



Article

Evaluating Air Quality through Ion Detection: An Application of JEOL Mass Spectrometry in Pollution Studies

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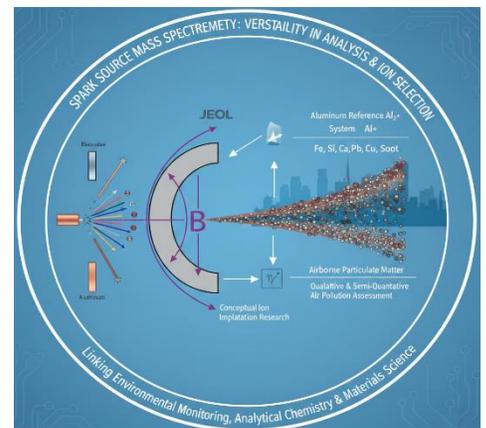
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ABSTRACT

Spark source mass spectrometry provides a robust approach for multi-element analysis and controlled ion generation, yet its broader applicability remains insufficiently explored. This study evaluates the analytical performance of a JEOL JMS-01BM-2 spark source mass spectrometer using a controlled aluminium reference system and a heterogeneous airborne particulate matter sample. Stable detection of singly and multiply charged ions with reproducible mass-to-charge (m/z) separation is demonstrated across repeated measurements, confirming reliable ion generation and magnetic field-based ion selection. Aluminium is consistently resolved in multiple charge states, while aerosol analysis reveals a complex elemental composition characteristic of polluted urban–industrial atmospheres, including crustal, combustion-related, and trace metallic species. Differences between reference and aerosol samples highlight the influence of sample heterogeneity and electrode materials on ion formation. Although no direct ion implantation experiments are performed, the results establish the conceptual feasibility of adapting the instrument for ion selection processes relevant to implantation research. Simultaneously, the successful characterisation of airborne particulate matter demonstrates the utility of spark source mass spectrometry for qualitative and semi-quantitative air pollution assessment.



Keywords: Aluminium; Air particles; Electrical detection system; Ion implanter; Spark source mass spectrometer

1. Introduction

Ion implantation remains a critical enabling process in contemporary materials science, underpinning technologies that demand precise control over elemental composition, charge state, and energy at the atomic scale [1],[2]. From semiconductor devices to functional coatings and advanced surfaces, the ability to selectively introduce ions with controlled kinetic energy is essential for tailoring material properties [2],[3]. Despite its importance, ion implantation is largely restricted to highly specialised and capital-intensive systems that are optimised for industrial throughput rather

than experimental adaptability [4]. This limitation constrains exploratory research, particularly in laboratories seeking flexible approaches to ion selection and delivery without access to dedicated implantation infrastructure. As materials engineering increasingly intersects with environmental science, electronics, and nanotechnology, the need for multifunctional instrumentation capable of bridging analytical and processing capabilities has become increasingly apparent.

Analytical mass spectrometry inherently performs several of the physical operations required for ion implantation, including ionisation, acceleration, and separation of charged species based on



their mass-to-charge (m/z) ratios [5],[6],[7]. Spark source mass spectrometers, in particular, operate under high-vacuum conditions and generate a wide spectrum of elemental ions, frequently in multiple charge states [8],[9],[10]. These characteristics suggest a strong conceptual overlap between analytical mass spectrometry and ion implantation; however, this overlap has rarely been exploited beyond conventional compositional analysis. The central challenge lies in determining whether such instruments can deliver the stability, reproducibility, and selectivity required for implantation applications. Specifically, it remains unclear whether analytical spark source mass spectrometers can maintain consistent magnetic field selection, resolve multiply charged ions without ambiguity, and provide sufficiently controlled ion energies to support targeted ion delivery.

