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The Development of Miniature Electron Multipliers for Use In Portable Mass Spectrometers

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Introduction

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- Easy to use, truly field portable mass spectrometers have been the dream of industrial hygienists, forensic pathologists, law enforcement officials, geologists, arson investigators and a host of others interested in moving lab quality analysis into the field location.

- Although much progress has been made in reducing room sized instruments to benchtop size, most portable instruments today would best be described as transportable.

Discussion

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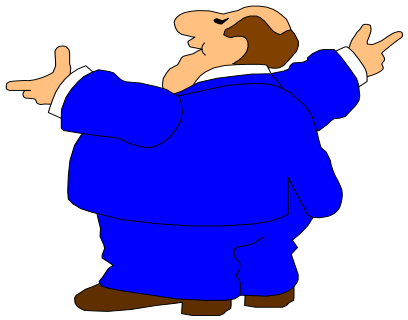
- Designers of field portable mass spectrometers face three challenges:



Reduce The Size
Reduce The Weight
Reduce The Power Consumption

- A quick assessment of most existing systems reveals that the high vacuum system is the most significant contributor in all three categories.

Discussion cont.

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- The purpose of the high vacuum housing and pumping system is simply to provide an environment in which the analyte molecules can be converted into ions, separated by mass, and then detected and identified.

- All mass separation techniques (quadrupole, time of flight, sector, and ion trap) require the ions to travel some distance in order to be separated and identified. The vacuum environment must therefore be sufficient to prevent a significant number of collisions with residual gas molecules.

Discussion cont.

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- According to the kinetic theory of gases, the mean free path of an ion is described by the following equation:

$$L = \frac{1}{\sqrt{2p n \sigma^2}} \quad \text{with} \quad n = \frac{p}{kT}$$

Discussion cont.

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- Typical MALDI Time-of-Flight Mass Spectrometers require an ion flight path length of 1 to 2 meters.
- Modern quadrupole based instruments typically operate at vacuum pressures in the high 10^{-6} Torr range because ions need to travel 25 cm or more before they reach the detector.
- If it were possible to shrink the flight path length requirement to less than 5 cm then it should be possible to operate a system in the milli-Torr range.
- milli-torr vacuum levels can be achieved with simple low cost vacuum pumps.

Discussion cont.

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- The sensitivity of a mass spectrometer can be greatly enhanced by the addition of an electron multiplier.
- The development of micro-machining technology has spawned a whole new generation of small, portable mass spectrometers. The entire source and mass filter can now be reduced to the size of a postage stamp.
- Miniature mass filters can operate at elevated pressures, enabling less complex pumping systems to be used. Unfortunately, conventional electron multipliers remain relatively large (greater than 8 cm long), and do not operate well above 10^{-4} torr.

There are 4 main types of Ion Detectors

- **Faraday Cup**: Good Linearity, Operates at atmospheric Pressure, Produces no Gain or signal amplification.
- **Discrete Dynode Multipliers**: Large, Bulky, Become Noisy when operated above 10^{-5} Torr
- **Single Channel Electron Multipliers**: Channeltrons®, Spiraltrons™ and MAGNUM® - Compact, High Gain, Low noise Electron Multipliers, operate well at pressures extending into the 10^{-4} Torr range.
- **Microchannel Plate (MCP) Detectors:** Miniature and subminiature designs produce high gain and low noise, and have demonstrated operation at 3×10^{-2} Torr.

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Recent Advances in Electron Multiplier Technology have enabled the development of compact Ion Detectors for use in:

- Leak Detectors
- Portable Mass Spectrometers
- Dedicated Sensors
- Environmental Sensors
- Industrial Sensors

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The Ideal Detector for Portable Mass Spectrometers

- Small
- High Gain and Low Noise
- Rugged
- Tolerate poor vacuum conditions
- Long Life
- Low Power Consumption
- Should Tolerate system failures
- Easily Replaced
- Excellent Temporal Resolution (TOF only)

Size and Weight Comparison For Typical Ion Detectors

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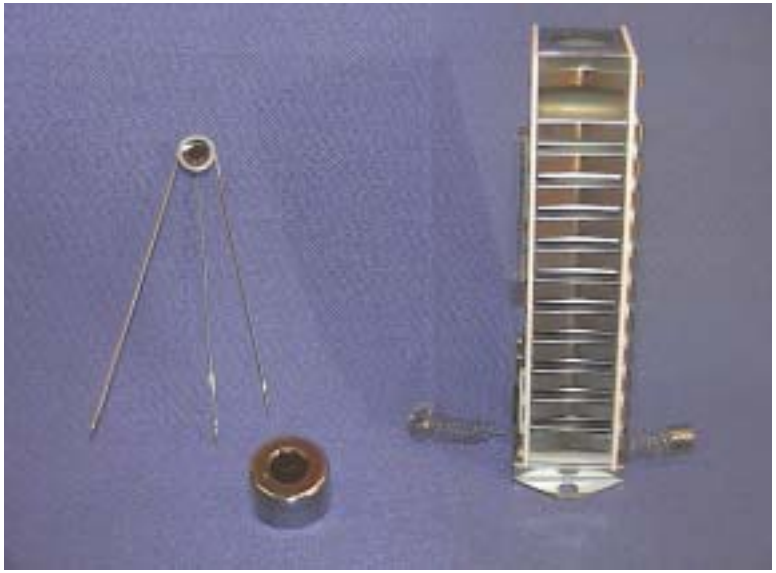

