Final Examination
2017/2018 Academic Session

May/June 2018

JIK321 – Analytical Chemistry II
[Kimia Analitis II]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains **NINETEEN** printed pages before you begin the examination.

Answer **FIVE (5)** questions. Answer the questions in English. You may also answer the questions in Bahasa Malaysia, but not a mix of both languages.

All answers must be written in the answer booklet provided.

Each question is worth 20 marks and the mark for each sub question is given at the end of that question.

In the event of any discrepancies in the exam questions, the English version shall be used.

*Sila pastikan bahawa kertas peperiksaan ini mengandungi **SEMBILAN BELAS** muka surat yang bercetak sebelum anda memulakan peperiksaan ini.*

*Jawab **LIMA (5)** soalan. Jawab soalan-soalan dalam Bahasa Inggeris. Anda juga dibenarkan menjawab soalan dalam Bahasa Malaysia, tetapi campuran antara kedua-dua bahasa ini tidak dibenarkan.*

Setiap jawapan mesti dijawab di dalam buku jawapan yang disediakan.

Setiap soalan bernilai 20 markah dan markah subsoalan diperlihatkan di penghujung subsoalan itu.

Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.

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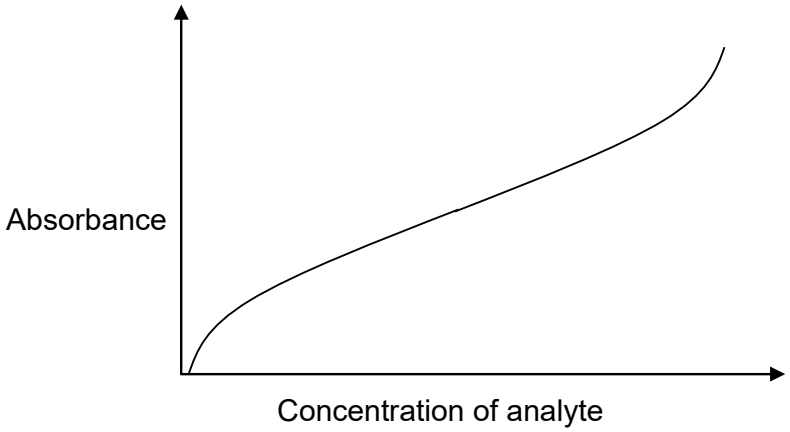
Answer any **FIVE (5)** questions.
*Jawab mana-mana **LIMA (5)** soalan.*

1. (a). Explain the following concepts/items given below:
   (i). Fluorescence process explained using the molecular orbital energy diagram
   (ii). Calibration curve for atomic spectroscopy, using an atomic absorption determination as an example
   (iii). Isotope ratio for a halogen
   (iv). Mass analyser based on time of flight of species in mass spectrometry

   Terangkan konsep-konsep/perkara-perkara yang diberikan di bawah:
   (i). Proses pendarflor diterangkan menggunakan gambar rajah tenaga orbital molekul
   (ii). Keluk tentukuran untuk spektroskopi atom menggunakan penentuan penyerapan atom sebagai contoh
   (iii). Nisbah isotop untuk suatu unsur halogen
   (iv). Penganalisis jisim berasaskan masa penerbangan spesies dalam spektrometri jisim

   (10 marks/*markah*)

(b). Consider the calibration curve given below:
Pertimbangkan keluk kalibrasi yang diberikan di bawah:



(i). Describe the **TWO (2)** deviations from linearity in the above calibration curve.

(ii). Propose one method to reduce the deviations from linearity as seen in the above case.

*(i). Terangkan **DUA (2)** percanggahan daripada keselanjaran dalam keluk kalibrasi di atas.*

(ii). Cadangkan satu cara untuk mengurangkan percanggahan daripada keselanjaran dalam keluk kalibrasi seperti di atas.

(5 marks/*markah*)

(c). Many elements that can be determined using flame atomic absorption spectroscopy can also be determined using flame atomic emission spectroscopy. Discuss **THREE (3)** advantages of using flame atomic emission spectroscopy compared to flame atomic absorption spectroscopy.