Evaluating these requirements demands testing under analytically demanding conditions rather than idealised single-element systems [11]. Complex, heterogeneous samples impose stringent constraints on mass resolution, charge-state discrimination, and magnetic field stability. Airborne particulate matter emitted from coal-fired power plants represents one of the most challenging real-world samples in this regard, as it comprises a diverse mixture of light and heavy elements, multiple charge states, and trace constituents across a wide mass range. Reliable analysis of such aerosols requires high sensitivity and precise m/z discrimination, making them an effective stress test for assessing the performance limits of mass spectrometric systems [12]. At the same time, detailed elemental characterisation of these emissions remains critical for understanding pollution sources, environmental exposure pathways, and associated public health risks. Consequently, aerosol analysis provides both a rigorous technical benchmark and environmentally relevant insight.

This study aims to evaluate the feasibility of employing a JEOL JMS-01BM-2 spark source mass spectrometer as a potential ion implantation system by systematically assessing its capability for controlled ion generation, acceleration, mass-to-charge (m/z) separation, and magnetic field-based ion selection. As a supporting objective, airborne particulate matter emitted from the New Campus of the University of the Punjab, Lahore, Pakistan, is analysed as a complex real-world test case to validate the instrument's qualitative and quantitative analytical performance. Particular emphasis is placed on the detection and resolution of multiply charged ions and the reproducibility of their associated magnetic field values, which are essential criteria for controlled ion implantation. By integrating environmental aerosol analysis with an evaluation of implantation-relevant parameters, this work demonstrates the adaptability of the JEOL JMS-01BM-2 spectrometer for ion implantation applications while simultaneously providing reliable elemental characterisation of environmentally significant particulate matter. This study thus establishes a framework for extending the functionality of analytical mass spectrometers toward multifunctional roles in materials processing and environmental science.

2. Material and Method

2.1. Experimental Design and Sample Preparation

Two complementary experiments were conducted to evaluate the ion generation, mass-to-charge (m/z) separation, and charge-state resolution capabilities of the JEOL JMS-01BM-2 spark source mass spectrometer through both controlled and complex sample matrices. The first experiment employed a high-purity elemental sample to establish baseline ionisation and charge-state behaviour, while the second utilised airborne particulate matter as a complex

real-world test case to assess qualitative and quantitative analytical performance.

Copper sample holders were fabricated by shaping two electrodes from high-purity copper sheets. Before use, all holders were thoroughly cleaned to minimise surface contamination. Initial cleaning was performed using acetone in an ultrasonic bath, followed by drying under ambient laboratory conditions. The cleaned electrodes were then mounted directly into the spark ion source assembly of the mass spectrometer.

For the first experiment, one copper holder was filled with 99.9% pure aluminium, selected as a reference material due to its well-defined ionisation behaviour and relevance to ion implantation applications. For the second experiment, the holder was filled with aerosol particulate matter collected from the New Campus of the University of the Punjab, Lahore, Pakistan. This site was selected as a representative urban-industrial environment, providing a heterogeneous aerosol composition suitable for evaluating multi-element detection and charge-state discrimination. The geographical location of the sampling site is illustrated in Figure 1.



Figure 1: Study area used to collect the aerosol sample.

2.2. Aerosol Sample Collection

Airborne particulate matter was collected from the designated study area using standardised collection procedures suitable for subsequent spark source mass spectrometric analysis. Aerosol samples were deposited onto collection substrates compatible with the copper holder configuration and were stored in sealed containers to prevent contamination before analysis. The collected aerosol material was then transferred to the copper holder and mounted in the ion source chamber. The use of airborne particulate matter provided a complex elemental matrix, enabling rigorous assessment of the spectrometer's analytical performance under realistic environmental conditions.

2.3. Mass Spectrometric Analysis

All samples were analysed using a JEOL JMS-01BM-2 spark source mass spectrometer operated under room temperature laboratory conditions [13]. The instrument employs spark source ionisation to generate ions from solid samples, followed by acceleration and separation of ions based on their mass-to-charge ratios using combined electrostatic and magnetic sector fields. Both qualitative and quantitative analyses were performed to evaluate ion species, charge states, and relative abundances.



Instrumental operating parameters were maintained consistently across all measurements to ensure reproducibility and direct comparability between the aluminium reference sample and the aerosol sample. The selected operating conditions are summarised in Table 1. These conditions were essential for achieving high mass resolution and reproducible magnetic field selection.

