Application of Single Program K_o - Factor for Instrumental Neutron Activation Analysis (INAA)

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Abstract

In this present work a computer program has been design to calculate the concentrations of elements by instrumental neutron activation analysis (INAA) using a single comparator method ($K_\circ$ -factor). A neutron source of 14 MeV was used as an irradiation source. irradiated samples were measured by a multi- channel system connected to high-purity germanium (HPGe) detector of high efficiency and an energy resolution of 1.9 KeV for Co-60 isotopes (1332KeV). Aluminum foils (AL-27) have been irradiation to calculate the neutron flux. Other samples were also in vales to gaiters like Au,Zr foil and used for neutron flux monitoring procedures. Result of concentrations were in agreement with theoretical predications and experimental measurements of previous studies and an accurate with 10%.

Introduction

One important aspect of instrumental neutron activation analysis (INAA) is the simplification of the applied standardization procedure. A new method ,using compound nuclear constants (i.e.so called $K_\circ$-factors determined experimentally with high accuracy).The INAA method described above was applied to study the concentration distributions of typical multielements such as air particulate fractions, water samples, food and also different samples in metals. This analysis is called single comparator method and has many advantages for multielements analysis are as follows[1]:-

1- Preparation of synthetic standards for each element to be determined can be avoided.
2- Additional elements can be determined without knowing their certified element contents in the standard material.

Experimental

The irradiation facility characterization requires the determination of neutron flux for 14Mev and full peak efficiency calibration determined by using Al-0.1%Au wire and Zr foil(99.9%).Full peak efficiency calibration of the detector was carried out at various heights using ^{241}Am ,^{133}Ba,^{60}Cs,^{60}Co,^{152}Eu point calibration sources .Full peak efficiency calibration curve of the detector used in this study covered the energy range of 59 to 1408 KeV. All γ-ray activities were determined with a p-type coaxial high-purity germanium (HPGe detector coupled with MCA complete system. The result show in Table(1) and Table (2) [2,3,4].

Theory of Single Comparator Method

This program is quantitative analysis on the identification of the radionuclide's present in the sample by comparing the observed energies of the γ-lines with energies of data library. The weight (W) of an irradiated element is related to the photo peak counting rate, A, of the radioisotope measured by the relation:[5,6,7,8]

$$W= \left(\frac{A}{G\Phi SD}\right)\left(\frac{\lambda M}{\sigma\delta N\varepsilon a}\right) \quad \text{.....(1)}$$

Where:-

A=Activity of radiation sample.

M=atomic weight of the irradiated element.

δ=isotopic abundance of the target nuclide.

σ=cross section, i.e., probability of absorbing neutrons in cm^2.

N=Avogadronumber.

ε =efficiency of the detector for the γ-ray measured.

a= γ-ray abundance in decay scheme.

Φ=neutron flux in neutrons/cm^2 sec.

S=saturation factor.

$S=1-e^{-\lambda t_{irr}}$

Where: Depending on irradiation time (t_{irr}) and decay constant λ ,

(a) $t_{irrad} >> t_{1/2}$, S = 1

(b) $t_{irrad} << t_{1/2}$, $e^{-\lambda t} \sim 1-\lambda t$

$$\lambda = \frac{0.693}{T_{\frac{1}{2}}}$$

$G=1- e^{-\lambda t_c}$

$D=1- e^{-\lambda t_d}$

t_{irr}= irradiation time

t_c =counting time

t_d = decay time

D = decay factor

When the neutron flux is measured by irradiating a known weight of an element (neutron flux monitor) and measuring the induced radioactivity by γ-ray spectrometry , the same relation holds .

$$\Phi = \left(\frac{A^*}{G^*S^*D^*W^*}\right)\left(\frac{\lambda^*\mathrm{M}^*}{\sigma^*\delta^*\mathrm{N}^*\varepsilon^*a^*}\right) \quad \text{.....(2)}$$

where the asterisks (*)refer to the neutron flux monitor

By substituting Φ taken from eq (2) in eq(1),we have .

$$K = \frac{WA^*GSD\varepsilon}{W^*AG^*S^*D^*\varepsilon^*} \quad \text{.....(3)}$$

So that

$$K= \left[\frac{\sigma^*S^*Na^*/\lambda^*\mathrm{M}^*}{\delta\sigma\mathrm{N}a/\lambda\mathrm{M}}\right] \quad \text{.....(4)}$$

K can be evaluated theoretically by using eq(4) after evaluating the individual nuclear constants appearing in eq (4) on the basis of literature data .

But K can also be obtained experimentally from eq. (3) by irradiating a known amount of element and of the single comparator chosen and measuring their photo peak counting rates and saturation and decay factors. Once the K- value has been determined, the unknown sample can be irradiated with a known weight of the single comparator and eq(3) used, if it is assumed that K is constant that is ,that no variations occurred in quantities appearing in eq(4) between the moment of the determination of K and the actual analysis[9].

