

## CHAPTER IV



### RESULTS AND DISCUSSION

The percentages of copper nitrate trihydrate, cadmium nitrate tetrahydrate, mercuric nitrate, lead nitrate, and zinc nitrate hexahydrate in their analar grade reagents which were determined by potentiometric titration with EDTA and amperometric titration with potassium dichromate, were found to be 99.20, 99.34, 99.42, 99.80 and 99.53, respectively.

Air particulate sampling was performed in daytime during March 23-April 6, 1979 at the level of 1.50-1.60 m above the ground.

The sampling areas are Patumwan, Ratchaprasong, Chit Lom, Phloenchit, Sukhumvit soi 10 (San Samrarn), and Sukhumvit soi 21 (Asoke). The location of sampling stations is illustrated in Figure 2. Four samples at each station were collected in two days, two samples in the morning and other two samples in the afternoon. A total of 24 samples were obtained. The meteorological data for Bangkok Metropolis, are shown in Table 2.

Before the analyses of air particulate samples for mercury, copper, lead, cadmium, and zinc, the optimum conditions for analyzing each metal ion and their mixtures by anodic stripping voltammetry were firstly investigated. Then the relationship between the concentration of the metal ion and its signal response from either

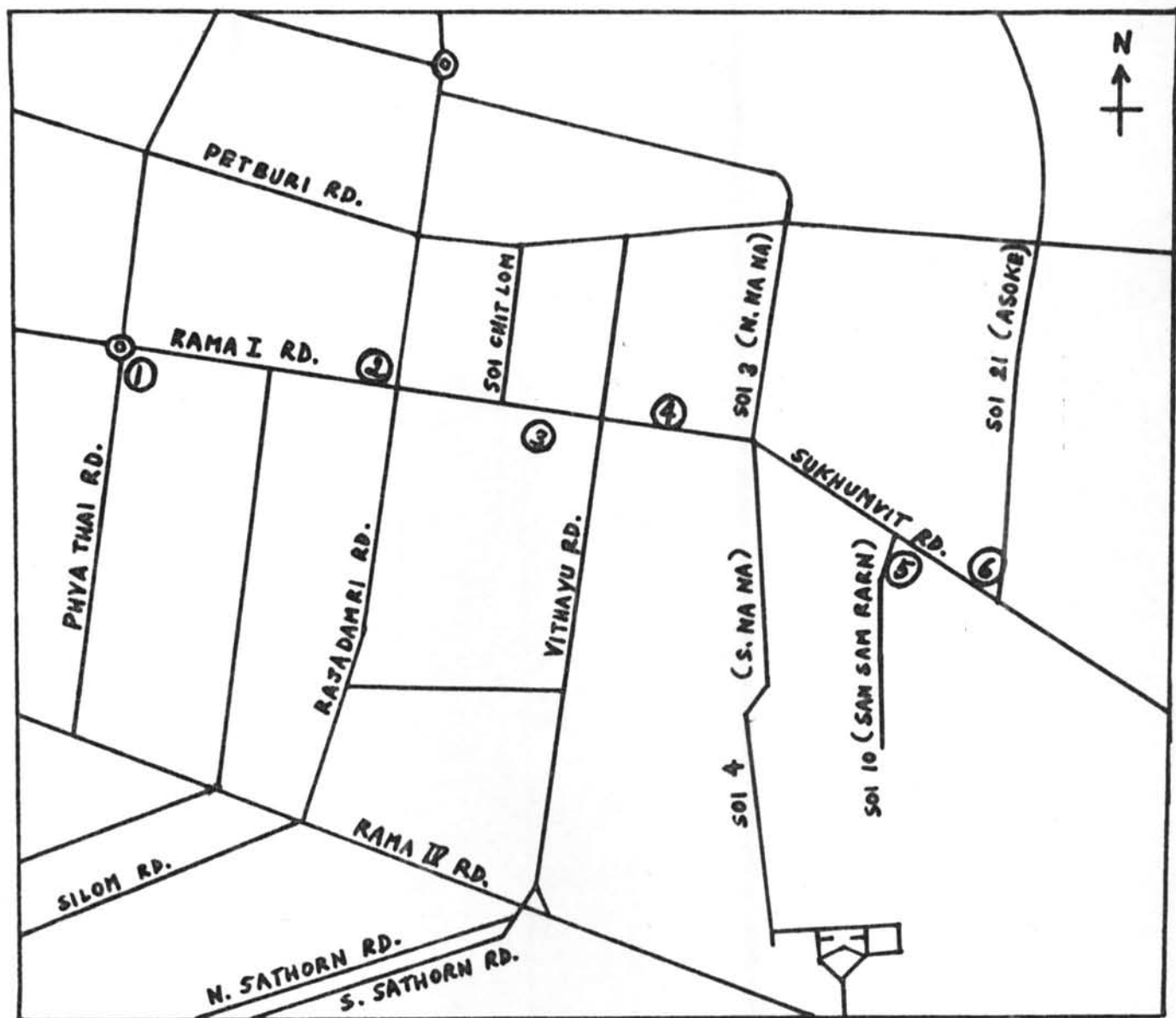


Figure 2. Location of the sampling stations ;

- ① Patumwan , ② Ratchaprasong , ③ Chit Lom ,  
 ④ Phloenchit , ⑤ Sukhumvit soi 10 (San Sam Rarn) ,  
 and ⑥ Sukhumvit soi 21 (Asoke).

Table 2 Meteorological observation from Bangkok Station for Bangkok  
Metropolis<sup>(45)</sup>

Date	Temperature			Relative			Amount of Rainfall (mm.)	Surface Wind	
	( $^{\circ}$ C)			Humidity(%)				Prevailing Direction	Mean Velocity (Km/Hr.)
	Max.	Min.	Mean	Max.	Min.	Mean			
23 March 79	34.7	27.0	29.8	88	52	74.4	0.0	S	16.9
24 March 79	34.1	25.6	29.4	94	61	78.5	0.0	S	15.6
25 March 79	34.5	27.3	30.2	85	54	74.5	0.0	S	16.2
26 March 79	35.3	27.0	30.2	87	53	72.3	0.0	S	15.1
27 March 79	35.3	27.4	30.6	88	48	73.5	0.0	S	14.3
28 March 79	35.3	27.2	30.5	87	50	71.2	0.0	S	18.8
29 March 79	35.2	27.6	30.6	89	56	76.0	0.0	S	15.4
30 March 79	34.4	27.7	30.3	88	58	76.1	0.0	S	16.0
31 March 79	33.9	25.8	29.9	91	56	76.5	0.0	S	15.1
1 April 79	35.1	27.7	30.5	90	57	77.3	0.0	S	18.2
2 April 79	36.1	27.2	30.8	93	48	74.3	0.0	S	16.8
3 April 79	35.1	27.6	30.7	87	53	72.5	0.0	S	17.0
4 April 79	37.3	26.9	31.1	89	41	65.8	0.0	SW	15.0
5 April 79	35.4	27.8	30.9	83	45	69.9	0.0	S	17.9
6 April 79	35.5	27.6	30.6	85	48	72.5	0.0	S	14.7

S South and SW South-West

anodic stripping voltammetric method or atomic absorption spectrophotometric method was studied.

#### 4.1 Anodic stripping analysis

Corresponding to the amalgamated formations of copper, cadmium, lead and zinc metals with mercury, a simultaneous determination of mercury and the other metal ions by anodic stripping analysis cannot be performed. Mercury ion was firstly analyzed, then copper, cadmium and lead ions were simultaneously determined. The sensitivity of the determination of copper, cadmium, lead, and zinc ions by electrochemical methods is improved by the amalgamated formation and a one step process for this improvement has been reported to be mercury plated "in situ" (46,47). Mercuric nitrate is added to the solution of the metal ions and is plated at the same time as the metals under investigation. Thus, the glassy carbon mercury plated "in situ" electrode was used throughout these anodic stripping analyses.

Lead ion formed electroinactive lead hydroxy complexes in basic solution (48). To insure that all metal ions were in electroactive forms the air particulate sample was digested with  $\text{HNO}_3$  and the anodic stripping analyses of  $\text{Cu(II)}$ ,  $\text{Cd(II)}$ , and  $\text{Pb(II)}$  were performed in the solution of pH 2 (48). In acidic solution, the hydrogen peak covered that of zinc peak, therefore  $\text{Zn(II)}$  species was determined in the acetate buffer pH 5.8 (49).

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#### 4.1.1 Study of metal ion species.

##### 4.1.1.1 Hg(II)

The cathodic voltammogram of Hg(II) ion in 0.1M  $\text{KNO}_3$  at the glassy carbon electrode showed a single peak at the potential of +0.10 V. Therefore, the potential of +0.10V was selected for the electrodeposition of Hg(II) ion.

In anodic stripping voltammetry of Hg(II), Luong and Vydra reported that the appearance of double peaks of Hg(II) ion in 0.1M  $\text{KNO}_3$  was not observed at pH 2<sup>(50)</sup>. This was experimentally proved by carrying the anodic stripping analysis of Hg(II) ion in 0.1M  $\text{KNO}_3$  at pH 2 and the result indicated a single sharp peak at the potential of +0.25 V (see Figure 3).

The anodic peak of Cu(II) in 0.1M  $\text{KNO}_3$  at pH 2 occurred at the potential of +0.05 V. This anodic peak of Cu(II) is quite close to the anodic peak of Hg(II). Therefore, the analysis of Hg(II) species in the presence of Cu(II) ion was studied. The anodic stripping analysis for Hg(II) species in this mixture was performed in 0.1M  $\text{KNO}_3$  at pH 2 by electrodeposition at the potential of +0.10 V for 20 minutes (see Figure 4). It was found that the Cu(II) concentration up to 1000.0  $\text{ng/cm}^3$  did not affect the determination of Hg(II) species (see Table 3). The anodic stripping voltammograms of these mixtures scanning from +0.10 to + 0.50 V showed one single peak at potential +0.25 V which is the anodic stripping peak of Hg(II).

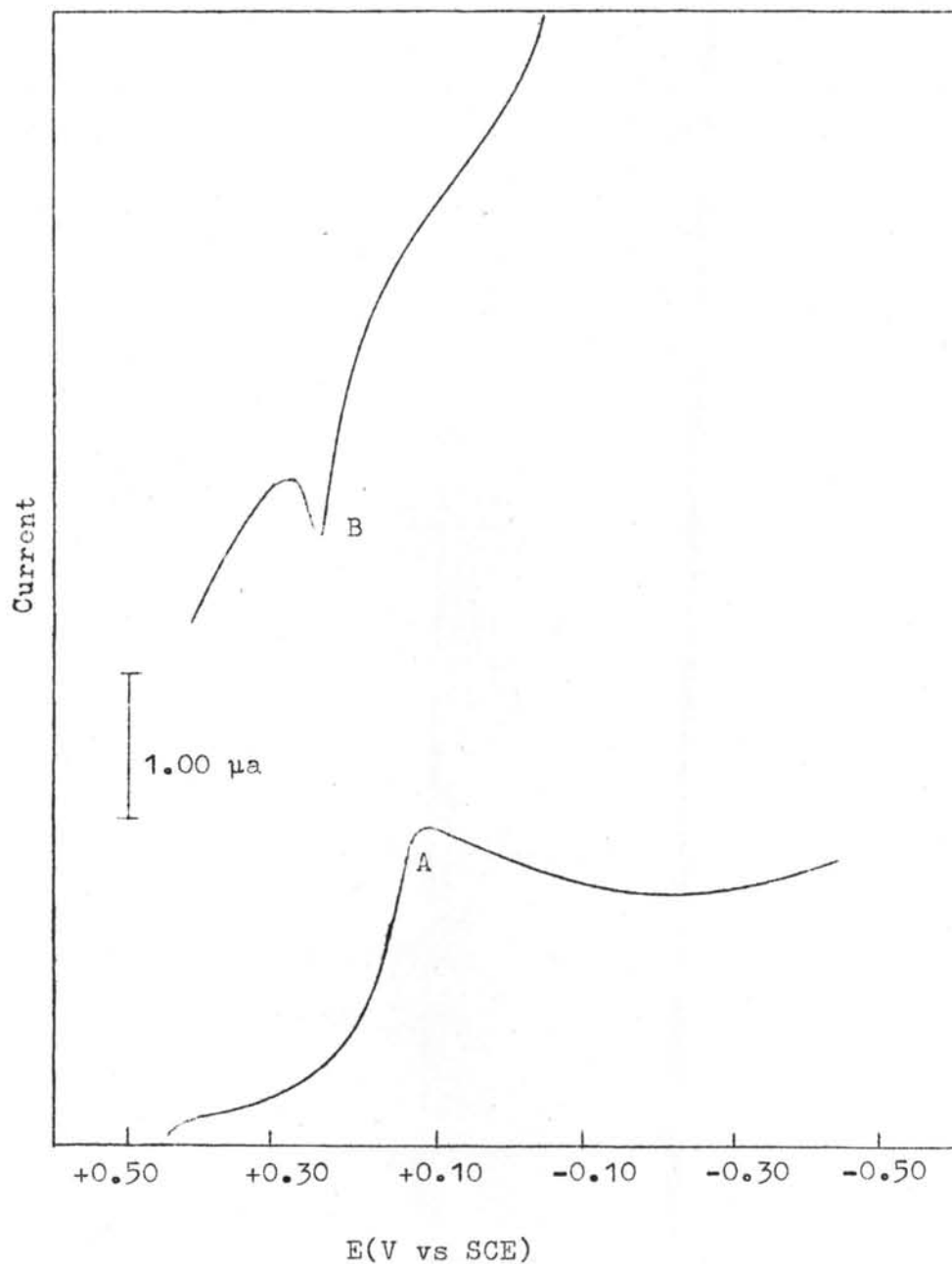


Figure 3 Voltammograms of Hg(II) ion in 0.1 M  $\text{KNO}_3$ ; A) cathodic voltammogram of  $100.0 \mu\text{g}/\text{cm}^3$  of Hg(II), and B) anodic stripping voltammogram after 20 minutes deposition of  $400.0 \text{ ng}/\text{cm}^3$  of Hg(II) solution.