Detector Type	Weight	Height
	(grams)	(mm)
3 X 3 mm MCP	0.016	0.2
Mini Channeltron	0.51	12.5
Quantum MCP Detector	1.39	7.8
Spiraltron	2.6	65
Microtron	4.59	9
Mini TOF	10	15
5900 Magnum	26	35
XPR	25	25
Typical Discrete Dynode Multiplier	35	100

Assorted Miniature Electron Multipliers

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Channeltron® Electron Multiplier Operation

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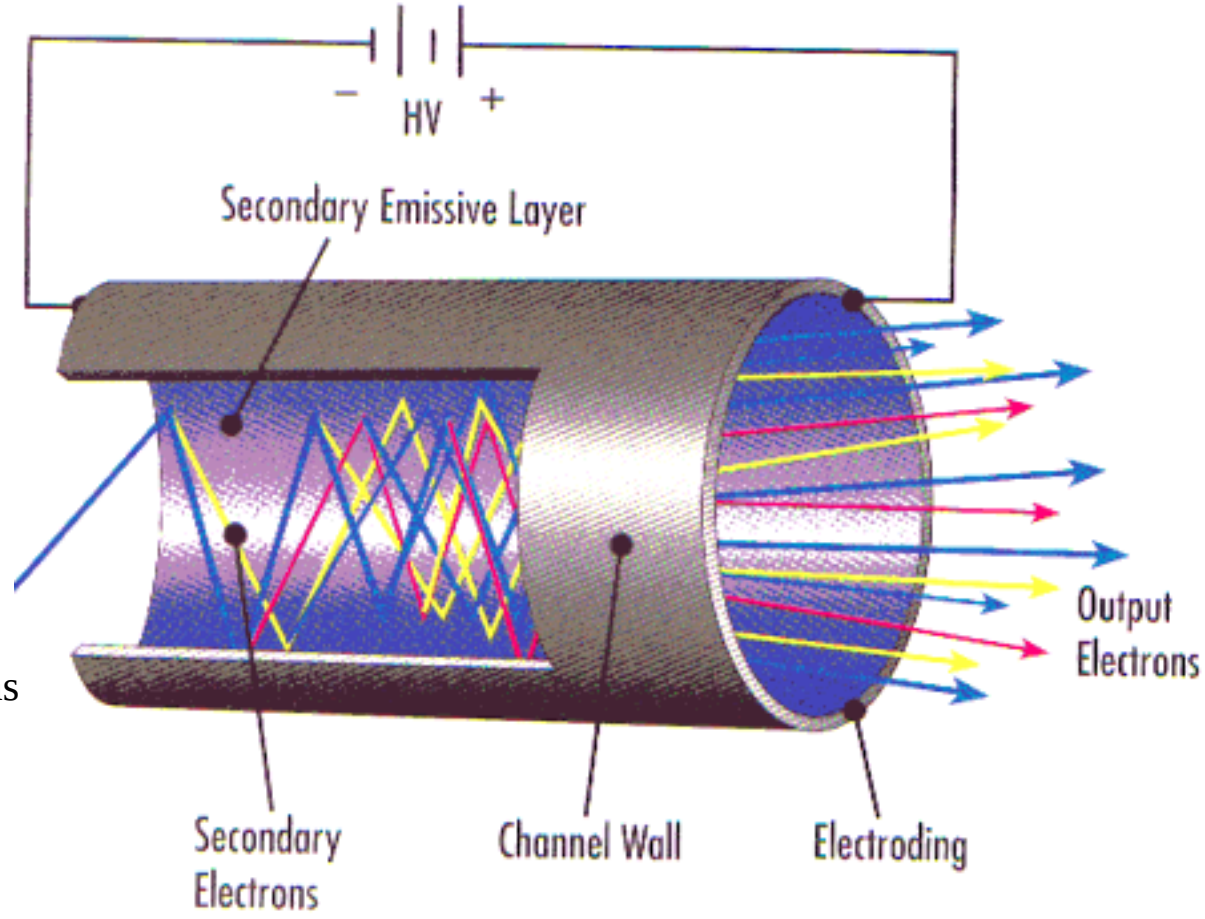

