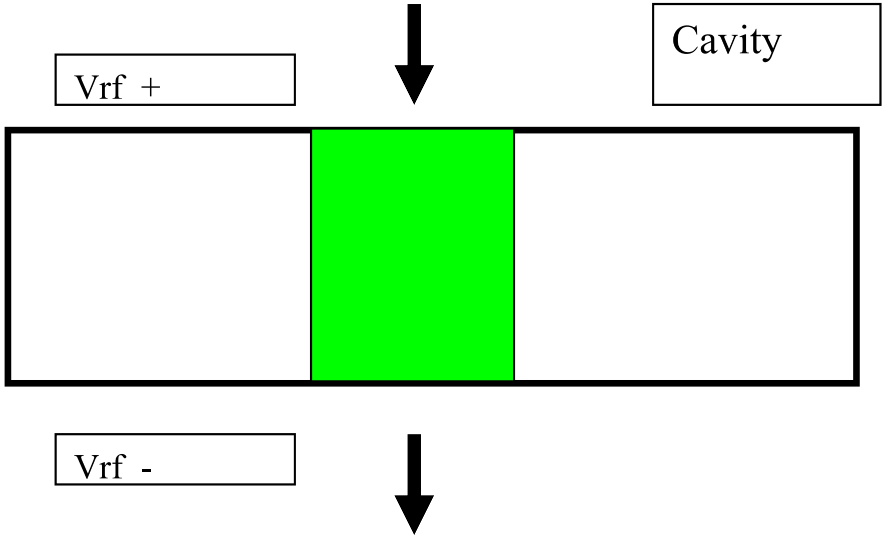


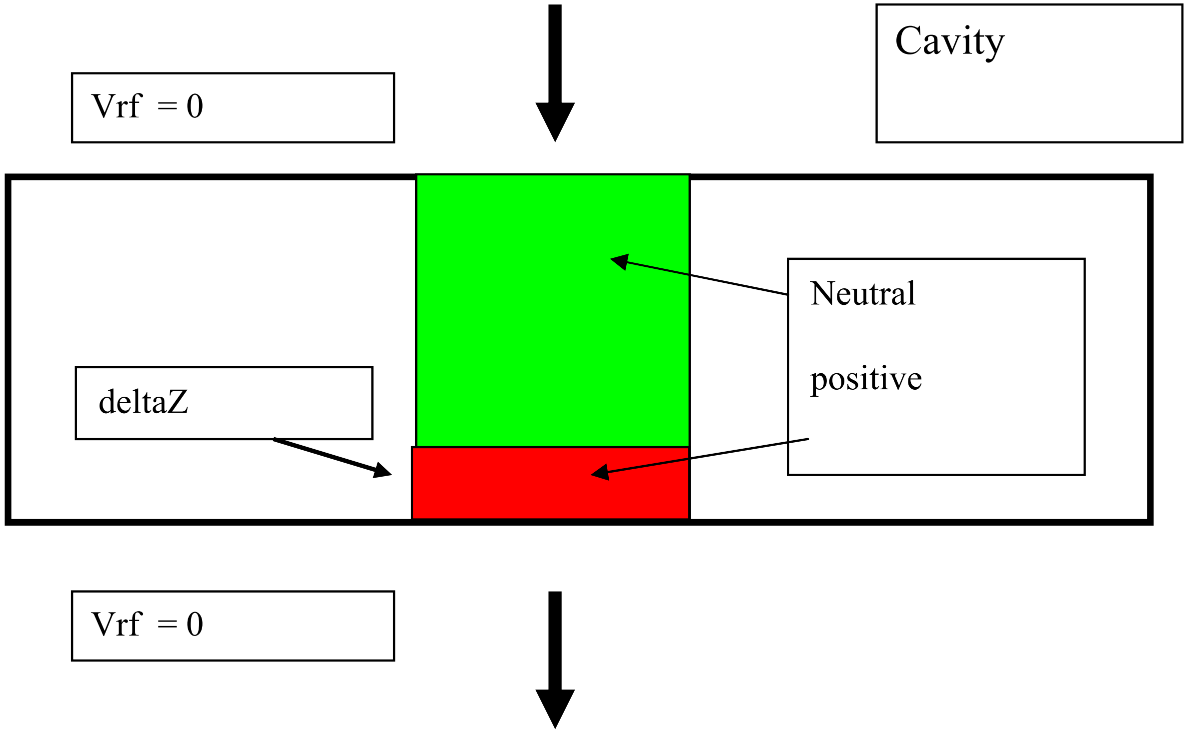
Figure 3: Measurements of the maximum stable TC gradient as a function of hydrogen gas pressure at 800 MHz with no magnetic field for three different electrode materials, copper (red), molybdenum (green), and beryllium (blue). As the pressure increases, the mean free path for ion collisions shortens so that the maximum gradient increases linearly with pressure. At sufficiently high pressure, the maximum gradient is determined by electrode breakdown and has little if any dependence on pressure. Unlike predictions for evacuated cavities, the Cu and Be electrodes behave almost identically while the Mo electrodes allow a maximum stable gradient that is 28% higher. The cavity was also operated in a 3 T solenoidal magnetic field with Mo electrodes (magenta); these data show no dependence on the external magnetic field, achieving the same maximum stable gradient as with no magnetic field.