*Banyak unsur yang boleh ditentukan menggunakan spektroskopi penyerapan atom nyalaan boleh juga ditentukan dengan menggunakan spektroskopi pemancaran atom nyalaan. Bincangkan **TIGA (3)** kelebihan menggunakan spektroskopi pemancaran atom nyalaan berbanding dengan spektroskopi penyerapan atom nyalaan.*

(5 marks/*markah*)

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2. (a). High performance liquid chromatography (HPLC) deals with liquid samples at high pressures whereas mass spectrometer (MS) involves gaseous state and requires high vacuum conditions. Describe in detail how these very conflicting conditions are taken care of in the process of combining the two techniques resulting in a hybrid technique known as HPLC-MS. Use appropriate diagrams if needed to clarify your explanation.

Kromatografi cecair berprestasi tinggi (HPLC) melibatkan sampel cecair pada tekanan tinggi manakala spektrometer jisim (MS) melibatkan fasa gas dan memerlukan keadaan vakum yang tinggi. Terangkan secara terperinci bagaimana keadaan yang sangat bercanggah ini diambil kira dalam proses menggabungkan dua teknik untuk menghasilkan teknik hibrid yang dikenali sebagai HPLC-MS. Gunakan gambar rajah yang sesuai jika perlu untuk menjelaskan penerangan anda.

(10 marks/*markah*)

(b). What are the advantages of HPLC-MS technique compared to conventional HPLC equipped with UV-vis detector?

Apakah kelebihan teknik HPLC-MS berbanding teknik HPLC konvensional dilengkapi pengesan UV-nampak?

(5 marks/*markah*)

(c). The following data was obtained from a liquid chromatographic analysis of a fatty acids sample:
Data berikut telah diperolehi daripada analisis kromatografi cecair suatu sampel asid lemak:

Column used: C-18, 12 cm
Solvent: Water-acetonitrile, 10% to 90% in 20 minutes

Peak number	t_R (min)	Ion Count
1	1.95	12359.5
2	2.43	348876.5
3	3.59	87553.0
4	5.72	191120.0
5	7.33	772372.5
6	11.40	70224.0
7	14.38	43338.5
8	18.42	66851.0

(i). Was the analysis done using isocratic or gradient elution condition?
(ii). How can you tell that the technique used was HPLC-MS?
(iii). Suggest an alternative solvent that can be used to replace acetonitrile.

(i). Adakah analisis dilakukan menggunakan keadaan elusi isokratik atau elusi kecerunan?
(ii). Bagaimana anda boleh tahu teknik yang digunakan ialah suatu HPLC-MS?
(iii). Cadangkan suatu pelarut lain yang boleh digunakan untuk menggantikan asetonitril.

(5 marks/*markah*)

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3. (a). The following standard solutions were used in determining Ce^{4+}, a common titrant used in various applications. A flame atomic absorption spectrometer was used.

Larutan piawai berikut telah digunakan dalam menentukan Ce^{4+}, suatu titran yang biasa digunakan dalam pelbagai aplikasi. Suatu spektrometer penyerapan atom nyalaan telah digunakan.

Solution	Ce^{4+} concentration (ppb)	Absorbance
Standard solution 1	1.0	0.41
Standard solution 2	5.0	1.92
Standard solution 3	10.0	4.00
Standard solution 4	20.0	10.20
Standard solution 5	50.0	21.15
Standard solution 6	100.0	39.85
Solution A with unknown Ce^{4+} conc.	?	44.50
Solution B with unknown Ce^{4+} conc.	?	11.68

(i). Construct an appropriate calibration curve based on those standard solutions (graph paper is not needed).

(ii). Determine the concentrations Ce^{4+} in unknowns A and B. Show how those values are obtained.

(iii). Can the concentration of Ce^{4+} in both unknowns A and B be accurately determined using the calibration curve? Give reason(s) for your answer.

(iv). Suggest a way that will enable the unknown concentration of Ce^{4+} in both samples be accurately determined.

(i). Lakarkan suatu keluk tentukuran yang bersesuaian berdasarkan kepada larutan piawai itu (kertas graf tidak diperlukan).

(ii). Tentukan kepekatan Ce^{4+} dalam anu A dan B. Tunjukkan bagaimana nilai-nilai itu diperolehi.

(iii). Bolehkah kepekatan Ce^{4+} dalam kedua-dua anu A dan B ditentukan dengan tepat menggunakan keluk tentukuran itu? Beri sebab (-sebab) kepada jawapan anda.

(iv). Cadangkan suatu cara yang akan membolehkan kepekatan Ce^{4+} dalam kedua-dua sampel ditentukan dengan tepat.

(10 marks/*markah*)

(b). (i). Draw a schematic diagram of an ICP-MS spectrometer. Label all the components.

