Ion Pumps – Operation and Applications

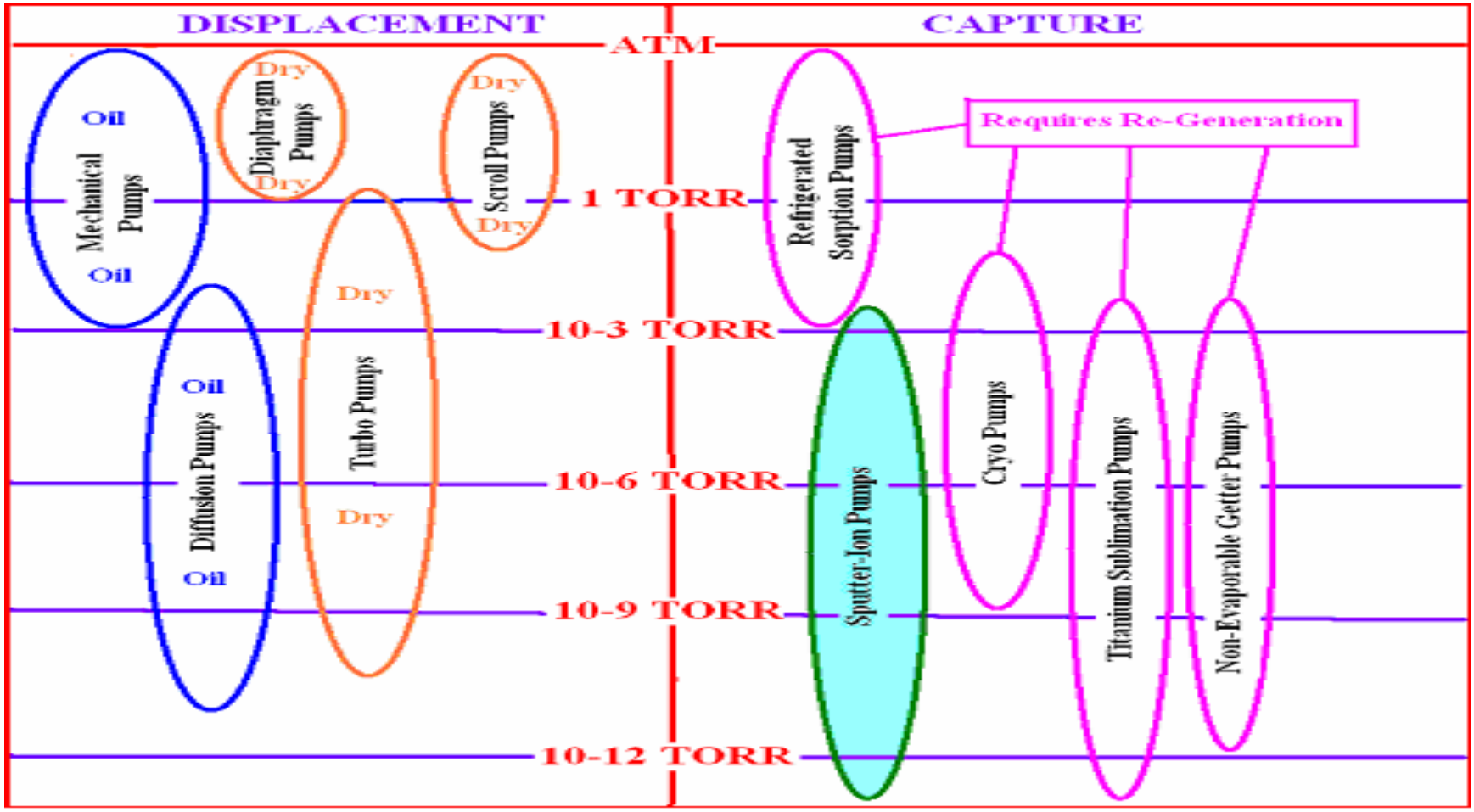
DUNIWAY STOCKROOM CORP.

VACUUM EQUIPMENT AND SUPPLIES

Ion Pumps - Outline

- Where they fit in the vacuum pumping realm
- Basic principles of operation
- Genealogy of ion pump configurations
- Parameters ‘BVD’
- Pumping mechanisms for common gases
- Typical operating cycle
- Common applications
- Applications in microscopy
- Problems and troubleshooting

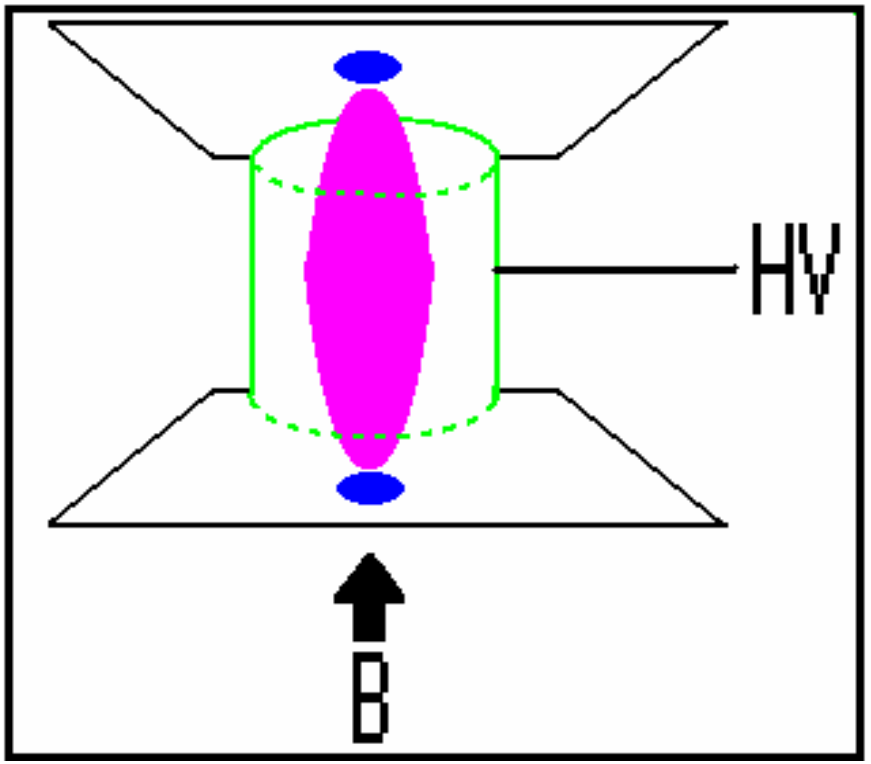
Vacuum Pumps
Types & Ranges



Ion Pumps
Main Characteristics

- “Capture” Pumping; No Backing Required
- Contamination-Free
- Vibration-Free
- Ion Current Provides Pressure Indication
- Long Life at HV and UHV
- Low Maintenance
- Simple Operation

