UNIVERSITI SAINS MALAYSIA

Final Examination
2015/2016 Academic Session

May/June 2016

JIK 321 – Analytical Chemistry II
[Kimia Analitis II]

Duration : 3 hours
[Masa : 3 jam]

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

Answer **FIVE** 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 **TUJUH BELAS** muka surat yang bercetak sebelum anda memulakan peperiksaan ini.*

*Jawab **LIMA** 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.

Answer any **FIVE** questions.

*Jawab mana-mana **LIMA** soalan.*

1. Explain the DIFFERENCES in the pair of concepts/items given below, use appropriate diagrams if needed.

   (a) Molecular emission and molecular fluorescence
   (b) Spectroscopy and spectrometer
   (c) Liquid chromatography and high performance liquid chromatography
   (d) Capillary GC and temperature programmed GC
   (e) Mass analyser and mass spectrometer

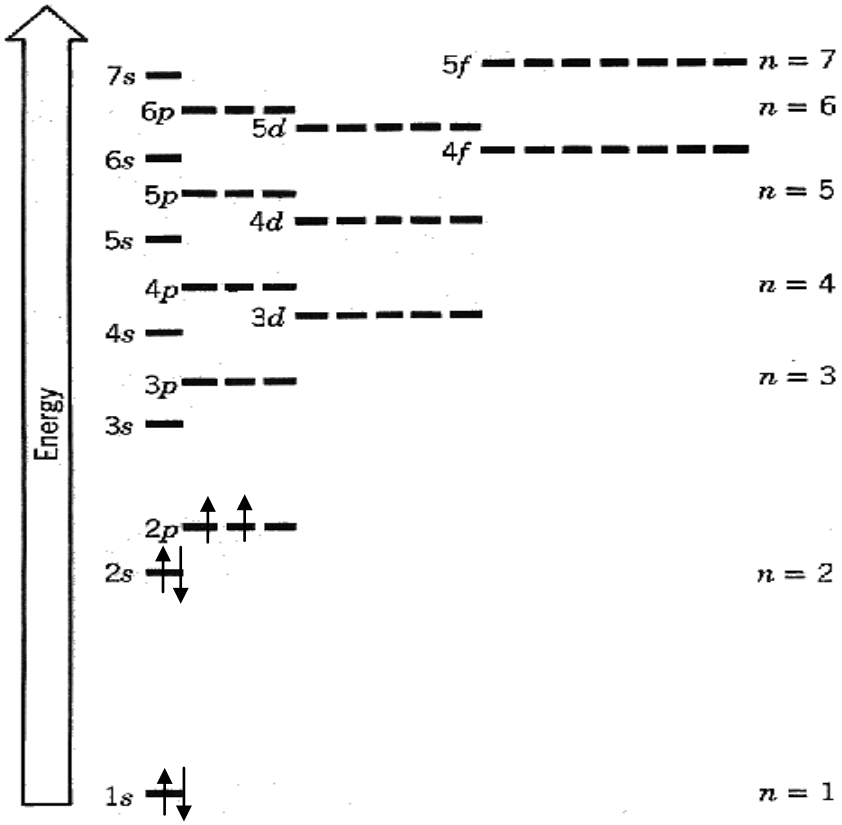
   Terangkan PERBEZAAN dalam pasangan konsep/perkara yang diberikan di bawah, gunakan gambar rajah yang sesuai jika perlu.

   (a) Pemancaran molekul dan pendarfluoran molekul
   (b) Spektroskopi dan spektrometer
   (c) kromatografi cecair dan kromatografi cecair berprestasi tinggi
   (d) kromatografi gas kapilari dan kromatografi gas dengan suhu terprogram
   (e) Penganalisis jisim dan spektrometer jisim

   (20 marks/*markah*)

2. (a) Using the following atomic orbital energy diagram as a guide, show by using arrows and lines an excitation process, an absorption process and an emission process involving three different electrons:

Dengan menggunakan gambar rajah tenaga orbital atom berikut sebagai panduan, tunjukkan menggunakan anak panah dan garisan proses pengujaan, proses penyerapan dan proses pemancaran melibatkan tiga elektron yang berbeza:



(5 marks/*markah*)