(ii). What are the **TWO (2)** most critical component in the ICP-MS instrument? Give reason(s) to your answer.

(iii). Why is the operating cost for ICP-MS much higher than flame atomic emission spectrometer?

(i). Lukiskan gambar rajah skema peralatan ICP-MS. Labelkan semua komponen.

*(ii). Apakah **DUA (2)** komponen paling kritikal dalam peralatan ICP-MS? Beri sebab (-sebab) kepada jawapan anda itu.*

(iii). Mengapakah kos operasi ICP-MS jauh lebih tinggi berbanding spektroskopi pemancaran atom nyalaan?

(10 marks/*markah*)

4. (a). Estimate the value of absorption coefficient, epsilon (ε) of Mn by using the data provided. The data was obtained using a flame atomic absorption spectrometer. Assume the sample path length used was 1.0 cm.

Anggarkan nilai pekali penyerapan, epsilon (ε) untuk Mn dengan menggunakan data yang disediakan. Data diperoleh dengan menggunakan spektrometer penyerapan atom nyalaan. Anggapkan panjang laluan sampel yang digunakan adalah 1.0 cm.

Standard Solution No.	Mn concentration in standard solution (ppm)	Absorption Signal intensity
1	1	6.5
2	5	31.0
3	10	64.0
4	20	126.0
5	50	312.0

(10 marks/*markah*)

(b). Using appppropriate graphs/figures, explain the differences between calibration curve and standard addition curve.

Dengan menggunakan graf/rajah yang sesuai, terangkan perbezaan antara keluk tentukuran dan keluk penambahan piawai.

(4 marks/*markah*)

(c). An aqueous sample known to contain the following seven (7) elements was analysed using ICP-MS:

B, Na, Al, P, Sc, Mn and Co

By studying the resulting ICP-MS spectrum carefully (refer to Spectrum A),

(i). how can you be certain that there are only the seven (7) elements present in the sample? Give your reason(s).

(ii). it can be concluded that there is most probably no iron (Fe) in the sample even though Fe has very similar atomic mass as Mn. Explain your answer.

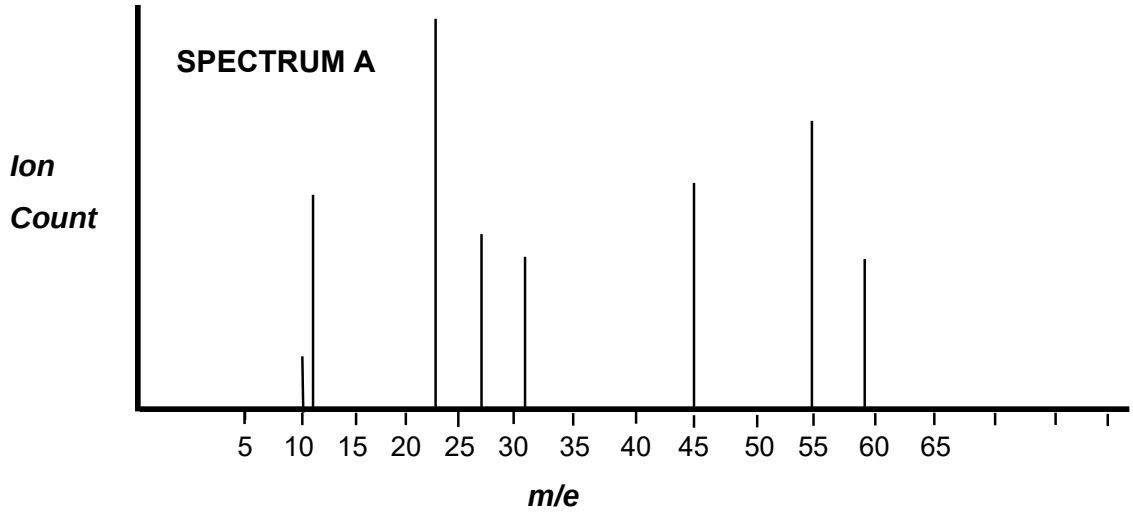
Suatu sampel akueus yang diketahui mengandungi tujuh (7) unsur berikut dianalisis dengan menggunakan ICP-MS:

B, Na, Al, P, Sc, Mn dan Co

Dengan mengkaji secara teliti spektrum ICP-MS yang dihasilkan (rujuk kepada Spektrum A),

(i). bagaimanakah anda pasti bahawa terdapat hanya tujuh (7) unsur yang ada di dalam sampel? Berikan alasan anda.