Ion Pump Principle
Penning Discharge



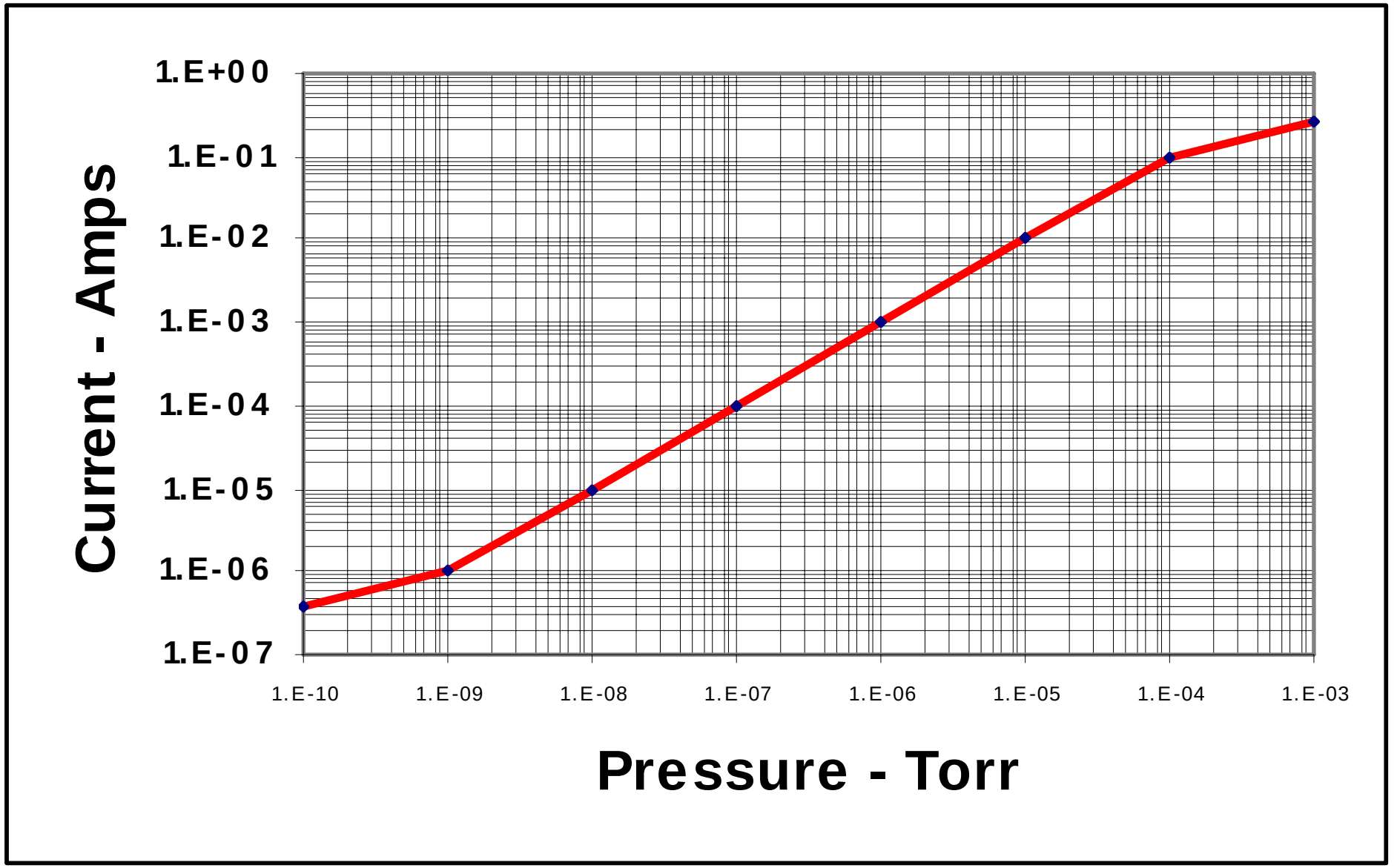
Ion Pump Current Provides Pressure Indication

- Ion Current is Proportional to Pressure
- Wide Range Pressure Indicator
  - UHV – Limited by Field Emission Current
  - High Pressure (>10-4 Torr) Power Limited
- Approximate Relationship:
  - I/P = 10 x S, for example:
  - I/P = 1000 amps/torr for typical 100 l/s Pump
  - See Table on Next Page

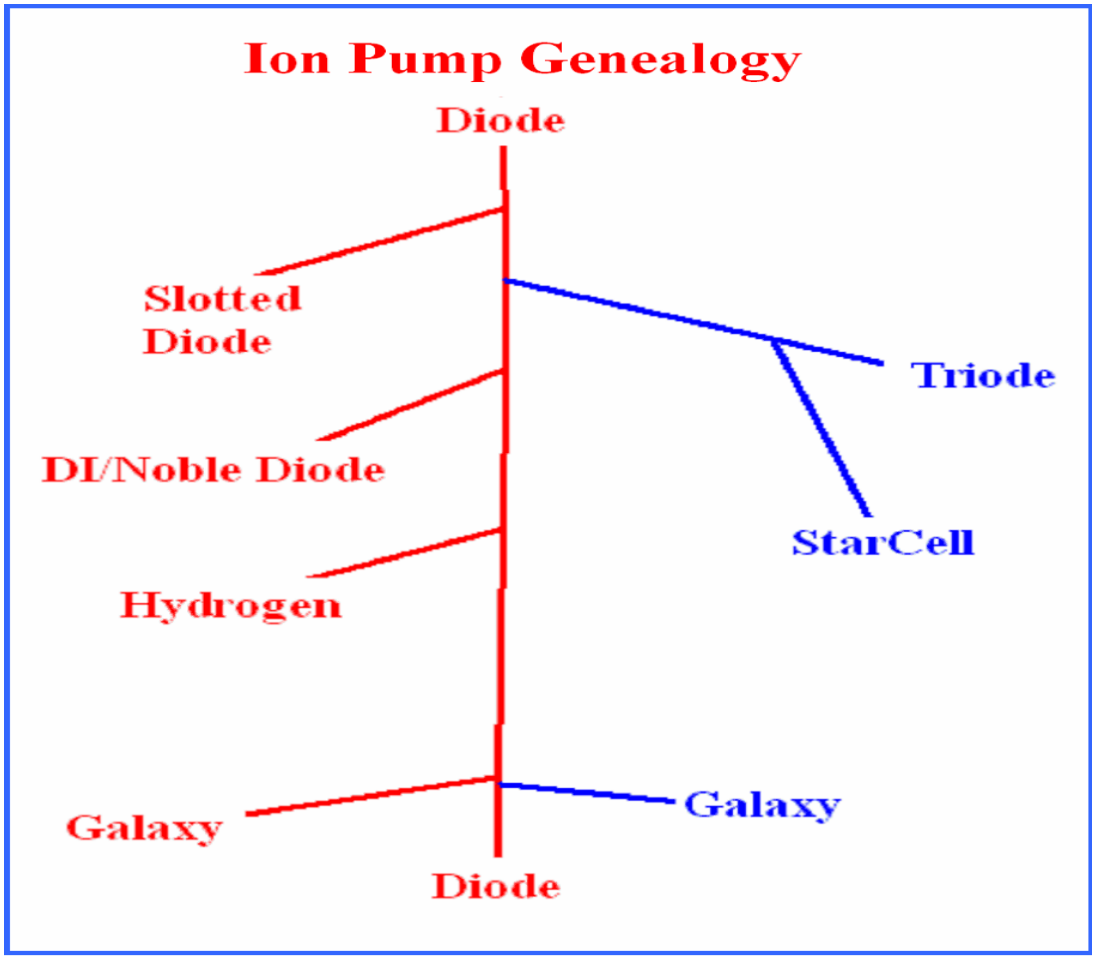
Current vs Pressure
Typical 100 L/S Ion Pump

Pressure - Torr	Ion Current - Amps	Comment
1×10^{-3}	3×10^{-1}	Power Supply Limited
1×10^{-4}	1×10^{-1}	I = 1000 P
1×10^{-5}	1×10^{-2}	I = 1000 P
1×10^{-6}	1×10^{-3}	I = 1000 P
1×10^{-7}	1×10^{-4}	I = 1000 P
1×10^{-8}	1×10^{-5}	I = 1000 P
1×10^{-9}	1×10^{-6}	I = 1000 P
1×10^{-10}	5×10^{-7}	Field Emission Limited