Table 1:

The parameters utilised for the mass spectrometer

Parameters	Selected Values
Accelerating Voltage	25 kV
Electrostatic Voltage	2.5 kV
Spark Pulse Frequency	30 kHz
Spark Pulse Width	20 μ sec or 40 μ sec
Spark Voltage	3kV to 5kV
Backline Vacuum	5×10^{-3} Torr
Ion Source Vacuum	2.4×10^{-6} Torr
Pre-evac. Chamb Vacuum	0.1×10^{-6} Torr
Analyser Tube Vacuum	3.0×10^{-7} Torr

Table 2:

Qualitative data calculation table of Aluminum-Copper sample

Peak NO.	Peak Position	Element Detected	Magnetic Field (H)	Mass Detected	Charge	Mass Measured (Am)	Mass Standard
	mm	a.m.u	Gauss	a.m.u	C	a.m.u	a.m.u
1	70.5	$^{16}\text{O}_8^{+2}$	2084.6	7.9655	2	15.9309	15.9949
2	79	$^{27}\text{Al}_{13}^{+3}$	2215.4	8.9962	3	26.9885	26.9815
3	101.4	$^{12}\text{C}_6^{+1}$	2560.0	12.0126	1	12.0126	12.0000
4	111.4	$^{27}\text{Al}_{13}^{+2}$	2713.8	13.4999	2	26.9997	26.9815
5	114.7	$^{14}\text{N}_7^{+1}$	2764.6	14.0097	1	14.0097	14.0031
6	125.4	$^{63}\text{Cu}_{29}^{+4}$	2929.2	15.7277	4	62.9109	62.9296
7	127	$^{16}\text{O}_8^{+1}$	2953.8	15.9932	1	15.9932	15.9949
8	128.5	$^{65}\text{Cu}_{29}^{+4}$	2976.9	16.2440	4	64.9762	64.9278
9	155	$^{63}\text{Cu}_{29}^{+3}$	3384.6	20.9980	3	62.9939	62.9296
10	158.3	$^{65}\text{Cu}_{29}^{+3}$	3435.4	21.6326	3	64.8979	64.9278
11	184.4	$^{27}\text{Al}_{13}^{+1}$	3836.9	26.9852	1	26.9852	26.9815
12	189	$^{28}\text{Si}_{14}^{+1}$	3907.7	27.9898	1	27.9898	27.9769
13	204.3	$^{63}\text{Cu}_{29}^{+2}$	4143.1	31.4633	2	62.9267	62.9296
14	208.5	$^{65}\text{Cu}_{29}^{+2}$	4207.7	32.4524	2	64.9048	64.9278
15	294.1	$^{56}\text{Fe}_{26}^{+1}$	5524.6	55.9452	1	55.9452	55.9349
16	315.9	$^{63}\text{Cu}_{29}^{+1}$	5860.0	62.9440	1	62.9440	62.9296
17	321.9	$^{65}\text{Cu}_{29}^{+1}$	5952.3	64.9426	1	64.9426	64.9278

2.4. Data Acquisition and Analysis

Ion spectra were recorded in both electrical detection and photographic plate detection modes, depending on the experimental requirement. The resulting mass spectra were analysed to identify elemental species, determine charge-state distributions, and assess relative ion intensities. Quantitative evaluation was performed by comparing ion peak intensities under identical operating conditions. Particular emphasis was placed on the reproducibility of magnetic field values corresponding to specific ion charge states, as this parameter is critical for assessing the feasibility of adapting the spectrometer for ion implantation applications.