(ii). ianya dapat disimpulkan bahawa tidak mungkin ada besi (Fe) dalam sampel walaupun Fe mempunyai jisim atom yang sangat mirip dengan Mn. Terangkan jawapan anda.



(6 marks/*markah*)

5. (a). HPLC-MS have its own strengths, advantages and problems when they are used in analytical determinations. Describe the followings:

(i). **TWO (2)** major strengths/benefits of HPLC-MS.

(ii). **TWO (2)** shortcomings of HPLC-MS.

(iii). the advantage of using HPLC-MS/MS compared to HPLC-MS.

HPLC-MS mempunyai kekuatan, kelebihan dan masalah tersendiri apabila ia digunakan dalam penentuan analitis. Huraikan perkara berikut:

(i). ***DUA (2)*** *kekuatan/faedah utama HPLC-MS.*

(ii). ***DUA (2)*** *kelemahan HPLC-MS.*

(iii). kelebihan menggunakan HPLC-MS/MS berbanding dengan HPLC-MS.

(10 marks/*markah*)

(b). GC-MS is a very powerful technique used for the determination of structures and thus identity of a compound. However high resolution capillary GC using a conventional detector is still needed for the determination of isomers of certains compounds such as polycyclic aromatic hydrocarbons (PAHs). Explain why is it difficult to use GC-MS to distinguish those isomers.

GC-MS adalah teknik yang sangat ampuh yang digunakan untuk menentukan struktur dan dengan itu identiti suatu sebatian. Walau bagaimanapun kromatografi gas kapilari resolusi tinggi menggunakan suatu pengesan konvensional masih diperlukan untuk penentuan sesetengah isomer sebatian seperti polisiklik aromatik hidrokarbon (PAHs). Jelaskan mengapa GC-MS sukar digunakan untuk membezakan isomer-isomer tersebut.

(5 marks/*markah*)

(c). Both GC-MS and HPLC-MS are very powerful techniques used for the separation and determination of structures of compounds. Explain **TWO (2)** advantages of HPLC-MS when compared to GC-MS.

*Kedua-dua teknik GC-MS dan HPLC-MS sangat ampuh yang boleh digunakan untuk pemisahan dan penentuan struktur sebatian-sebatian. Jelaskan **DUA (2)** kelebihan HPLC-MS jika dibandingkan dengan GC-MS.*

(5 marks/*markah*)

6. For the following samples, suggest the simplest/quickest/cheapest technique that can be used to do the required analysis. The technique can be spectroscopic, chromatographic or a combination of both. Explain why you choose that method/technique.
Bagi sampel-sampel berikut, cadangkan teknik paling mudah/paling cepat/ termurah yang boleh digunakan untuk melakukan analisis yang diperlukan. Teknik itu boleh berbentuk spektroskopi, kromatografi atau gabungan kedua-duanya. Terangkan mengapa anda memilih kaedah/teknik itu.

(a). A fresh water sample obtained from a river suspected to be contaminated with various agrochemicals residues. The contaminating chemicals need to be determined at ppm levels.
Sampel air tawar yang diperoleh dari sungai yang disyaki dicemari dengan pelbagai residu agrokimia. Bahan kimia yang tercemar perlu ditentukan pada tahap ppm.

(b). A synthethic reaction product known to contain a mixture of up to fifteen different compounds including some isomers. The compounds' structure need to be identified.
Hasil suatu tindak balas sintetik diketahui mengandungi campuran sehingga lima belas sebatian yang berbeza termasuk beberapa isomer. Struktur sebatian-sebatian itu perlu dikenalpasti.

(c). An essential oil extracted from the bark of a camphor tree. The structures and identities of the various components in that essential oil needs to be identified.
Suatu minyak pati yang diekstrak daripada kulit pohon kapur barus. Struktur dan identiti pelbagai komponen dalam minyak pati itu perlu dikenalpasti.

(d). A mineral water sample marketed under a well known brand has claimed to be sourced from underground spring in Taiping. The various atomic/ionic species need to be determined up to ppb levels for comparison with an actual spring water sample collected from the known source in Taiping.

Sampel air mineral yang dipasarkan dengan suatu jenama terkenal telah didakwa diperoleh dari sumber bawah tanah di Taiping. Pelbagai spesies atom/ion perlu ditentukan sehingga ketahap ppb untuk dibandingkan dengan sampel air sebenar yang dikutip dari sumber yang diketahui di Taiping.