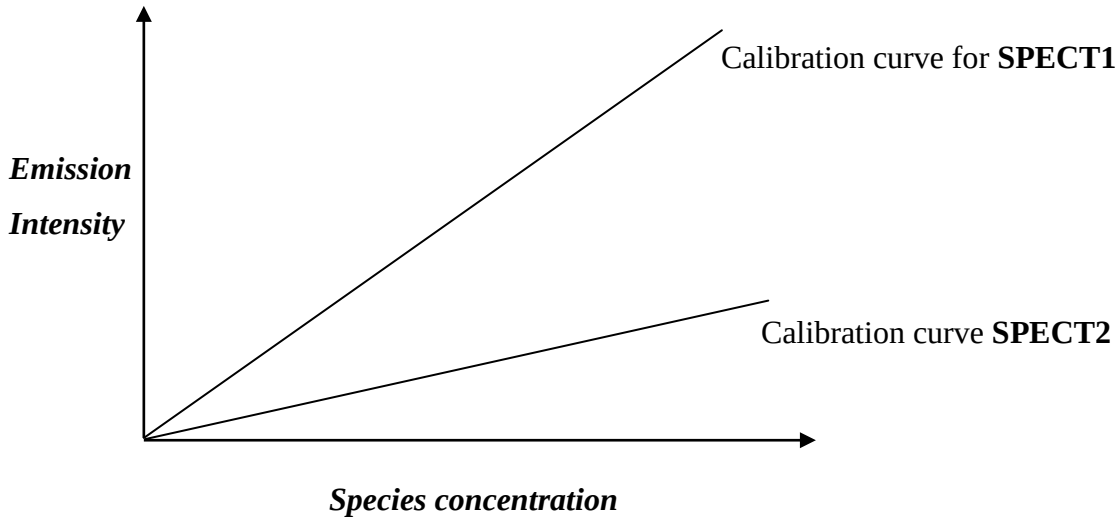
(b) (i) Draw schematic diagrams of an atomic absorption spectrometer and an atomic emission spectrometer. Label all the key components.

Lukiskan gambar rajah skematik spektrometer penyerapan atom dan spektrometer pemancaran atom. Labelkan semua komponen utama.

(ii) Discuss the one MAJOR difference that exists between the two spectrometers.
Bincangkan satu perbezaan UTAMA yang wujud antara kedua spektrometer itu.

(10 marks/*markah*)

(c) Study the two calibration curves given below. The lines represent the determination of cadmium (Cd) simultaneously with 14 other elements using two different spectroscopic techniques:
Kaji dua keluk tentukuran yang diberikan di bawah. Garisan-garisan itu mewakili penentuan kadmium (Cd) secara serentak bersama-sama dengan 14 unsur lain menggunakan dua teknik spektroskopi yang berbeza:



(i) Which one of the two calibration curves represent a better determination? Give the reason(s) for your answer.

(ii) Name the two possible spectroscopic techniques represented by SPECT1 and SPECT2.

(i) *Yang manakah antara dua keluk tentukuran itu mewakili penentuan yang lebih baik? Beri alasan/alasan-alasan kepada jawapan anda.*

(ii) *Namakan dua teknik spektroskopi yang mungkin diwakili oleh SPECT1 dan SPECT2.*

(5 marks/*markah*)

3. (a) The following standard solutions were used in determining vanadium (V) in used jet engine oil. An atomic emission spectrometer with nitrous oxide-acetylene flame was used.

Larutan piawai berikut telah digunakan untuk penentuan vanadium (V) dalam minyak enjin jet terpakai. Spektrometer penyerapan atom dengan nyalaan nitrus oksida-asetilena telah digunakan.

Solution	V concentration (ppb)	Emission Intensity
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 from jet engine oil with unknown V	?	54.50

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

(ii) Determine the concentrations of V in the jet engine oil sample. Show how that value is obtained.

(iii) How can the concentration of V in the jet engine oil be more accurately determined using the same calibration curve? Explain your answer.

(iv) Suggest a way to improve the calibration curve.

(i) Lukiskan keluk tentukuran yang sesuai berdasarkan larutan piawai yang digunakan. (Kertas graf tidak diperlukan).

(ii) Tentukan kepekatan V dalam sampel minyak enjin jet. Tunjukkan bagaimana nilai itu diperolehi.

(iii) Bagaimanakah kepekatan V dalam minyak enjin jet itu dapat ditentukan dengan lebih tepat menggunakan keluk tentukuran yang sama? Terangkan jawapan anda.

(iv) Cadangkan satu cara untuk memperbaiki keluk penentukuran itu.

(10 marks/*markah*)

(b) (i) In any elemental/isotopic mass spectrometric determination, interferences can cause error in the determination of the species. Discuss THREE kinds of interference that can occur in mass spectrometric determinations.

(ii) Briefly discuss TWO interferences that can occur in an inductively coupled plasma optical emission spectrometry (ICP-OES) determinations particularly at parts per billion (ppb) and parts per trillion (ppt) levels.

(*i) Dalam mana-mana penentuan jisim unsur/isotop menggunakan spektrometri jisim, gangguan boleh menyebabkan kesilapan dalam penentuan spesies. Bincangkan TIGA jenis gangguan yang boleh berlaku dalam penentuan spektrometri jisim.*

(ii) Secara ringkas bincangkan DUA gangguan yang boleh berlaku dalam penentuan menggunakan plasma teraruh – spektroskopi pemancaran (ICP-OES) terutamanya pada tahap bahagian per bilion (ppb) dan bahagian per trilion (ppt).