The black line is at E/P = 13.2 for breakdown in hydrogen. This comes from $U_e = eE\lambda$ and $\lambda = 1/N\sigma$ and the postulate that the physics depends only on the energy of the electrons at the point of collision. A more useful variable is E/N where N is the # molecules.cm^3. E/N for breakdown = 4 $10^{-16.}$

Beam passes thru cavity at max Vrf as a delta function



After a ¼ cycle the electrons have all drifted upwart by a distance deltaZ. This discharges the top plate and leaves a layer of positive charge against the bottom. The field in this region remains the same and the field outside decreases. A ¼ cycle later the image is reversed.



P= 200 Bo=13.6` betaPerp= 0.0981

emit= 0.000422 minEmit= 0.000209

Nbeam= $1.\times10^{11}$ rhoGas= 0.03`

RF Gradient V/m =$25.\times10^{6}$,Frf Hz= $400.\times10^{6}$

Example

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1. beamRadius, cm	0.643745
2. H molecule density	9.033×10^{21}
3. av. molecule Spacing in microns	0.000480245
4. muons/cm^2 =	7.68108×10^{10}
5. Averge μ spacing microns	0.0360819
6. Radius 2 eV electron, Bo T field, microns	0.350413
7. spacing between ions along track, microns	2.91667
8. path length to ionize, microns	0.54
9. tforIonization ps	0.522413
10. positive ion density/cm^3	2.63351×10^{14}
11. plasma Frequency	9.14864×10^{11}
12. EoverP, KV/cm/torr =	0.919481
13. Mobility=	0.0187169
14. electron velocity cm/sec=	1.0207×10^{6}
15. deltaZ, cm	0.000977355
16. q/cm^2 cavity,No. electrons	1.38349×10^{11}
17. plasma density x deltaZ/2	1.28694×10^{11}
18. plasma Charge/ Cavity Charge	0.930212
19. deltaW/cm^3 / cycle	0.00686796
20. Qeffective	2.53138
20. E/n (V/cm /Molecules/cm^3	2.78977×10^{-17}
	Null

Mobility

$$v = \frac{1}{2} a t = \frac{1}{2} e/m E t = \frac{1}{2} e/m E \langle \lambda / Vr \rangle$$

V: drift velocity; Vr random velocity within the swarm. It is not related to kT of the molecules!

$$\lambda = 1 / N \sigma$$

$v = \frac{1}{2} e/m \langle 1 / (N \sigma Vr) \rangle E = \mu E$ and is proportional to E /P or E/N.