(e). Samples from two brands of RON-95 gasoline. The major and minor components in the two brands need to be identified and quantified up to ppb level.

Sampel dari dua jenama petrol RON-95. Komponen utama dan komponen minor dalam kedua-dua jenama perlu dikenalpasti dan dikira sehingga ketahap ppb.

(20 marks/*markah*)

Table of Isotope Abundance for Elements, N = 1 to N = 92

Table of Isotopic Masses and Natural Abundances

This table lists the mass and percent natural abundance for the stable nuclides. The mass of the longest lived isotope is given for elements without a stable nuclide. Nuclides marked with an asterisk (*) in the abundance column indicate that it is not present in nature or that a meaningful natural abundance cannot be given. The isotopic mass data is from G. Audi, A. H. Wapstra *Nucl. Phys A.* **1993**, *565*, 1-65 and G. Audi, A. H. Wapstra *Nucl. Phys A.* **1995**, *595*, 409-480. The percent natural abundance data is from the 1997 report of the IUPAC Subcommittee for Isotopic Abundance Measurements by K.J.R. Rosman, P.D.P. Taylor *Pure Appl. Chem.* **1999**, *71*, 1593-1607.

Z	Name	Symbol	Mass of Atom (u)	% Abundance
1	Hydrogen	^{1}H	1.007825	99.9885
	Deuterium	^{2}H	2.014102	0.115
	Tritium	^{3}H	3.016049	*
2	Helium	^{3}He	3.016029	0.000137
		^{4}He	4.002603	99.999863
3	Lithium	^{6}Li	6.015122	7.59
		^{7}Li	7.016004	92.41
4	Beryllium	^{9}Be	9.012182	100
5	Boron	^{10}B	10.012937	19.9
		^{11}B	11.009305	80.1
6	Carbon	^{12}C	12.000000	98.93
		^{13}C	13.003355	1.07
		^{14}C	14.003242	*
7	Nitrogen	^{14}N	14.003074	99.632
		^{15}N	15.000109	0.368
8	Oxygen	^{16}O	15.994915	99.757
		^{17}O	16.999132	0.038
		^{18}O	17.999160	0.205
9	Fluorine	^{19}F	18.998403	100
10	Neon	^{20}Ne	19.992440	90.48
		^{21}Ne	20.993847	0.27
		^{22}Ne	21.991386	9.25
11	Sodium	^{23}Na	22.989770	100
12	Magnesium	^{24}Mg	23.985042	78.99
		^{25}Mg	24.985837	10.00
		^{26}Mg	25.982593	11.01
13	Aluminum	^{27}Al	26.981538	100
14	Silicon	^{28}Si	27.976927	92.2297
		^{29}Si	28.976495	4.6832
		^{30}Si	29.973770	3.0872
15	Phosphorus	^{31}P	30.973762	100
16	Sulphur	^{32}S	31.972071	94.93
		^{33}S	32.971458	0.76
		^{34}S	33.967867	4.29
		^{36}S	35.967081	0.02
17	Chlorine	^{35}Cl	34.968853	75.78
		^{37}Cl	36.965903	24.22
18	Argon	^{36}Ar	35.967546	0.3365
		^{38}Ar	37.962732	0.0632
		^{40}Ar	39.962383	99.6003
19	Potassium	^{39}K	38.963707	93.2581
		^{40}K	39.963999	0.0117
		^{41}K	40.961826	6.7302
20	Calcium	^{40}Ca	39.962591	96.941
		^{42}Ca	41.958618	0.647
		^{43}Ca	42.958767	0.135
		^{44}Ca	43.955481	2.086
		^{46}Ca	45.953693	0.004
		^{48}Ca	47.952534	0.187
21	Scandium	^{45}Sc	44.955910	100
22	Titanium	^{46}Ti	45.952629	8.25
		^{47}Ti	46.951764	7.44
		^{48}Ti	47.947947	73.72
		^{49}Ti	48.947871	5.41
		^{50}Ti	49.944792	5.18
23	Vanadium	^{50}V	49.947163	0.250
		^{51}V	50.943964	99.750
24	Chromium	^{50}Cr	49.946050	4.345
		^{52}Cr	51.940512	83.789
		^{53}Cr	52.940654	9.501
		^{54}Cr	53.938885	2.365
25	Manganese	^{55}Mn	54.938050	100
26	Iron	^{54}Fe	53.939615	5.845
		^{56}Fe	55.934942	91.754