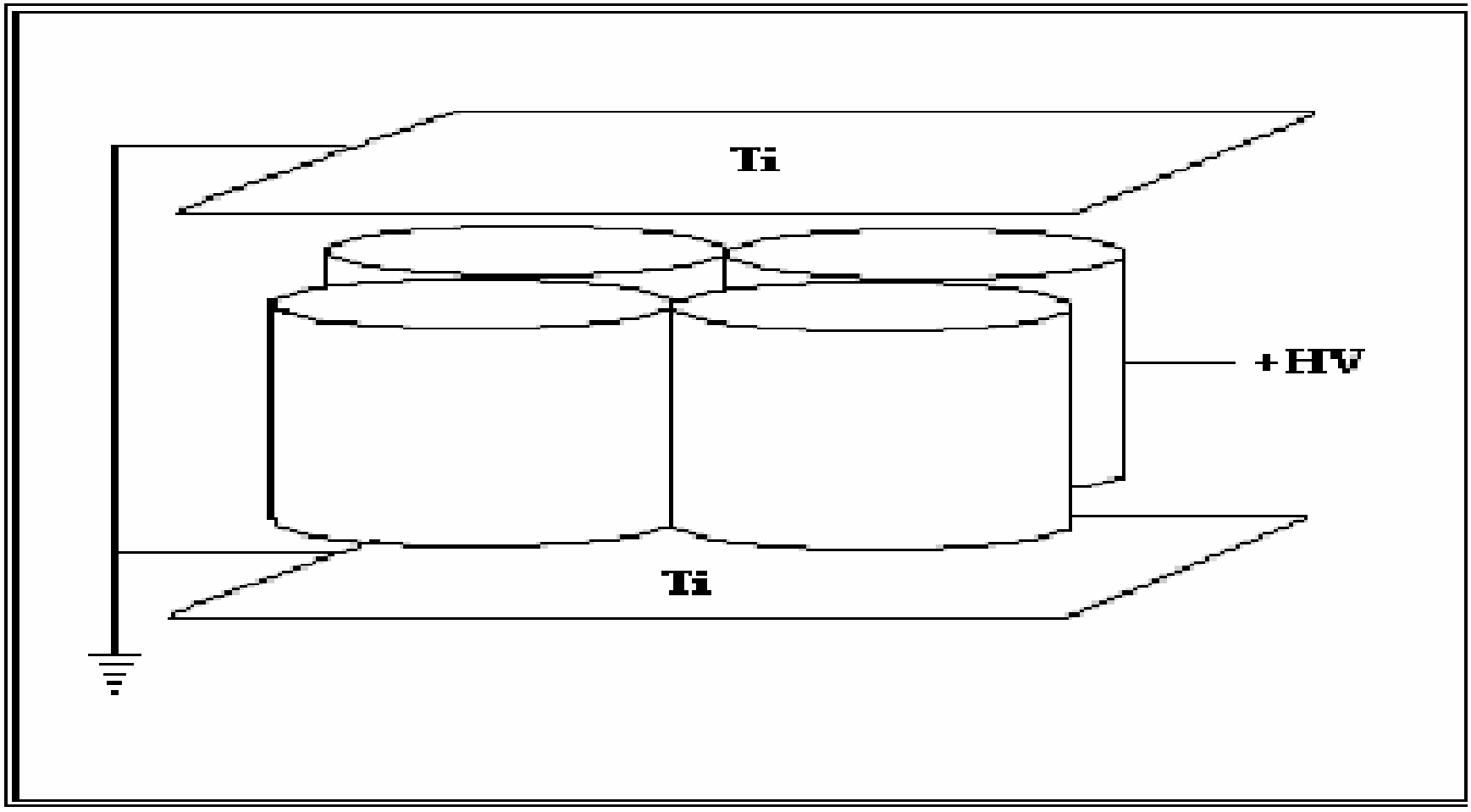
Current vs. Pressure 100 L/S Ion Pump



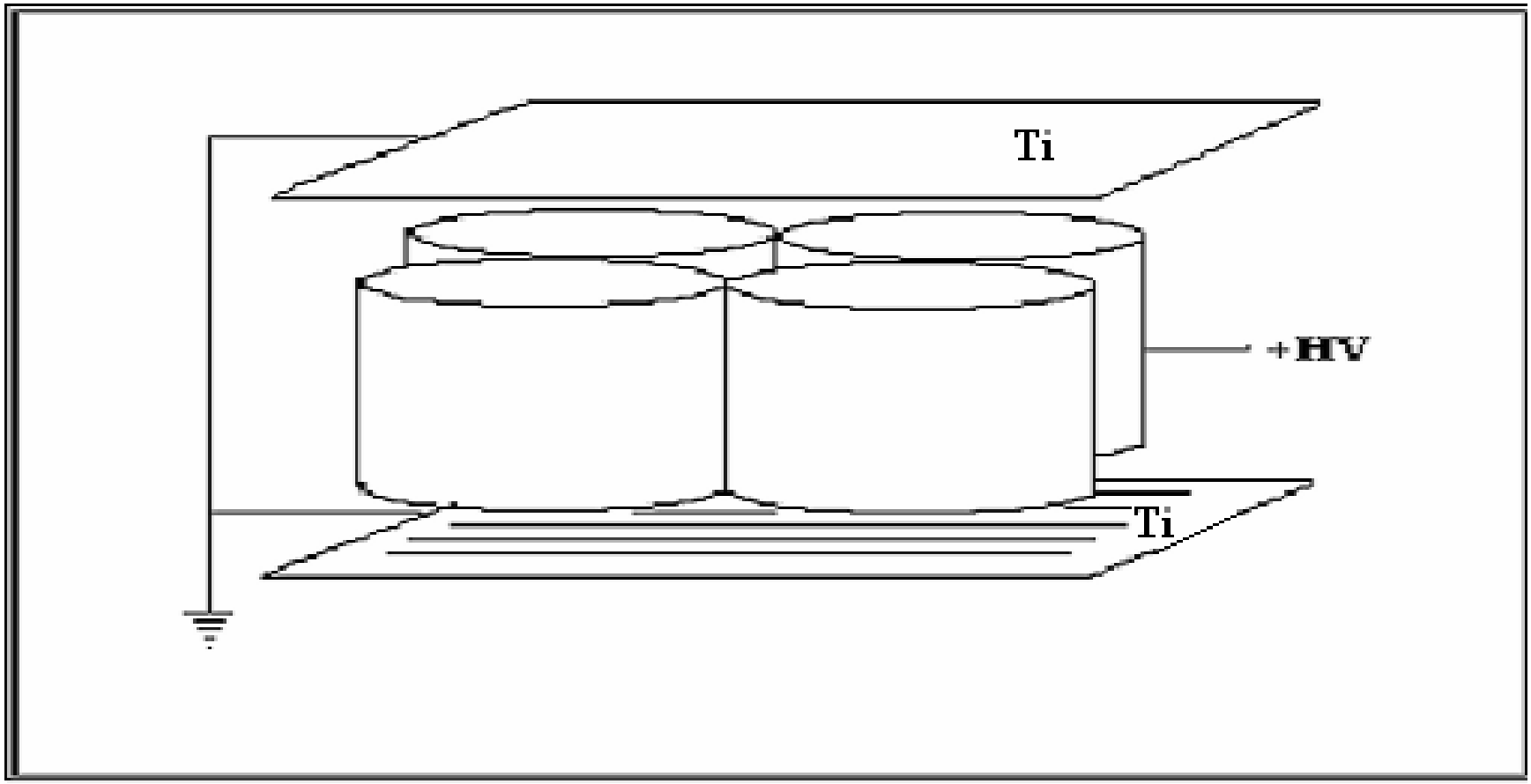
Ion Pumps
Element/Cathode Genealogy



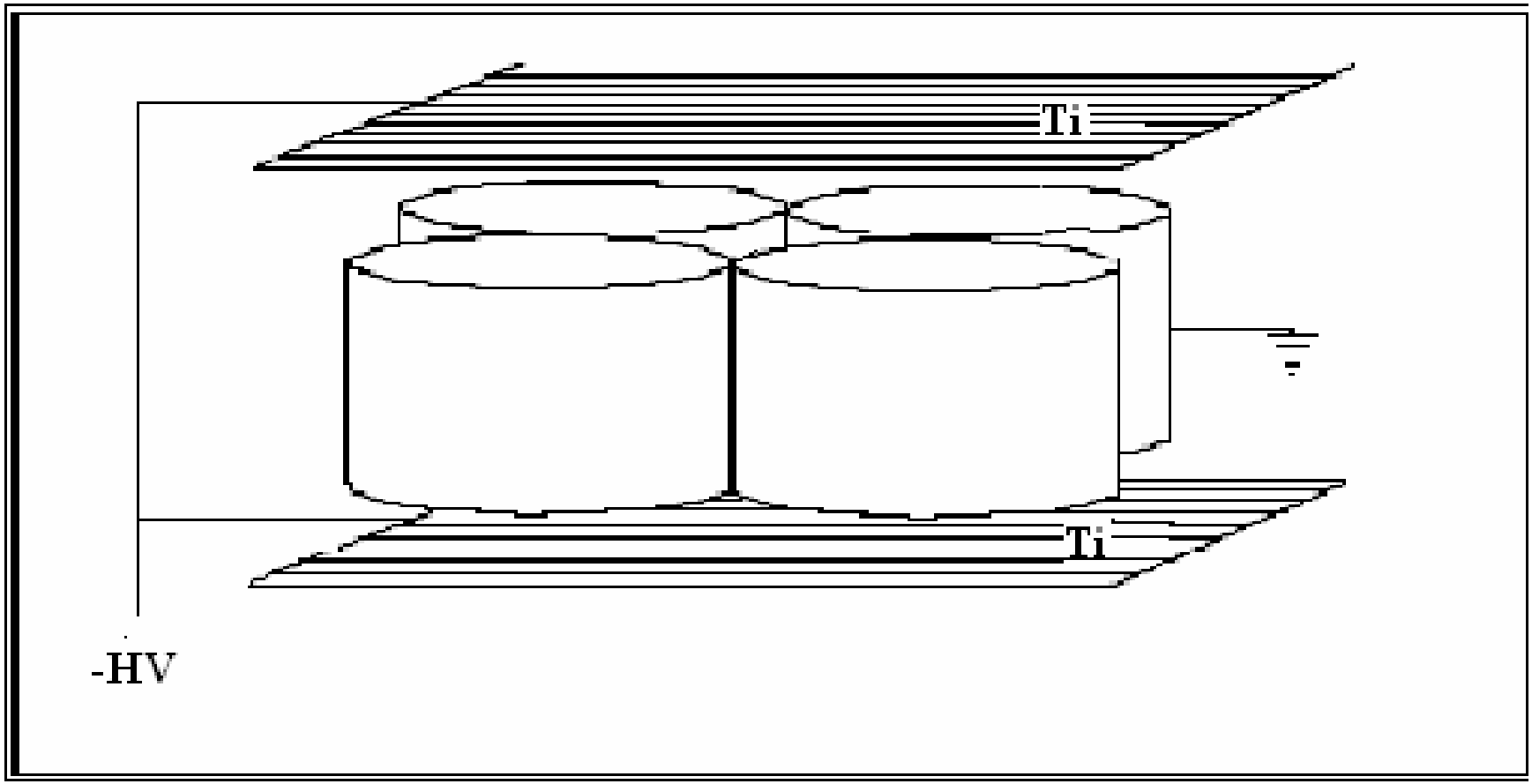