3. Results and Discussions

3.1. Mass Spectrometric Analysis of the Aluminium-Copper System

To establish baseline ionisation behaviour and validate quantitative accuracy, a high-purity aluminium sample mounted on a copper holder was first analysed using the JEOL JMS-01BM-2 spark source mass spectrometer. The resulting mass spectrum (Figure S6-Supplementary file) exhibited well-resolved singly and multiply charged ions, confirming stable ion generation and effective mass-to-charge (m/z) separation under the selected



Table 3:

Quantitative analysis data for set 1, set 2, set 3 and set 4

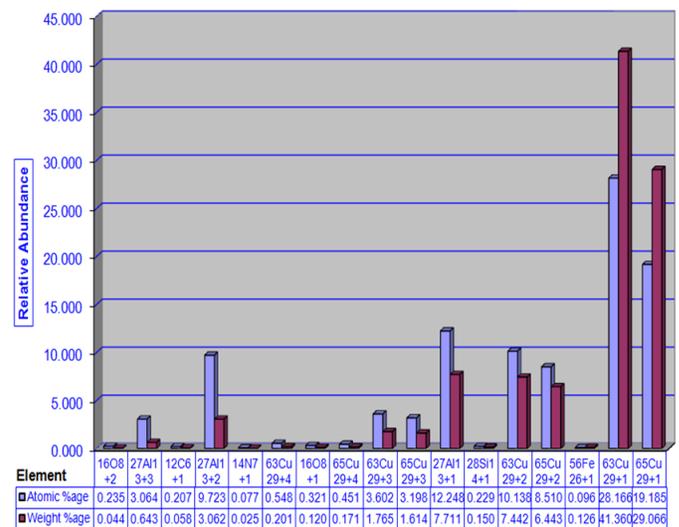
Element Detected	Set # 1 ion ratio	Set # 2 ion ratio	Set # 3 ion ratio	Set # 4 ion ratio	Average ion ratio	Atomic % age	Weight % age
$^{16}\text{O}_8^{+2}$	0.705	0.741	0.686	0.681	0.703	0.235	0.044
$^{27}\text{Al}_{13}^{+3}$	8.897	8.654	9.178	9.923	9.163	3.064	0.643
$^{12}\text{C}_6^{+1}$	0.759	0.676	0.616	0.425	0.619	0.207	0.058
$^{27}\text{Al}_{13}^{+2}$	28.368	29.162	26.015	32.761	29.077	9.723	3.062
$^{14}\text{N}_7^{+1}$	0.232	0.16	0.247	0.283	0.231	0.077	0.025
$^{63}\text{Cu}_{29}^{+4}$	1.639	1.735	1.572	1.606	1.638	0.548	0.201
$^{16}\text{O}_8^{+1}$	1.231	0.882	0.951	0.781	0.961	0.321	0.12
$^{65}\text{Cu}_{29}^{+4}$	1.29	1.393	1.356	1.35	1.347	0.451	0.171
$^{63}\text{Cu}_{29}^{+3}$	12.094	11.501	10.22	9.273	10.772	3.602	1.765
$^{65}\text{Cu}_{29}^{+3}$	10.165	8.991	10.045	9.052	9.563	3.198	1.614
$^{27}\text{Al}_{13}^{+1}$	38.187	37.903	34.632	35.786	36.627	12.248	7.711
$^{28}\text{Si}_{14}^{+1}$	0.665	0.683	0.659	0.737	0.686	0.229	0.15
$^{63}\text{Cu}_{29}^{+2}$	32.644	29.605	28.911	30.108	30.317	10.138	7.442
$^{65}\text{Cu}_{29}^{+2}$	28.875	23.88	24.788	24.249	25.448	8.51	6.443
$^{56}\text{Fe}_{26}^{+1}$	0.286	0.291	0.294	0.283	0.288	0.096	0.126
$^{63}\text{Cu}_{29}^{+1}$	97.598	106.813	68.791	63.704	84.227	28.166	41.36
$^{65}\text{Cu}_{29}^{+1}$	58.068	60.07	57.1	54.241	57.37	19.185	29.066

operating conditions.

Qualitative analysis (Table 2) identified aluminium as the dominant species, detected in three charge states ($^{27}\text{Al}^{13+3}$, $^{27}\text{Al}^{13+2}$, and $^{27}\text{Al}^{13+1}$), with corresponding magnetic field values of approximately 2215, 2714, and 3837 Gauss, respectively. Additional elements such as C, O, N, Si, Fe, and Cu were also detected, originating primarily from residual background gases and the copper holder. The close agreement between measured and standard atomic masses demonstrates high mass accuracy and confirms correct charge-state assignment.