Miniature Channeltron® Electron Multiplier

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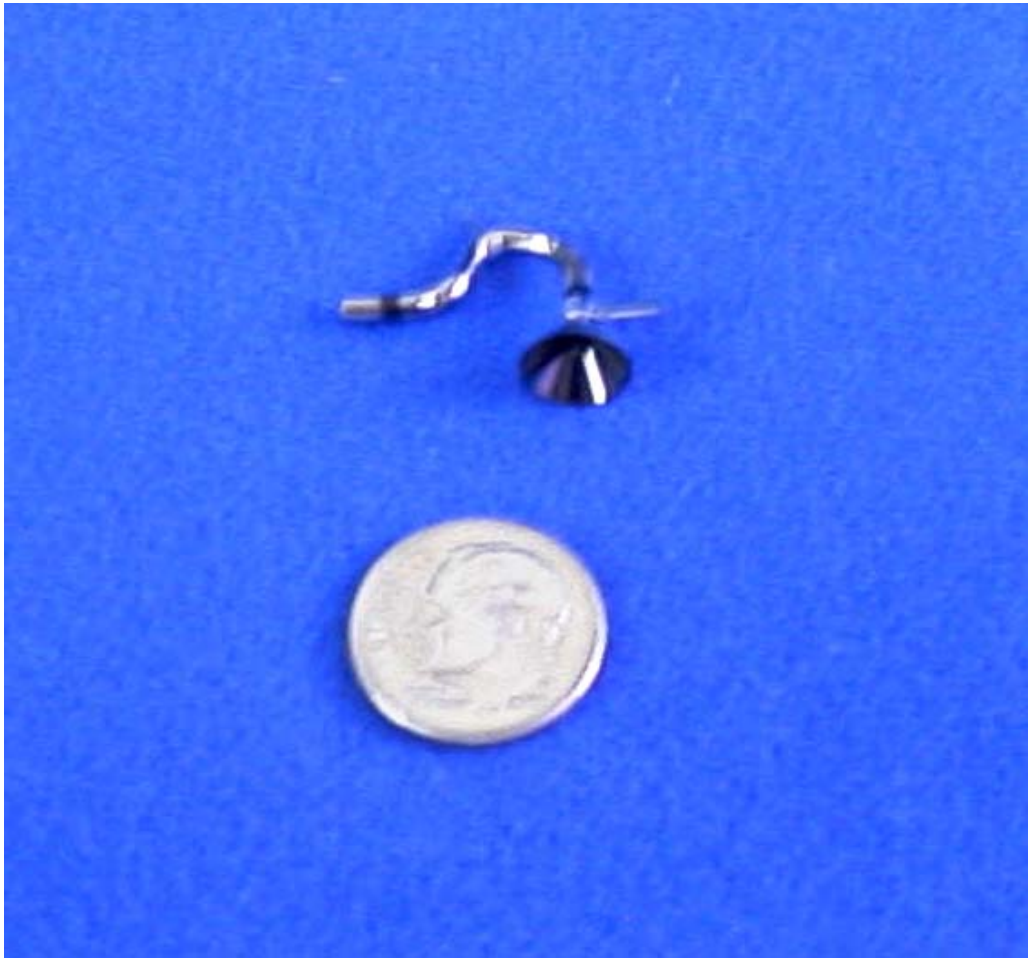

Miniature Channeltron®
Electron Multiplier Mechanicals

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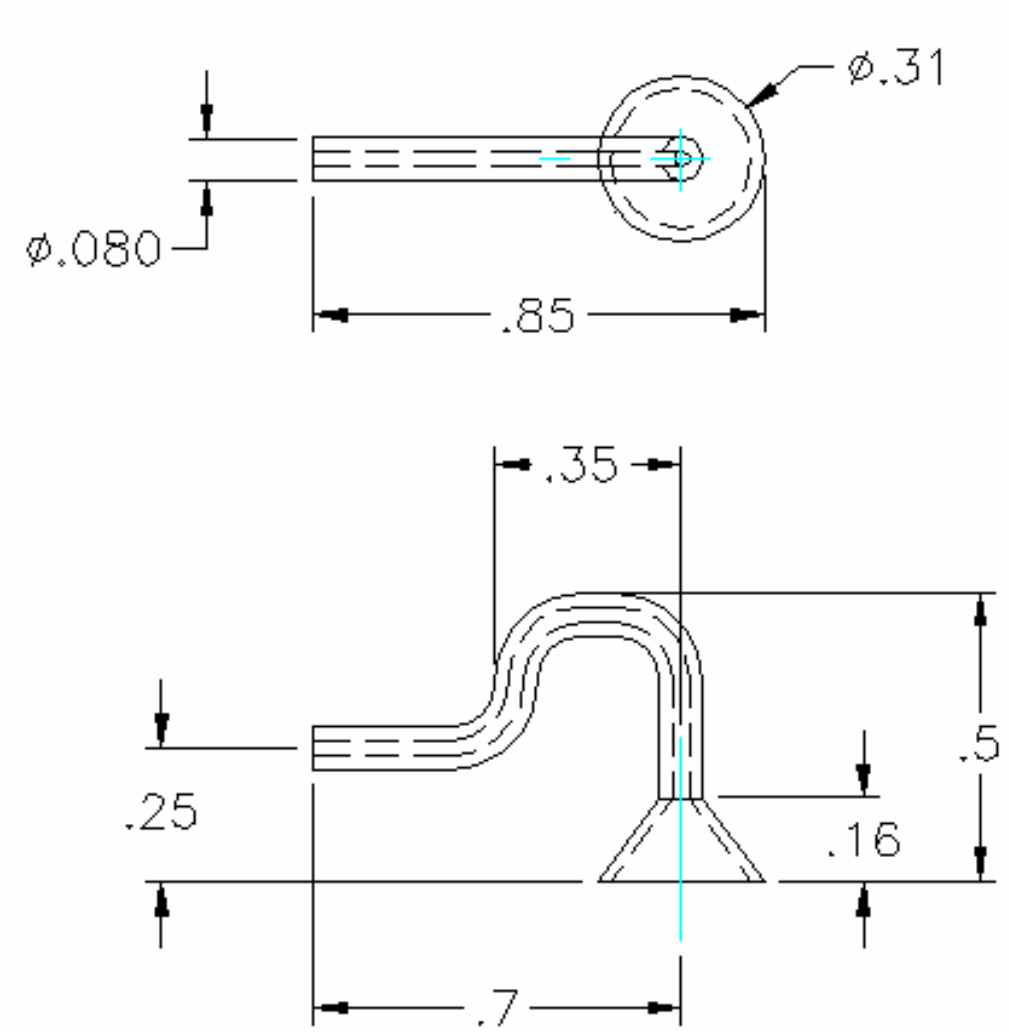
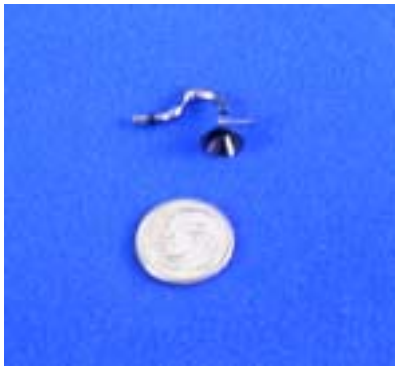