Table 3 Anodic stripping peak currents of  $200.0 \text{ ng/cm}^3$  of Hg(II) in the presence of various concentrations of Cu(II) ion.

concn. of Cu(II) ion ( $\text{ng/cm}^3$ )	$i_{p,a}$ of Hg(II) ( $\mu\text{a}$ )
50.0	0.89
100.0	0.85
300.0	0.87
500.0	0.83
800.0	0.84
1000.0	0.87

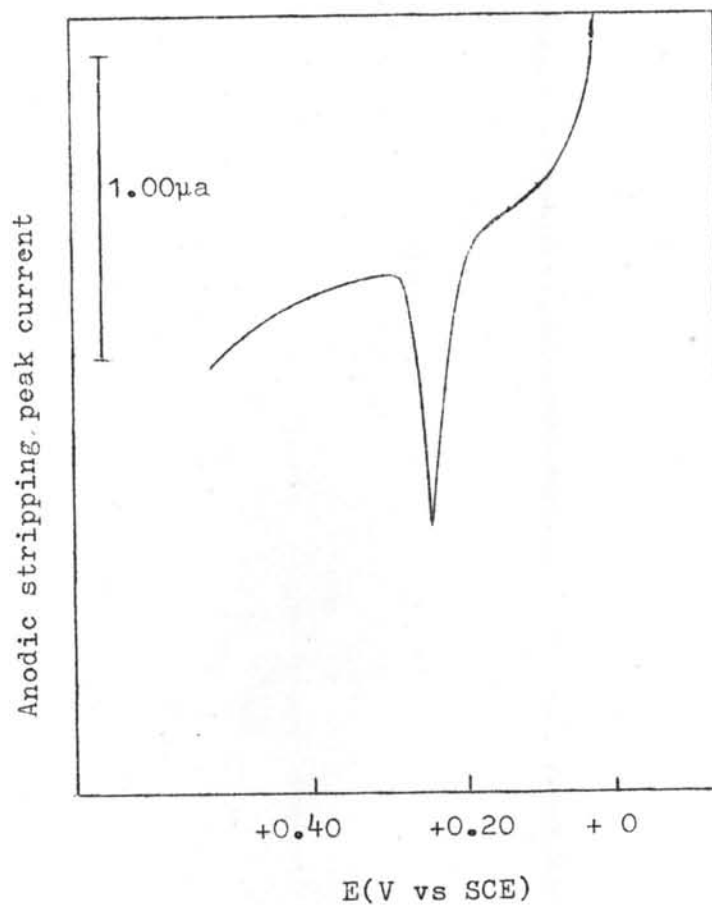


Figure 4

Anodic stripping voltammogram of  
200.0 ng/cm<sup>3</sup> of Hg(II) ion in the  
presence of 1.0 μg/cm<sup>3</sup> of Cu(II) ion  
after a 20 - minute - deposition.



Thus, the anodic stripping analysis of Hg(II) species was performed in 0.1 M  $\text{KNO}_3$  at pH 2 by electrodeposition at the potential of +0.10 V. For the concentration range 100.0 - 1000.0  $\text{ng/cm}^3$ , a 20 - minute electrodeposition was performed. Data of this study are shown in Table 4. A linear proportion between the anodic stripping peak current and the concentration of Hg(II) ion was resulted (see Figure 5) •

#### 4.1.1.2 Cu(II), Pb(II), Cd(II) and their mixtures

The cathodic voltammogram of each metal ion species in 0.1M  $\text{KNO}_3$  at pH 2 using the glassy carbon mercury plated "in situ" electrode, indicated a single peak at potential of -0.10 V for Cu(II), - 0.55 V for Pb(II), and - 0.73V for Cd(II). Thus, the deposition potential for the simultaneous analysis of Cu(II), Pb(II), and Cd(II) was chosen at V. At this potential, Zn(II) species is not reduced but Hg(II), Cu(II), Pb(II), and Cd(II) ions are reduced and form metal amalgam.

The cathodic and anodic stripping voltammograms of Cu(II), Pb(II), and Cd(II) ions are shown in Figures 6, 7, and 8, respectively. The anodic stripping voltammogram of each metal ion showed a single peak at +0.05 V for Cu(II), -0.50 V for Pb(II), and -0.68 V for Cd(II). Using a 20 - minute - deposition at potential of -0.80 V, the anodic stripping peak currents of these metal ion species in the concentration range of 10.0 - 100.0  $\text{ng/cm}^3$  were measured and the data are shown in Tables 5,6 and 7. The relationship between the anodic stripping peak

Table 4 The conditions for electrodeposition and data of anodic stripping analysis of Hg(II) ion in 0.1M KNO<sub>3</sub> at pH 2.

Deposition		Concentration of Hg(II) ( ng/cm <sup>3</sup> )	i <sub>p,a</sub> <sup>*</sup> ( $\mu$ a)
potential (V)	time (min.)		
+ 0.10	20	100.0	0.67 $\pm$ 0.01
		200.0	0.77 $\pm$ 0.01
		300.0	0.95 $\pm$ 0.03
		500.0	1.10 $\pm$ 0.02
		700.0	1.35 $\pm$ 0.04
		990.0	1.75 $\pm$ 0.07

\* average peak current  $\pm$  mean deviation of 3 trials

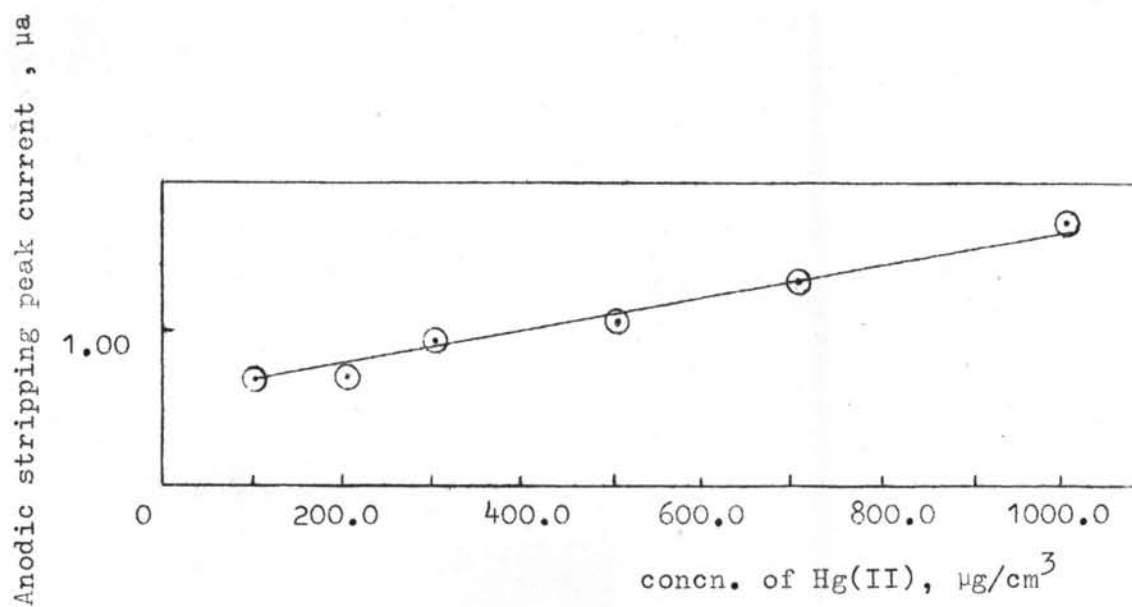


Figure 5 Dependence of the anodic stripping peak current on the concentration for anodic stripping analysis of Hg(II) species, using electrodeposition time of 20 minutes and scan rate 0.8V/minute.

Table 5 The conditions for electrodeposition and data of anodic stripping analysis of Cu(II) ion in 0.1M KNO<sub>3</sub> at pH 2

Deposition		Concentration of Cu(II) (ng/cm <sup>3</sup> )	$i_{p,a}^*$ ( $\mu$ a)
potential (V)	time (min)		
-0.80	20	5.0	2.48 $\pm$ 0.01
		10.0	4.03 $\pm$ 0.03
		30.0	9.57 $\pm$ 0
		50.0	17.12 $\pm$ 0.04
		79.0	24.97 $\pm$ 0.02
		99.0	31.43 $\pm$ 0.05

\* average peak current  $\pm$  mean deviation of 3 trials.

Table 6 The conditions for electrodeposition and data of anodic stripping analysis of Pb(II) ion in 0.1M  $\text{KNO}_3$  at pH 2

Deposition		Concentration of Pb(II) (ng/cm <sup>3</sup> )	$i_{p,a}^*$ ( $\mu\text{a}$ )
potential (V)	time (min)		
-0.80	20	15.0	1.03 $\pm$ 0.03
		30.0	4.25 $\pm$ 0.06
		50.0	7.25 $\pm$ 0.08
		59.0	10.75 $\pm$ 0.10
		70.0	12.50 $\pm$ 0.05
		100.0	19.50 $\pm$ 0.08

\* average peak current  $\pm$  mean deviation of 3 trials

Table 7 The conditions for electrodeposition and data of anodic stripping analysis of Cd(II) ion in 0.1M  $\text{KNO}_3$  at pH 2

Deposition		Concentration of Cd(II) (ng/cm <sup>3</sup> )	$i_{p,a}^*$ ( $\mu\text{a}$ )
potential (V)	time (min)		
-0.80	20	10.0	0.50 $\pm$ 0.01
		20.0	3.90 $\pm$ 0.03
		29.0	0.72 $\pm$ 0.02
		49.0	13.33 $\pm$ 0.05
		69.0	18.47 $\pm$ 0.07
		99.0	27.55 $\pm$ 0.10

\*

average peak current  $\pm$  mean deviation of 3 trials

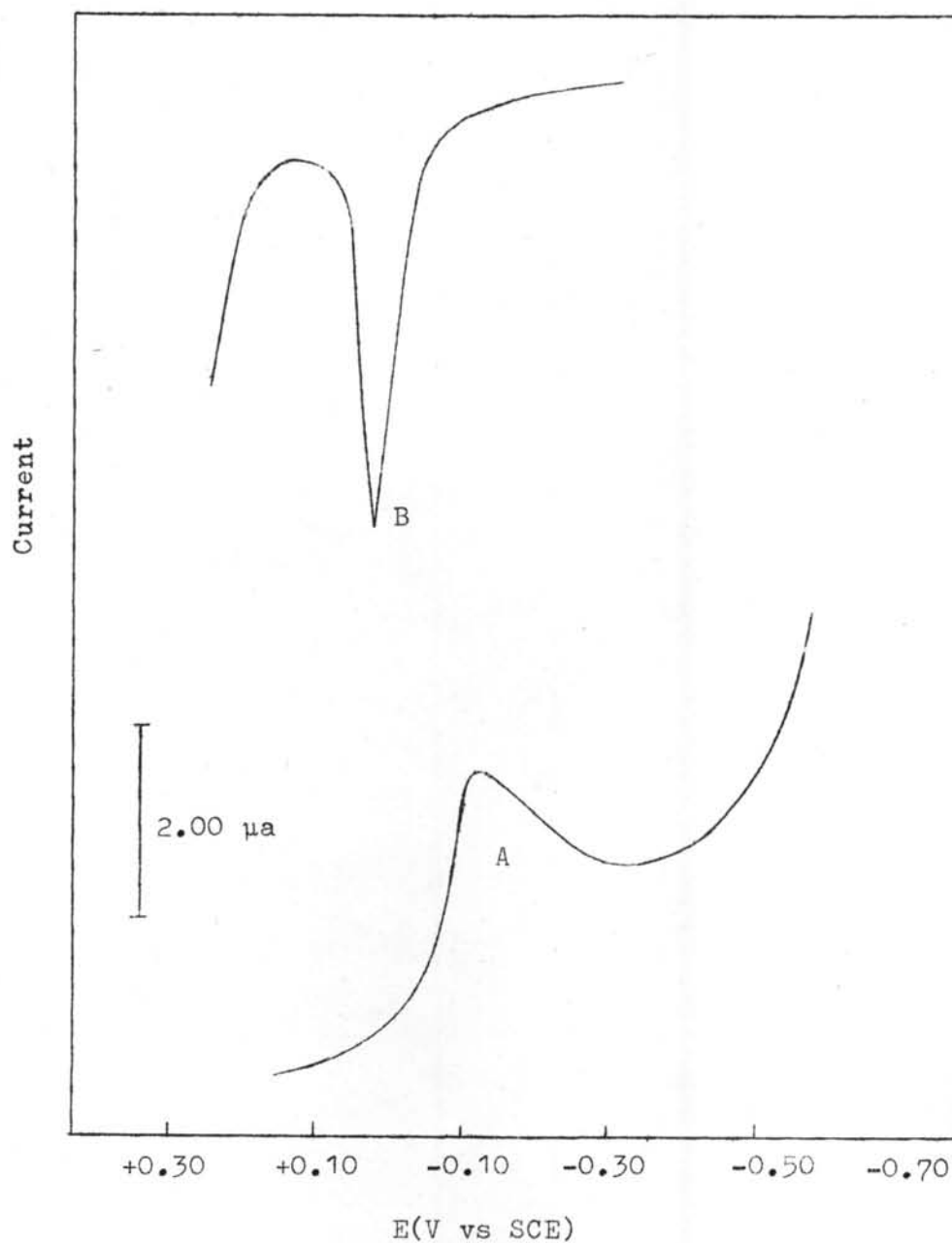


Figure 6 Voltammograms of  $\text{Cu(II)}$  ion in  $5.0 \mu\text{g}/\text{cm}^3$  of  $\text{Hg(II)}$  and  $0.1 \text{ M KNO}_3$  solution ; A) cathodic voltammogram of  $30.0 \mu\text{g}/\text{cm}^3$  of  $\text{Cu(II)}$ , and B) anodic stripping voltammogram after 20 minutes deposition of  $9.0 \text{ ng}/\text{cm}^3$  of  $\text{Cu(II)}$  solution.

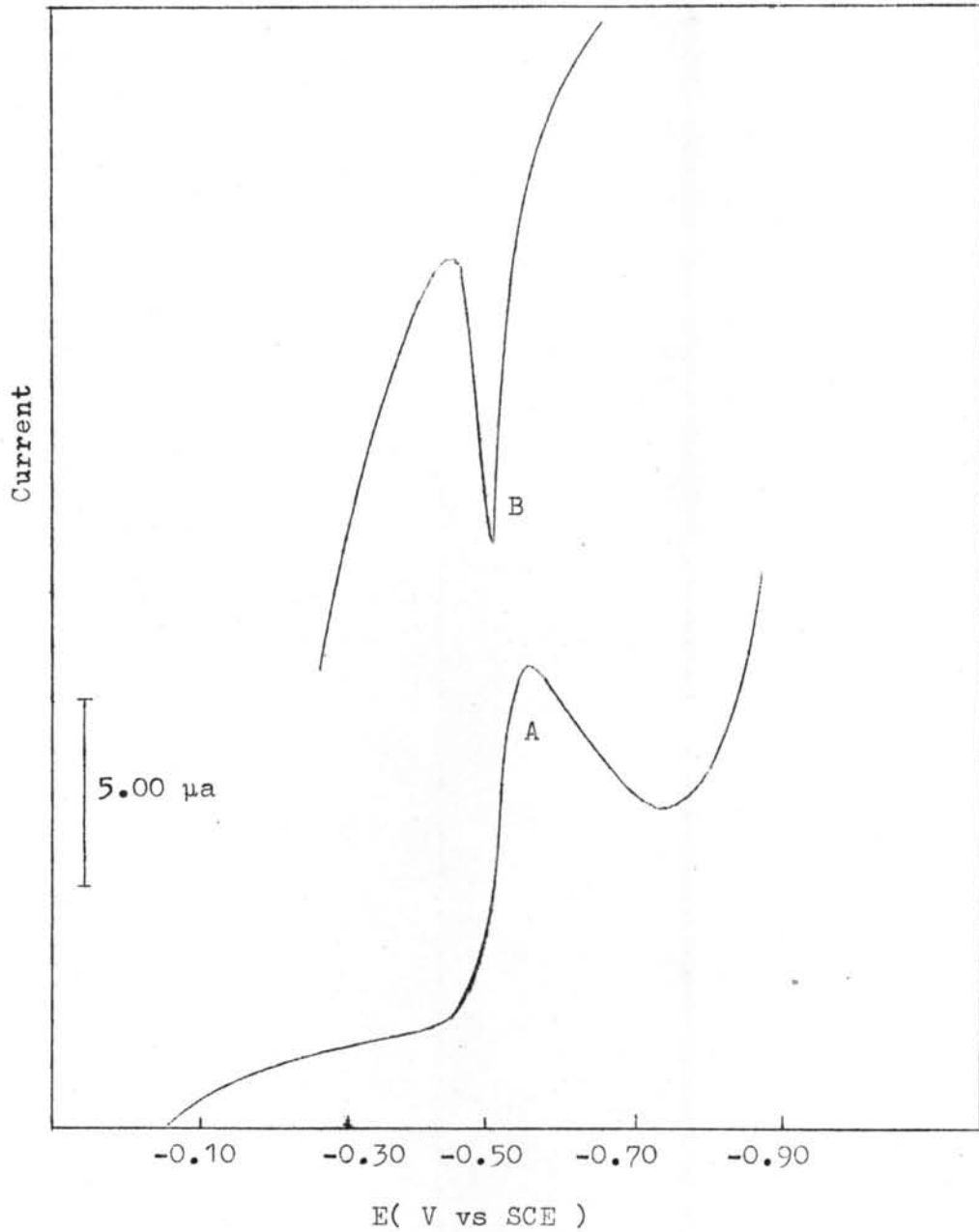


Figure 7 Voltammograms of Pb(II) ion in  $5.0 \mu\text{g}/\text{cm}^3$  of Hg(II) and  $0.1 \text{ M KNO}_3$  solution ; A) cathodic voltammogram of  $50.0 \mu\text{g}/\text{cm}^3$  of Pb(II), and B) anodic stripping voltammogram after 20 minutes deposition of  $59.0 \text{ ng}/\text{cm}^3$  of Pb(II) solution.