For high E, Vr is much higher than given by kT as the electrons absorb energy from the field and then scatter generating hot random electrons. μ is a function of E/P.

deltaZ is given by the following formula:

$$\text{deltaZ} = \int_0^{T/4} \mu[E_0 \cos[\omega t] / P]\, E_0 \cos[\omega t]\, dt$$

Density effect in He

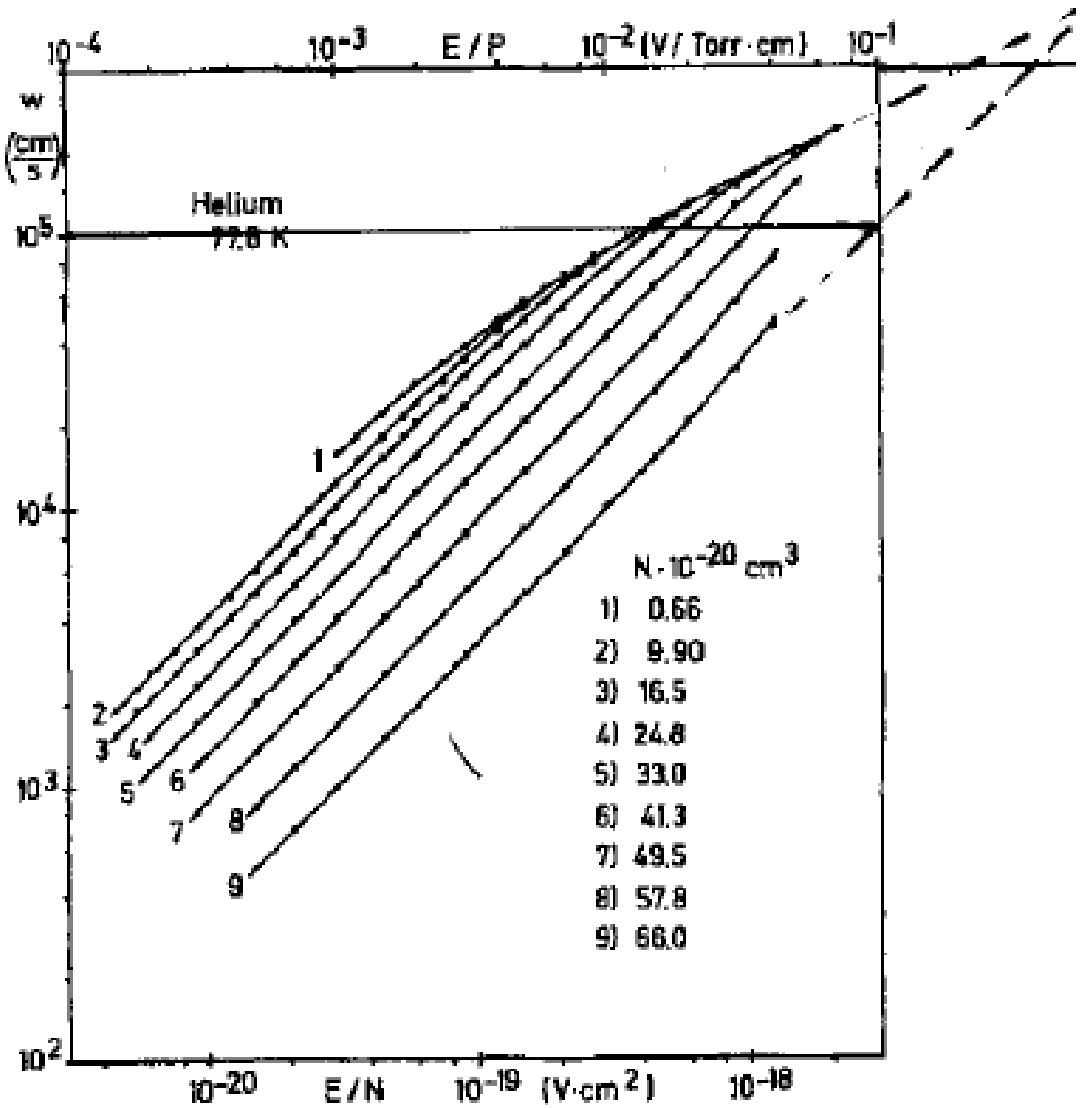

Fig. 1. Electron drift velocity versus E/N in helium at 77.6 K and at nine densities. The points are experimental values. In the scale of E/P is 1 Torr $= 3.3 \times 10^{16}$ cm^{-3}

