Modified Oscillating Mirror Rapid Scanning Spectrometer as a Detector for Simultaneous Multi-element Determination

Oliver Rose, Jr.,* William R. Heineman and Joseph A. Caruso
Department of Chemistry, University of Cincinnati, Cincinnati, Ohio 45221, USA

and Fred L. Fricke
Cincinnati District Food and Drug Administration, 1141 Central Parkway, Cincinnati, Ohio 45202, USA

An oscillating mirror rapid scanning spectrometer has been modified to improve its light throughput and resolution. Results of the application of this spectrometer to simultaneous microwave-induced atomic-emission spectrometry and simultaneous carbon furnace atomic-absorption spectrometry are given.

Keywords: Oscillating mirror rapid scanning spectrometer; microwave-induced atomic-emission spectrometry; carbon furnace atomic-absorption spectrometry; multi-element determination

An oscillating mirror rapid scanning spectrometer can be classified as a sequential linear scan spectrometer. The oscillating galvanometer provides a scanning wavelength window and each spectral element is detected in rapid sequence by a single photomultiplier tube. In a preliminary evaluation of this type of spectrometer as applied to simultaneous multi-element emission spectrometry, it was found that its photomultiplier detection system and wide optical range would make it suitable as a multi-element detector. However, modifications were needed in order to improve the optical throughput and resolution. This paper describes the modified rapid scanning spectrometer (RSS) and its application to simultaneous atomic-emission spectrometry using the microwave-induced plasma (MIP) as the source and to simultaneous carbon furnace atomic-absorption spectrometry.

Experimental

Apparatus
Detection system
Basically, the detection system, consisting of the Harrick Rapid Scan Spectrometer (Model RSS-B), the RSS signal processing module, the Nicolet NMR-80 minicomputer with the FT-74 software package, was similar to that described previously.

In order to avoid a lengthy re-alignment of the optics from one application of the RSS to the next, the instrument being also used extensively in other projects as a dual-beam spectrophotometer with a xenon arc lamp source, two modifications of the optical layout of the Model RSS-B described by Denton et al. were made. Firstly, a telescope entrance lens (5 cm focal length, 2.5 cm diameter), aligned with the entrance slit (S1) and the first spherical mirror (SM1), was added with the first plane mirror removed, and secondly, a 1P28 photomultiplier tube was inserted immediately after the exit slit. Fig. 1 is a diagram of the modified optical layout and indicates that only the optical T was found to be necessary for atomic spectrometry. A photomultiplier power supply (MPI Model MP-1031) and a laboratory-constructed signal amplifier were used. By using the 1P28 photomultiplier tube and the separate amplifier, the signal to noise ratio was improved. (The amplifier circuit supplied by the manufacturer contained a pre-amplifier section and a log amplifier section. Only the output of the pre-amplifier section was displayed in the preliminary study.)

* Present address: Shepherd Chemical Company, 4900 Beech Street, Cincinnati, Ohio 45212, USA.
Improvement of the signal to noise ratio permitted the slit widths to be reduced, resulting in better resolution. Slit widths of 0.06 and 0.18 mm for entrance and exit slits, respectively, were used in the present emission studies.

\[
\text{Fig. 1. Diagram of modified optical layout of Harrick RSS-B rapid scan spectrometer as used for trace metal emission work: } S \text{ is the emission source; } S_1, \text{ the entrance slit; } SM_1, \text{ the first spherical mirror; } GM, \text{ the galvanometer mirror; } SM_2, \text{ the second spherical mirror; } GR, \text{ the grating; } M_2, \text{ the flat mirror; } S_2, \text{ the exit slit; and PMT, the photomultiplier tube.}
\]

In order to evaluate the performance of the RSS with optical components other than those supplied by the manufacturer, other sources including a copper hollow-cathode lamp (Tekmar), a zinc, cadmium, lead and copper multi-element hollow-cathode lamp (Tekmar) and a low-pressure mercury vapour lamp were utilised for well defined spectral lines. The hollow-cathode lamps were powdered by a d.c. supply (Model GPS-2, Barnes Engineering Co.) and both lamps were operated at 8 mA. Before spectra were recorded following a change of an optical component, the optical alignment was optimised.