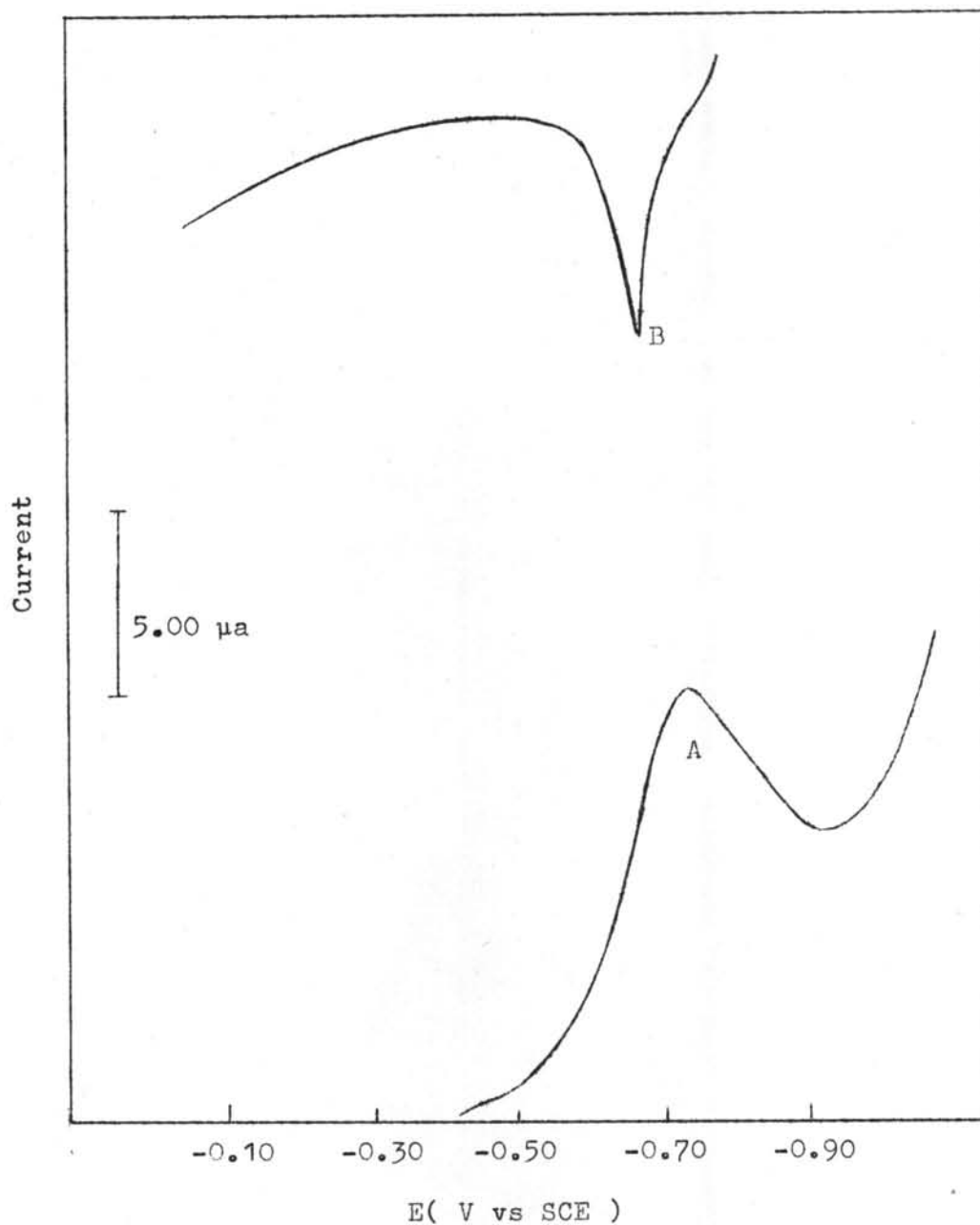


Figure 8 Voltammograms of Cd(II) ion in  $5.0 \mu\text{g}/\text{cm}^3$  of Hg(II) and  $0.1 \text{ M KNO}_3$  solution; A) cathodic voltammogram of  $50.0 \mu\text{g}/\text{cm}^3$  of Cd(II), and B) anodic stripping voltammogram after 20 minutes deposition of  $29.0 \text{ ng}/\text{cm}^3$  of Cd(II) solution.

current and its concentration is illustrated in Fig 9. The anodic stripping peak current of each species is directly proportional to the concentration in the range studied.

The simultaneous analysis of Cu(II), Pb(II), and Cd(II) was studied by standard addition technique from two mixture solutions of these metal ions in the presence of  $5.0 \mu\text{g}/\text{cm}^3$  of Hg(II) and  $0.1\text{M KNO}_3$  at pH 2. Mixture 1 contained  $49.0 \mu\text{g}/\text{cm}^3$  of Cu(II),  $30.0 \text{ ng}/\text{cm}^3$  of Pb(II),  $10.0 \text{ ng}/\text{cm}^3$  of Cd(II), and  $20.0 \text{ ng}/\text{cm}^3$  of Zn(II). Mixture 2 contained  $20.0 \text{ ng}/\text{cm}^3$  of Cu(II),  $20.0 \text{ ng}/\text{cm}^3$  of Pb(II),  $20.0 \text{ ng}/\text{cm}^3$  of Cd(II) and  $50.0 \text{ ng}/\text{cm}^3$  of Zn(II).

The anodic stripping voltammogram of the simultaneous analysis of Cu(II), Pb(II), and Cd(II) species in the mixture 2 is shown in Figure 10. The results of these analyses were tabulated as shown in Table 8 . These results indicated the maximum errors of 4.5 % for Cu(II), 3.6 % for Pb(II), and 5.0 % for Cd(II).

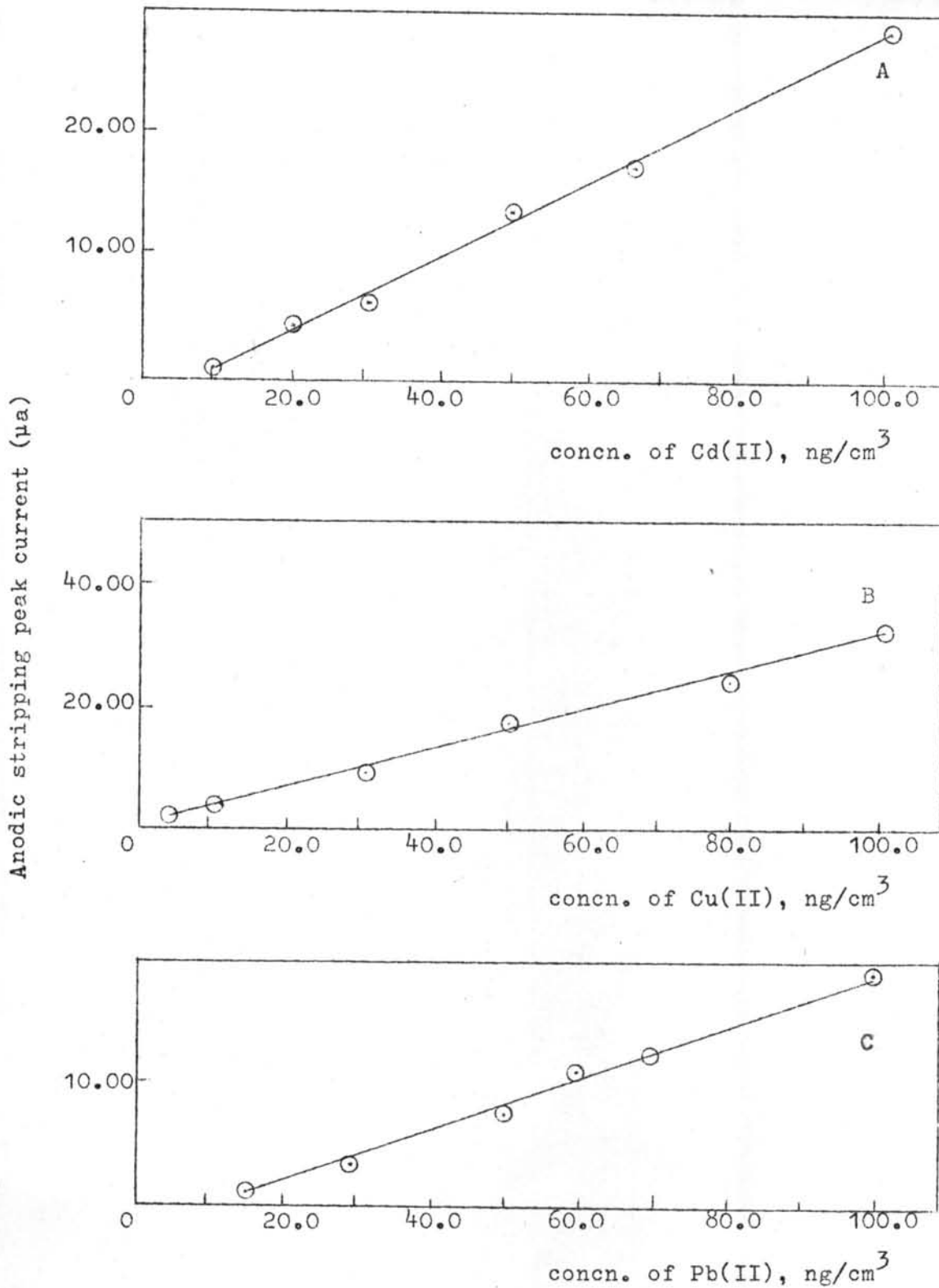


Figure 9 Dependences of anodic stripping peak currents on concentrations for anodic stripping analyses of A) Cd(II), B) Cu(II), and C) Pb(II) ions, using the electrodeposition time of 20 minutes and the scan rate of 0.8 V/minute.

Table 8 The simultaneous determinations of Cu(II), Pb(II), and Cd(II) ions in the mixtures by anodic stripping analysis

Mixture	Concn. of standard added (ng/cm <sup>3</sup> )			i <sub>p,a</sub> <sup>*</sup> (μa)			Concn. found <sup>*</sup> (ng/cm <sup>3</sup> )		
	Cu(II)	Pb(II)	Cd(II)	Cu(II)	Pb(II)	Cd(II)	Cu(II)	Pb(II)	Cd(II)
1	0	0	0	18.00 ±0.07	5.11 ±0.02	1.15 ±0.02	50.0 ±0.37	29.0 ±0.25	9.5 ±0.12
	14.8	14.9	14.8	23.22 ±0.05	7.71 ±0.03	2.93 ±0.02			
2	0	0	0	6.53 ± 0.04	8.12 ± 0.01	3.02 ±0.05	13.9 ± 0.31	48.2 ± 0.39	19.5 ± 0.41
	14.8	14.9	14.8	11.60 ± 0.05	10.58 ±0.06	5.30 ±0.03			

\* average ± mean deviation of 3 trials.

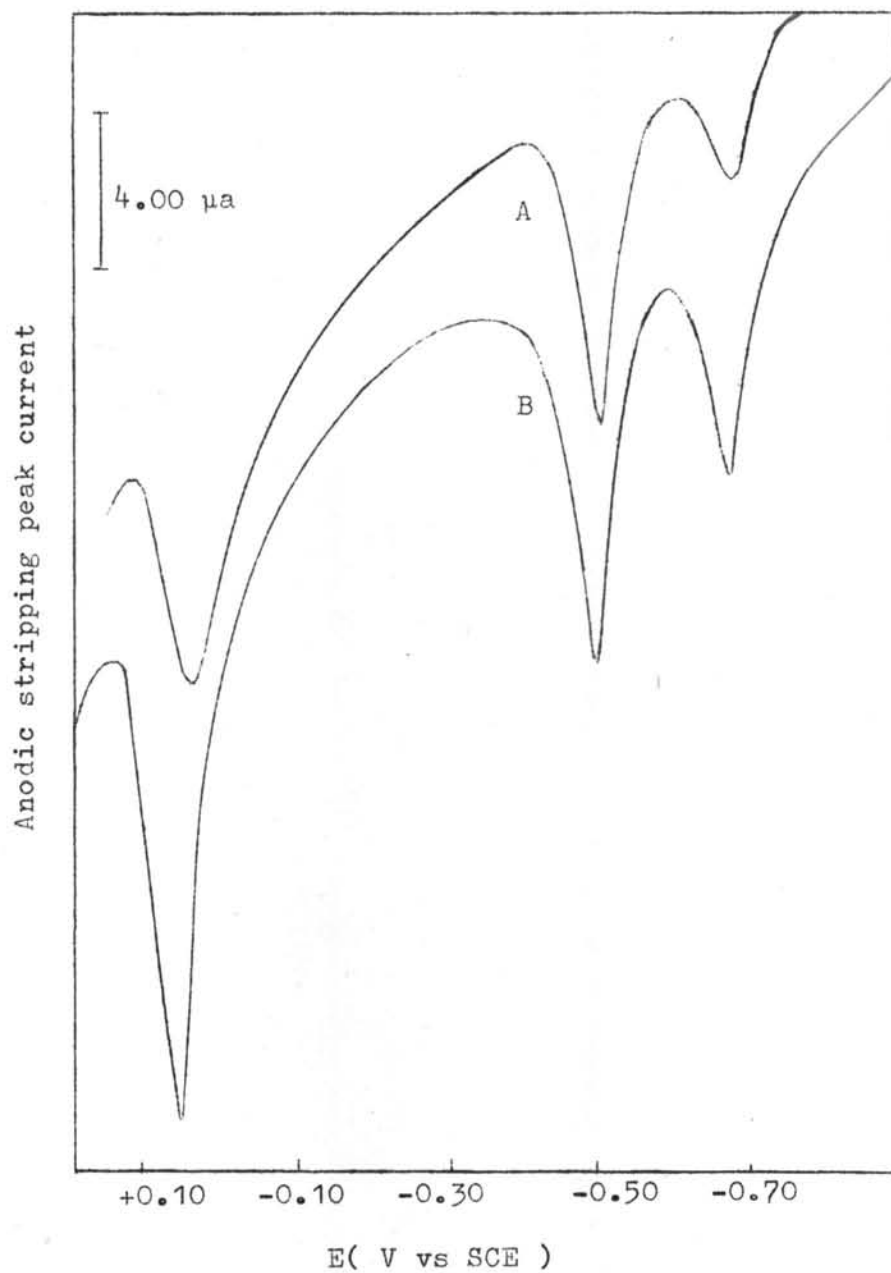


Figure 10 Anodic stripping voltammograms of A) mixture 2 and B) the mixture from the addition of  $14.8 \text{ ng/cm}^3$  of  $\text{Cd(II)}$ ,  $14.8 \text{ ng/cm}^3$  of  $\text{Cu(II)}$ , and  $14.9 \text{ ng/cm}^3$  of  $\text{Pb(II)}$  ions in the mixture 2 by using the scan rate of  $0.8 \text{ V/minute}$ .