Diode Element



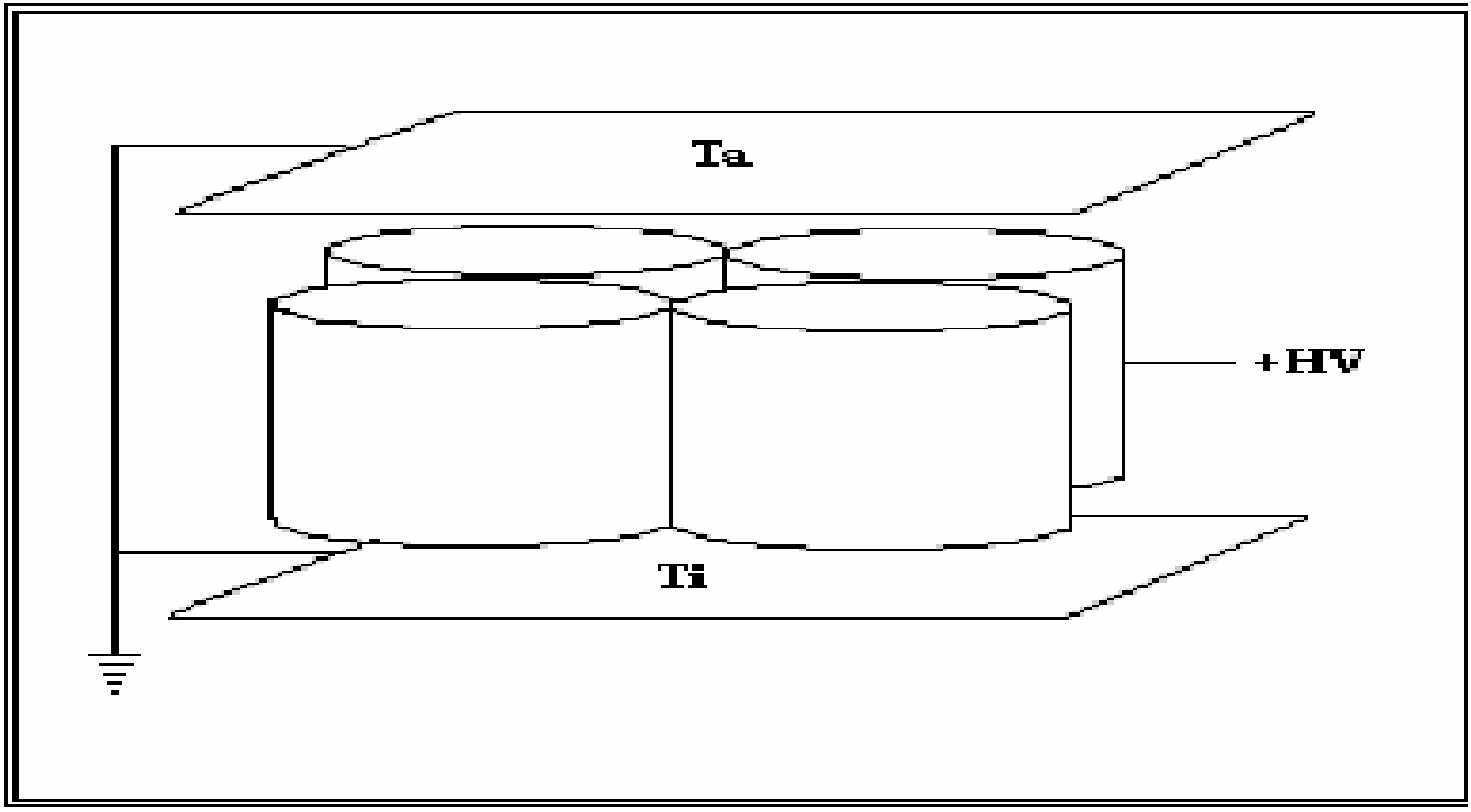
Slotted Diode Element



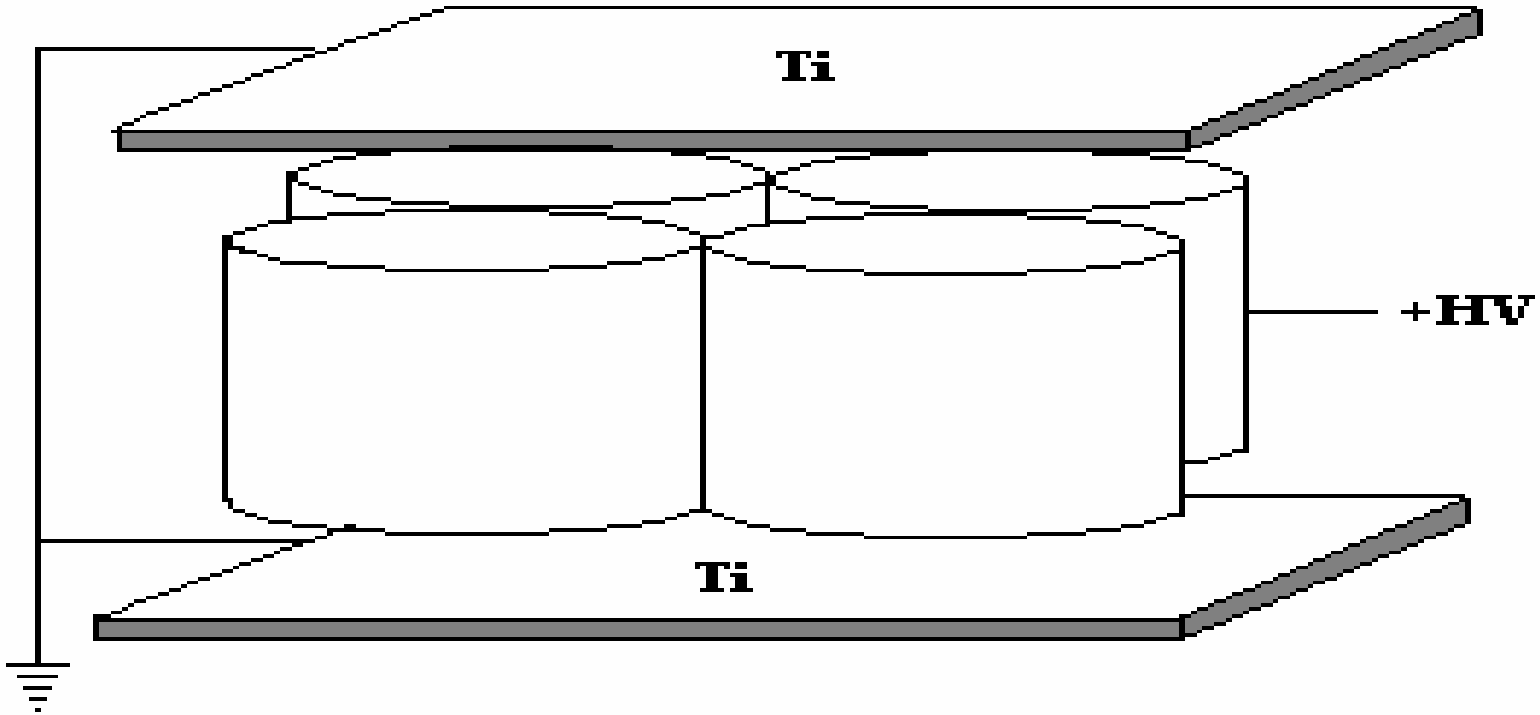
Triode Element



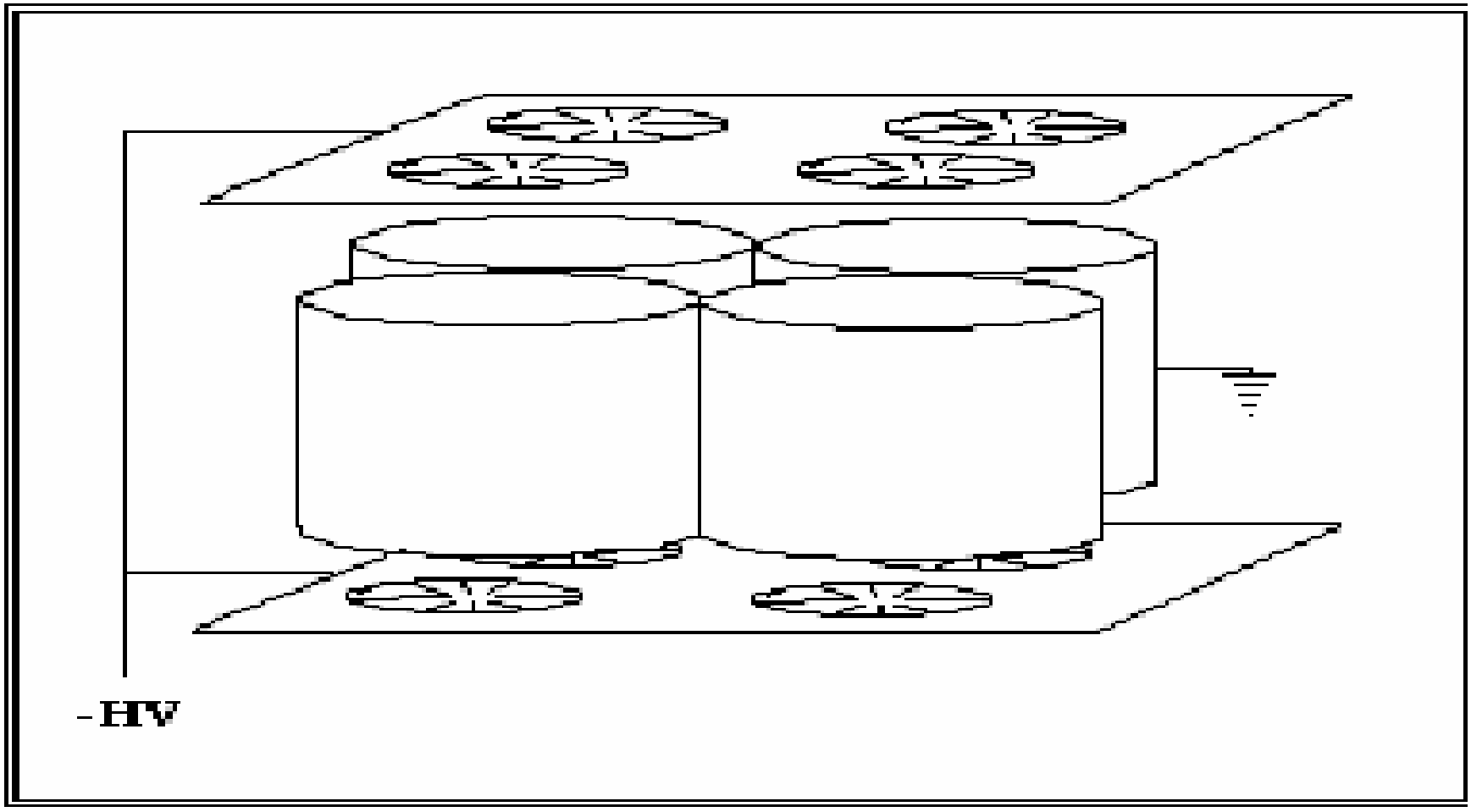
Differential/DI/Noble Diode Element