To improve the resolution, the grating supplied by the manufacturer, which was ruled at 300 lines mm\(^{-1}\) and blazed at 300 nm, was replaced with one ruled at 1200 lines mm\(^{-1}\) and blazed at 250 nm. A comparison of the two gratings is made in Table I. In order to enhance the sensitivity by increasing the light throughput, and to improve the resolution by illuminating more lines of the grating, the galvanometer mirror (4.8 mm diameter) was replaced by a larger mirror (8.9 mm diameter) after a study of various galvanometer mirror sizes with respect to repetition rate. To fill the larger mirror with radiation, a larger first spherical mirror (SM\(_1\)) was installed. An ultraviolet sapphire hemicylinder, 20 × 25 mm with a 10-mm radius, fitted in well with the use of the 8.9 mm diameter galvanometer mirror.

In the preliminary study,\(^3\) the minicomputer determined the repetition rate of the RSS. However, it was found that identical spectra could be stored in different 1K memory locations and coincide more precisely (permitting exact subtraction of background) if the galvanometer mirror oscillated continuously. A square-wave generator (Model 126C, Exact Electronics Inc.) was then used to trigger each scan of the galvanometer mirror and each sweep of the minicomputer. Thus, while the RSS collected spectral information continuously, the minicomputer stored data only upon command.

**Carbon cup vaporisation assembly - MIP system**

The carbon cup vaporisation assembly and the procedure for introducing analyte into the
MIP has been described previously. The set power level of the microwave generator was 50 W direct and 0.5 W reflected, while the optimum flow-rate of argon was 600 ml min$^{-1}$.

**Desolvation apparatus - MIP system**

This system was similar to that described by Margoshes and Veillon and modified by Skogerboe and Coleman, except the microwave cavity was an Evenson $\frac{1}{4}$-wave cavity. Small droplets of water splashed into the side-arm below the condenser that led to the quartz tube and extinguished the plasma. A piece of PTFE tape was suspended in front of the side-arm opening in order to minimise this interruption of the signal. The microwave power was 90 W direct and 0.5 W reflected. The flow-rate of argon was 800 ml min$^{-1}$ and the solution aspiration rate was 2.2 ml min$^{-1}$.

**Carbon furnace atomic-absorption system**

Radiation from the zinc, cadmium, lead and copper multi-element hollow-cathode lamp operated at 8 mA was passed through the carbon rod atomiser (Model 63, Varian Techtron) and then detected by the RSS. The atomisation temperature was chosen to be the optimum for the determination of copper with a corresponding flow-rate of argon of 41 ml min$^{-1}$.

**Reagents**

Aqueous standards pipetted into the carbon cup or carbon rod were diluted from stock solutions, which were either Fisher atomic-absorption standards or solutions prepared by dissolving pure metals or laboratory-reagent grade salts in an acid and diluting the solution with de-ionised water. Solutions aspirated into the desolvation apparatus were made 0.1 N in hydrochloric acid. All other reagents were of ACS reagent grade.

**Data Acquisition**

As in the preliminary study, the difference between the signal observed for the sample and that observed for the solvent was used as a direct measure of the emission (absorption for the carbon furnace atomic-absorption system) of the elements.

For a determination using the carbon cup vaporisation assembly - MIP and the carbon furnace atomic-absorption systems, a 130-nm wavelength window was observed by the RSS with a repetition rate of 73 Hz. For both systems, the minicomputer accumulated data only when the transient signals were detected by the RSS. For the emission system, 200 spectra were accumulated, while for the carbon furnace atomic-absorption system, 140 spectra were accumulated.

For a determination involving the use of the desolvation apparatus - MIP system, an 80-nm wavelength window was observed by the RSS with a repetition rate of 20 Hz and 500 spectra were accumulated after aspiration of the sample solution.

**Results and Discussion**

**Evaluation of Modified RSS**

**Grating**

The use of a more finely ruled grating in the RSS results in a compromise between increased resolution and reduced maximum wavelength window size as the angular displacement (excursion) of the galvanometer mirror needs to be greater to display the same wavelength window size than that with less spectral dispersion. Table I lists the maximum wavelength

<table>
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<tr>
<th>TABLE I</th>
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<tr>
<td><strong>Comparison of performance of the RSS with mounting of different gratings</strong></td>
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<tr>
<td>Maximum wavelength window size/nm</td>
</tr>
<tr>
<td>Line half-width of Cu 324.8-nm line/nm</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>* Limited by spectral response of 1P28 photomultiplier.</td>
</tr>
<tr>
<td>† Limited by size of second spherical mirror (see Fig. 1).</td>
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<td>‡ Wavelength window size 17 nm.</td>
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window size and line half-width observed when the 300 and the 1 200 lines mm\(^{-1}\) gratings were mounted with all other components unchanged. The improvement in resolution was substantial as the line half-width (full width at half maximum height) of the copper 324.8-nm line decreased from 1.9 to 0.4 nm.