#### 4.1.1.3 Zn(II)

Since the hydrogen peak covered the zinc peak in an acidic solution, Zn(II) species was determined in the acetate buffer pH 5.8. The cathodic voltammogram of Zn(II) species in the acetate buffer pH 5.8, using the glassy carbon mercury plated "in situ" electrode, showed a single peak at the potential of -1.20 V. Thus, the electrodeposition of Zn(II) was performed at -1.40 V and an anodic stripping peak was produced at -1.10 V (see Figure 11). The anodic stripping peak currents obtained are directly proportional to the concentrations of Zn(II) species in the range 10.0 - 100.0 ng/cm<sup>3</sup>. Data from this study are shown in Table 9 and Figure 12.

Since copper and zinc form intermetallic compound in mercury film or drop<sup>(51,52)</sup>, one single experiment for the simultaneous determination of Cd(II), Cu(II), Pb(II), and Zn(II) species by anodic stripping voltammetry cannot provide correct results for Cu(II) and Zn(II) species. The formation of Cu-Zn intermetallic compound decreased the height of zinc peak. However, copper formed this compound quantitatively, and the stoichiometry of the formation of Cu-Zn compound was concluded to be 1:1<sup>(53)</sup>.

It was reported that the interference of copper in the determination of zinc can be eliminated by the addition of an excess of gallium<sup>(51,54)</sup> and the gallium-copper intermetallic compound has a higher formation constant than the corresponding zinc - copper compound<sup>(55-58)</sup>. Abdullah et al. reported that

Table 9 The conditions for electrodeposition and data of anodic stripping analysis of Zn(II) ion in the acetate buffer pH 5.8.

Deposition		Concentration of Zn (II) ( ng/cm <sup>3</sup> )	$i_{p,a}^*$ ( $\mu$ a)
potential (V)	time (min)		
- 1.40	20	10.0	0.98 $\pm$ 0.02
		20.0	4.95 $\pm$ 0.05
		29.0	11.00 $\pm$ 0.01
		50.0	19.84 $\pm$ 0.04
		70.0	29.01 $\pm$ 0.10
		100.0	42.50 $\pm$ 0.08

\* average peak current  $\pm$  mean deviation of 3 trials.

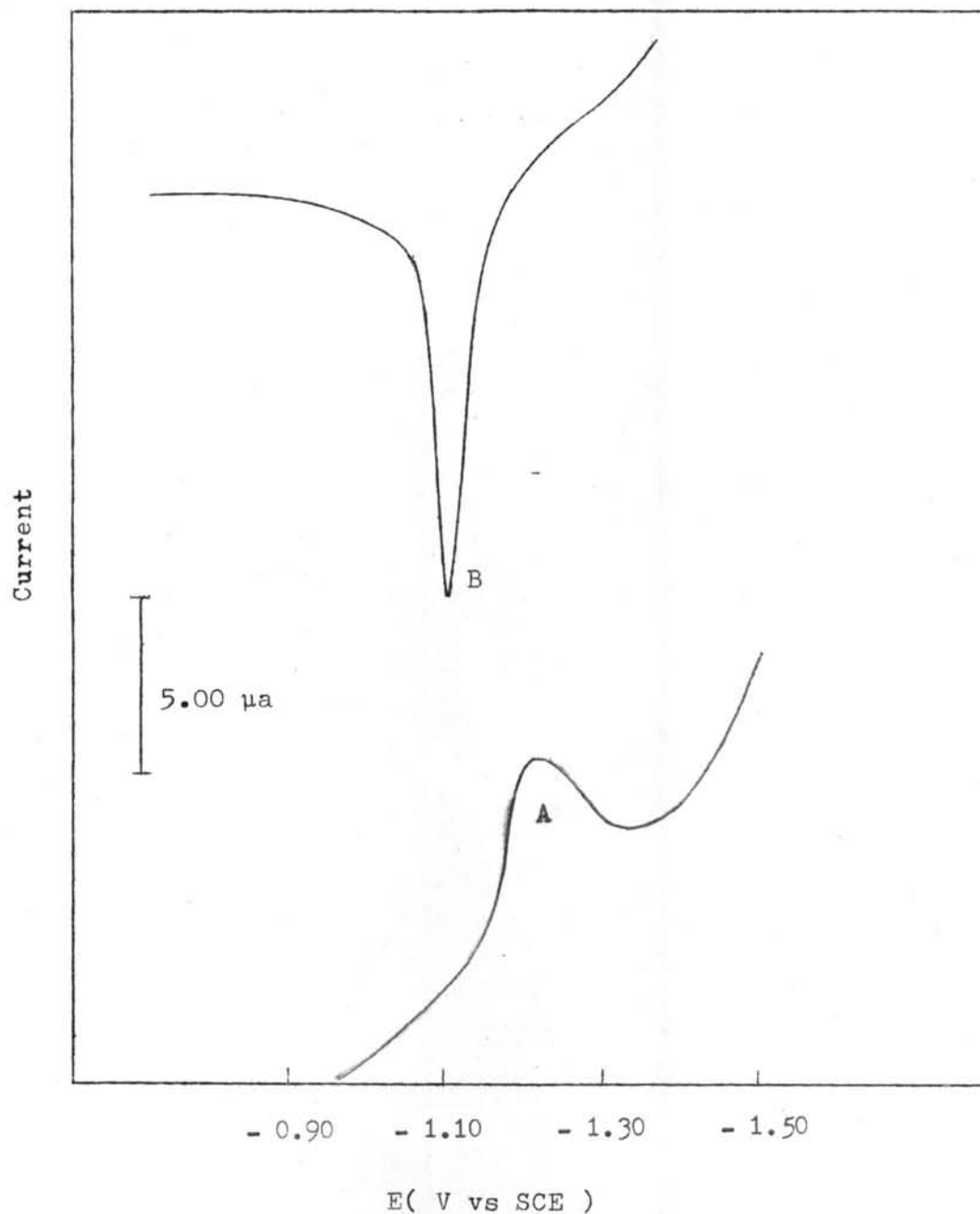


Figure 11 Voltammograms of Zn(II) ions in  $5.0 \mu\text{g}/\text{cm}^3$  of Hg(II) and the acetate buffer pH 5.8 : A) cathodic voltammogram of  $50.0 \mu\text{g}/\text{cm}^3$  of Zn(II), and B) anodic stripping voltammogram after a 20-minute-deposition of  $29.0 \text{ ng}/\text{cm}^3$  of Zn(II).



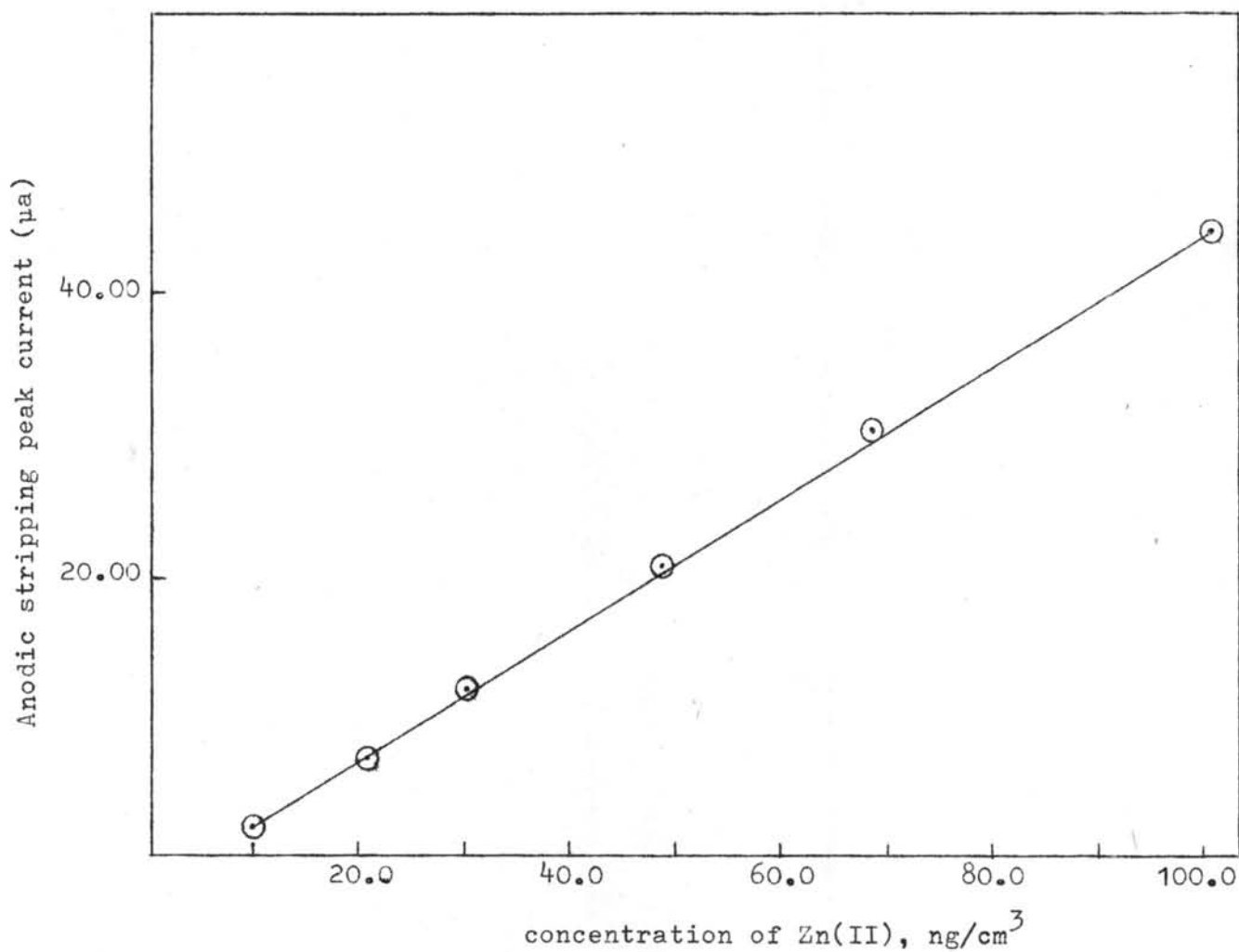


Figure 12 Dependence of the anodic stripping peak current on the concentration for anodic stripping analysis of Zn(II) ions, using an electrodeposition time of 20 minutes and the scan rate of 0.8 V/minute.

the molar ratio of Ga(III) : Cu(II) was 2:1<sup>(52)</sup>.

In this study, the cathodic voltammogram of Ga(III) in the acetate buffer pH 5.8 was not observed but a well defined stripping peak exhibited at -0.95 V (see Figure 13). The molar ratio of Ga(III) : Cu(II) for the intermetallic formation was determined from the decrease of gallium peak current on the successive addition of Cu(II) species. The experiment was performed in 5.0  $\mu\text{g}/\text{cm}^3$  of Hg(II) by using a 10-minute-electrodeposition at -1.40 V. The results are presented in Table 10 and Figure 14. It was found that the molar ratio of Ga(III) to Cu(II) bound as intermetallic compound in the acetate buffer pH 5.8 was 2:1.

The effect of Ga(III) concentration on the anodic stripping peak current of Zn(II) was also studied. The anodic stripping peak of Ga(III) interfered that of Zn(II) when the molar ratio of Ga(III) to Cu(II) was over 2000:1 (see Figure 15). Data of this study are shown in Table 11.