Miniature Channeltron® Electron Multipliers



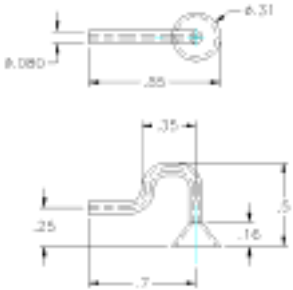
- **Compact**
- **Single Piece Construction**
- **Ideal for Portable Low Cost Instruments**
- **Can be mounted in various configurations**
- **Analog or Pulse Counting Applications**
- **Gain Greater than 10 million**
- **Low Noise**

Typical Mechanical and Electrical Characteristics

ELECTRICAL CHARACTERISTICS	SPECIFICATIONS
Operation:	Analog or Pulse Counting
Maximum Operating Pressure:	5.0×10^{-5} Torr
Maximum Specified Operating Voltage:	3000 Volts
Bias Current @ 3,000 Volts:	10 to 55 Microamps
Resistance (For Reference Only):	55 to 85 Megohms
Minimum Gain @ 3,000 Volts:	1.0×10^{7}
Maximum Dark Current @ 3,000 Volts:	1.0×10^{-12} Amps
Maximum Dark Count @ 3,000 Volts:	1 ct./sec
Maximum Linear Output Current:	10% of Bias Current (Typical)

Typical Applications:

- Leak Detectors
- Portable Mass Spectrometers
- Dedicated Sensors
- Environmental Sensors
- Industrial Sensors



Typical Spiraltron Performance Specification

PHYSICAL CHARACTERISTICS	SPECIFICATIONS
Cone Mechanical Dimensions:	10 mm round or 6 X 20 mm rectangular
Maximum Vacuum Bake Specification:	8 Hours at 300°C at 1.0×10^{-5} Torr or Lower
Operating Temperature Range	-50° to 120°C
ELECTRICAL CHARACTERISTICS	**SPECIFICATIONS**
Operation:	Pulse Counting
Maximum Operating Pressure:	$5X10^{-4}$ Torr
Maximum Specified Operating Voltage:	3000 Volts
Bias Current Range @ 3000 Volts:	10 - 75 Microamps
Resistance (For Reference Only):	40 - 100 Megaohms
Minimum Gain @ 3000 Volts:	$1x10^{8}$
Maximum Dark Count @ 3000 Volts:	counts in 60 seconds
Maximum Linear Output Current:	10% of Bias Current (Typical)
Maximum Pulse Height Distribution:	75% Full Width Half Maximum

MAGNUM Family of Products

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- High performance Analog or pulse counting electron multipliers

- 6-Channel Structure Provides:
  - Long Life
  - High Output Current
  - Improved Linearity
  - Reduced Ion Feedback
  - Low Manufacturing Cost
  - Fewer Components
  - End User Replacements
  - Tolerates operation at higher pressure

Miniature Microchannel Plate Electron Multiplier

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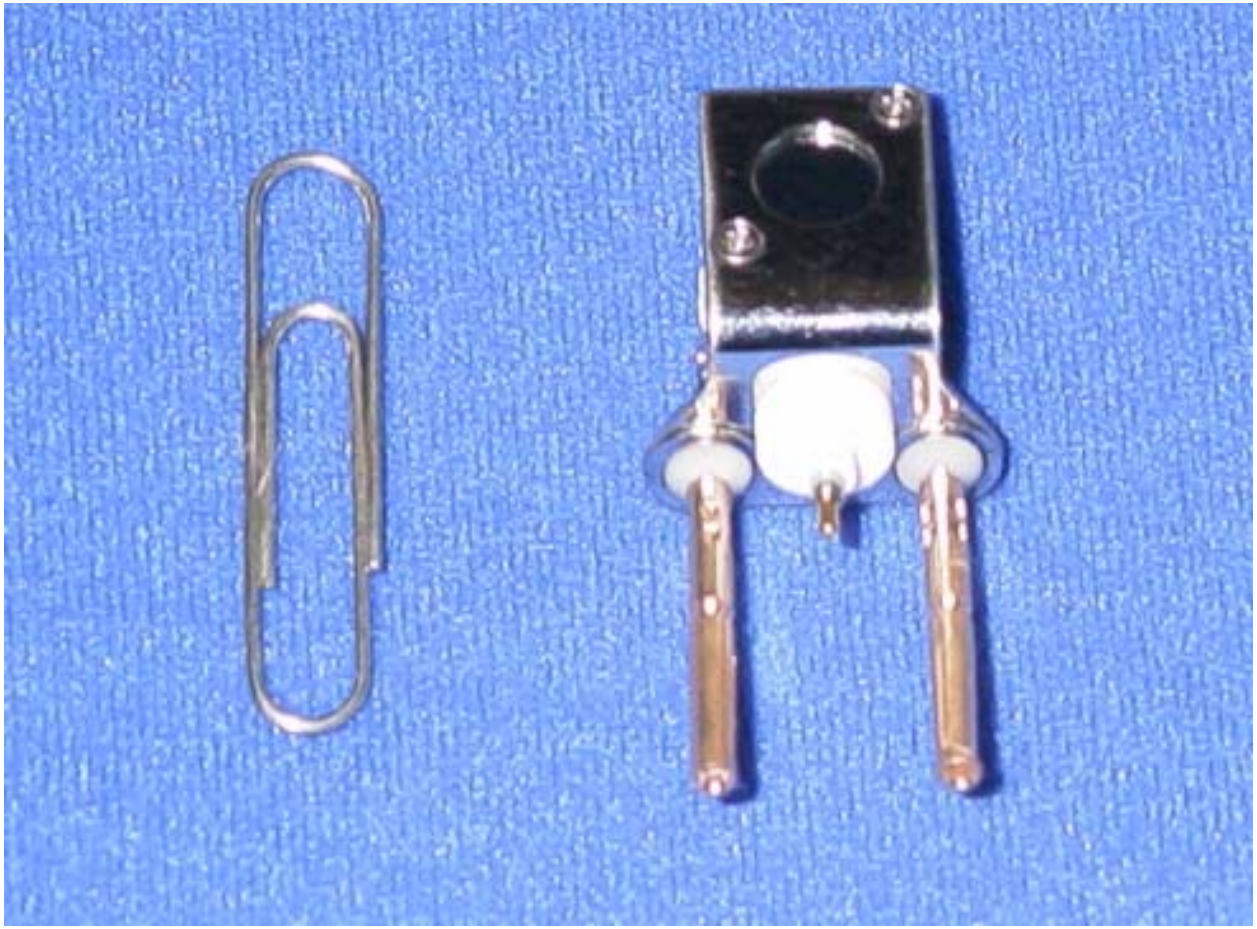