Results and Discussion

In this study, we have used a computer program to find the theoretical and experimental K-values.

Our program has been listed in Appendix (1) while the input data of this program have been listed in Appendix (2) .We use these data to evaluate the theoretical K-values while the other data of Table(1) can be obtained experimentally, by irradiating a known amount of element and of the single comparator chosen and measuring their photo peak counting rates and saturation and decay factor, to find the experimental K-values, where in this study ,the ^{27}Al is used as single comparator. Table (2) shows the K-values obtained experimentally for (3) elements, the theoretical values are also reported for comparison. It is obvious from this table that the agreement between the theoretical and the experimental K-values, remarkable. Hence, the error of our results is always less than±10%. The accuracy of the results depends on the determination of the quantities appearing in eq(3), and the constancy of the K-values the percent deviation of the measured elemental concentrations are found to be within ±10% to that of the certified value whereas the percent relative standard deviation ranged from 2% to 10% for most of the elements analyzer .The determination of A, A*and W* is also necessary for analysis and if the half life of the radioisotope measured is short ratio D*/D must also be determined .The single comparator method introduces as additional sources of errors only those related to the measurement of SD,S*D* and K. The first two factors are depend only on irradiation and decay times as well as generally easily determined with good precision .The other sources of error are related to the measurement of K and its constancy with time

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Table (1)

This data were obtained experimentally by irradiating a known amount of element and of single comparator (^{27}Al),by the 14 MeV neutron generator

	Elements	*W (gm)*	t_{irr} *(sec)*	t_c *(sec)*	t_d *(sec)*	*A*	*comparator*	W^* *(gm)*	t^*_{irr} *(s)*	t^*_c *(s)*	t^*_d *(s)*	A^*	ε^*	ε
1		2.375	600	180	180	444485	^{27}Al	0.69987	600	220	780	68794	0.38	0.55
2		4.01752	900	200	240	570898	^{27}Al	0.618	900	300	600	167792	0.38	0.75
3	^{60}Ni	3.00058	900	600	200	4198	^{27}Al	0.638	900	260	800	142237	0.38	0.34

Table (2)

The comparison betweenK_{theo}[5,9]and K_{EXP}

	elements	*comparators*	K_{theo}	K_{EXP}
1		^{27}Al	0.1738	0.1879
2		^{27}Al	4.9721	3.7360
3	^{60}Ni	^{27}Al	174.000	220.323

Appendix (1)

A program for calculating the theoretical and experimental K-values

```
DIMENSION AW(92),DELTA(92),SIGMA(92),THALF(92),AA(92)
OPEN(1,FILE='AA.DAT',STATUS='OLD')
OPEN(2,FILE='RAA.DAT',STATUS='OLD')
  W=2.375
  WS=0.69987
  A=444485.
  AS=68794.
  TIRR=600.
  TIRRS=600.
  TC=180.
  TCS=220.
  TD=180.
  TDS=780.
  EFF=0.55
  EFFS=0.38
  IZZ=29
  IZS=13
 AWS=26.981
 DELTAS=100.
 SIGMAS=0.075
 THALFS=9.45*60.
 AAS=72.
 ALIMBDS=0.693/THALFS
 SS=1.-EXP(-ALIMBDS*TIRRS)
 GS=1.-EXPALIMBDS*TCS)
 DS=1.-EXP(-ALIMBDS*TDS)
 DO 10 I=1,92
  READ(1,*) I,AW(I),DELTA(I),SIGMA(I),THALF(I),AA(I)
IF(I.EQ.IZZ) GO TO 20
10CONTINUE
20WRITE(*,*) I,AW(I),DELTA(I),SIGMA(I),THALF(I),AA(I)
 ALIMBD=0.693/THALF(I)
 S=1.-EXP(-ALIMBDS*TIRR)
 G=1.-EXPALIMBDS*TC)
 D=1.-EXP(-ALIMBDS*TD)
AKHEO=SIGMAS*AAS*AW(I)*ALIMBD/(SIGMA(I)*DELTA(I)*ALIMBDS*AA(I)*AWS)
AKEXP=W*AS*S*D*G*EFF/WS*A*SS*DS*GS*EFFS)
WRITE(*,*)AKTHEO,AKEXP
END
```

Appendix (2)
14 MeV neutron activation analysis[5,9].