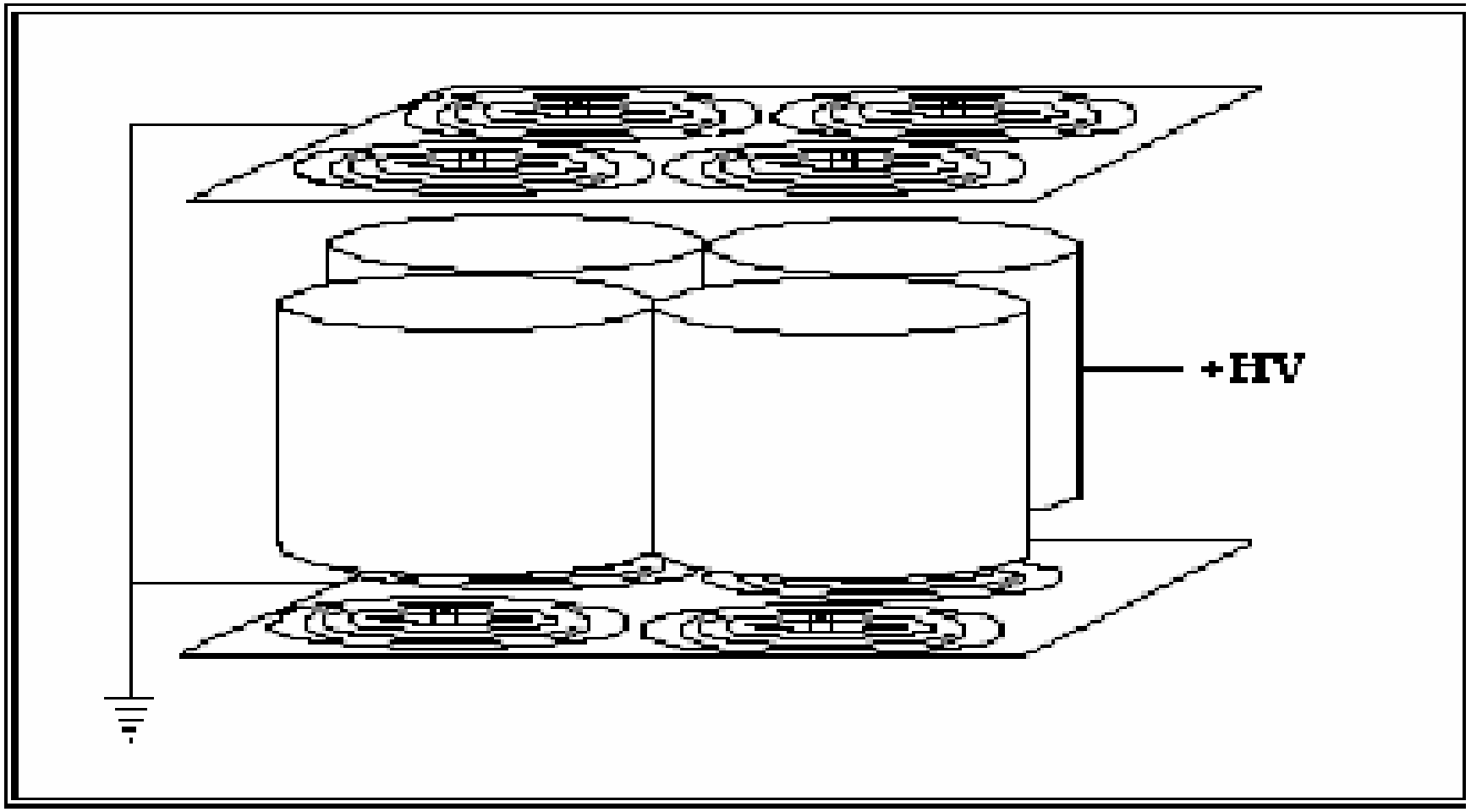
Hydrogen Element



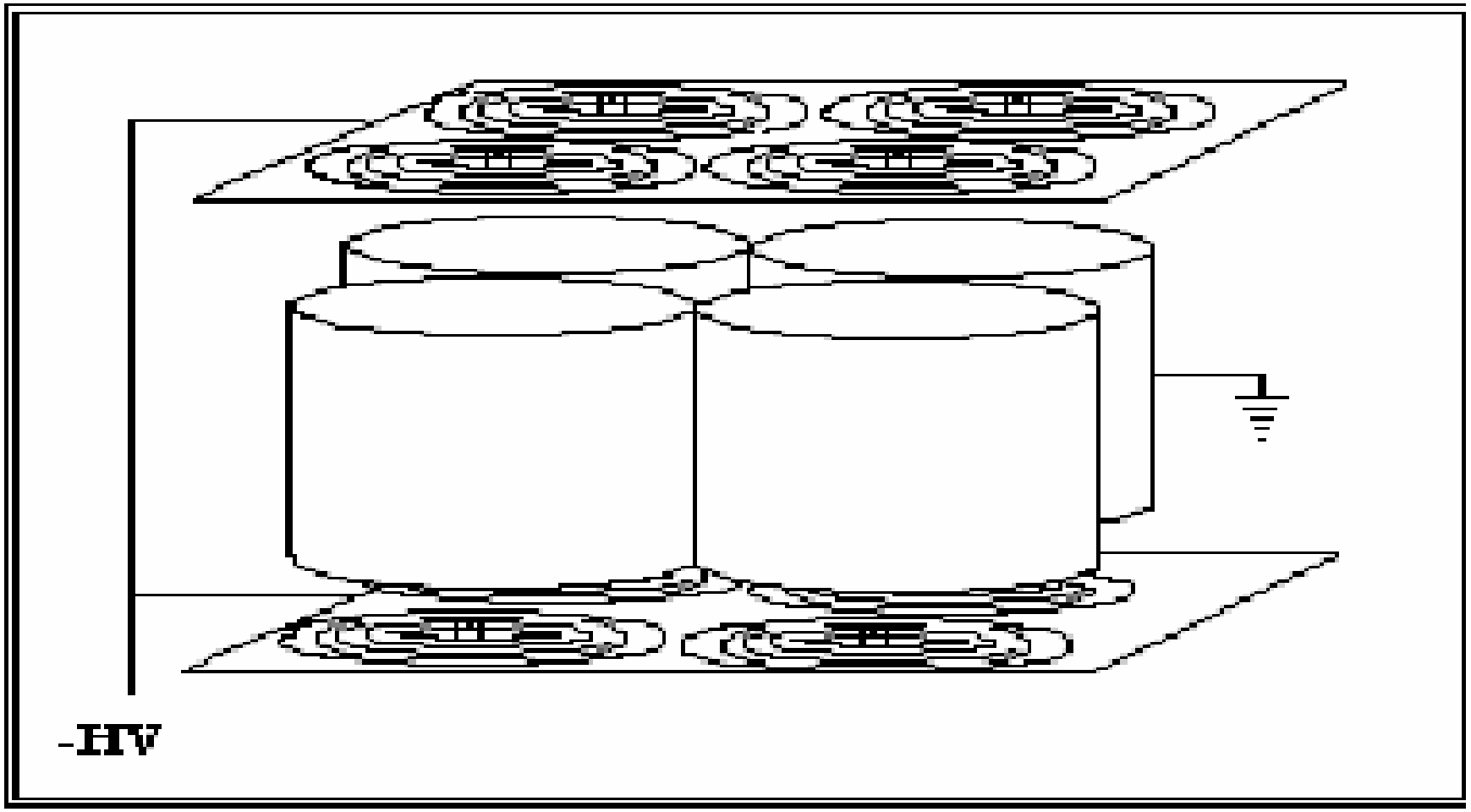
StarCell™ Element



Galaxy™ Diode Element



Galaxy™ Triode Element



Ion Pump Parameters ‘BVD’

- B = Magnetic Field Strength
- V = Operating Voltage
- D = Anode Cell Diameter

B = Magnetic Field

Low Pressure Operation Improves with Higher B
Typical Magnetic Field 1200 to 1500 Gauss