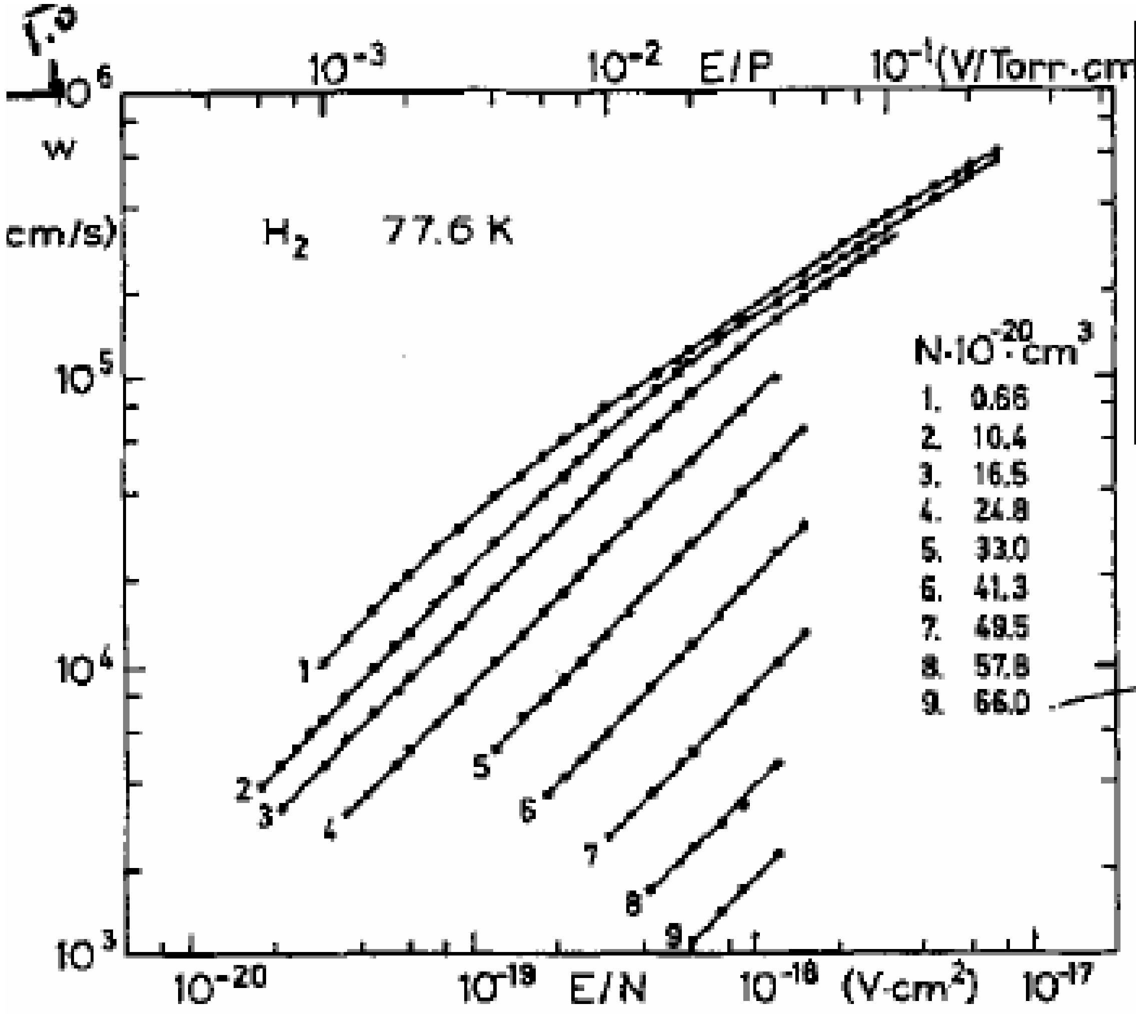

Fig. 2. Electron drift velocity versus E/N in hydrogen at 77.6 K and at nine densities. The points are experimental values. In the scale of E/P is 1 Torr $= 3.3 \times 10^{16}$ cm^{-3}

Conversion from N in the graph at left to gas density in the middle column and equivalent P in torr for the last column.