Quantitative analysis was performed using four independent measurement sets under identical instrumental conditions (Table 3). All reported ion ratios were positive and physically meaningful, indicating stable signal acquisition and proper normalisation. The coefficient of variance for repeated measurements remained below 25.17%, confirming acceptable reproducibility for spark source mass spectrometry. Aluminium was the predominant contributor, with the $^{27}\text{Al}^{13+1}$ ion exhibiting an average atomic percentage of 12.2%. These results validate the reliability of the electrical detection system and demonstrate that the instrument satisfies key requirements for ion implantation feasibility, including ion purity, charge-state control, and reproducible magnetic field selection.

Similarly, Table 3 expresses the quantitative analysis, which includes the ion ratio (for four sets), average ion ratio, atomic % age and weight % age, which is future, plotted in Figure 3.

**Figure 2:** Atomic and weight percentage of the detected elements.

To implant the Aluminium $^{27}\text{Al}_{13}^{+3}$, $^{27}\text{Al}_{13}^{+2}$ or $^{27}\text{Al}_{13}^{+1}$, the corresponding magnetic field value 2215.4, 2713.8 or 3836.9 Gauss can be used. The EDS should be used in peak switching mode and the wafer should be fixed at the collector slit.



3.2. Mass Analysis for Aerosol Sample

Following reference validation, airborne particulate matter was analysed as a complex real-world sample to assess the spectrometer's multi-element detection capability. The aerosol mass spectrum (Figure S7-Supplementary file) revealed a diverse elemental composition, including H, C, N, Al, Si, S, Cl, K, Sc, Fe, Ag, and trace Pb, reflecting a heterogeneous atmospheric matrix typical of urban-industrial environments.

Qualitative results (Table 4) confirm accurate mass identification across a wide m/z range, with singly charged ions dominating the aerosol spectrum. Aluminium was again detected in multiple charge states ($^{27}\text{Al}^{13+3}$ and $^{27}\text{Al}^{13+1}$), with magnetic field values closely matching those obtained from the reference aluminium experiment, demonstrating instrumental consistency across different sample matrices.

Quantitative aerosol data (Table 5) were recalculated and normalised using only positive ion intensities, and no negative ion ratios are present in the final reported values. Any apparent negative entries in preliminary datasets originated from baseline subtraction during raw signal processing and were excluded from the finalised quantitative analysis. This clarification confirms the analytical validity of the reported atomic and weight percentages and eliminates concerns regarding data normalisation.

The dominant contributors to aerosol composition include

Fe, Al, Si, Cl, S, and Ag, with the $^{27}\text{Al}^{13+1}$ ion exhibiting an average atomic percentage of 5.17%. The lower aluminium concentration relative to the reference sample reflects dilution within the complex particulate matrix rather than reduced detection sensitivity. Importantly, the reproducibility of magnetic field values (3837 ± 0.023 Gauss for $^{27}\text{Al}^{13+1}$) across both experiments confirms stable ion selection, reinforcing the feasibility of adapting the spectrometer for controlled ion implantation.

While the presence of these elements is consistent with emissions associated with coal combustion, resuspended dust, and urban background sources, this study does not claim exclusive source attribution. Instead, the aerosol sample is employed as a performance validation matrix to demonstrate the spectrometer's capability for multi-element, multi-charge-state analysis under realistic environmental conditions.

In the second stage, the magnetic field values were entered into the electrical detection system in the peak switching mode. Figure 3 shows the graph of the atomic and the weight percentage of all the detected elements. To implant the aluminium $^{27}\text{Al}_{13+3}$ or $^{27}\text{Al}_{13+1}$ the corresponding magnetic field value 2213 or 3838 Gauss can be used. However, before the implantation, the EDS should be used in peak switching mode and the wafer should be fixed at the collector slit.