(10 marks/*markah*)

4. (a) Inductively coupled plasma optical emission spectrometry (ICP-OES) and inductively coupled plasma mass spectrometry (ICP-MS) are very powerful analytical techniques. Both have their strengths and weakness when compared against each other.

(i) Which technique can perform simultaneous multielement analysis? Explain your answer.

(ii) Explain one major advantage of ICP-OES over ICP-MS

(iii) Outline two major advantages of ICP-MS over ICP-OES

(iv) There is one elemental analysis that can only be performed using ICP-MS and not ICP-OES. What is that analysis?

Plasma teraruh spektroskopi pemancaran atom (ICP-OES) dan plasma teraruh spektrometri jisim (ICP-MS) adalah teknik analisis yang berkuasa tinggi. Kedua-duanya mempunyai kekuatan dan kelemahan masing-masing jika dibandingkan antara satu sama lain..

(i) Teknik manakah yang boleh melakukan analisis pelbagai unsur secara serentak? Jelaskan jawapan anda.

(ii) Terangkan satu kelebihan utama ICP-OES berbanding ICP-MS

(iii) Berikan dua kelebihan utama ICP-MS berbanding ICP-OES

(iv) Terdapat satu jenis analisis unsur yang hanya boleh dilakukan dengan menggunakan ICP-MS dan tidak ICP-OES. Apakah analisis itu?

(10 marks/*markah*)

(b) The following data was obtained from a chromatographic analysis done under the following conditions:
Data berikutnya diperolehi daripada analisis kromatografi yang telah dilakukan dalam keadaan berikut:

Column: C-8, 15 cm.
Condition: Solvent A = Isopropanol; Solvent B = n-Hexane;
Gradient: Solvent A 0% - 100% at 10% intervals
Solvent B 100% - 0% at 10% intervals

Peak number	t_R (min)	Ion Count
1	2.10	4235
2	2.55	112887
3	4.05	5755
4	6.00	18112
5	9.30	87237
6	12.50	7022
7	14.30	4633
8	17.45	4385
9	21.05	4022
10	25.30	3333
11	29.45	2685

(i) Name the specific chromatographic technique used? Give the reason for your answer.

(ii) What detector was used in this technique? Give the reason for your answer.

(iii) Why were two solvents used in the analysis?

(iv) Propose possible alternative solvents that can be used for solvent A and solvent B? Explain your answer.

(i) Namakan teknik kromatografi khusus yang telah digunakan? Berikan alasan bagi jawapan anda.

(ii) Apakah pengesan yang digunakan dalam teknik ini? Berikan alasan bagi jawapan anda.

(iii) Mengapa dua pelarut digunakan dalam analisis ini?

(iv) Cadangkan pelarut alternatif yang boleh digunakan sebagai pelarut A dan pelarut B? Jelaskan jawapan anda.

(10 marks/*markah*)

5. (a) Draw the chromatogram and all the mass spectra that can be obtained from a GC-MS analysis of a sample containing the following four compounds. Assume all the four compound are well separated. Label all the axes.
Lukiskan kromatogram dan semua spektrum jisim yang boleh diperolehi daripada analisis GC-MS sampel mengandungi empat sebatian berikut. Anggap semua sebatian dipisahkan dengan baik. Labelkan semua paksi.

CH_3OH; CH_3CH_2OH; $CH_3CH_2CH_2OH$ and $CH_3CH(OH)CH_3$

(10 marks/*markah*)

(b) The following spectrum of a sample containing various elements was obtained via ICP-MS technique. Some of the possible elements in the sample are: C, N, O, F, Na, Mg, Al, Si, P and S. By studying the spectrum carefully,

(i) can you be certain that Na, Si and P are present in the sample? Give your reasons.

(ii) can you concluded that there is most probably NO sulphur and fluorine in the sample? Explain your answer.