Fig. 2 shows the same 17-nm window of the radiation from the copper hollow-cathode lamp, which includes the 324.8- and 327.4-nm lines recorded after optical components were changed. A comparison of spectra \((a)\) and \((b)\) indicates the enhancement of resolution with a more finely ruled grating mounted in the RSS. However, the maximum possible wavelength window decreased from 500 to 170 nm. With the 300 lines mm\(^{-1}\) grating mounted in the RSS, the maximum wavelength window size was determined by the spectral response of the photomultiplier tube. For example, with the photomultiplier tube supplied by the manufacturer (RCA C31025Q), the maximum wavelength window is 730 nm, while with the 1P28, the maximum width is 500 nm. The spherical mirror, SM\(_2\), limits the maximum wavelength window size with the 1 200 lines mm\(^{-1}\) grating mounted in the RSS. Any greater angular displacement (excursion) of the galvanometer mirror does not result in an increase in wavelength window because the path of the light beam produced by the oscillating mirror is greater than the width of SM\(_2\).

Galvanometer mirror size

The use of the 4.8 mm diameter galvanometer mirror supplied by the manufacturer provided a repetition rate fast enough to permit a sufficient accumulation of transient signals.\(^3\) In order to select the size of a larger mirror that would increase the light throughput and resolution, but still provide a reasonable repetition rate, the performance of several galvanometer mirrors was studied by mounting these on the same optical scanner (General Scanning, Model 0612). For example, the use of a 12.7 mm square galvanometer mirror (area 161.3 mm\(^2\)), which increased the light throughput markedly, decreased the repetition rate to 16 Hz (at a scanning rate of 41 Hz) with the wavelength window of 50 nm. (Any subsequent reference to wavelength window size implies that the 1 200 lines mm\(^{-1}\) grating was mounted in the RSS.) Any faster repetition rate caused significant distortion of the spectrum displayed. This decrease in repetition rate is due, in part, to the unfavourable ratio of mirror inertia to scanner armature inertia.\(^9\) The time required for the mirror to come to rest after each scan is much greater than that required for a smaller mirror and there is much more inertia to overcome at the beginning of each scan. The maximum repetition rate would decrease still further if the wavelength window size were increased because the rate of angular displacement would be larger. This increased rate provides greater momentum to reverse as the mirror re-sets after the scan is completed and more time is required to bring to rest the resulting increased surface distortions of the mirror. However, in applications that need only a slower repetition rate (less than 20 Hz), but high light throughput, the use of a larger galvanometer mirror can be an important modification.

<table>
<thead>
<tr>
<th>TABLE II</th>
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<tr>
<td><strong>Comparison of performance of the RSS with mounting of different galvanometer mirrors</strong></td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>4.8 mm diameter mirror (area 18.1 mm(^2))</th>
<th>8.9 mm diameter mirror (area 62.2 mm(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum repetition rate/Hz(^*)</td>
<td>73</td>
<td>20</td>
</tr>
<tr>
<td>Scan rate at maximum repetition rate/Hz</td>
<td>101</td>
<td>50.5</td>
</tr>
<tr>
<td>Relative intensity of Cu</td>
<td>1</td>
<td>3.1</td>
</tr>
<tr>
<td>Line half-width of Cu 324.8-nm line</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>Linearity of scan (correlation coefficient of wavelength versus position plot(\dagger))</td>
<td>0.999 4</td>
<td>0.999 4</td>
</tr>
</tbody>
</table>

\(\ast\) Wavelength window size 130 nm.
\(\dagger\) Wavelength window size 17 nm.
\(\dagger\) Thirteen emission lines of radiation from a low-pressure mercury vapour lamp.
to the RSS-B spectrometer. It was not possible to utilise a larger optical scanner without totally rebuilding the RSS-B. By use of a different monochromator, much larger optical scanners and corresponding mirrors (e.g., an 875-mm² mirror such as are found on General Scanning 300 Series models) could be employed.