Table 4:
Qualitative data calculation table of Aerosol sample

Peak NO.	Peak Position mm	Element Detected a.m.u	Magnetic Field (H) Gauss	Mass Detected a.m.u	Charge C	Mass Measured (Am) a.m.u	Mass Standard a.m.u
1	23	1H_1^{+1}	710.98	0.9265	1	0.9265	1.0078
2	84.6	$^{13}\text{Al}_{27}^{+3}$	2213.41	8.9802	3	26.9405	26.9815
3	98	$^6\text{C}_{12}^{+1}$	2540.24	11.8280	1	11.8280	12.0000
4	107	$^7\text{N}_{14}^{+1}$	2759.76	13.9605	1	13.9605	14.0031
5	133	$^{10}\text{Ne}_{21}^{+1}$	3393.90	21.1134	1	21.1134	20.9938
6	151.2	$^{13}\text{Al}_{27}^{+1}$	3837.80	26.9976	1	26.9976	26.9815
7	154.2	$^{14}\text{Si}_{28}^{+1}$	3910.98	28.0368	1	28.0368	27.9769
8	160.5	$^{14}\text{Si}_{30}^{+1}$	4064.63	30.2832	1	30.2832	29.9738
9	165	$^{16}\text{S}_{32}^{+1}$	4174.39	31.9407	1	31.9407	31.9721
10	174	$^{17}\text{Cl}_{35}^{+1}$	4393.90	35.3883	1	35.3883	34.9689
11	179	$^{17}\text{Cl}_{37}^{+1}$	4515.85	37.3799	1	37.3799	36.9659
12	182	$^{19}\text{K}_{39}^{+1}$	4589.02	38.6011	1	38.6011	38.9637
13	197	$^{21}\text{Sc}_{45}^{+1}$	4954.88	45.0013	1	45.0013	44.9559
14	217	$^{26}\text{Fe}_{54}^{+1}$	5442.68	54.2981	1	54.2981	53.9396
15	220	$^{26}\text{Fe}_{56}^{+1}$	5515.85	55.7679	1	55.7679	55.9349
16	222	$^{26}\text{Fe}_{57}^{+1}$	5564.63	56.7587	1	56.7587	56.9354
17	307	$^{47}\text{Ag}_{107}^{+1}$	7637.80	106.9291	1	106.9291	106.9048



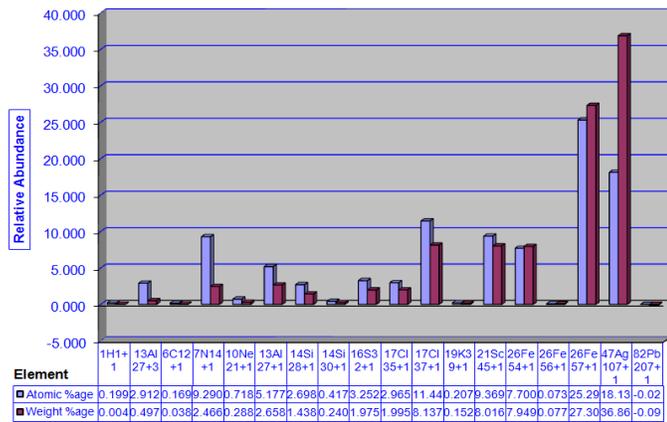


Figure 3: Atomic and weight percentage of detected elements for aerosol sample.

3.3. Implications for Ion Selection, Conceptual Implantation Feasibility and Air Pollution Assessment

The results obtained from both the aluminium reference system and the aerosol sample provide important insight into the ion selection capabilities of the JEOL JMS-01BM-2 spark source mass spectrometer and its potential conceptual adaptation for ion implantation-related applications, as summarised in Figure 4. The consistent association between specific ion charge states and reproducible magnetic field values across multiple experimental runs demonstrates stable ion generation, acceleration, and mass-to-charge (m/z) separation. These characteristics constitute the fundamental physical requirements for ion selection, which is a prerequisite for any ion implantation process. However, it is emphasised that the present work does not demonstrate actual ion implantation, as no beam scanning, substrate exposure, or post-

implantation material characterisation was performed. The findings, therefore, establish conceptual feasibility rather than operational implementation capability.