Sub-Miniature Microchannel Plate Detector

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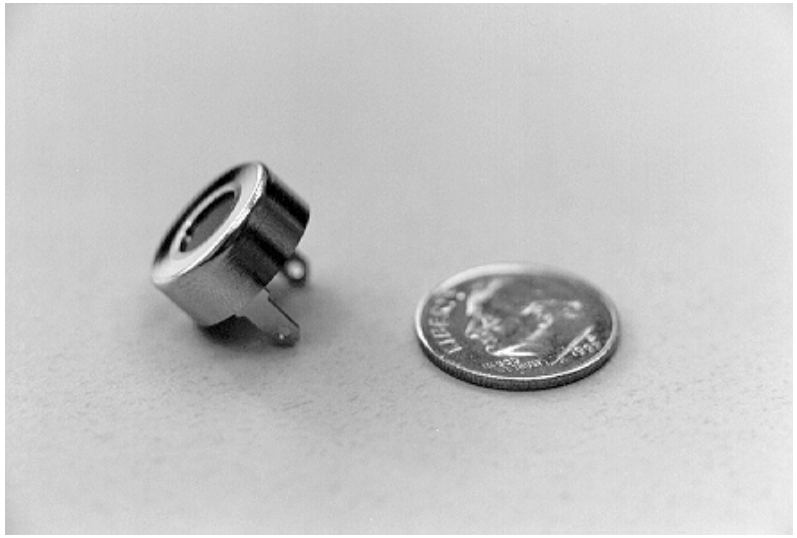

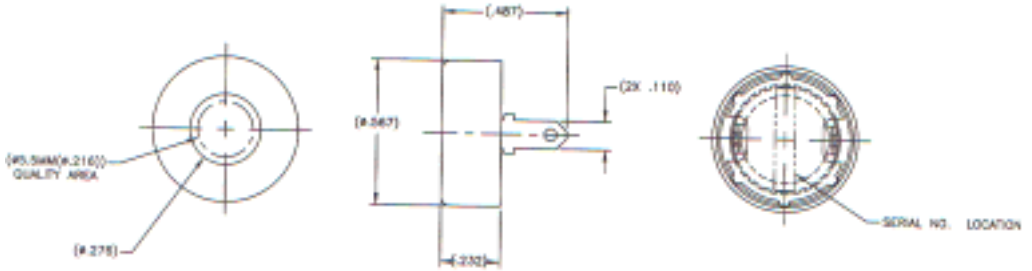

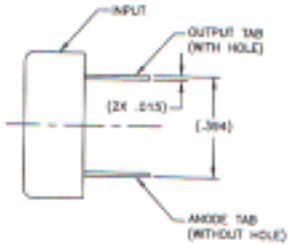

Microtron™ Detector

PHYSICAL CHARACTERISTICS of The Detector	**SPECIFICATION**
Package Outside Diameter:	14.2mm (0.56”)
Package Height:	5.8mm (0.23”)
Overall Package Height (Including Leads):	12.4mm (0.49”)
Quality Diameter:	5.5mm (0.217”)
Center-to-Center Spacing:	32µm Nominal
Pore Size:	25µm Nominal
Bias Angle:	8° ± 1°
Open Area Ratio:	45% Minimum
Quality Level:	Detection
ELECTRICAL CHARACTERISTICS of DETECTOR	**SPECIFICATION**
Electron Gain @ 2000 Volts:	2×10^6 Minimum
Bias Current Range @ 2000 Volts:	10-30 Microamps
Resistance:	67-200 Megohms Reference
Dark Noise:	< 5 ct. / sec.
Linear Output Current Density: (Microamps/cm^2)	Typically 10% of Bias Current Density

The Microtron detector assembly contains two matched Detection Quality Long-Life™ Microchannel Plates mounted in stainless steel hardware. The assembly is bakeable to 300°C.

Detection Quality detector assemblies are intended for use in applications where only signal detection is required. These economical devices are used as signal detectors and amplifiers and are typically used in applications such as leak detection, residual gas analysis (RGA), or point source detection.