An 8.9 mm diameter galvanometer mirror was chosen as a compromise between increased light throughput and repetition rate for the RSS-B spectrometer. Table II gives a comparison of the performance of the RSS when the 4.8 mm diameter and 8.9 mm diameter mirrors are mounted in the RSS with all other optical components unchanged. The light throughput was increased by a factor of 3.1 even though the actual observation time (scan period multiplied by the repetition rate) was decreased and the resolution of the RSS increased. A comparison of spectra (b) and (c) in Fig. 2 indicates the improvement of the spectral output of the RSS with the use of the larger galvanometer mirror. Spectrum (c) has been attenuated by a factor of two for display purposes. The maximum repetition rate was reduced to 20 Hz with a wavelength window of 130 nm, compared with 73 Hz for the same wavelength window width with the smaller mirror mounted in the RSS. With the Model 0612 optical scanner, the larger mirror is best utilised in applications in which the observed signals are continuous so that a more favourable signal to noise ratio is obtained. It should be indicated at this point that even with the larger mirror mounted, the grating was severely under-illuminated, which appears not to be a drawback in other applications but needs to be improved for future atomic-emission work, probably by building a new instrument.

\[\text{Fig. 2. Identical wavelength windows (width 17 nm) of the emission of a copper hollow-cathode lamp. Slit widths: entrance 0.06 mm, exit 0.18 mm. Display attenuation: (a), 16000 counts cm}^{-1}; (b), 160000 counts cm}^{-1}; (c), 32000 counts cm}^{-1}. \]

\[\text{Optical components mounted in the RSS: (a), 4.8 mm diameter galvanometer mirror, 300 lines mm}^{-1} \text{ grating; (b), 4.8 mm diameter galvanometer mirror, 1200 lines mm}^{-1} \text{ grating; (c), 8.9 mm diameter galvanometer mirror, 1200 lines mm}^{-1} \text{ grating.} \]

\[\text{Fig. 3. Identical wavelength windows (width 35 nm) of the emission of a zinc, cadmium, lead and copper hollow-cathode lamp. Slit widths: entrance 0.06 mm, exit 0.18 mm. Optical components mounted in the RSS: (a), 4.8 mm diameter galvanometer mirror, 300 lines mm}^{-1} \text{ grating; (b), 8.9 mm diameter galvanometer mirror, 1200 lines mm}^{-1} \text{ grating.} \]
In the preliminary study of the RSS, it was noted that zinc and cadmium could not be determined simultaneously as the zinc 213.9-nm and cadmium 214.4-nm lines were unresolved. By mounting the 8.9 mm diameter galvanometer mirror and the 1 200 lines mm⁻¹ grating in the RSS, these two lines can be resolved. Fig. 3 gives a comparison of the same 35-nm window of radiation from a zinc, cadmium, lead and copper multi-element hollow-cathode lamp recorded with different optical components mounted in the RSS. An increase in the wavelength window size decreases the resolution because fewer data points per nanometer are accumulated. The maximum wavelength window size that can be used for multi-element determinations while still resolving the zinc 213.9- and cadmium 214.4-nm lines according to the Rayleigh criterion of resolution was 80 nm.

Atomic-emission and -absorption Spectrometry

After modifying the RSS spectrometer as described above, it was again evaluated as a detector in simultaneous multi-element determinations. Both the transient signals produced by the carbon cup vapourisation assembly - MIP system and the carbon furnace atomic-absorption system, and the continuous signals produced by the desolvation apparatus - MIP system, were observed. In order to obtain an enhanced signal to noise ratio, the 4.8 mm diameter galvanometer mirror was mounted in the RSS for the detection of the transient signals, although the 8.9 mm diameter mirror was mounted for the detection of continuous signals.

Table III lists the limits of detection for the three systems. These limits are not as low as it is possible to achieve with the MIP, as Skogerboe and Coleman indicate. It is likely that these high limits result from the low duty cycle (see below) as well as from the rather limited optical throughput available with the RSS-B. With the carbon cup vapourisation assembly - MIP system, bismuth, cadmium, manganese, lead, magnesium and copper were determined simultaneously; Fig. 4 shows a typical background-corrected emission spectrum of this determination. Of note is the resolution of the manganese triplet that appeared as one peak in an identical wavelength window recorded in the preliminary study. As a result of the intensity and randomness of the argon background, its subtraction was not precise. Zinc was determined separately owing to the spectral overlap of the zinc 213.9- and cadmium 214.4-nm lines. Typical analytical graphs for this system are shown in Figs. 5 and 6. Two sets of units are given in the abscissae as the system is mass sensitive. In this study, the sample volume used was 5 μl. The linear range is approximately one order of magnitude. This range is more compressed than is desirable; however, that is to be expected when the limited optical throughput of the system, which in part leads to higher detection limits than might otherwise be possible, is considered. Indeed, scanners capable of supporting mirrors greater than ten times the largest area that we could mount in the RSS-B are readily available with sufficient frequency response (see above). In order to utilise such scanners, however, a different instrument is required as size restrictions in the RSS-B prohibit further modification.