The anodic stripping analysis of Zn (II) species in the mixture containing Cd(II), Cu(II), Hg(II), Pb(II) and Zn(II) species by the addition of an excess of Ga(III) species was examined. The mixtures which consisted of different ratios of Cu(II) and Zn(II) such as  $[\text{Zn(II)}] < [\text{Cu(II)}]$ ,  $[\text{Zn(II)}] > [\text{Cu(II)}]$ , and  $[\text{Zn(II)}] = [\text{Cu(II)}]$  were selected. The concentrations of Cd(II), Cu(II), Pb(II), and Zn(II) species understudied were the maximum concentrations of these metal species in air

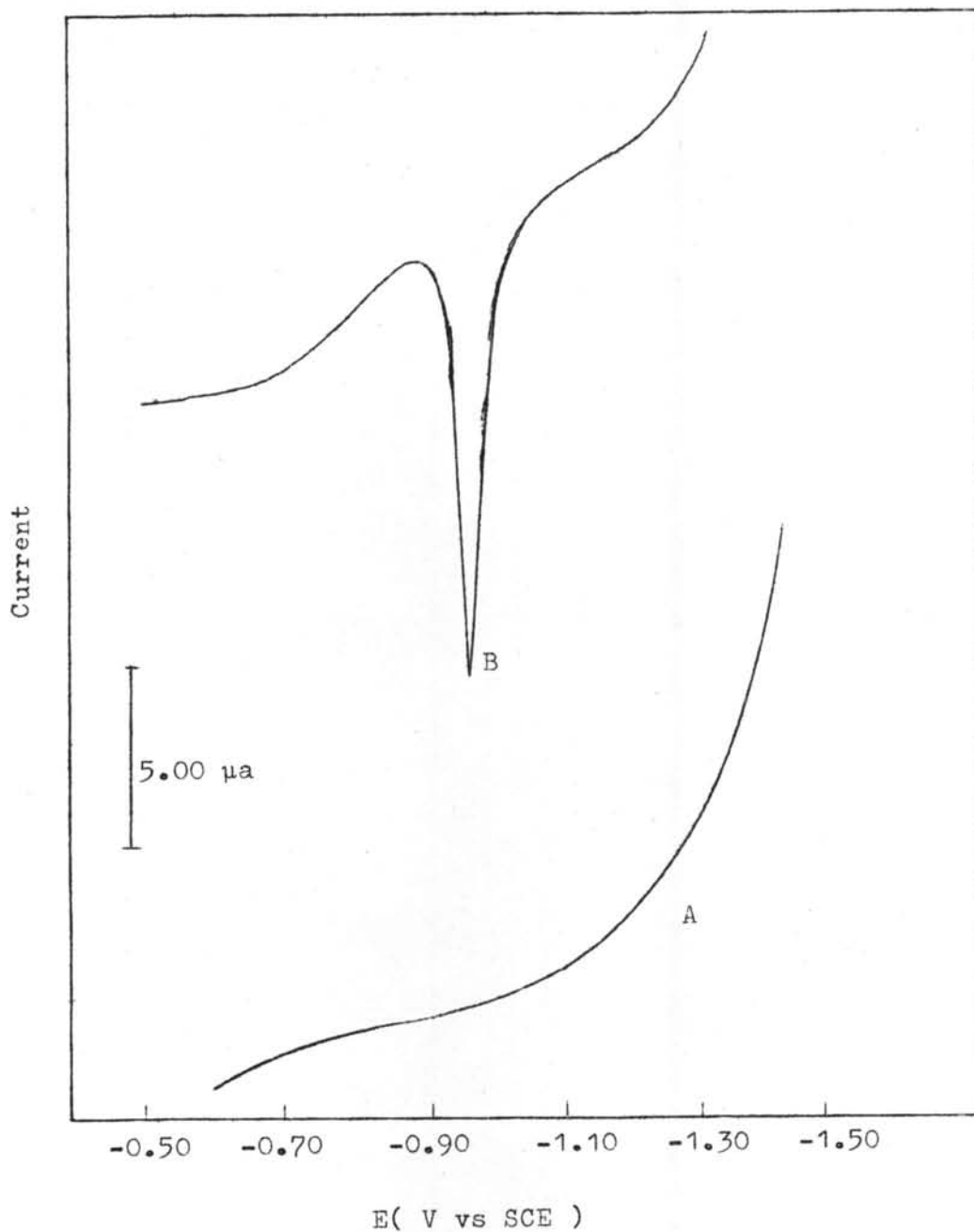


Figure 13 Voltammograms of Ga(III) ions in the acetate buffer pH 5.8 : A) cathodic voltammogram of  $100.0 \mu\text{g}/\text{cm}^3$  of Ga(III), and B) anodic stripping voltammogram after a 20-minute- deposition of  $100.0 \text{ ng}/\text{cm}^3$  of Ga(III).

Table 10 Effect of Cu(II) concentration on the anodic stripping peak current of Ga(III) in the acetate buffer pH5.8 ; using a 10-minute-deposition at -1.40 V and the scan rate rate of 0.8 V/min. The original concentration of Ga(III) was  $1.0 \mu\text{g}/\text{cm}^3$ .

Concn. of Cu(II) added ( $\text{ng}/\text{cm}^3$ )	$i_{p,a}^*$ ( $\mu\text{A}$ )
0	$19.81 \pm 0.44$
100.0	$16.20 \pm 0.37$
200.0	$12.80 \pm 0.25$
300.0	$8.61 \pm 0.32$
400.0	$4.23 \pm 0.22$
500.0	$1.02 \pm 0.15$
600.0	0

\* average  $\pm$  mean deviation of 3 trials.

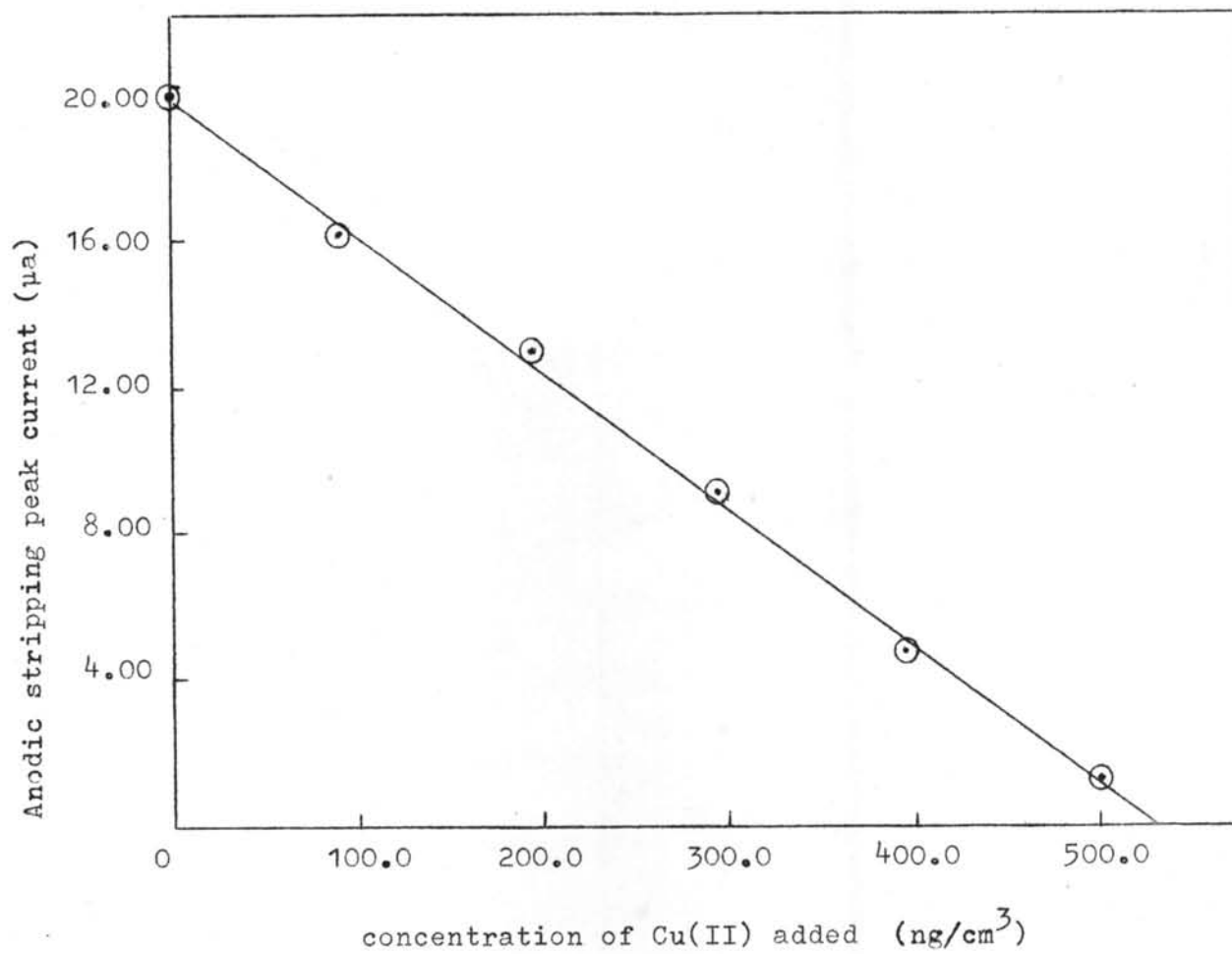


Figure 14 Dependence of anodic stripping peak currents of Ga(III) on the concentrations of Cu(II) species added.

Table 11 Effect of Ga(III) concentration on the anodic stripping peak current of Zn(II) at various concentration ratios of Ga(III) to Zn(II) in the acetate buffer pH 5.8; using a 20 - minute - deposition at - 1.40 V. The original concentration of Zn(II) was 20.0 ng/cm<sup>3</sup>.

Molar ratio, [ Ga(III) ] : [ Zn(II) ]	$i_{p,a}^*$ ( $\mu\text{a}$ )
100 : 1	6.02 $\pm$ 0.54
500 : 1	5.88 $\pm$ 0.42
1000 : 1	5.95 $\pm$ 0.63
1500 : 1	6.08 $\pm$ 0.32
2000 : 1	5.97 $\pm$ 0.19
2250 : 1	3.10 $\pm$ 0.23
2500 : 1	1.24 $\pm$ 0.34

\* average  $\pm$  mean deviation of 3 trials

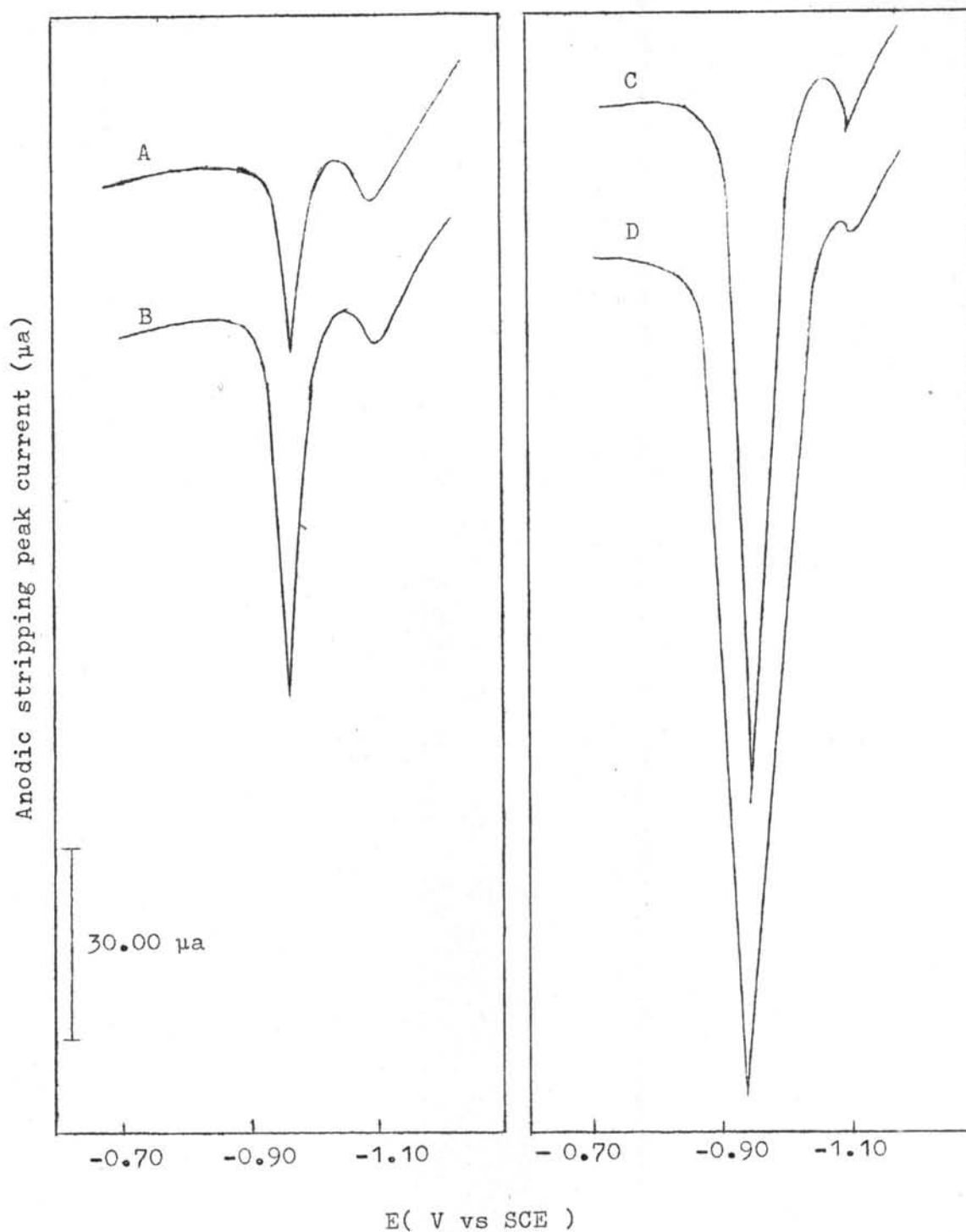


Figure 15

Anodic stripping voltammograms of the mixtures of Ga(III) and Zn(II) ions in the acetate buffer pH 5.8 at various molar ratios of Ga(III) to Zn(II) ions : A) 500 : 1 , B) 1000 : 1 , C) 2000 : 1 , D) 2250 : 1 .

particulates in Bangkok Metropolitan area which were reported by Kanatharana et al.<sup>(59)</sup> .

The data of these analyses are shown in Tables 12 - 14 for the mixtures containing Cd(II), Cu(II), Pb(II), Hg(II), and Zn(II) species, and in Tables 15 - 17 for the mixtures containing only Cu(II), Hg(II), and Zn(II) species. It was found that the anodic stripping peak current of Zn(II) increased on the addition of Ga(III), and reached a constant value when the molar ratio of Ga(III) to Cu(II) was more than 140:1 as seen in Tables 12 - 17. Thus, Pb(II) and Cd(II) did not interfere the determination of Zn(II) species by this method.

The hydrolysis of Ga(III) in the acetate buffer pH 5.8 to form an electroinactive Ga(III) was also reported<sup>(52,60)</sup>, and the other element which may be consisted in air particulate such as Ni(II) can be formed intermetallic compound with Ga(III)<sup>(52)</sup>. Therefore, the molar ratio of Ga(III) to Cu(II) as 200 : 1 was used in this study. If the maximum concentration of Cu(II) is  $50.0 \text{ ng/cm}^3$ , this value equals  $10.0 \text{ } \mu\text{g/cm}^3$  of Ga(III) solution. Thus, the Ga(III) concentration as  $10.0 \text{ } \mu\text{g/cm}^3$  was added to all air particulate samples. The concentrations of Zn(II) species in the standard mixtures of Cd(II), Cu(II), Hg(II), and Pb(II) were determined by standard addition method and their data are shown in Table 18. The maximum error obtained by these determinations is 4.6 % .



Table 12 Effect of Ga(III) concentration on the anodic stripping peak current of zinc in the mixture A : containing 20.0 ng/cm<sup>3</sup> of Zn(II), 50.0 ng/cm<sup>3</sup> of Cu(II), 30.0 ng/cm<sup>3</sup> of Pb(II), 10.0 ng/cm<sup>3</sup> of Cd(II), and 5.0 µg/cm<sup>3</sup> of Hg(II), in the acetate buffer pH 5.8 ; using a 20 - minute - deposition at - 1.40 V.

Molar ratio, [Ga(III)] : [Cu(II)]	$i_{p,a}^*$ (µa)	
	Zn	Ga
20 : 1	-	-
40 : 1	0.58 ± 0.09	15.08 ± 0.47
60 : 1	1.34 ± 0.12	20.60 ± 0.58
80 : 1	2.79 ± 0.15	25.43 ± 0.45
100 : 1	3.84 ± 0.21	31.35 ± 0.52
120 : 1	4.93 ± 0.27	37.92 ± 0.71
140 : 1	5.89 ± 0.34	42.68 ± 0.83
160 : 1	5.92 ± 0.25	47.04 ± 0.76
180 : 1	6.01 ± 0.30	53.60 ± 0.89

\* average ± mean deviation of 3 trials.

