



# Contents

<b>1. Introduction</b>	<b>1</b>
<b>2. Collisionless Space Charge Phenomena</b>	<b>5</b>
2.1 Scope	5
2.2 Plane parallel electrodes (The Child Equation)	5
2.3 Coaxial cylinders	8
2.4 Concentric spheres	11
2.5 Momentum balance method	12
2.6 Relativistic Child Equation	12
2.7 Sheath with nonzero initial velocities	14
2.8 Generalized planar space charge problem	18
2.9 Maxwellian distribution of emitted velocities	23
2.10 Double sheath with zero emitted velocities	31
2.11 Space charge effects in beams—perveance and poissance	33
A. Long narrow beams, poissance $< 1$	33
B. Axially symmetric beams, poissance $< 1$	37
C. High current beams	38
Problems	41

<b>3. Collisionless Plasmas</b>	<b>45</b>
3.1 Scope	45
3.2 Formation of a plasma	45
3.3 Debye shielding distance	48
3.4 Bohm criterion	50
3.5 General theory	52
A. Planar geometry	53
B. Cylindrical and spherical geometry	60
3.6 Ion velocity distribution	61
3.7 Ion current density	63
3.8 Ion extraction sheaths	64
A. The sheath approximation	65
B. Exact numerical solutions	68
3.9 The cathode double sheath	74
3.10 Neutral gas density	76
3.11 Characteristic frequencies. Electromagnetic wave propagation	80
Problems	82
<b>4. Collisional Effects</b>	<b>85</b>
4.1 Types of collisions and general effects	85
4.2 Effect of ionization on neutral gas density	85
4.3 Ion-atom collisions	87
4.4 Collisions between charged particles	88
4.5 Scattering by a plasma	91
4.6 Relaxation times	96
Problems	97
<b>5. Positive Ion Extraction and Acceleration</b>	<b>99</b>
5.1 The problem of ion extraction	99
5.2 Electrode perveance and poissance	100
5.3 Pierce electrodes	103
A. Parallel flow in long slit beams	103
B. Parallel flow in circular beams	106
C. Converging flow	107
5.4 Emittance and brightness	109
5.5 Multiaperture accel-decel extraction	112
5.6 Extraction electrode design	117
5.7 Effect of neutral vapor	122
5.8 Beam steering	124

5.9	Insulator coated electrodes	125
5.10	Fine mesh ion extraction	127
A.	Angular divergence	128
B.	Power limitation	129
C.	Sputtering limitations	131
D.	Contoured fine mesh	131
E.	Double grid system	131
F.	Application hints	133
G.	Not so fine single grid extraction	133
5.11	Magnetic double sheath acceleration	134
	Problems	136
<b>6.</b>	<b>Propagation of High Poissance Beams</b>	<b>139</b>
6.1	Ion beam neutralization	139
6.2	The ion beam as a plasma	143
A.	Slow ions to the beam boundary	147
B.	Calculation of beam plasma potential	148
C.	Experimental measurements	151
<b>7.</b>	<b>Ion Source Cathodes</b>	<b>155</b>
7.1	Importance of the cathode problem	155
7.2	Free electron theory of thermionic emission	155
7.3	The Schottky Effect	158
7.4	Power balance at a cathode	161
7.5	Tungsten, tantalum, and molybdenum	162
7.6	Some thin film and oxide emitters	164
7.7	The Hull dispenser cathode	165
7.8	Dispenser, impregnated, and pressed cathodes	167
7.9	Lanthanum hexaboride	168
7.10	Lanthanum oxide doped molybdenum cathodes	173
7.11	Liquid mercury cathodes	173
7.12	Hollow cathodes	174
<b>8.</b>	<b>Taxonomy of Positive Ion Sources</b>	<b>181</b>
8.1	Desired plasma density	181
8.2	Single aperture sources, no magnetic field	183
A.	Canal-ray discharge sources	183
B.	Capillaritron	184
C.	Low voltage capillary arcs	186

8.3	Single aperture sources, magnetic fields	188
A.	Oscillating electron, cold cathode (Penning) sources	188
B.	Oscillating electron, hot cathode (Finkelstein) sources	189
C.	Transverse extraction (Calutron) sources	191
D.	Duoplasmatron ion source	193
E.	Single ring magnetic cusp ion source	194
8.4	Broad multiaperture sources, no magnetic field	195
8.5	Broad oscillating electron (Kaufman) sources	197
8.6	Radial field source	199
8.7	DuoPIGatron	201
8.8	An idealized source	203
8.9	Magnetic boundaries	204
8.10	Magnetic materials	210
8.11	Magnetoelectrostatic confinement sources	213
8.12	MacKenzie bucket sources	216
8.13	Modified duoPIGatrons	221
8.14	Magnetic filtering. The tandem cusp configuration	223
8.15	Periplasmatron	224
8.16	Radio frequency ion sources	226
	Problems	227
<b>9.</b>	<b>Surface Ionization Sources</b>	<b>229</b>
9.1	Description of surface ionization	229
9.2	Surface adsorption	230
9.3	Ion current density	232
9.4	Electron emission	233
9.5	A possible front feed ion source	235
9.6	Surface diffusion rates and characteristic lengths	236
9.7	Porous tungsten ionizers	240
9.8	Ion source configurations	242
9.9	Alternative ions and ionizers	246
9.10	A critical comparison with plasma sources	247
<b>10.</b>	<b>Negative Ion Sources</b>	<b>249</b>
10.1	The need for intense $H^-$ and $D^-$ ion beams	249
10.2	Double charge transfer	251
10.3	Surface production of $H^-$ or $D^-$	259
A.	First observation of high current density surface ionization	259
B.	Theory and basic experiments	261

C.	Magnetron-type surface plasma sources	264
D.	Penning-type $H^-$ ion source	267
E.	Modified calutron or SITEX source	268
F.	Hollow cathode discharge sources	269
G.	Multipole containment source with a converter	271
10.4	Volume production of $H^-$	272
A.	Historical development	272
B.	Fundamental processes	274
C.	Tandem multicusp plasma sources	276
D.	Variations on the tandem plasma source	278
E.	Some speculative sources of $H^-$	282
10.5	Negative ion extraction and acceleration	283
<b>References</b>		<b>285</b>
<b>Appendix: Problem Solutions</b>		<b>299</b>
<b>Index</b>		<b>321</b>