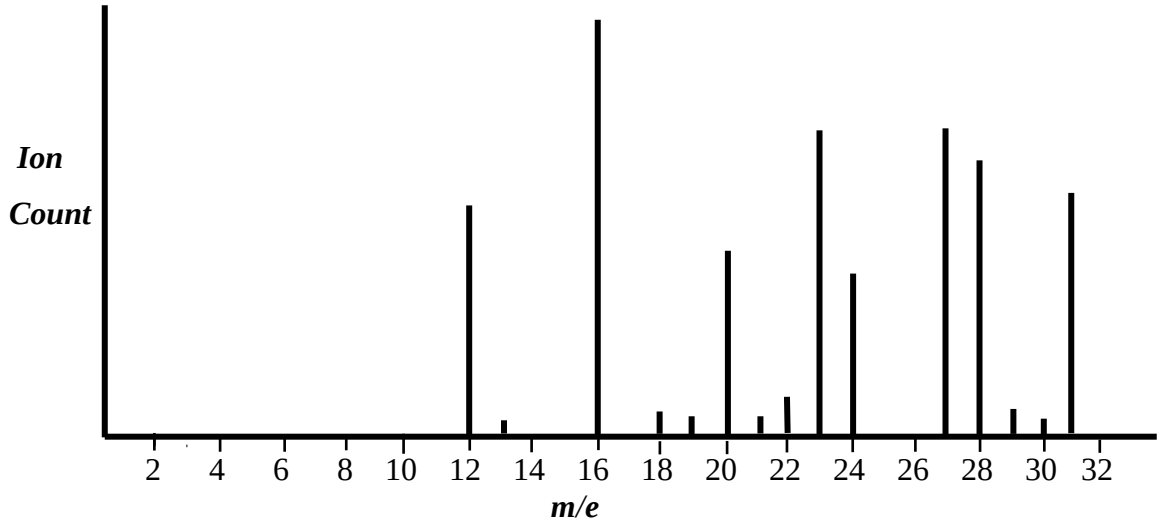
(iii) what element(s) are represented by the peaks at m/e 20, 21 and 22? Explain your answer.

Spektrum bagi suatu sampel berikut yang mengandungi pelbagai unsur telah diperolehi melalui teknik ICP-MS. Sebahagian daripada unsur yang mungkin ada dalam sampel itu adalah: C, N, O, F, Na, Mg, Al, Si, P dan S. Dengan mengkaji spektrum itu secara teliti,

(i) *adakah anda yakin terdapat Na, Si dan P dalam sampel itu? Berikan alasan anda.*

(ii) *bolehkah anda membuat kesimpulan bahawa besar kemungkinan TIADA sulfur dan fluorin dalam sampel? Terangkan jawapan anda.*

(iii) *apakah unsur/unsur-unsur yang diwakili oleh puncak-puncak pada m / e 20, 21 dan 22? Terangkan jawapan anda.*



(10 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.

(a) The constituents of an essential oil extracted from poppy seeds (often used in cooking muffins and bagels) need to be identified. The structures and identities of the various components in that essential oil needs to be determined.

(b) Fresh water sample obtained from a lake is suspected to be contaminated with various metals and non-metals. The contaminants need to be determined up to ppb levels.

(c) A routine analyis of heavy metals content in many traditional medical products need to be done as cheaply and quickly as possible. Typically, more than 100 samples are analysed daily and more than 20 metals are determined up to ppm level.

(d) A rock sample containing traces of precious metals has been claimed to be obtained from Hindu Kush mountain in Afghanistan. How can it be proven that the rock is really from that mountain?

(e) An organic sample extract of contaminated soil suspected to contain a mixture of up to fifty different compounds. The compounds' identities need to be identified.

Bagi sampel-sampel berikut, cadangkan teknik yang paling mudah/cepat/murah yang dapat digunakan untuk melakukan analisis yang diperlukan. Teknik itu boleh jadi berbentuk spektroskopi, kromatografi atau kombinasi keduanya. Jelaskan mengapa anda memilih kaedah /teknik berkenaan.

(a) Konstituen pati minyak yang diekstrak dari biji popi (sering digunakan dalam pembuatan muffin dan bagel) perlu dikenalpasti. Struktur dan identiti pelbagai komponen dalam pati minyak itu perlu ditentukan.

(b) *Sampel air tawar dari suatu tasik disyaki dicemari berbagai unsur logam dan bukan logam. Bahan pencemar itu perlu ditentukan sehingga ke tahap ppb.*

(c) *Analisis rutin kandungan logam berat dalam kebanyakan produk perubatan tradisional perlu dilakukan dengan murah dan secepat mungkin. Biasanya, lebih daripada 100 sampel perlu dianalisis setiap hari dan lebih dari 20 logam perlu ditentukan sehingga ke tahap ppm.*

(d) *Suatu sampel batuan mengandungi kesan-kesan logam berharga didakwa diperolehi dari Gunung Hindu Kush di Afghanistan. Bagaimanakah dapat dibuktikan bahawa batuan itu adalah benar-benar dari gunung berkenaan?*

(e) *Suatu ekstrak sampel organik dari tanah yang dicemari disyaki mengandungi sehingga lima puluh sebatian yang berbeza. Identiti sebatian-sebatian itu perlu dikenalpasti.*

(20 marks/*markah*)

Table of Isotopic Masses and Natural 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

…14/-

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

Z	Name	Symbol	Mass of Atom (u)	% Abundance
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

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	^{136}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

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

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)	*