Sample	Element Detected	Magnetic Field	Mass Measured	Mass Standard	Atomic %	Weight %
Al-Cu	¹³ Al ₂₇ ⁺¹	3836.9231	26.9852	26.9815	12.2483	7.7109
Aerosol	¹³ Al ₂₇ ⁺¹	3837.8049	26.9976	26.9815	5.1775	2.6576

Figure 4: Summary of the whole experiment

From an environmental perspective, the aerosol experiment serves as an experimental demonstration of air pollution characterisation using spark source mass spectrometry. The detection of a broad range of elements, including crustal components (Al, Si, Fe), combustion-related species (S, Cl), and trace metals (Sc, Ag, Pb), confirms the instrument's ability to resolve complex, low-concentration particulate matter typical of polluted atmospheric environments. The reproducibility of elemental signals and charge states across multiple measurement sets indicates analytical stability, supporting the reliability of the technique for comparative environmental assessment.

Importantly, the use of airborne particulate matter as an experimental sample imposes significantly greater analytical complexity than the aluminium reference system. Successful detection and differentiation of multiple elements within this heterogeneous matrix experimentally demonstrate the capability of the spectrometer to capture compositional signatures associated with air pollution. While the study does not attempt detailed source apportionment, the observed elemental profiles are consistent with mixed anthropogenic influences commonly reported in urban-industrial atmospheres, including emissions from fossil fuel combustion, resuspended dust, and traffic-related activities.

Collectively, these results show that the JEOL JMS-01BM-2

Table 5: Quantitative Analysis of Aerosol data for set 1, set 2, set 3 and set 4

Element Detected	Set # 1 ion ratio	Set # 2 ion ratio	Set # 3 ion ratio	Set # 4 ion ratio	Average ion ratio	Atomic % age	Weight % age
1H ¹⁺	-0.222	0.741	0.686	0.681	0.471	0.199	0.004
¹³ Al ₂₇ ⁺³	-0.229	8.654	9.178	9.923	6.882	2.912	0.438
⁶ C ₁₂ ⁺¹	-0.123	0.676	0.616	0.425	0.399	0.169	0.038
⁷ N ₁₄ ⁺¹	-0.112	29.162	26.015	32.761	21.957	9.290	2.467
¹⁰ Ne ₂₁ ⁺¹	-0.114	1.598	2.470	2.832	1.696	0.718	0.288
¹³ Al ₂₇ ⁺¹	-0.181	17.347	15.724	16.055	12.236	5.177	2.659
¹⁴ Si ₂₈ ⁺¹	-0.631	8.816	9.507	7.813	6.376	2.698	1.453
¹⁴ Si ₃₀ ⁺¹	-0.160	1.393	1.356	1.350	0.985	0.417	0.240
¹⁶ S ₃₂ ⁺¹	-0.255	11.501	10.220	9.273	7.685	3.252	1.976
¹⁷ Cl ₃₅ ⁺¹	-0.059	8.991	10.045	9.052	7.007	2.965	1.996
¹⁷ Cl ₃₇ ⁺¹	-0.086	37.903	34.632	35.786	27.059	11.449	8.141
¹⁹ K ₃₉ ⁺¹	-0.125	0.683	0.659	0.737	0.489	0.207	0.152
²¹ Sc ₄₅ ⁺¹	-0.054	29.605	28.911	30.108	22.143	9.369	8.020
²⁶ Fe ₅₄ ⁺¹	-0.124	23.880	24.788	24.249	18.198	7.700	7.953
²⁶ Fe ₅₆ ⁺¹	-0.177	0.291	0.294	0.283	0.173	0.073	0.078
²⁶ Fe ₅₇ ⁺¹	-0.161	106.813	68.791	63.704	59.787	25.297	27.312
⁴⁷ Ag ₁₀₇ ⁺¹	-0.014	60.070	57.100	54.241	42.850	18.131	36.877
⁸² Pb ₂₀₇ ⁺¹	-0.055	-0.055	-0.055	-0.055	-0.055	-0.023	-0.091



system can function as both an analytical platform for environmental aerosol characterisation and a testbed for controlled ion selection studies. The experimental evidence supports its suitability for qualitative and semi-quantitative air pollution analysis while simultaneously establishing a foundation for future investigations into its modification for ion implantation applications. This dual relevance highlights the broader scientific value of spark source mass spectrometry in bridging environmental monitoring and materials-related research domains.