Quantum™ Detector

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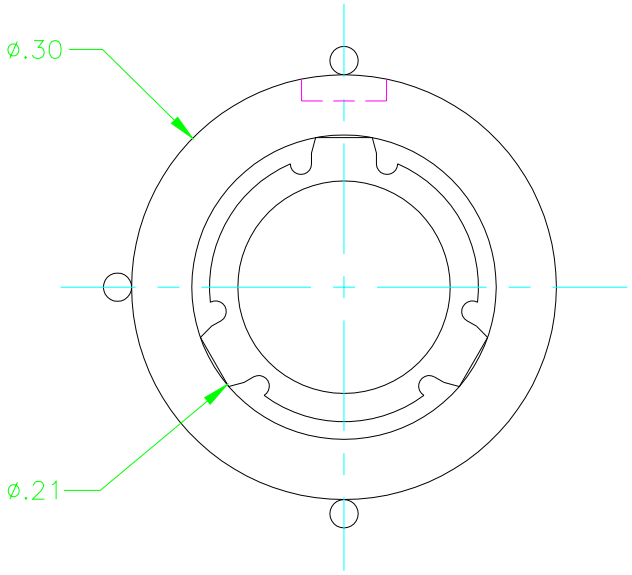

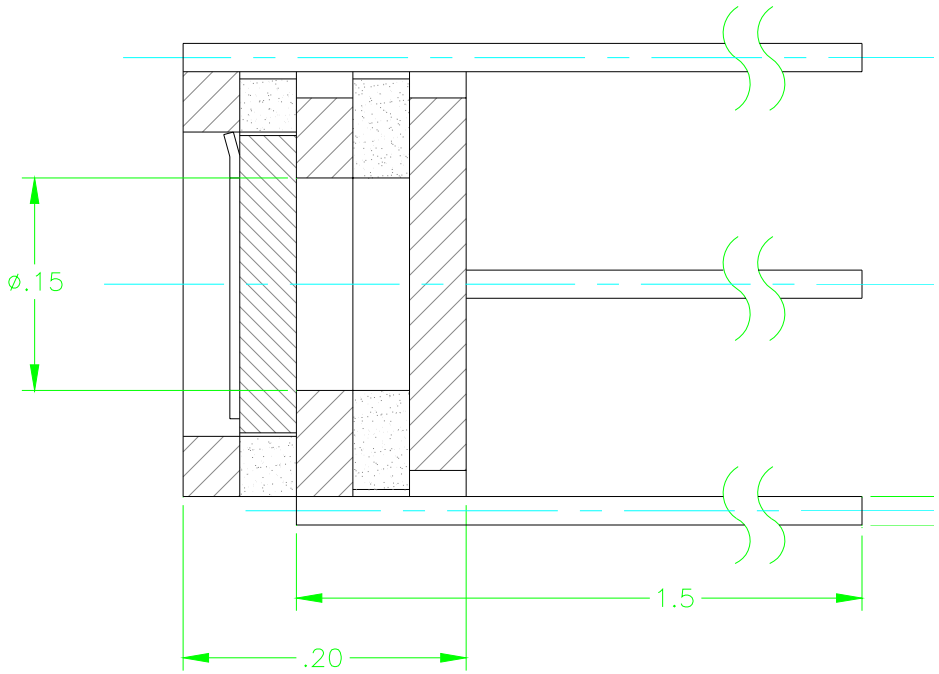

Quantum™ Detector

PHYSICAL CHARACTERISTICS of MCP	SPECIFICATION
Quality Diameter:	3.3mm Minimum
Center-to-Center Spacing:	32μm Nominal
Pore Size:	25μm Nominal
Bias Angle:	8° ± 1°
Open Area Ratio:	40% Minimum
Quality Level:	Detection
ELECTRICAL CHARACTERISTICS of DETECTOR	**SPECIFICATION**
Electron Gain @ 1000 Volts:	1×10^4 Minimum
Bias Current Range @ 1000 Volts:	0.40 – 5 Microamps
Resistance:	100 – 1000 Megaohms (Reference)
Dark Noise:	0.5×10^{-12} Amps Maximum (Typical)
Linear Output Current Density: (Microamps/cm^2)	Typically 10% of Bias Current Density

The CEMA Model 603.8MA detector assembly contains one Detection Quality Advanced Performance Lon-Life™ Microchannel Plate and a metal anode readout mounted in ceramic and kovar hardware. The assembly is bakeable to 300°C.

Detection Quality detector assemblies are intended for use in applications where image quality is not critical. These economical devices are used as signal detectors and amplifiers and are typically used in applications such as time-of-flight mass spectrometry, residual gas analysis (RGA), or point source detectors