The onset of self-absorption gives rise to a slope of about 0.5 at higher concentrations. This is not unexpected, particularly with the carbon cup experiments where the particle density in the transient pulse is likely to be high enough to give rise to this phenomenon.

**Table III**

<table>
<thead>
<tr>
<th>Element</th>
<th>Wavelength/nm</th>
<th>Carbon cup vapourisation assembly - MIP⁺</th>
<th>Desolvation apparatus - MIP</th>
<th>Carbon furnace atomic absorption†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>213.9</td>
<td>0.1</td>
<td>0.07</td>
<td>—</td>
</tr>
<tr>
<td>Bi</td>
<td>223.1</td>
<td>0.2</td>
<td>0.7</td>
<td>—</td>
</tr>
<tr>
<td>Cd</td>
<td>226.8</td>
<td>0.03</td>
<td>0.02</td>
<td>0.003</td>
</tr>
<tr>
<td>Mn</td>
<td>257.6</td>
<td>0.04</td>
<td>0.04</td>
<td>—</td>
</tr>
<tr>
<td>Pb</td>
<td>283.3</td>
<td>0.2</td>
<td>—</td>
<td>0.007</td>
</tr>
<tr>
<td>Mg</td>
<td>285.2</td>
<td>0.06</td>
<td>0.02</td>
<td>—</td>
</tr>
<tr>
<td>Cu</td>
<td>324.8</td>
<td>0.05</td>
<td>0.09</td>
<td>0.005</td>
</tr>
</tbody>
</table>

* Defined as that concentration which produces a net signal twice the standard deviation of the background signal.

† Sample volume 5 μl.
Unquestionably, the MIP is capable of providing lower detection limits and extended linear ranges. Nevertheless, the limits of detection for the carbon cup vaporisation system and the desolvation system are in the sub-parts per million range and are mutually comparable. These detection limits are surprising in view of the low duty cycle for the analytical line (line sampling time). For example, consider a typical carbon cup experiment with a 130-nm window, a repetition rate of 73 Hz and a scanning rate of 101 Hz. Also, assume that the maximum residence time for cadmium in the plasma is 1 s and that 0.5 nm represents the cadmium “slice” of the 130-nm total. Based on the repetition and scanning rates, 73 spectra are taken per second with the total time per 130-nm spectrum given as 0.0099 s (1/101). Thus, in the residence time of 1 s, a total of 0.73 s is spent in sampling the 130-nm window giving 2.8 ms “on time” for the cadmium line. Thus, while the detection levels for direct-reading plasma emission spectrographs are less, the observation time per analytical line is at least 1 000 times greater.

Fig. 4. Typical background-corrected emission spectrum obtained for a simultaneous determination of bismuth, cadmium, manganese, lead, magnesium and copper using the carbon cup vaporisation assembly - MIP system.

Fig. 5. Log - log plots of analytical graphs for cadmium, copper and bismuth obtained using the carbon cup vaporisation assembly - MIP system.

Fig. 6. Log - log plots of analytical graphs for manganese and lead obtained using the carbon cup vaporisation assembly - MIP system.
As the larger mirror was mounted for determination using the desolvation apparatus-MIP system, zinc and cadmium were determined simultaneously in an 80-nm window that also includes bismuth, manganese and magnesium. The emission of lead at low concentration levels was obscured by background emission. Copper was determined in a separate window. Typical analytical graphs for this system are shown in Figs. 7 and 8. The linear range is also approximately one order of magnitude for this system.

![Graph](image1)

**Fig. 7. Log-log plots of analytical graphs for magnesium, manganese and copper obtained using the desolvation assembly - MIP system.**

![Graph](image2)

**Fig. 8. Log-log plots of analytical graphs for cadmium and zinc obtained using the desolvation assembly - MIP system.**

Cadmium, lead and copper were determined simultaneously by using the carbon furnace atomic-absorption system. No data were obtained for zinc owing to the presence of zinc in the de-ionised water and the problems associated with it for furnace atomic-absorption determination. However, the determination of zinc is sensitive, being in the parts per 10⁹ range. As is to be expected, considering the sensitivity of the carbon furnace atomic-absorption method, the limits of detection for this system are superior to those for the two emission systems. However, the linear range is narrow, especially for cadmium, making an optimum dilution difficult when working with complex samples.