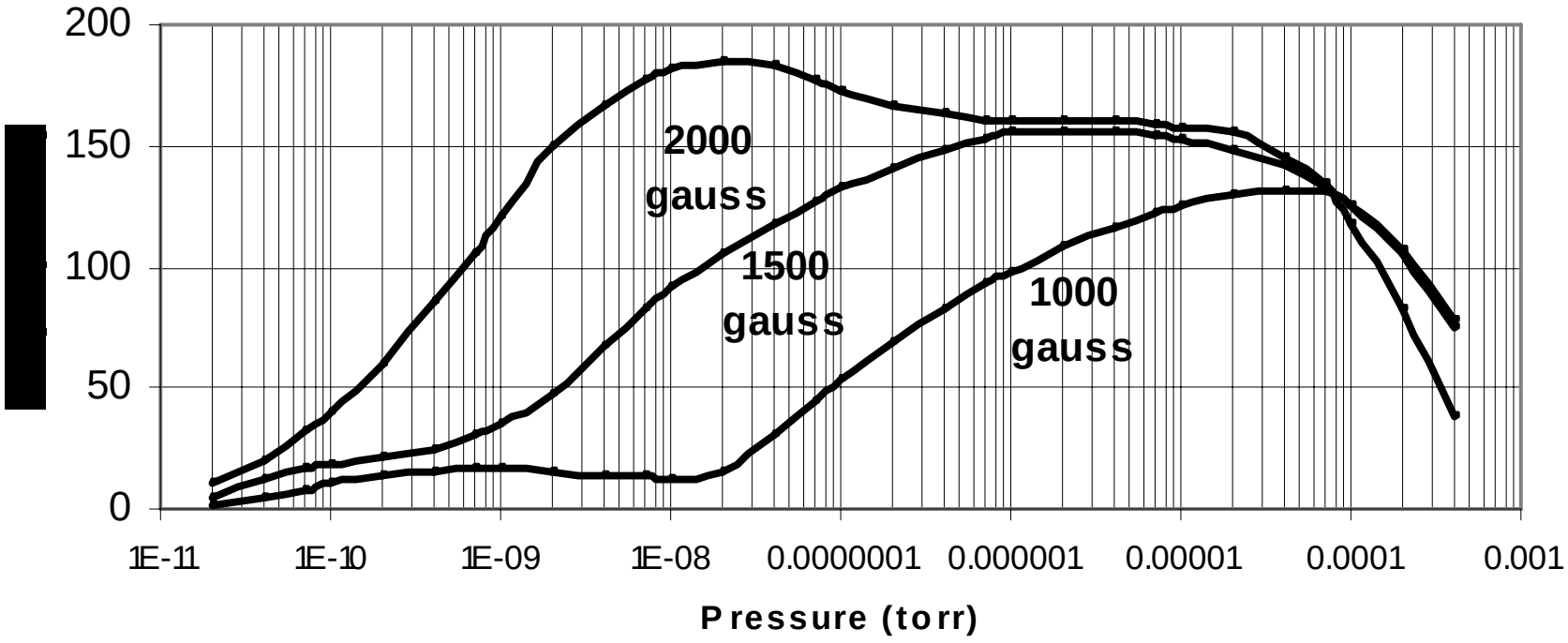


Figure 5: Discharge Intensity vs. Pressure

Three Different Magnetic Fields

(36 Anode Cells, 0.5" Diameter, 3000 Volts)

V = Operating Voltage

Pumping Speed Increases Linearly with Voltage
Typical Operating Voltage 4000 to 7000 Volds DC

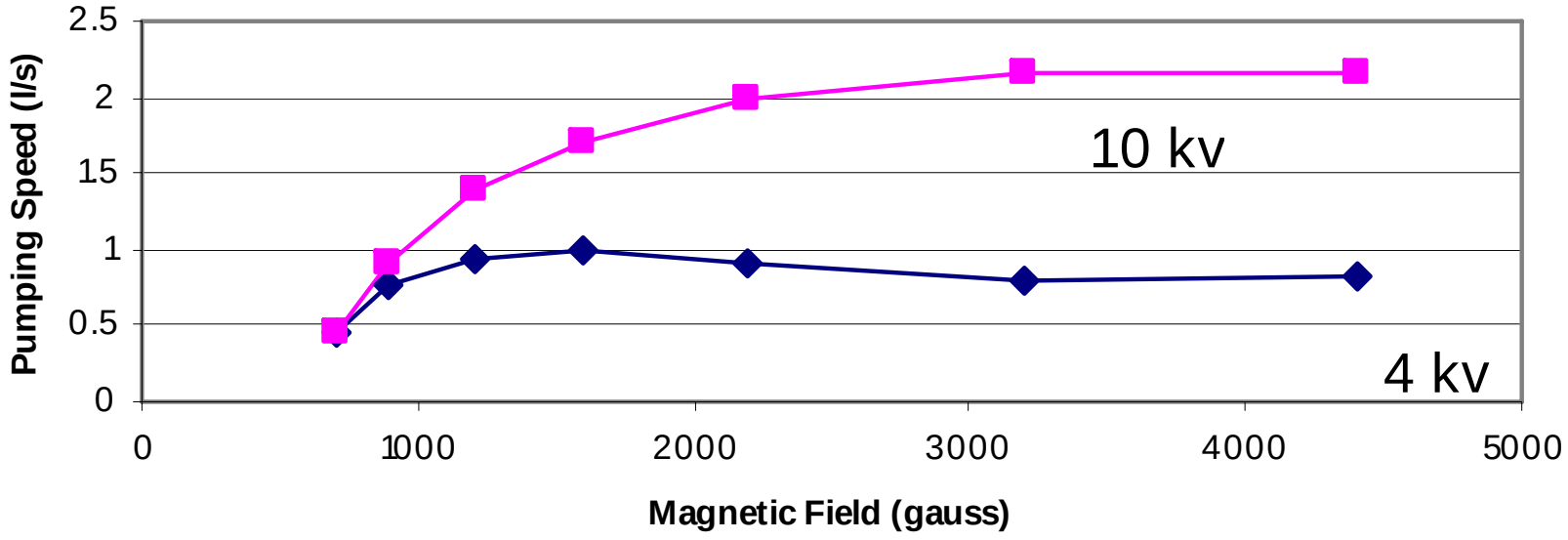


Figure 4:
Pumping Speed (l/s) vs. Magnetic Field & Voltage

D = Anode Cell Diameter

Low Pressure Operation Improves with Larger D
Typical Anode Cell Diameter 0.5 to 1.0 inch

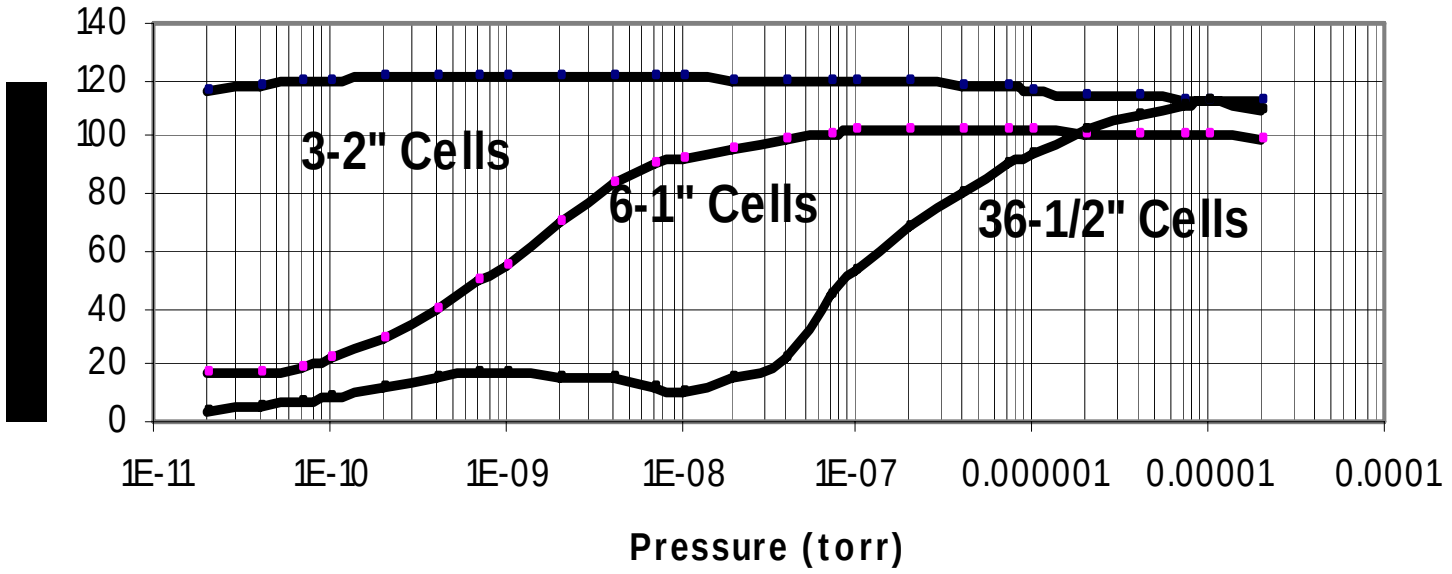


Fig. 6: Discharge Intensity (amps/torr) vs. Pressure (torr)

Three Different Cell Diameters (1000 gauss, 3000 volts)

Pumping Mechanisms for Common Gases

- Chemically active:

  N, O, H

- Common small molecules:

  H_2O, CO, CO_2, CH_4, NH_3, NO

- Noble gases:

  Ar, He, Ne, Kr, Xe

Chemically Active Gases

$N_2 - O_2 - H_2$

- Dissociated & Ionized in Discharge
- Accelerated to Cathode
- Nitrogen and Oxygen
  - Sputter Titanium Cathode Material
  - Neutralized
  - Form stable, chemical combination in regions of sputtered titanium
- Hydrogen
  - Solution/Diffusion into Titanium
  - Mostly in the Cathodes