6.6×10^{19}	0.00022044	1876.39
9.9×10^{20}	0.0033066	28 145.8
1.65×10^{21}	0.005511	46 909.6
2.48×10^{21}	0.0082832	70 506.6
3.3×10^{21}	0.011022	93 819.3
4.13×10^{21}	0.0137942	117 416.
4.95×10^{21}	0.016533	140 729.
5.78×10^{21}	0.0193052	164 326.
6.6×10^{21}	0.022044	187 639.

I have found no measurements for H in our range

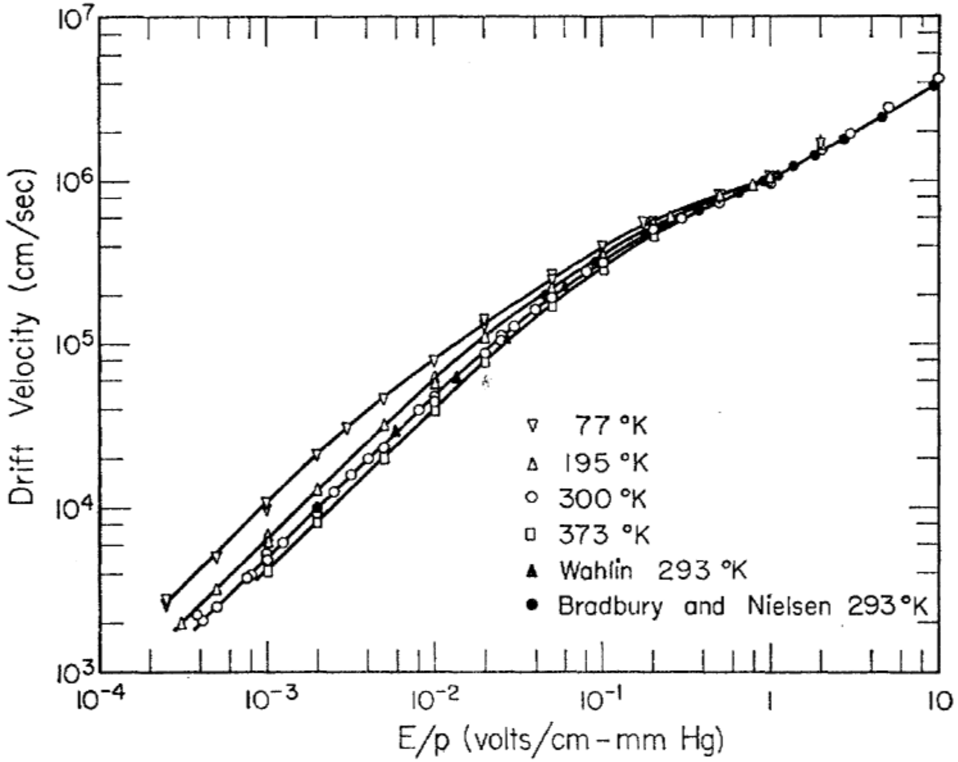

FIG. 7. Electron drift velocity as a function of E/p in hydrogen at 77°K, 195°K, 300°K, and 373°K. For $E/p < 3\times10^{-3}$ the electrons are in thermal equilibrium with the gas at each temperature.