Table 13 Effect of Ga(III) concentration on the anodic stripping peak current of zinc in the mixture B : containing 50.0 ng/cm<sup>3</sup> of Zn(II), 20.0 ng/cm<sup>3</sup> of Cu(II), 30.0 ng/cm<sup>3</sup> of Pb(II), 10.0 ng/cm<sup>3</sup> of Cd(II), and 5.0 μg/cm<sup>3</sup> of Hg(II), in the acetate buffer pH5.8; using a 20-minute - deposition at -1.40 V.

Molar ratio, [ Ga(III) ] : [ Cu(II) ]	$i_{p,a}^*$ (μa)	
	Zn	Ga
25 : 1	-	-
50 : 1	3.82 ± 0.52	23.02 ± 0.87
100 : 1	9.13 ± 0.60	28.46 ± 0.80
150 : 1	17.89 ± 0.54	32.33 ± 0.97
200 : 1	18.12 ± 0.57	35.85 ± 0.90
250 : 1	18.26 ± 0.72	39.21 ± 0.88
300 : 1	17.93 ± 0.65	45.73 ± 1.12
350 : 1	18.14 ± 0.89	50.92 ± 1.08

\* average ± mean deviation of 3 trials.

Table 14 Effect of Ga(III) concentration on the anodic stripping peak current of zinc in the mixture C : containing 50.0 ng/cm<sup>3</sup> of Zn(II), 50.0 ng/cm<sup>3</sup> of Cu(II), 30.0 ng/cm<sup>3</sup> of Pb(II), 10.0 ng/cm<sup>3</sup> of Cd(II), and 5.0 μg/cm<sup>3</sup> of Hg(II), in the acetate buffer pH 5.8; using a 20-minute - deposition at - 1.40 V.

Molar ratio, [Ga(III)] : [Cu(II)]	$i_{p,a}^*$ (μa)	
	Zn	Ga
20 : 1	-	-
40 : 1	3.21 ± 0.15	13.28 ± 0.63
60 : 1	5.43 ± 0.21	18.15 ± 0.55
80 : 1	8.73 ± 0.34	24.71 ± 0.68
100 : 1	10.54 ± 0.28	30.32 ± 0.70
120 : 1	15.93 ± 0.47	36.47 ± 0.56
140 : 1	18.97 ± 0.41	44.05 ± 0.63
160 : 1	19.03 ± 0.50	51.06 ± 0.59
180 : 1	19.10 ± 0.33	57.48 ± 0.81

\* average ± mean deviation of 3 trials

Table 15 Effect of Ga(III) concentration of the anodic stripping peak current of zinc in the mixture D: containing 20.0 ng/cm<sup>3</sup> of Zn(II), 50.0 ng/cm<sup>3</sup> of Cu(II), and 5.0 µg/cm<sup>3</sup> of Hg(II), in the acetate buffer pH 5.8; using a 20 - minute - deposition at - 1.40 V.

Molar ratio , [Ga(III)] : [Cu(II)]	$i_{p,a}^*$ (µa)	
	Zn	Ga
40 : 1	-	-
60 : 1	2.06 ± 0.22	23.60 ± 0.41
80 : 1	3.05 ± 0.25	28.13 ± 0.57
100 : 1	4.33 ± 0.32	33.20 ± 0.52
120 : 1	4.80 ± 0.37	38.41 ± 0.73
140 : 1	5.93 ± 0.46	42.93 ± 0.81
160 : 1	6.16 ± 0.59	48.0 ± 0.95
180 : 1	6.06 ± 0.42	55.46 ± 0.98

\* average ± mean deviation of 3 trials.

Table 16 Effect of Ga(III) concentration on the anodic stripping peak current of zinc in the mixture E : containing 50.0 ng/cm<sup>3</sup> of Zn(II), 20.0 ng/cm<sup>3</sup> of Cu(II) , and 5.0 μg/cm<sup>3</sup> of Hg(II), in the acetate buffer pH 5.8; using a 20 - minute - deposition at - 1.40 V.

Molar ratio , [Ga(III)] : [Cu(II)]	$i_{p,a}^*$ (μa)	
	Zn	Ga
25 : 1	-	-
50 : 1	2.6 ± 0.13	25.06 ± 0.67
100 : 1	8.53 ± 0.42	30.24 ± 0.74
150 : 1	17.06 ± 0.65	35.85 ± 0.83
200 : 1	17.46 ± 0.79	38.66 ± 0.71
250 : 1	18.23 ± 0.86	41.13 ± 0.94
300 : 1	17.92 ± 0.54	47.93 ± 0.86
350 : 1	17.86 ± 0.43	52.57 ± 1.05

\* average ± mean deviation of 3 trials.

Table 17 Effect of Ga(III) concentration on the anodic stripping peak current of zinc in the mixture F: Containing 50.0 ng/cm<sup>3</sup> of Zn(II), 50.0 ng/cm<sup>3</sup> of Cu(II), and 5.0 μg/cm<sup>3</sup> of Hg(II), in the acetate buffer pH 5.8; using a 20 - minute - deposition at - 1.40 V.

Molar ratio , [Ga(III)] : [Cu(II)]	$i_{p,a}^*$ (μa)	
	Zn	Ga
40 : 1	-	-
60 : 1	2.66 ± 0.08	18.40 ± 0.96
80 : 1	10.26 ± 0.56	25.33 ± 0.81
100 : 1	12.40 ± 0.47	30.72 ± 0.75
120 : 1	15.46 ± 0.52	38.13 ± 0.86
140 : 1	18.93 ± 0.61	46.43 ± 1.15
160 : 1	18.89 ± 0.73	52.0 ± 0.97
180 : 1	19.01 ± 0.45	59.24 ± 1.08

\* average ± mean deviation of 3 trials.

Table 18

The determination of Zn(II) ion in the mixtures by anodic stripping analysis

Concn. of metal species in the mixture	Concn. of standard Zn(II) added	$i_{p,a}^*$ of Zn(II) ( $\mu a$ )	Concn. of Zn(II) found* ( $ng/cm^3$ )
(1) 20.0 $ng/cm^3$ Zn(II) 50.0 $ng/cm^3$ Cu(II) 30.0 $ng/cm^3$ Pb(II) 10.0 $ng/cm^3$ Cd(II) 5.0 $\mu g/cm^3$ Hg(II)	} none	6.02 $\pm$ 0.04	19.20 $\pm$ 0.68
(1)	24.0 $ng/cm^3$ Zn(II)	13.79 $\pm$ 0.12	
(2) 50.0 $ng/cm^3$ Zn(II) 20.0 $ng/cm^3$ Cu(II) 30.0 $ng/cm^3$ Pb(II) 10.0 $ng/cm^3$ Cd(II) 5.0 $\mu g/cm^3$ Hg(II)	} none	18.67 $\pm$ 0.20	51.0 $\pm$ 0.80
(2)	49.0 $ng/cm^3$ Zn(II)	36.60 $\pm$ 0.60	

Table 18 (Continued)

Concn. of metal species in the mixture	Concn. of standard Zn(II) added	$i_{p,a}^*$ of Zn(II) ( $\mu a$ )	Concn. of Zn(II) found* ( $ng/cm^3$ )
(3) 50.0 $ng/cm^3$ Zn(II) 50.0 $ng/cm^3$ Cu(II) 30.0 $ng/cm^3$ Pb(II) 10.0 $ng/cm^3$ Cd(II) 5.0 $\mu g/cm^3$ Hg(II)	} none	19.02 $\pm$ 0.45	52.30 $\pm$ 0.73
(3)	49.0 $ng/cm^3$ Zn(II)	36.83 $\pm$ 0.80	

\* average  $\pm$  mean deviation of 3 trials



#### 4.1.2 Determination of metal species in air particulate samples

For the determination of metal species in air particulate samples, firstly, anodic stripping analysis of Hg(II) was performed ; secondly, the simultaneous anodic stripping analysis of Cd(II), Cu(II), and Pb(II) was proceeded, and finally the anodic stripping voltammetry of Zn(II) was analyzed. The results of these anodic stripping analyses are listed in Tables 19 - 23.

No mercury was found in the air particulate samples since the detection limit for determining Hg(II) at the described conditions was as high as  $0.1 \mu\text{g}/\text{cm}^3$  (see Figure 5). The detection limits of Cd(II), Cu(II), Pb(II), and Zn(II) were  $10.0 \text{ ng}/\text{cm}^3$ ,  $5.0 \text{ ng}/\text{cm}^3$ ,  $15.0 \text{ ng}/\text{cm}^3$ , and  $10.0 \text{ ng}/\text{cm}^3$ , respectively (see Figures 9, and 12).

#### 4.2 Atomic absorption spectrophotometry

##### 4.2.1 Flame atomic absorption spectrophotometry.

In order to analyze Cd(II), Cu(II), Pb(II), and Zn(II) species in air particulate samples by atomic absorption technique, it was necessitated to study the relationships between the absorbances and the concentrations of each metal species in both the single metal ion solution and the mixture of these metal species.

Table 19 Range of cadmium contents in air particulate samples at each station by ASV method.

Station	Concn. * ( $\mu\text{g}/\text{m}^3$ )	
	Min.	Max.
Patumwan	n	$4.27 \pm 0.16$
Ratchaprasong	n	n
Chit Lom	n	$2.83 \pm 0.57$
Phloenchit	n	$5.26 \pm 0.14$
Sukhumvit 10 (san Sam Rarn)	n	$4.16 \pm 0.22$
Sukhumvit 21 (Asoke)	n	$5.09 \pm 0.20$

\* average  $\pm$  mean deviation of 3 trials.

n undetectable

Table 20 Range of copper contents in air particulate samples at each station by ASV method.

Station	Concn. * ( $\mu\text{g}/\text{m}^3$ )	
	Min.	Max.
Patumwan	$3.76 \pm 0.20$	$16.21 \pm 1.74$
Ratchaprasong	n	$8.47 \pm 0.11$
Chit Lom	$9.70 \pm 0.17$	$13.81 \pm 0.69$
Phloenchit	$6.44 \pm 0.55$	$12.42 \pm 0.86$
Sukhumvit 10 (San Sam Rarn)	$5.62 \pm 0.32$	$23.15 \pm 1.02$
Sukhumvit 21 (Asoke)	$3.85 \pm 0.77$	$10.91 \pm 0.35$

\* average  $\pm$  mean deviation of 3 trials.

n undetectable

Table 21 Range of lead contents in air particulate samples at each station by ASV method.

Station	Concn. * ( $\mu\text{g}/\text{m}^3$ )	
	Min.	Max.
Patumwan	14.61 $\pm$ 0.67	27.52 $\pm$ 0.42
Ratchaprasong	2.96 $\pm$ 0.04	17.60 $\pm$ 0.05
Chit Lom	7.97 $\pm$ 1.52	36.78 $\pm$ 0.11
Phloenchit	2.38 $\pm$ 0.51	47.25 $\pm$ 1.64
Sukhumvit 10 (San Sam Rern)	1.24 $\pm$ 0.10	35.90 $\pm$ 1.00
Sukhumvit 21 (Asoke)	0.60 $\pm$ 0.06	28.36 $\pm$ 0.75

\* average  $\pm$  mean deviation of 3 trials.

n undetectable

Table 22 Range of zinc contents in air particulate samples at each station by ASV method

Station	Concn. * ( $\mu\text{g}/\text{m}^3$ )	
	Min.	Max.
Patumwan	14.02 $\pm$ 0.63	15.06 $\pm$ 0.08
Ratchaprasong	10.84 $\pm$ 0.54	15.70 $\pm$ 0.32
Chit Lom	11.22 $\pm$ 0.45	13.95 $\pm$ 0.41
Phloenchit	9.36 $\pm$ 0.10	11.52 $\pm$ 0.89
Sukhumvit 10 (San Sam Rarn)	10.33 $\pm$ 0.57	14.35 $\pm$ 0.36
Sukhumvit 21 (Asoke)	n	9.50 $\pm$ 0.22

\* Average  $\pm$  mean deviation of 3 trials.

n undetectable

Table 23 Average contents of metal species in air particulates at each station by ASV method.

Station	Concentration * ( $\mu\text{g}/\text{cm}^3$ )				
	Cadmium	Copper	Mercury	Lead	Zinc
Patumwan	2.02 $\pm$ 2.02	10.23 $\pm$ 4.31	n	23.87 $\pm$ 8.43	14.36 $\pm$ 0.32
Ratchaprasong	n	4.23 $\pm$ 2.21	n	8.13 $\pm$ 5.04	12.44 $\pm$ 1.62
Chit Lom	0.70 $\pm$ 1.07	11.91 $\pm$ 1.35	n	19.11 $\pm$ 8.82	12.86 $\pm$ 0.88
Phloenchit	2.36 $\pm$ 2.35	9.33 $\pm$ 1.94	n	21.54 $\pm$ 13.36	10.84 $\pm$ 0.74
Sukhumvit 10 (San Sam Rarn)	1.27 $\pm$ 1.90	13.05 $\pm$ 5.58	n	16.59 $\pm$ 9.65	11.58 $\pm$ 1.37
Sukhumvit 21 (Asoke)	2.10 $\pm$ 2.11	8.36 $\pm$ 2.26	n	14.61 $\pm$ 11.92	4.36 $\pm$ 4.37

\* average  $\pm$  mean deviation of 4 air particulate samples.

n undetectable

The relationship between the absorbance and the concentration of the metal species in the range of 0.1 - 3.0  $\mu\text{g}/\text{cm}^3$  was examined. It resulted in a linear relationship for the single metal ion solution (see Table 24, and Figure 16 A,B,C and D). However, when the concentration of each metal species in the mixture exceeded 1.0  $\mu\text{g}/\text{cm}^3$ , the linear relationship was no longer occupy (see Table 25).

#### 4.2.2 Flameless atomic absorption spectrophotometry.

Mercury in the air particulate samples was determined by flameless atomic absorption spectrophotometry. The mercury content in the sample solution was directly read from the instrument. The concentration effect of other metal species in the mixture on the absorbance for the determination of mercury by this technique was studied. Data of this study are shown in Table 26. It was found that no interference was observed for the determination of mercury in the presence of Cd(II), Cu(II), Pb(II), and Zn(II) species in the concentration range of 0.3 - 2.0  $\mu\text{g}/\text{cm}^3$ .

#### 4.4.3 Determinations of metal species in air particulate samples.

Cadmium, copper, lead, and zinc in air particulate samples were determined by flame atomic absorption method and mercury was determined by flameless atomic absorption

Table 24 Relationship between the absorbance and concentration of each metal species in the single metal ion solution.

Concn. of metal species ( $\mu\text{g}/\text{cm}^3$ )	Absorbance			
	Cd(II)	Cu(II)	Pb(II)	Zn(II)
3.00	T	T	0.0477	1.0360
2.00	0.3468	0.0362	0.0315	0.7212
1.00	0.1739	0.0186	0.0177	0.3820
0.80	T	T	T	T
0.50	0.0731	0.0088	0.0075	0.1733
0.10	0.0246	0.0022	0.0022	0.0315

T no measurement.