Microchannel Plate Electron Multiplier

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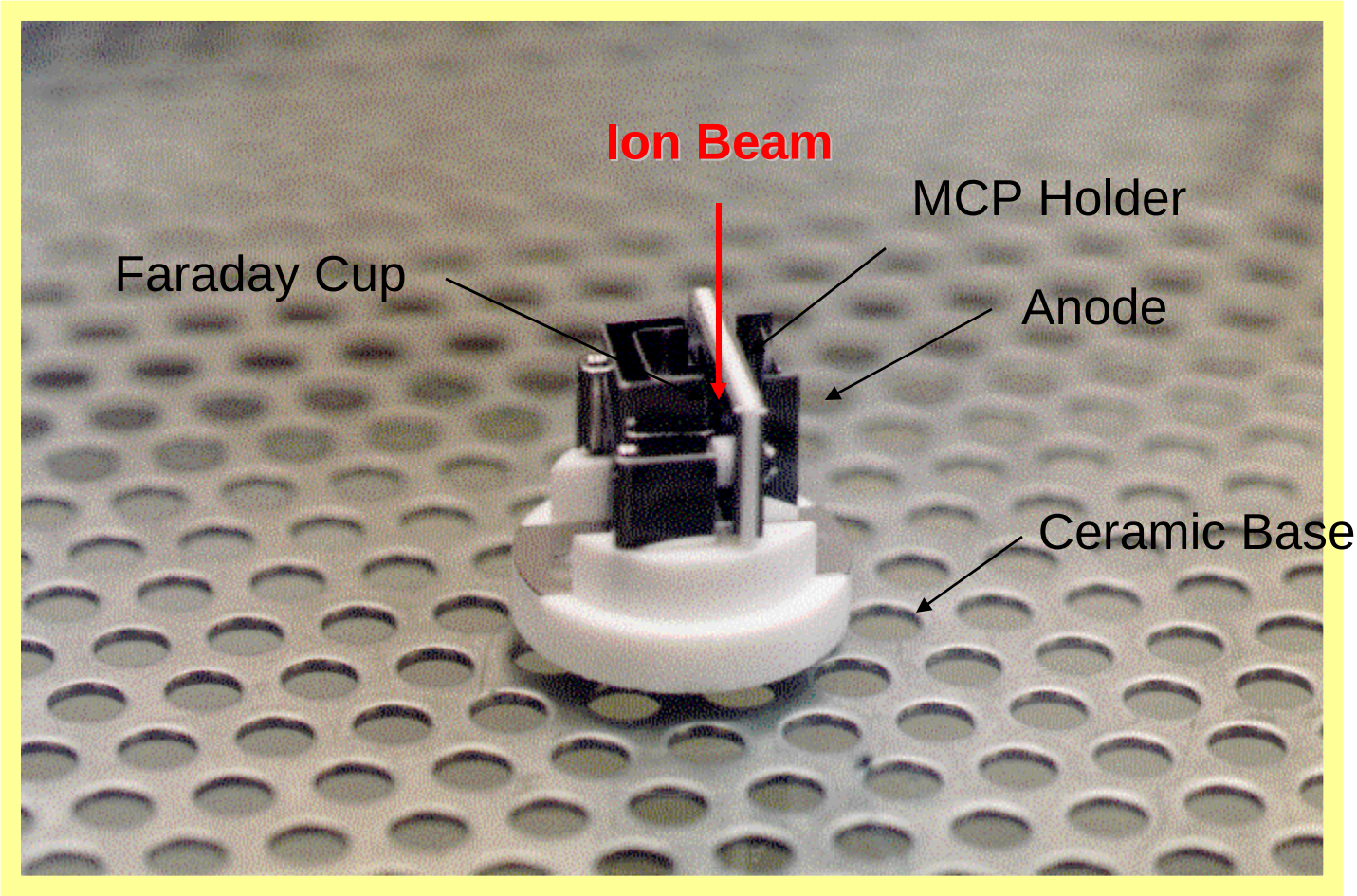

Designed for operation at up to 3 x 10^{-2} Torr

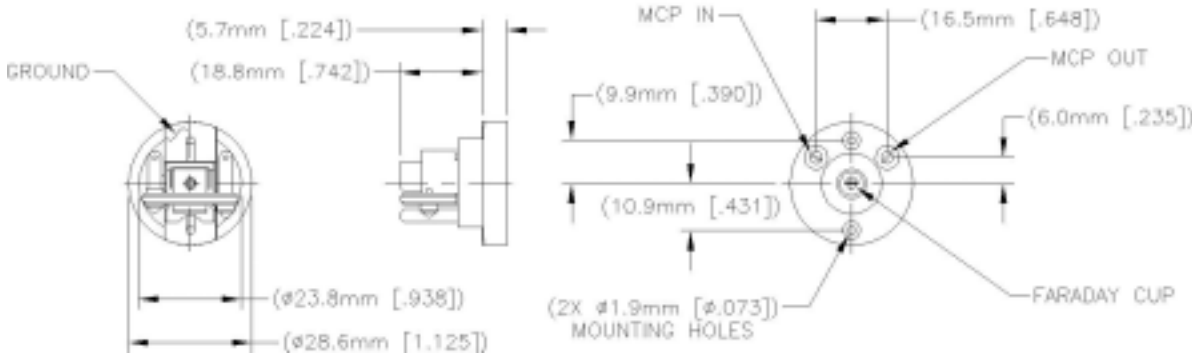

Figure 2-1. Dimensional Requirements

3. FUNCTIONAL SPECIFICATIONS

Test Characteristic	Value
Quality Diameter:	11.02mm (.434") x 12.65mm (.498") Minimum
Center-to-Center Spacing:	32µm Nominal
Pore Size:	25µm Nominal
Bias Angle:	19 ± 1°
Open Area Ratio:	50% Minimum
Quality Level:	Detection
Maximum Electron Gain @ 775 Volts:	5 x 10^{2} Maximum
Minimum Electron Gain @ 1225 Volts:	1 x 10^{4} Minimum
Bias Current Range @ 1100 Volts:	30-80 Microamps
Resistance:	14-37 Megohms Reference
Dark Current:	**(AMPS)**
Low Gain 300-500 @ 1x10^{-2} Torr (Mass 23)	-1.0x10^{-11} to 1.0x10^{-11} Average 1.0x10^{-11} Maximum Standard Deviation
High Gain 10,000 @ ≤ 1x10^{-6} Torr (Mass -1)	-1.0x10^{-12} to 1.0x10^{-12} Average 5.0x10^{-14} Maximum Standard Deviation
Faraday Cup Mode @ ≤ 1x10^{-6} Torr (Mass -1)	-1.0x10^{-13} to 1.0x10^{-13} Average 1.2x10^{-15} Maximum Standard Deviation