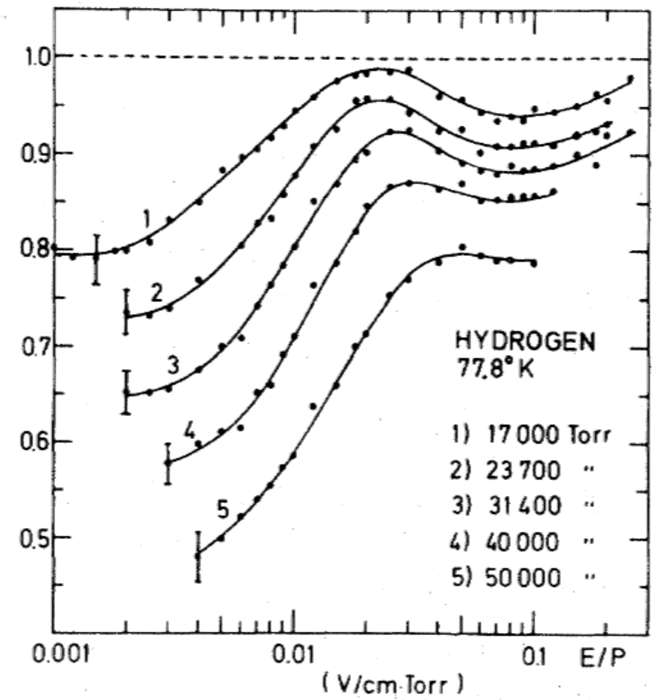

FIG. 1. The quotient q of the drift velocity at high pressures and the drift velocity at low pressure (here 2000 Torr) as a function of E/P.