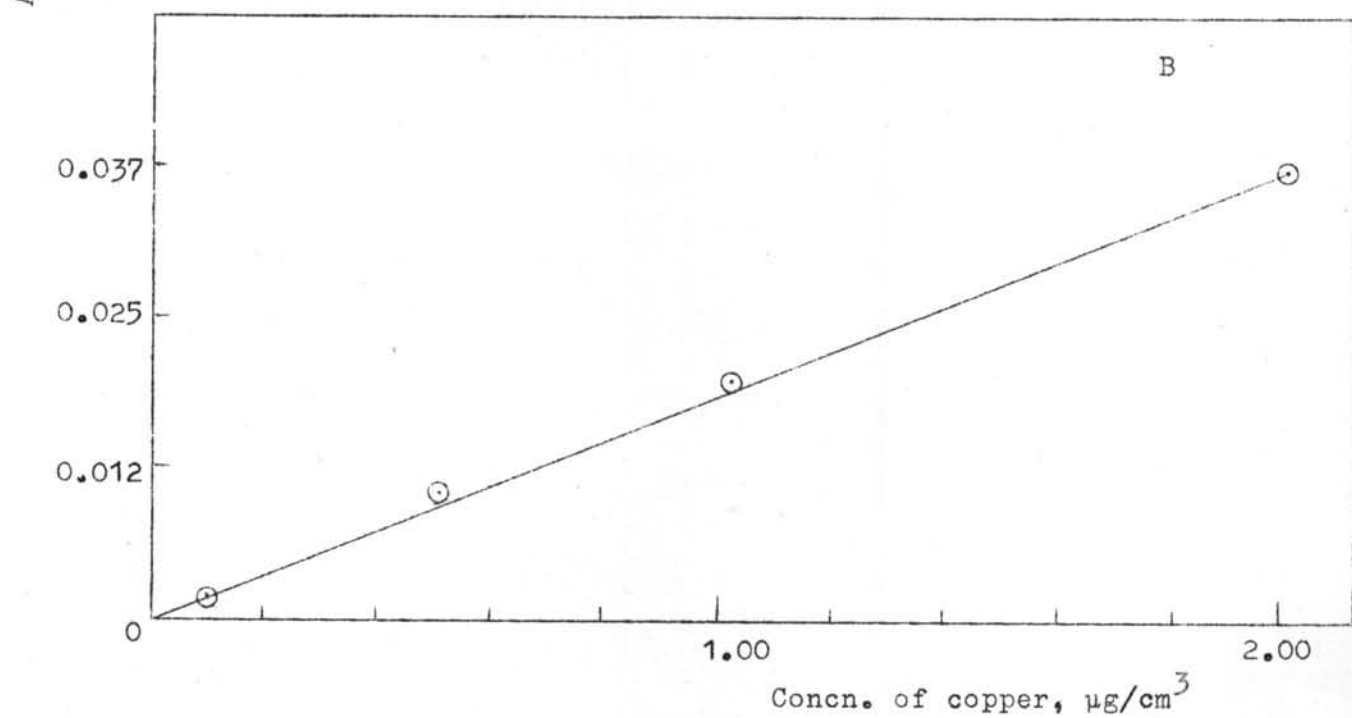
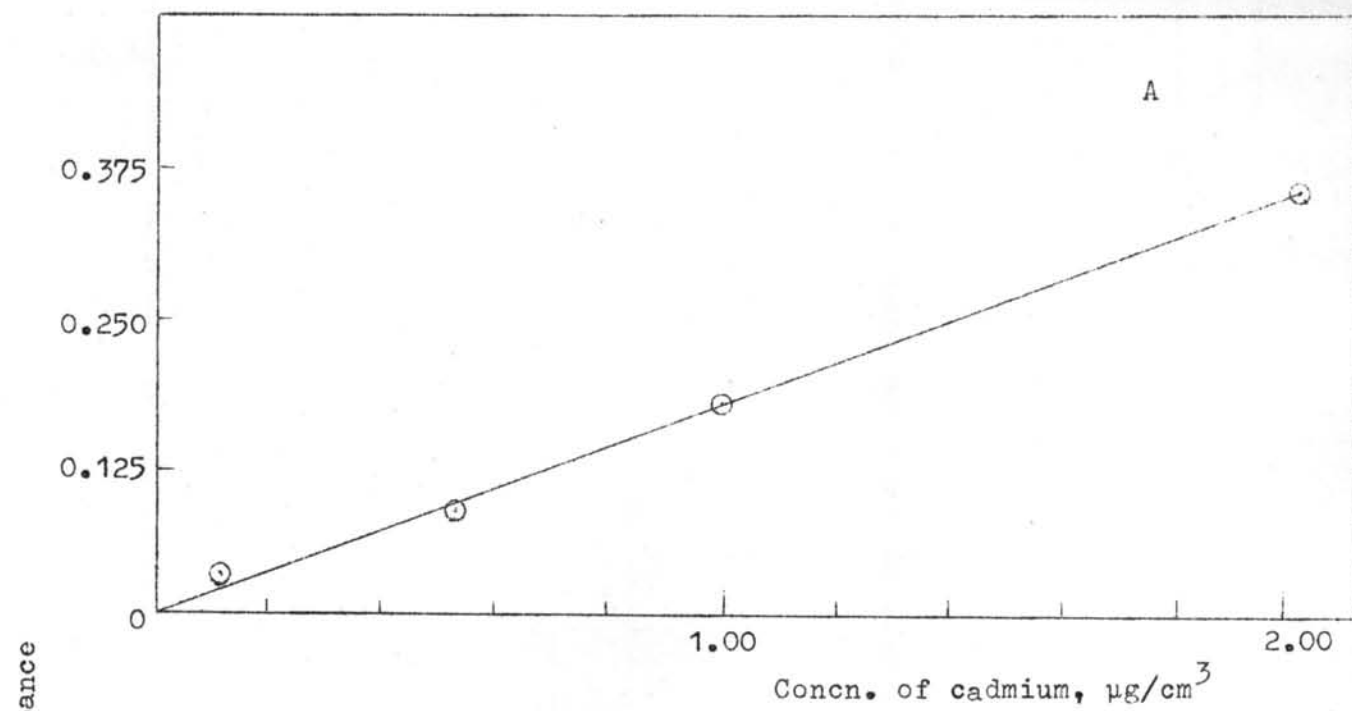


Figure 16 A and B Relationships between absorbances and concentrations for A) cadmium and B) copper.

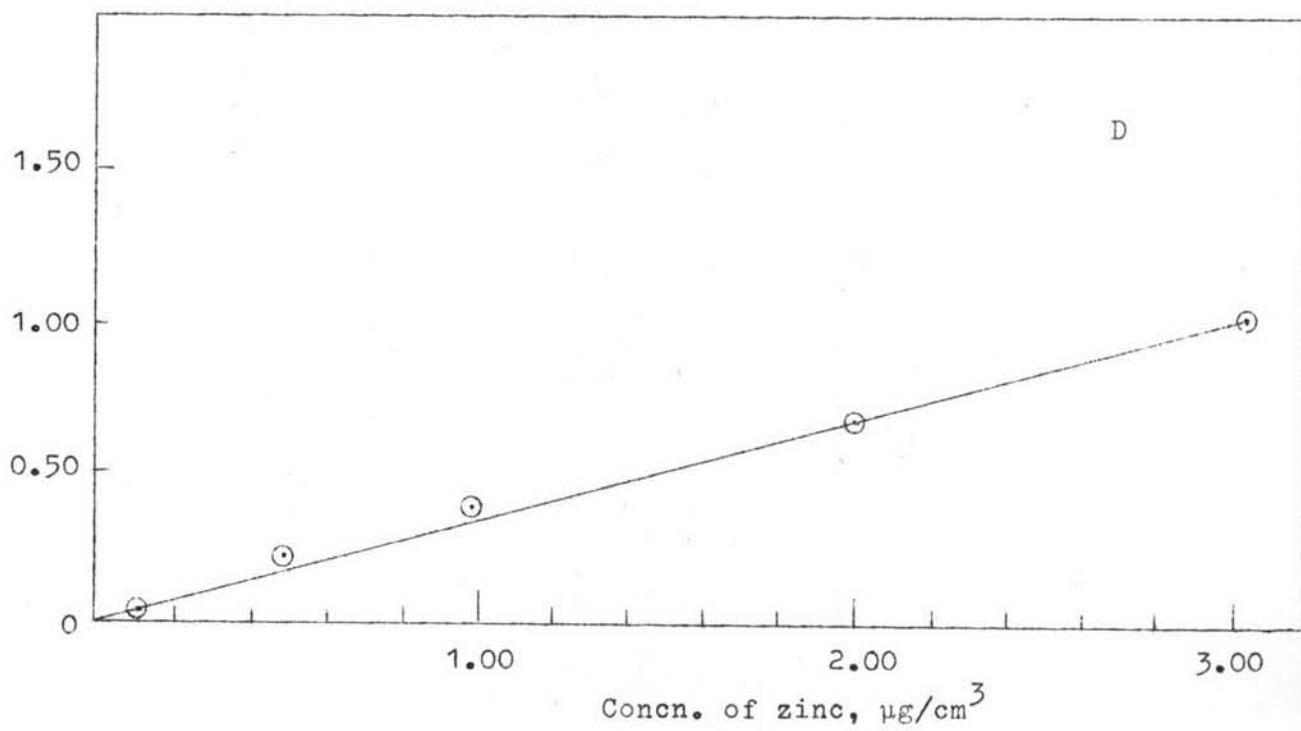
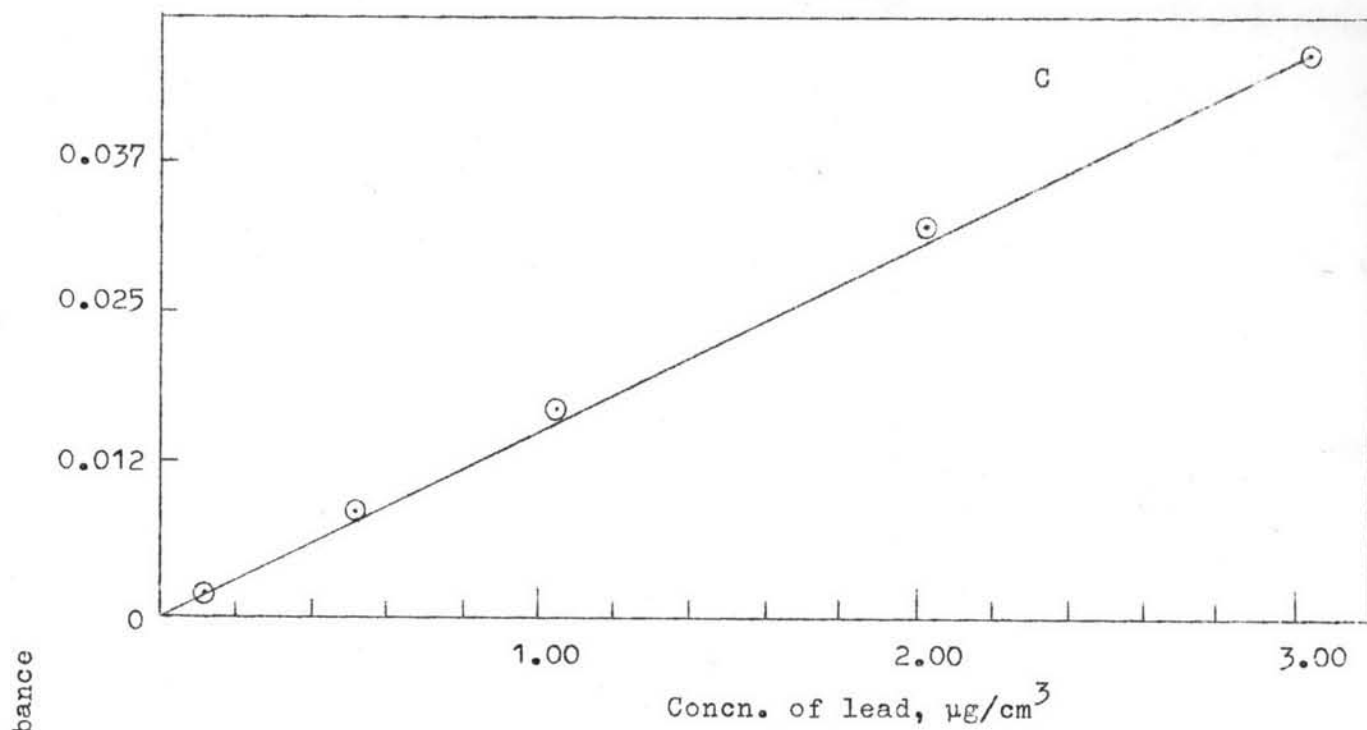


Figure 16 C and D Relationships between absorbances and concentrations for C) lead and D) zinc .

Table 25 Concentration effect of metal species in the mixture on the absorbance for the determination of Cd(II), Cu(II), Hg(II), Pb(II), and Zn(II) by atomic absorption spectrophotometry.

Concn. of metal species in the mixture	Absorbance	
	M	S
(1) 0.1 $\mu\text{g}/\text{cm}^3$ Cd(II)	0.0246	0.0246
0.1 $\mu\text{g}/\text{cm}^3$ Cu(II)	0.0022	0.0022
0.1 $\mu\text{g}/\text{cm}^3$ Hg(II)	T	T
0.1 $\mu\text{g}/\text{cm}^3$ Pb(II)	0.0022	0.0022
0.1 $\mu\text{g}/\text{cm}^3$ Zn(II)	0.0315	0.0315
(2) 0.5 $\mu\text{g}/\text{cm}^3$ Cd(II)	0.0731	0.0731
0.5 $\mu\text{g}/\text{cm}^3$ Cu(II)	0.0088	0.0088
0.5 $\mu\text{g}/\text{cm}^3$ Hg(II)	T	T
0.5 $\mu\text{g}/\text{cm}^3$ Pb(II)	0.0075	0.0075
0.5 $\mu\text{g}/\text{cm}^3$ Zn(II)	0.1733	0.1733
(3) 1.0 $\mu\text{g}/\text{cm}^3$ Cd(II)	0.1739	0.1739
1.0 $\mu\text{g}/\text{cm}^3$ Cu(II)	0.0180	0.0180
1.0 $\mu\text{g}/\text{cm}^3$ Hg(II)	T	T
1.0 $\mu\text{g}/\text{cm}^3$ Pb(II)	0.0177	0.0177
1.0 $\mu\text{g}/\text{cm}^3$ Zn(II)	0.3820	0.3820

Table 25 (continued)

Concn. of metal species in the mixture		Absorbance	
		M	S
(4)	2.0 $\mu\text{g}/\text{cm}^3$ Cd(II)	0.3325	0.3468
	2.0 $\mu\text{g}/\text{cm}^3$ Cu(II)	0.0362	0.0362
	2.0 $\mu\text{g}/\text{cm}^3$ Hg(II)	T	T
	2.0 $\mu\text{g}/\text{cm}^3$ Pb(II)	0.0200	0.0315
	2.0 $\mu\text{g}/\text{cm}^3$ Zn(II)	0.6990	0.7212
(5)	1.0 $\mu\text{g}/\text{cm}^3$ Cd(II)	0.1739	0.1739
	2.0 $\mu\text{g}/\text{cm}^3$ Cu(II)	0.0410	0.0362
	1.0 $\mu\text{g}/\text{cm}^3$ Hg(II)	T	T
	1.0 $\mu\text{g}/\text{cm}^3$ Pb(II)	0.0132	0.0177
	1.0 $\mu\text{g}/\text{cm}^3$ Zn(II)	0.3655	0.3820
(6)	1.0 $\mu\text{g}/\text{cm}^3$ Cd(II)	0.1739	0.1739
	1.0 $\mu\text{g}/\text{cm}^3$ Cu(II)	0.0186	0.0186
	0.05 $\mu\text{g}/\text{cm}^3$ Hg(II)	T	T
	1.0 $\mu\text{g}/\text{cm}^3$ Pb(II)	0.0177	0.0177
	1.0 $\mu\text{g}/\text{cm}^3$ Zn(II)	0.3820	0.3820