radionuclide	*Atomic Number Z*	*Mass Number A*	*Abundance Isotopes% A*	*Reaction*	*Cross section σ*	*Half live $T_{1/2}$*	*Product*	*Flux monitor c/sec.mg Φ=109*	*Energy KeV*	*Energy Intensity %*
^{11}B	5	10.811	80.2	(n,p)	25 mb	13.8s	^{11}Be	1.06^{1m}	2125	(33)
^{14}N	7	14.006	99.635	(n,p)	7 mb	9.96m	^{13}N	$2*10^{-2}$	511	---
^{16}O	8	15.999	99.756	(n,p)	39mb	7.13s	^{16}N	1.46	6128	(69)
^{19}F	9	18.998	100	(n,p)	19 mb	27.1s	^{19}O	0.474	197.4	(97)
^{23}Na	11	22.989	100	(n,p)	43mb	37.6s	^{23}Ne	0.754	439	(100)
^{24}Mg	12	24.305	78.99	(n,p)	190 mb	15.02h	^{24}Na	$2.86*10^{-3}$	1369.6	(100)
^{27}Al	13	26.981	100	(n,p)	75 mb	9.45m	^{27}Mg	0.118	843	(72)
^{29}Si	14	28.686	4.7	(n,p)	120 mb	6.52m	^{29}Al	$1.22*10^{-2}$	1273	(91)
^{31}p	15	30.973	100	(n,α)	118 mb	2.246m	^{28}Al	0.611	1778.8	(100)
^{34}S	16	32.064	4.2	(n,p)	75 mb	12.4S	^{34}p	$5.7*10^{-2}$	511	(200)
^{35}Cl	17	35.453	75.77	(N,2n)	17mb	32.2m	^{34n}Cl	$1.92*10^{-3}$	145.7	(36)
^{40}Ar	18	39.948	99.59	(n,p)	15.7mb	1.42m	^{46}Cl	$9.1*10^{-2}$	330	(22)
^{39}K	19	39.102	93.3	(n,2n)	3.5mb	7.63m	^{38g}K	$4.37*10^{-3}$	511	(200)
^{44}Ca	20	40.08	2.08	(n,p)	35.5mb	22m	^{44}K	$3.44*10^{-4}$	456	(85)
^{45}Sc	21	44.956	100	(n,2n)	182mb	3.93m	^{44g}Sc	$7.16*10^{-3}$	1157	(99.8)
^{50}Ti	22	47.90	5.3	(n,p)	17mb	1.71m	^{50}Sc	$3.78*10^{-3}$	523.5	(88)
^{51}V	23	50.0941	99.75	(n,p)	35.5mb	5.76m	^{51}Ti	$4.75*10^{-2}$	320	(95)
^{52}Cr	24	51.996	83.79	(n,p)	94mb	3.755m	^{52}V	0.154	1434.2	(100)
^{55}Mn	25	54.938	100	(n,α)	32mb	3.755m	^{52}V	$5.91*10^{-2}$	1434.2	(100)
^{56}Fe	26	55.847	91.7	(n,p)	103mb	2.582h	^{56}Mn	$4.55*10^{-3}$	846.6	(99)
^{59}Co	27	58.933	100	(n,α)	30mb	2.582h	^{56}Mn	$1.37*10^{-3}$	846.6	(99)
^{60}Ni	28	58.71	26.23	(n,p)	5.2mb	6.1m	^{60n}Co	$4.3*10^{-3}$	58.6	(99.75)
^{63}Cu	29	63.546	69.1	(n,2n)	522mb	9.87m	^{62}Cu	0.234	511	(196)
^{64}Zn	30	65.37	48.9	(n,2n)	165mb	38.5m	^{63}Zn	$1.33*10^{-2}$	511	(185)
^{69}Gu	31	69.72	60	(n,2n)	957mb	68.2m	^{68}Ga	$5*10^{-2}$	669.6	(8.5)
^{74}Ge	32	72.59	36.4	(n,p)	13mb	8.2m	^{74}Ga	$3.23*10^{-3}$	596	(92)
^{75}As	33	74.921	100	(n,p)	20mb	82.8m	^{15g}Ge	$1.69*10^{-3}$	265	(12)
^{82}Se	34	78.96	9	(n,2n)	8.4mb	57.3m	^{81m}Se	$7.38*10^{-3}$	103	(8)
^{79}Br	35	79.90	50.69	(n,2n)	932mb	6.4m	^{78}Br	0.366	613.6	(13.6)

الخلاصة

أنجزت الدراسة برنامج حسابي لتحديد تراكيز العناصرعن طريق استخدام التحليل بالتنشيط النيوتروني الآلي (طريقة المقارنة الأحادية Single factor for $K_{\circ}$ – INAA method. استخدم المولد النيوتروني 14MeV كمصدر للتشعيع, قيست النماذج المشعة باستخدام منظومة متعددة القنوات المربوطة بكاشف جرمانيوم عالي النقاوة HPGe ذات الكفاءة العالية وفصل طاقي 1.9Kev لنظير الكوبلت Co-60 ذي الخط الكامي 1332KeV. شععت رقائق من الالمنيوم AL-27 لحساب الفيظ النيوتروني وكذلك شععت رقائق من الذهب Au و Zr كمراقب للفيض اعتمد البرنامج المنجز على النتائج العملية والنظرية وكانت النتائج متوافقة وبنسبة خطاء تتراوح بحدود% 10.

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