Common Small Molecules

H_2O, CO, CO_2, CH_4, NH_3, NO

- **Dissociated & Ionized in Discharge**
- **Accelerated to Cathode**
- **Active Ions – O, N, H**
  - **Same pumping mechanism as active gases**
- **Carbon**
  - **Accelerated to cathode, neutralized**
  - **Deposited as free carbon**

Noble Gases
He, Ne, Ar, Kr, Xe

- **Ionized in Discharge**
- **Accelerated to Cathode**
- **Sputter/Neutralized**
- **Sputtering rate goes up with mass**
- **Pumped stably in areas of net buildup of sputtered material (cathode, pump walls, anode**
- **Heavier noble gases require proper element configuration for stable pumping**

  (Triode, DI/Noble, Starcell™, Galaxy™
- **Helium diffuses into titanium**

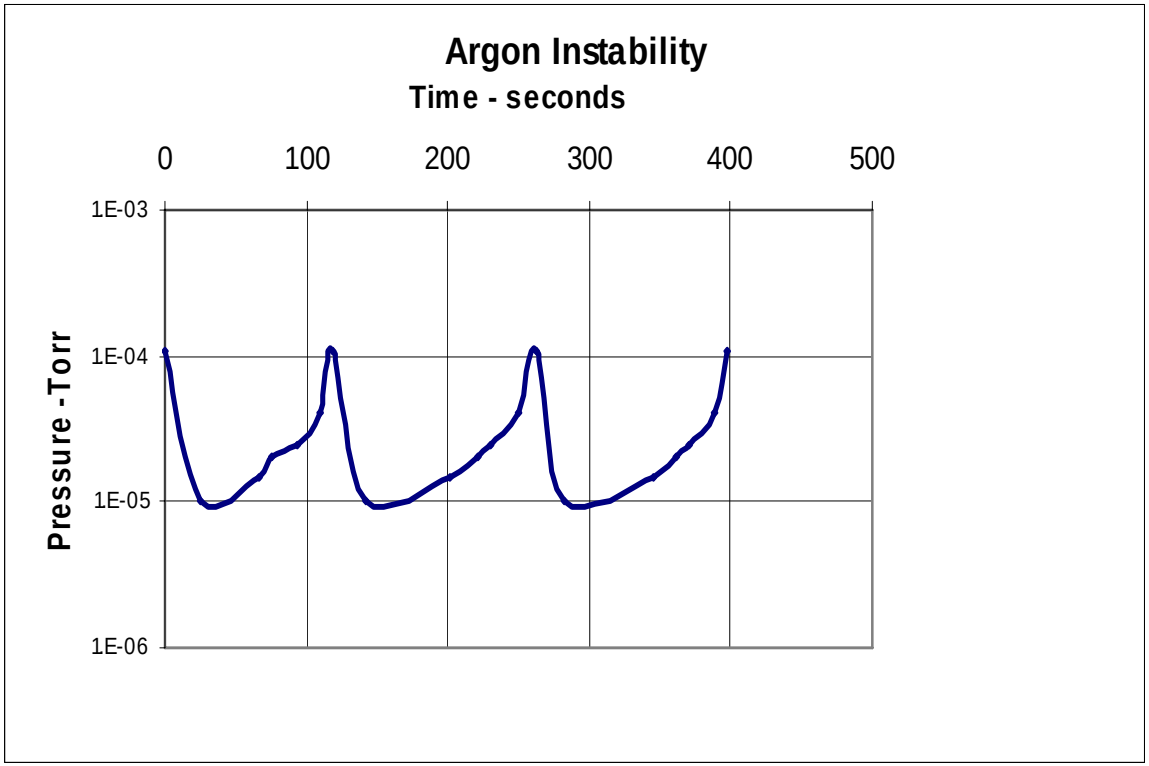
Argon Instability

Period Shorter at Higher Leak Rates

P_{max} ~ 2 x 10^{-4} Torr (Discharge Mode Shift)

Argon Displaced into Stably Pumped Areas During Mode Shift

Slow Rise/Rapid Decline Characteristic Wave Shape



Ion Pumps
Typical Operating Cycle

- **Rough Pump with Clean Technology**
  - **Turbo, Trapped Mechanical, Sorption**
  - **Rough to Pressure Below 10^{-3} T0rr**
  - **Lower Pressure Saves Time, Extends Life**
- **Turn on Ion Pump Control Unit High Voltage**
- **Cycle Power if Necessary to Avoid Overheating**
- **Valve Off Roughing Pump**
- **Walk Away**

Ion Pumps
Common Applications

- Electron Microscopes
- Accelerators
- Microwave Tubes
- X-ray Tubes
- Medical Equipment
- Coating Equipment
- Materials Research
- Mass Spectrometers

Ion Pumps
Applications in Microscopy

- Source
- Column
- Sample Chamber
- Sample Metallizing/Coating
- Sample Storage

Ion Pumps
Problems and Troubleshooting

- Initial Set-Up and Operation
- Field emission leakage
- ‘Noisy’
- Over-Heats
- Hard to Start – High Pressure
- Hard to Start – Low Pressure
- “Sluggish”, Low Pumping Speed
- Lifetime

Initial Set-Up and Operation

- Leak-Tight Connection
- Proper Conductance: > 5X Pump Speed
- Correct Magnet Strength/Orientation
- Visible Grounding Wire
- Good High Voltage Connection
  - Pump HV Feedthrough
  - HV Connecter – Pump End
  - HV Connector – Controller End

Field Emission Leakage

- Buildup of Sharp-Pointed Deposits
- Field Emission Current from Points
- Masks Ion Current at Low Pressures
- Doesn’t Influence Pumping Speed
- Can Be Removed by “Hi-Potting”

‘Noisy’

- Long-Term Operation Builds up Sputtered Deposits
- Deposits Can ‘Flake Off’
- Occurs Especially with Vibration, Shock
- Generates Current/Pressure Spikes as Flakes Fall into Discharge
- When Such Noise becomes a Problem, Pump Needs Cleaning/Rebuilding

Over-Heats

- Occurs at Higher Pressure, ie >10^{-5} Torr
- With Properly Matched Control Unit, Damage Will Not Occur
- Caused by Excessive Gas Load
- Reduce Gas Load or Add Auxiliary Pump
  - Titanium Sublimation, Cryo, Turbo, NEG
- May Require Re-Roughing if Excessive

Hard to Start – High Pressure

- May be Caused by Inadequate Roughing
- Badly-Matched Control Unit with
  Excessive Power Could Cause
  Over-Heating
- Older Pump May Have Adsorbed Gases on High Surface Area Deposits or Dissolved Gases (H, He) in Cathodes
- Improve Roughing or Clean/Rebuild

Hard to Start – Low Pressure

- Most Likely to Occur at UHV
- Discharge Needs an ‘Event’ to Initiate
- ‘Events’ Less Likely at Low Pressures
- Smaller Pumps Most Susceptible
- A Gentle Tap May Help
- Injected Electrons or UV Sometimes Used

“Sluggish”, Low Pumping Speed

- Older Pumps May Release Gas from Deposited High Surface Area
- Baking Pump During Start May Help
- Clean/Rebuild makes Pump Like New
- System Design May Limit Conductance to Pump, Limiting Speed
- Larger Diameter, Shorter Attachment Will Help

Ion Pumps
Lifetime

- Normal Lifetime is 30,000 – 40,000 Hours at a Pressure of 1 x 10^{-6} Torr
- Heavy Noble Gases May Cut Life
- Lifetime is Inversely Proportional to Pressure:
  - 1/10X at 1 X 10^{-5} Torr
  - 10X at 1 X 10^{-7} Torr
  - 100X at 1 X 10^{-8} Torr
  - ETC.

Ion Pumps - Conclusion

- **When applied properly, ion pumps are an excellent, reliable solution for HV and UHV**

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