Table 25 (continued)

Concn. of metal species in the mixture		Absorbance	
		M	S
(7)	1.0 $\mu\text{g}/\text{cm}^3$ Cd(II)	0.1739	0.1739
	1.0 $\mu\text{g}/\text{cm}^3$ Cu(II)	0.0190	0.0186
	0.1 $\mu\text{g}/\text{cm}^3$ Hg(II)	T	T
	1.0 $\mu\text{g}/\text{cm}^3$ Pb(II)	0.0177	0.0177
	1.0 $\mu\text{g}/\text{cm}^3$ Zn(II)	0.3820	0.3820
(8)	1.0 $\mu\text{g}/\text{cm}^3$ Cd(II)	0.1739	0.1739
	1.0 $\mu\text{g}/\text{cm}^3$ Cu(II)	0.0345	0.0186
	1.0 $\mu\text{g}/\text{cm}^3$ Hg(II)	T	T
	3.0 $\mu\text{g}/\text{cm}^3$ Pb(II)	0.0384	0.0477
	1.0 $\mu\text{g}/\text{cm}^3$ Zn(II)	0.3988	0.3820
(9)	1.0 $\mu\text{g}/\text{cm}^3$ Cd(II)	0.1739	0.1739
	1.0 $\mu\text{g}/\text{cm}^3$ Cu(II)	0.0299	0.0186
	1.0 $\mu\text{g}/\text{cm}^3$ Hg(II)	T	T
	1.0 $\mu\text{g}/\text{cm}^3$ Pb(II)	0.0088	0.0177
	3.0 $\mu\text{g}/\text{cm}^3$ Zn(II)	0.7350	1.0360

Table 25 (continued)

Concn. of metal species in the mixture		Absorbance	
		M	S
(10)	0.1 $\mu\text{g}/\text{cm}^3$ Cd(II)	0.0246	0.0246
	1.0 $\mu\text{g}/\text{cm}^3$ Cu(II)	0.0186	0.0186
	1.0 $\mu\text{g}/\text{cm}^3$ Hg(II)	T	T
	1.0 $\mu\text{g}/\text{cm}^3$ Pb(II)	0.0177	0.0177
	1.0 $\mu\text{g}/\text{cm}^3$ Zn(II)	0.3820	0.3820
(11)	0.5 $\mu\text{g}/\text{cm}^3$ Cd(II)	0.0731	0.0731
	1.0 $\mu\text{g}/\text{cm}^3$ Cu(II)	0.0190	0.0186
	1.0 $\mu\text{g}/\text{cm}^3$ Hg(II)	T	T
	1.0 $\mu\text{g}/\text{cm}^3$ Pb(II)	0.0177	0.0177
	1.0 $\mu\text{g}/\text{cm}^3$ Zn(II)	0.3820	0.3820

M in the mixture

S in the single metal ion solution

T no measurement.

Table 26 Concentration effect of other metal species on the absorbance for the determination of mercury by flameless atomic absorption spectrophotometry.

Concn. of metal species in the mixture	Hg(II) added (ng/cm <sup>3</sup> )	Hg(II) found (ng/cm <sup>3</sup> )
(1) 0.3 µg/cm <sup>3</sup> Cd(II) 0.3 µg/cm <sup>3</sup> Cu(II) 0.3 µg/cm <sup>3</sup> Pb(II) 0.3 µg/cm <sup>3</sup> Zn(II)	1.00	1.08
(2) 1.0 µg/cm <sup>3</sup> Cd(II) 1.0 µg/cm <sup>3</sup> Cu(II) 1.0 µg/cm <sup>3</sup> Pb(II) 1.0 µg/cm <sup>3</sup> Zn(II)	1.00	1.14
(3) 1.0 µg/cm <sup>3</sup> Cd(II) 1.0 µg/cm <sup>3</sup> Cu(II) 1.0 µg/cm <sup>3</sup> Pb(II) 1.0 µg/cm <sup>3</sup> Zn(II)	1.00	1.05
(4) 1.0 µg/cm <sup>3</sup> Cd(II) 2.0 µg/cm <sup>3</sup> Cu(II) 1.5 µg/cm <sup>3</sup> Pb(II) 1.5 µg/cm <sup>3</sup> Zn(II)	1.00	1.14

Table 26 (continued)

Concn. of metal species in the mixture	Hg(II) added (ng/cm <sup>3</sup> )	Hg(II) found (ng/cm <sup>3</sup> )
(5) 1.0 µg/cm <sup>3</sup> Cd(II) 1.5 µg/cm <sup>3</sup> Cu(II) 1.5 µg/cm <sup>3</sup> Pb(II) 1.5 µg/cm <sup>3</sup> Zn(II)	1.00	1.12
(6) 1.5 µg/cm <sup>3</sup> Cd(II) 1.5 µg/cm <sup>3</sup> Cu(II) 2.0 µg/cm <sup>3</sup> Pb(II) 2.0 µg/cm <sup>3</sup> Zn(II)	1.00	1.15



method. The results of these determinations are presented in Tables 27 - 31.

The average contents of metal species in air particulates at each station by both techniques are illustrated in Tables 23 and 32. It was seen that the results from both techniques did not differ predominantly from each other.

From Tables 19 and 27, the maximum concentration of cadmium in air particulates was found at Phloenchit area,  $5.26 \mu\text{g}/\text{cm}^3$  by anodic stripping method, or  $6.20 \mu\text{g}/\text{cm}^3$  by atomic absorption method. Since the sampling sites were in the traffic area, it was concluded that cadmium in air particulates came from fuel-oil, batteries and the corrosion of their alloys.

The copper content in air particulates was found at the level higher than cadmium. The maximum concentration of copper as  $23.15 \mu\text{g}/\text{m}^3$  by anodic stripping method or  $19.94 \mu\text{g}/\text{m}^3$  by atomic absorption method was detected at San Sam Rarn area. The minimum concentration of copper as  $8.47 \mu\text{g}/\text{m}^3$  by anodic stripping method or  $9.83 \mu\text{g}/\text{m}^3$  by atomic absorption method was observed at Ratchaprasong area. The maximum concentration of copper was found at San Sam Rarn area due to the copper residue in gasoline, and local industries.

Lead is a common air pollutant in the urban are, since one possible source is the exhaust gases from the motor

Table 27 Range of cadmium contents in air particulate samples at each station by AAS method

Station	Concn.* ( $\mu\text{g}/\text{m}^3$ )	
	Min.	Max.
Patumwan	n	$3.90 \pm 0$
Ratchaprasong	n	n
Chit Lom	n	$3.46 \pm 0.29$
Phloenchit	n	$6.20 \pm 0$
Sukhumvit 10 (San Sam Rarn)	n	$3.90 \pm 0$
Sukhumvit 21 (Asoke)	n	$6.20 \pm 0$

\* average  $\pm$  mean deviation of 3 trials.

n undetectable

Table 20 Range of copper contents in air particulate samples at each station by AAS method

Station	Concn. * ( $\mu\text{g}/\text{m}^3$ )	
	Min.	Max.
Patumwan	n	$17.63 \pm 2.31$
Ratchaprasong	n	$9.83 \pm 0.38$
Chit Lom	$9.83 \pm 0.38$	$11.27 \pm 1.15$
Phloenchit	$9.83 \pm 0.38$	$10.41 \pm 0$
Sukhumvit 10 (San Sam Rarn)	n	$19.94 \pm 0$
Sukhumvit 21 (Asoke)	n	$11.27 \pm 1.15$

\* average  $\pm$  mean deviation of 3 trials

n undetectable

Table 29 Range of lead contents in air particulate samples at each station by AAS method

Station	Concn * ( $\mu\text{g}/\text{m}^3$ )	
	Min.	Max.
Patumwan	$17.56 \pm 1.74$	$37.26 \pm 0$
Ratchaprasong	n	$17.56 \pm 1.74$
Chit Lom	$9.76 \pm 0$	$17.56 \pm 1.74$
Phloenchit	n	$46.21 \pm 1.73$
Sukhumvit 10 (San Sam Rarn)	n	$37.84 \pm 0.77$
Sukhumvit 21 (Asoke)	n	$27.89 \pm 1.62$

\* average  $\pm$  mean deviation of 3 trials.

n undetectable

Table 30 Range of mercury contents in air particulate samples at each station by AAS method.

Station	Concn. * ( $\mu\text{g}/\text{cm}^3$ )	
	Min.	Max.
Patumwan	n	$4.97 \pm 0.16$
Ratchaprasong	n	$1.38 \pm 0.21$
Chit Lom	n	$5.94 \pm 0.19$
Phloenchit	n	$1.40 \pm 0.06$
Sukhumvit 10 (San Sam Rarn)	n	$0.17 \pm 0.02$
Sukhumvit 21 (Asoke)	n	$1.21 \pm 0.06$

\* average  $\pm$  mean deviation of 3 trials.

n undetectable

Table 31 Range of zinc contents in air particulate samples at each station by AAS method.

Station	Concn. * ( $\mu\text{g}/\text{m}^3$ )	
	Min.	Max.
Patumwan	$12.73 \pm 1.92$	$16.47 \pm 1.20$
Ratchaprasong	$9.25 \pm 1.15$	$17.32 \pm 1.13$
Chit Lom	$9.25 \pm 1.15$	$17.32 \pm 1.20$
Phloenchit	$9.25 \pm 1.15$	$9.54 \pm 1.15$
Sukhumvit 10 (San Sam Rarn)	$8.96 \pm 0.96$	$9.25 \pm 1.15$
Sukhumvit 21 (Asoke)	n	$12.73 \pm 1.92$

\* average  $\pm$  mean deviation of 3 trials.

n undetectable

Table 32 Average contents of metal species in air particulates at each station by AAS method.

Station	Concentration* ( $\mu\text{g}/\text{m}^3$ )				
	Cadmium	copper	Mercury	Lead	Zinc
Patumwan	$1.84 \pm 1.84$	$9.32 \pm 4.66$	$2.41 \pm 1.38$	$26.25 \pm 8.69$	$16.17 \pm 1.72$
Ratchaprasong	n	$2.45 \pm 3.68$	$0.34 \pm 0.51$	$7.98 \pm 5.67$	$10.62 \pm 2.92$
Chit Lom	$0.86 \pm 1.29$	$11.05 \pm 0.32$	$1.87 \pm 2.04$	$18.73 \pm 9.55$	$13.0 \pm 4.32$
Phloenchit	$2.14 \pm 2.14$	$9.97 \pm 0.21$	$0.35 \pm 0.53$	$22.59 \pm 14.46$	$8.24 \pm 1.52$
Sukhumvit 10 (San Sam Rarn)	$1.57 \pm 1.57$	$10.54 \pm 5.27$	$0.04 \pm 0.06$	$17.59 \pm 10.12$	$10.05 \pm 1.62$
Sukhumvit 21 (Asoke)	$3.50 \pm 1.75$	$8.09 \pm 4.04$	$0.30 \pm 0.45$	$13.94 \pm 13.94$	$4.48 \pm 4.48$

\* average  $\pm$  mean deviation of 4 air particulate samples.

\*\* flameless atomic absorption.

n undetectable.

vehicles. Phloenchit area had heavier traffic than other areas,

therefore, the maximum concentration of lead as  $47.25 \mu\text{g}/\text{m}^3$  by anodic stripping method or  $46.21 \mu\text{g}/\text{m}^3$  by atomic absorption method was found at this area. The minimum concentration of lead as  $0.60 \mu\text{g}/\text{m}^3$  by anodic stripping technique or none by atomic absorption technique was detected at Asoke area (see Tables 21, and 29). Lead was found at every station studied since the sampling sites were in the traffic areas. Lead in air particulates, mostly came from gasoline antiknock chemicals, storage batteries and the corrosion of paints.

By flameless atomic absorption technique, mercury contents in air particulates were found at several stations. The maximum concentration of mercury as  $5.94 \mu\text{g}/\text{m}^3$  was found at Chit Lom area. The minimum concentration of mercury was undetectable (see Table 30). The lubricant additives <sup>(61)</sup> may be the source of mercury in air particulates. The contamination from the laboratory atmosphere may be another source, mercury vapor concentration could range from 10 to  $150 \mu\text{g}/\text{m}^3$  in the chemical laboratory <sup>(62)</sup>, since no mercury content in these air particulates was found by ASV.

Zinc was another pollutant that was found at every station examined. The maximum concentration of zinc as  $15.70 \mu\text{g}/\text{m}^3$  by anodic stripping method or  $17.32 \mu\text{g}/\text{m}^3$  by atomic absorption method was detected at Ratchaprasong. The minimum concentration of zinc was undetectable by both



techniques. (see Tables 22, and 31). Zinc additives in lubricating oil, corrosion of paint pigments, and roofing materials were the major sources of zinc in air particulates.

It was found that the sensitivity of anodic stripping voltammetric technique was better than atomic absorption technique. For examples, copper and lead, in air particulates at Patumwan area and Sukhumvit 21 (Asoke) area, were found to be  $3.76 \mu\text{g}/\text{m}^3$ , and  $0.60 \mu\text{g}/\text{m}^3$ , respectively by anodic stripping method, while, by atomic absorption these two pollutants were undetectable (see Tables 20, 21, 28, and 29).

In the case of selectivity, each element which was determined by anodic stripping technique, had a specific peak potential and provided a well - defined peak, except copper which was oxidized at the potential closed to mercury. In atomic absorption technique, the resonance lines of cadmium, lead, mercury and zinc were in the ultraviolet region, thus, the background absorption could occur. In this study, the correction of this background absorption was performed. However, the interference due to the overlapping of these resonance lines may happen since they are closed together<sup>(63)</sup>.

In anodic stripping voltammetry the preconcentration step, which was the common procedure for atomic absorption technique, was not required. Small amount of the sample

was used and the method was non-destructive, while atomic absorption method required more sample and the method was destructive.

The amounts of air particulates in the sampling areas are illustrated in Table 33. The maximum value,  $6.30 \text{ mg/m}^3$ , was found in Phloenchit area.

Table 33 Range of the amounts of the air particulates at each station.

Station	The amounts of the air particulates found (mg/m <sup>3</sup> )
Patumwan	0.11 - 5.07
Ratchaprasong	0.13 - 0.78
Chit Lom	1.00 - 2.18
Phloenchit	2.79 - 6.30
Sukhumvit 10 (San Sam Rarn)	1.53 - 3.41
Sukhumvit 21 (Asoke)	1.19 - 6.65