Miniature Time-of-Flight Detector

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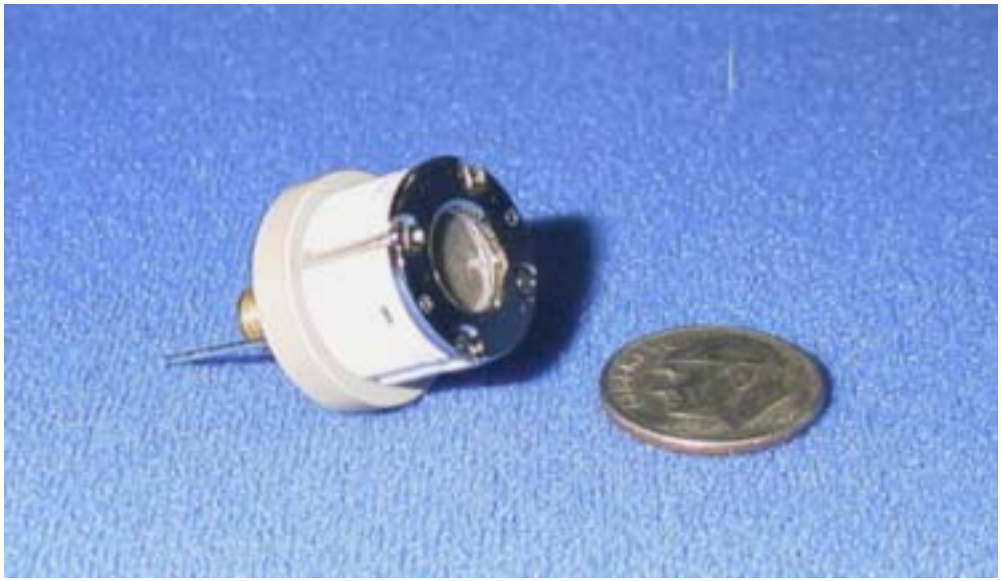

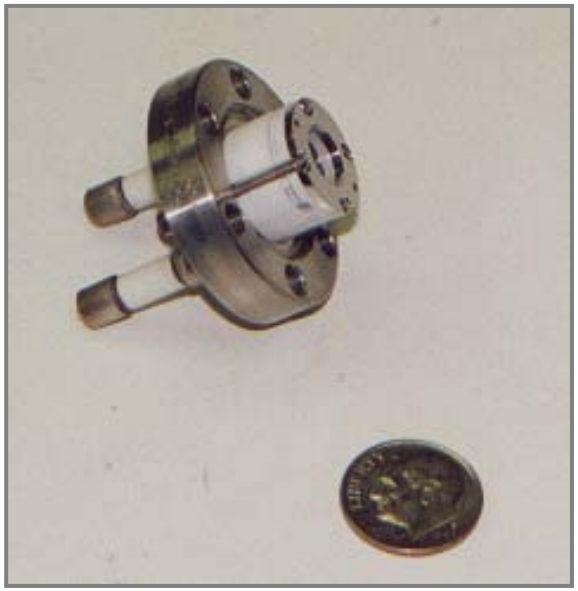

Miniature Time-Of-Flight Detectors for Portable Instruments. These detectors are light weight (less than 10 grams) and Consume less than 0.02 watts. The compact design features 750 ps pulse widths and rise times approaching 300 ps.

PHYSICAL CHARACTERISTICS	SPECIFICATIONS
Microchannel Plate Type:	Extended Dynamic Range Long-Life™
Active Diameter:	8mm Minimum
Center-to-Center Spacing:	6μm Nominal
Pore Size:	5μm Nominal
Bias Angle:	5° ± 1°
Open Area Ratio:	62% Minimum
Quality Level:	Detection

PHYSICAL CHARACTERISTICS of DETECTOR	SPECIFICATION
Mechanical Dimension Defined by Drawing Number:	31959
Vacuum Bake Specification (Not Operating):	Bakeable @ 150°C
Operating Temperature Range:	-50° to 100°C
Vacuum Flange:	1.33 Inch Conflat
Input Grid:	85% Transmission (Typical)

ELECTRICAL CHARACTERISTICS of DETECTOR	SPECIFICATION
Operating Pressure (Maximum):	1.0×10^{-5} Torr
Maximum Specified Operating Voltage:	2400 Volts
Bias Current Range @ 2000 Volts:	6-30 Microamps
Resistance (For Reference Only):	67-333 Megohms
Gain (Minimum):	1.0×10^{6} @ 2000 Volts
Linear Output Current Density (Microamps / cm^2)	Typically 10% of Bias Current Density
Dark Count (Maximum)[1]:	2.5 cts/second
Pulse Width (Minimum):	750 psec @ Half Height (Typical)

Summary

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- Microchannel Plate (MCP) and Single Channel Electron Multipliers have been developed and are in production that offer significant performance advantages Over Faraday Cup and Discrete Dynode Multipliers in field portable Mass Spectrometer applications Including:

  - Compact, Plug and Play Designs
  - Light Weight
  - Tolerant of Poor Vacuum Conditions
  - High Gain
  - Low Noise
  - High Dynamic Range
  - Long Life
  - Low Cost of Ownership