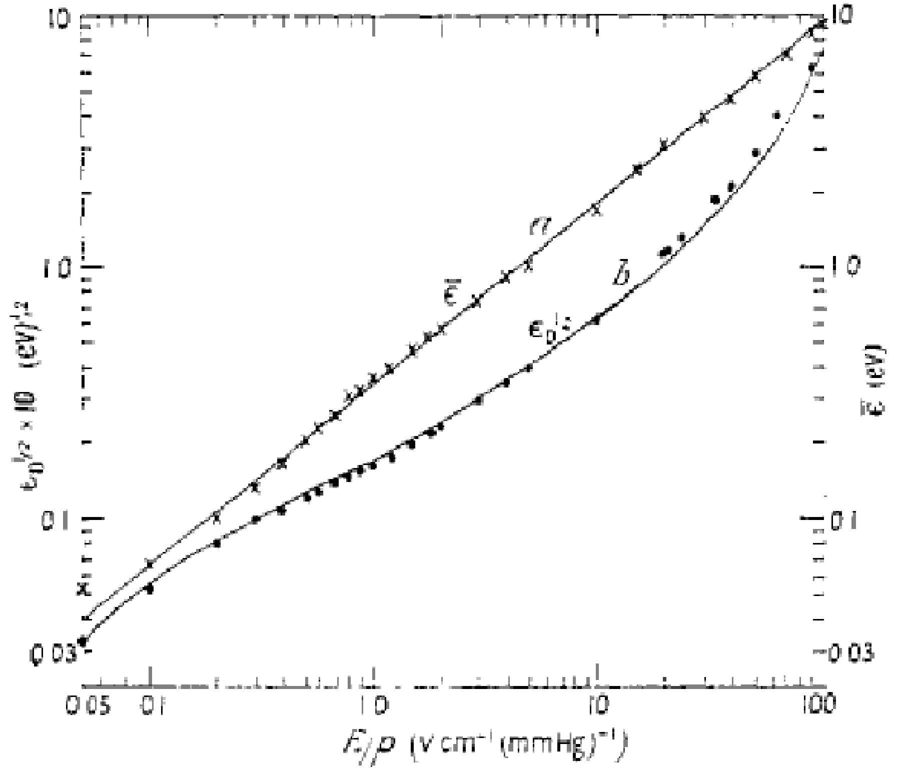

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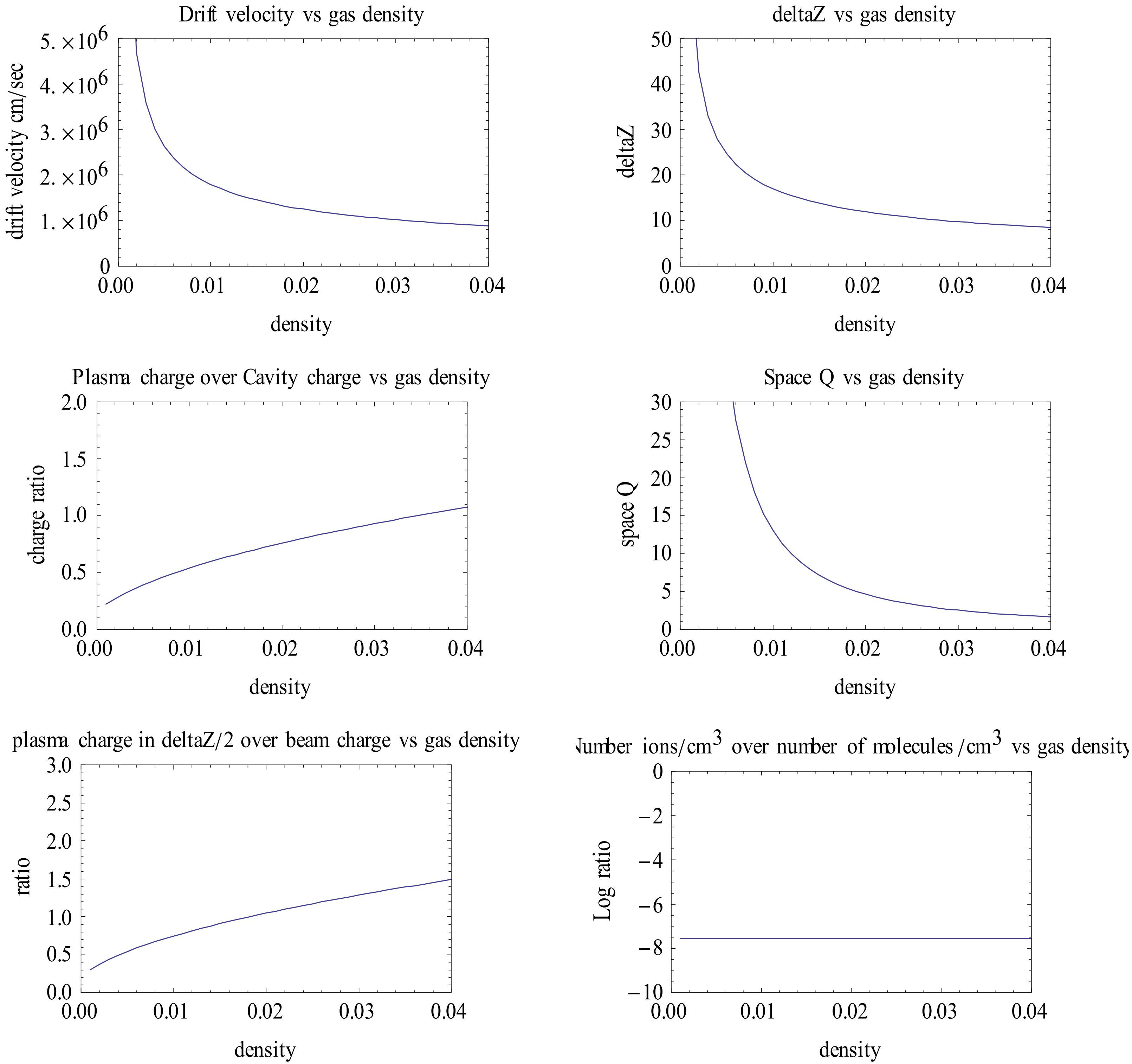
Figure 2. Electron mean energy: crosses, Crompton and Sutton (1952); curve a, according to equation (5). Electron drift velocity: points, Bradbury and Nielsen (1936) and Gill and von Engel (1949), curve b corresponds to equation (6)

Heylen has fit the data with an analytical expression that is valid for:

0.1 < E/P < 100 with an accuracy of less than 16%

This fit has been used for calculating deltaZ and other properties of the beam-cavity interaction



See “Example” for conditions other than density.

Questions and things to measure

1. What is the mobility at high pressures?
2. Can we get an estimate of the recombination rate? How long do the ions hang around? Does it matter?
3. What is the recombination time with a little SF_6 added?
   $1/n1\ dn1/dt = R\ n_2$ If the right side is 10^9 and n_2 is 1% of the hydrogen (X_0 SF6 is 1/150 X_H) $n_2 = 10^{22}/100$ Then $R = 10^{-11}$ This R seems to be in range I can find for various processes.
4. Need measurements for narrow beam and high intensity as exist at end of cooling change.
5. Open cell cavities are different. There is a column of plasma and no end electrodes. B keeps the plasma from diffusing in radial direction very fast so at peak of cycle there are blobs of positive charge between cells.

6. The linac has 10 μSec pulse. Is there any way to get single bunches?
7. A small light pipe leading out of the cavity to observe light could be useful.