**Matrix Effects**

In order to study possible matrix effects for the carbon cup experiment, 500 ng of sodium (5 µl of a 100 p.p.m. sodium solution from a stock solution of sodium nitrate) were vaporised into the plasma. As the sodium passed through the plasma the intense orange emission was noted, but the plasma appeared to be stable. The direct power increased only slightly and the reflected power did not change. After several vaporisations, the quartz tube above the plasma was coated with a white residue. Table IV gives the limits of detection of cadmium, manganese, magnesium, copper and zinc in 100 p.p.m. solutions of a sodium salt. There was little difference between these values in comparison with the limits of detection in aqueous solutions (Table III). As can be seen, the concentration of the matrix element is usually more than 1 000 times that of the analyte and in one instance about 5 000 times. Five microlitres of a 1 000 p.p.m. solution of sodium were injected into the cup and 5 000 ng of sodium were vaporised into the plasma, causing the plasma to contract appreciably. Also, there was a considerable memory effect as the sodium signal persisted for several minutes. However, casual observations indicate that it may be possible to tune the MIP with a continuous flow of sodium salt solution comparable with the amount that passes through the plasma upon vaporisation of 5 000 ng of sodium in a carbon cup. Tuning the MIP to the matrix is very important in sustaining a plasma.

Skogerboe and Coleman aspirated solutions containing 1 000 p.p.m. of sodium into a desolvation - MIP system without extinguishing the plasma. However, when a 1 000 p.p.m. sodium solution was aspirated in the desolvation apparatus described above, it was not possible to sustain a plasma, although it must be mentioned that the tuner had been
Table IV

<table>
<thead>
<tr>
<th>Element</th>
<th>Wavelength/nm</th>
<th>Carbon cup vaporisation assembly - MIP</th>
<th>Desolvation apparatus - MIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn†</td>
<td>213.9</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Cd</td>
<td>228.8</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>Mn</td>
<td>257.6</td>
<td>0.02</td>
<td>0.2</td>
</tr>
<tr>
<td>Mg</td>
<td>285.2</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Cu†</td>
<td>324.8</td>
<td>0.1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

*Defined as that concentration which results in a net signal twice the standard deviation of the background.
† Zinc determined separately in the carbon cup experiment; copper determined separately in the desolvation experiment.

rebuilt in our laboratories and was not operating completely satisfactorily. A plasma was sustained with a 100 p.p.m. solution of sodium aspirating into the desolvation apparatus after the aspiration rate had been decreased to 0.9 ml min⁻¹ and the argon flow-rate increased to 1.91 min⁻¹. With the aspiration of the 100 p.p.m. sodium solution into the desolvation apparatus the entrance lens became coated with salt, because the stream of gas leaving the quartz tube is directed at the lens. Limits of detection for zinc, cadmium, manganese, magnesium and copper in a 100 p.p.m. solution are also given in Table IV. The higher detection limits in solution in 0.1 N hydrochloric acid in the presence of the 100 p.p.m. solution of sodium as compared with those in just the 0.1 N hydrochloric acid (Table III) are attributed to the reduction in transport efficiency in the presence of sodium, to changes in the plasma energy characteristics as a result of the large excess of sodium⁹ and, to a large extent, the decrease in the aspiration rate.

Conclusions

Each of the three systems has distinct advantages. The carbon cup vaporisation assembly - MIP system has the potential for simultaneous determination when sample volume is critical. The desolvation apparatus - MIP system offers the advantage of observation of a continuous signal. For example, in this study, the larger mirror could only be mounted in the RSS for the detection of a continuous signal. The carbon furnace atomic-absorption system gives superior sensitivity of detection, but is limited by the availability of multi-element sources of radiation.

This study indicates that rapid scanning spectrometry may provide a useful detector for simultaneous atomic spectrometry. However, future work must increase the light throughput still further in order to lower the limits of detection, thereby increasing the linear range and fulfilling the capabilities of the MIP.¹⁰ Also, more fully illuminated optics will enhance the resolution still further. The general concept of an oscillating mirror rapid scanning spectrometer with photomultiplier detection may well provide an answer to the growing need for an inexpensive detector for simultaneous multi-element determinations.

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