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Z	Name	Symbol	Mass of Atom (u)	% Abundance
		^{57}Fe	56.935399	2.119
		^{58}Fe	57.933280	0.282
27	Cobalt	^{59}Co	58.933200	100
28	Nickel	^{58}Ni	57.935348	68.0769
		^{60}Ni	59.930791	26.2231
		^{61}Ni	60.931060	1.1399
		^{62}Ni	61.928349	3.6345
		^{64}Ni	63.927970	0.9256
29	Copper	^{63}Cu	62.929601	69.17
		^{65}Cu	64.927794	30.83
30	Zinc	^{64}Zn	63.929147	48.63
		^{66}Zn	65.926037	27.90
		^{67}Zn	66.927131	4.10
		^{68}Zn	67.924848	18.75
		^{70}Zn	69.925325	0.62
31	Gallium	^{69}Ga	68.925581	60.108
		^{71}Ga	70.924705	39.892
32	Germanium	^{70}Ge	69.924250	20.84
		^{72}Ge	71.922076	27.54
		^{73}Ge	72.923459	7.73
		^{74}Ge	73.921178	36.28
		^{76}Ge	75.921403	7.61
33	Arsenic	^{75}As	74.921596	100
34	Selenium	^{74}Se	73.922477	0.89
		^{76}Se	75.919214	9.37
		^{77}Se	76.919915	7.63
		^{78}Se	77.917310	23.77
		^{80}Se	79.916522	49.61
		^{82}Se	81.916700	8.73
35	Bromine	^{79}Br	78.918338	50.69
		^{81}Br	80.916291	49.31
36	Krypton	^{78}Kr	77.920386	0.35
		^{80}Kr	79.916378	2.28
		^{82}Kr	81.913485	11.58
		^{83}Kr	82.914136	11.49
		^{84}Kr	83.911507	57.00
		^{86}Kr	85.910610	17.30
37	Rubidium	^{85}Rb	84.911789	72.17
		^{87}Rb	86.909183	27.83
38	Strontium	^{84}Sr	83.913425	0.56
		^{86}Sr	85.909262	9.86
		^{87}Sr	86.908879	7.00
		^{88}Sr	87.905614	82.58
39	Yttrium	^{89}Y	88.905848	100
40	Zirconium	^{90}Zr	89.904704	51.45
		^{91}Zr	90.905645	11.22
		^{92}Zr	91.905040	17.15
		^{94}Zr	93.906316	17.38
		^{96}Zr	95.908276	2.80
41	Niobium	^{93}Nb	92.906378	100
42	Molybdenum	^{92}Mo	91.906810	14.84
		^{94}Mo	93.905088	9.25
		^{95}Mo	94.905841	15.92
		^{96}Mo	95.904679	16.68
		^{97}Mo	96.906021	9.55
		^{98}Mo	97.905408	24.13
		^{100}Mo	99.907477	9.63
43	Technetium	^{98}Tc	*97.907216	*
44	Ruthenium	^{96}Ru	95.907598	5.54
		^{98}Ru	97.905287	1.87
		^{99}Ru	98.905939	12.76
		^{100}Ru	99.904220	12.60
		^{101}Ru	100.905582	17.06
		^{102}Ru	101.904350	31.55
		^{104}Ru	103.905430	18.62
45	Rhodium	^{103}Rh	102.905504	100
46	Palladium	^{102}Pd	101.905608	1.02
		^{104}Pd	103.904035	11.14
		^{105}Pd	104.905084	22.33
		^{106}Pd	105.903483	27.33
		^{108}Pd	107.903894	26.46
		^{110}Pd	109.905152	11.72
47	Silver	^{107}Ag	106.905093	51.839
		^{109}Ag	108.904756	48.161
48	Cadmium	^{106}Cd	105.906458	1.25
		^{108}Cd	107.904183	0.89
		^{110}Cd	109.903006	12.49
		^{111}Cd	110.904182	12.80