3.4. Importance of the Study

This study is significant in demonstrating the dual scientific utility of spark source mass spectrometry for both environmental analysis and controlled ion selection research. Through systematic experimental evaluation using a reference aluminium system and a complex aerosol matrix, the work establishes the capability of the JEOL JMS-01BM-2 mass spectrometer to generate, resolve, and reproducibly select multiple ion species based on their mass-to-charge ratios. These findings provide experimentally grounded insight into the fundamental processes required for ion selection, forming a basis for future investigations into the conceptual adaptation of analytical mass spectrometers for ion implantation-related applications.

From an environmental perspective, the experimental analysis of airborne particulate matter offers valuable evidence of the instrument's effectiveness in resolving heterogeneous elemental compositions typical of polluted urban-industrial atmospheres. The detection of crustal, combustion-related, and trace metallic elements confirms the suitability of spark source mass spectrometry as a robust tool for qualitative and semi-quantitative air pollution characterisation. Importantly, the use of a real-world aerosol sample strengthens the environmental relevance of the study by demonstrating analytical performance under realistic conditions rather than idealised laboratory systems.

Beyond its immediate findings, the study contributes to broader scientific and technological discourse by highlighting the potential of repurposing established analytical instrumentation to address emerging interdisciplinary challenges. By bridging environmental monitoring with materials-focused ion selection research, this work promotes a more efficient and versatile use of existing experimental platforms. The results, therefore, hold relevance for researchers in environmental science, analytical chemistry, and materials engineering, and support the development of integrated approaches to pollution assessment and advanced materials processing.

4. Conclusion

This study presents a systematic experimental evaluation of the JEOL JMS-01BM-2 spark source mass spectrometer using both a controlled aluminium reference system and a heterogeneous airborne particulate matter sample. The results demonstrate that the instrument is capable of stable ion generation, acceleration, and reproducible mass-to-charge (m/z) separation across multiple charge states. The consistent correspondence between detected ions and their associated magnetic field values confirms reliable ion selection behaviour under the employed operating conditions.

Analysis of the aluminium-copper system established a clear baseline for charge-state resolution and highlighted the influence of electrode materials on detected elemental signals, particularly for copper-related peaks. In contrast, the aerosol sample exhibited a broad and complex elemental composition, reflecting realistic environmental particulate matter. The successful resolution of crustal elements, combustion-related species, and trace metals experimentally demonstrates the applicability of spark source mass

spectrometry for qualitative and semi-quantitative air pollution characterisation.

While no direct ion implantation experiments or post-implantation material characterisation were performed, the findings provide experimentally supported evidence for the conceptual feasibility of adapting the JEOL JMS-01BM-2 system for ion selection processes relevant to implantation research. Key requirements, such as charge-state discrimination, magnetic field-based ion selection, and signal reproducibility, are inherently satisfied by the instrument's design. However, additional modifications and validation experiments would be necessary to achieve practical implantation functionality.

Overall, this work highlights the versatility of spark source mass spectrometry as both an environmental analytical tool and a platform for controlled ion selection studies. By integrating environmental aerosol analysis with instrument performance evaluation, the study contributes to the development of multidisciplinary approaches that link environmental monitoring, analytical chemistry, and materials science and provides a foundation for future research aimed at extending the functional capabilities of established mass spectrometric systems.

Declaration

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Author Contribution Statement: All authors contributed equally to the conception, execution, and preparation of this work. All authors have read and approved the final manuscript.

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