…16/-

Z	Name	Symbol	Mass of Atom (u)	% Abundance
		^{112}Cd	111.902757	24.13
		^{113}Cd	112.904401	12.22
		^{114}Cd	113.903358	28.73
		^{116}Cd	115.904755	7.49
49	Indium	^{113}In	112.904061	4.29
		^{115}In	114.903878	95.71
50	Tin	^{112}Sn	111.904821	0.97
		^{114}Sn	113.902782	0.66
		^{115}Sn	114.903346	0.34
		^{116}Sn	115.901744	14.54
		^{117}Sn	116.902954	7.68
		^{118}Sn	117.901606	24.22
		^{119}Sn	118.903309	8.59
		^{120}Sn	119.902197	32.58
		^{122}Sn	121.903440	4.63
		^{124}Sn	123.905275	5.79
51	Antimony	^{121}Sb	120.903818	57.21
		^{123}Sb	122.904216	42.79
52	Tellurium	^{120}Te	119.904020	0.09
		^{122}Te	121.903047	2.55
		^{123}Te	122.904273	0.89
		^{124}Te	123.902819	4.74
		^{125}Te	124.904425	7.07
		^{126}Te	125.903306	18.84
		^{128}Te	127.904461	31.74
		^{130}Te	129.906223	34.08
53	Iodine	^{127}I	126.904468	100
54	Xenon	^{124}Xe	123.905896	0.09
		^{126}Xe	125.904269	0.09
		^{128}Xe	127.903530	1.92
		^{129}Xe	128.904779	26.44
		^{130}Xe	129.903508	4.08
		^{131}Xe	130.905082	21.18
		^{132}Xe	131.904154	26.89
		^{134}Xe	133.905395	10.44
		^{136}Xe	135.907220	8.87
55	Cesium	^{133}Cs	132.905447	100
56	Barium	^{130}Ba	129.906310	0.106
		^{132}Ba	131.905056	0.101
		^{134}Ba	133.904503	2.417
		^{135}Ba	134.905683	6.592
		^{136}Ba	135.904570	7.854
		^{137}Ba	136.905821	11.232
		^{138}Ba	137.905241	71.698
57	Lanthanum	^{138}La	137.907107	0.090
		^{139}La	138.906348	99.910
58	Cerium	^{136}Ce	135.907144	0.185
		^{138}Ce	137.905986	0.251
		^{140}Ce	139.905434	88.450
		^{142}Ce	141.909240	11.114
59	Praseodymium	^{141}Pr	140.907648	100
60	Neodymium	^{142}Nd	141.907719	27.2
		^{143}Nd	142.909810	12.2
		^{144}Nd	143.910083	23.8
		^{145}Nd	144.912569	8.3
		^{146}Nd	145.913112	17.2
		^{148}Nd	147.916889	5.7
		^{150}Nd	149.920887	5.6
61	Promethium	^{145}Pm	144.912744	*
62	Samarium	^{144}Sm	143.911995	3.07
		^{147}Sm	146.914893	14.99
		^{148}Sm	147.914818	11.24
		^{149}Sm	148.917180	13.82
		^{150}Sm	149.917271	7.38
		^{152}Sm	151.919728	26.75
		^{154}Sm	153.922205	22.75
63	Europium	^{151}Eu	150.919846	47.81
		^{153}Eu	152.921226	52.19
64	Gadolinium	^{152}Gd	151.919788	0.20
		^{154}Gd	153.920862	2.18
		^{155}Gd	154.922619	14.80
		^{156}Gd	155.922120	20.47
		^{157}Gd	156.923957	15.65
		^{158}Gd	157.924101	24.84
		^{160}Gd	159.927051	21.86
65	Terbium	^{159}Tb	158.925343	100
66	Dysprosium	^{156}Dy	155.924278	0.06
		^{158}Dy	157.924405	0.10
		^{160}Dy	159.925194	2.34
		^{161}Dy	160.926930	18.91
		^{162}Dy	161.926795	25.51
		^{163}Dy	162.928728	24.90

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Z	Name	Symbol	Mass of Atom (u)	% Abundance
		^{164}Dy	163.929171	28.18
67	Holmium	^{165}Ho	164.930319	100
68	Erbium	^{162}Er	161.928775	0.14
		^{164}Er	163.929197	1.61
		^{166}Er	165.930290	33.61
		^{167}Er	166.932045	22.93
		^{168}Er	167.932368	26.78
		^{170}Er	169.935460	14.93
69	Thulium	^{169}Tm	168.934211	100
70	Ytterbium	^{168}Yb	167.933894	0.13
		^{170}Yb	169.934759	3.04
		^{171}Yb	170.936322	14.28
		^{172}Yb	171.936378	21.83
		^{173}Yb	172.938207	16.13
		^{174}Yb	173.938858	31.83
		^{176}Yb	175.942568	12.76
71	Lutetium	^{175}Lu	174.940768	97.41
		^{176}Lu	175.942682	2.59
72	Hafnium	^{174}Hf	173.940040	0.16
		^{176}Hf	175.941402	5.26
		^{177}Hf	176.943220	18.60
		^{178}Hf	177.943698	27.28
		^{179}Hf	178.945815	13.62
		^{180}Hf	179.946549	35.08
73	Tantalum	^{180}Ta	179.947466	0.012
		^{181}Ta	180.947996	99.988
74	Tungsten	^{180}W	179.946706	0.12
		^{182}W	181.948206	26.50
		^{183}W	182.950224	14.31
		^{184}W	183.950933	30.64
		^{186}W	185.954362	28.43
75	Rhenium	^{185}Re	184.952956	37.40
		^{187}Re	186.955751	62.60
76	Osmium	^{184}Os	183.952491	0.02
		^{186}Os	185.953838	1.59
		^{187}Os	186.955748	1.96
		^{188}Os	187.955836	13.24
		^{189}Os	188.958145	16.15
		^{190}Os	189.958445	26.26
		^{192}Os	191.961479	40.78
77	Iridium	^{191}Ir	190.960591	37.3
		^{193}Ir	192.962924	62.7
78	Platinum	^{190}Pt	189.959930	0.014
		^{192}Pt	191.961035	0.782
		^{194}Pt	193.962664	32.967
		^{195}Pt	194.964774	33.832
		^{196}Pt	195.964935	25.242
		^{198}Pt	197.967876	7.163
79	Gold	^{197}Au	196.966552	100
80	Mercury	^{196}Hg	195.965815	0.15
		^{198}Hg	197.966752	9.97
		^{199}Hg	198.968262	16.87
		^{200}Hg	199.968309	23.10
		^{201}Hg	200.970285	13.18
		^{202}Hg	201.970626	29.86
		^{204}Hg	203.973476	6.87
81	Thallium	^{203}Tl	202.972329	29.524
		^{205}Tl	204.974412	70.476
82	Lead	^{204}Pb	203.973029	1.4
		^{206}Pb	205.974449	24.1
		^{207}Pb	206.975881	22.1
		^{208}Pb	207.976636	52.4
83	Bismuth	^{209}Bi	208.980383	100
84	Polonium	^{209}Po	208.982416	*
85	Astatine	^{210}At	209.987131	*
86	Radon	^{222}Rn	222.017570	*
87	Francium	^{223}Fr	223.019731	*
88	Radium	^{226}Ra	226.025403	*
89	Actinium	^{227}Ac	227.027747	*
90	Thorium	^{232}Th	232.038050	100
91	Protactinium	^{231}Pa	231.035879	100
92	Uranium	^{234}U	234.040946	0.0055
		^{235}U	235.043923	0.7200
		^{238}U	238.050783	99.2745

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Z	Name	Symbol	Mass of Atom (u)	% Abundance
93	Neptunium	^{237}Np	237.048167	*
94	Plutonium	^{244}Pu	244.064198	*
95	Americium	^{243}Am	243.061373	*
96	Curium	^{247}Cm	247.070347	*
97	Berkelium	^{247}Bk	247.070299	*
98	Californium	^{251}Cf	251.079580	*
99	Einsteinium	^{252}Es	252.082972	*
100	Fermium	^{257}Fm	257.095099	*
101	Mendelevium	^{258}Md	258.098425	*
102	Nobelium	^{259}No	259.101024	*
103	Lawrencium	^{262}Lr	262.109692	*
104	Rutherfordium	^{263}Rf	263.118313	*
105	Dubnium	^{262}Db	262.011437	*
106	Seaborgium	^{266}Sg	266.012238	*
107	Bohrium	^{264}Bh	264.012496	*
108	Hassium	^{269}Hs	269.001341	*
109	Meitnerium	^{268}Mt	268.001388	*
110	Ununnilium	^{272}Uun	272.001463	*
111	Unununium	^{272}Uuu	272.001535	*
112	Ununbium	^{277}Uub	(277)	*
114	Ununquadium	^{289}Uuq	(289)	*
116	Ununhexium	^{289}Uuh	(289)	*
118	Ununoctium	^{293}Uuo	(293)	*

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Periodic Table of the Elements

1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]

Lanthanide Series	57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967
Actinide Series	89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

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