



NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF INDUSTRIAL TECHNOLOGY

DEPARTMENT OF CHEMICAL ENGINEERING

PROCESS ENGINEERING FUNDAMENTALS

ECE 1101

December 2024

This examination paper consists of 8 pages

Time Allowed: 3 hours

Total Marks: 100

Special Requirements: Chemical Engineering Tables

INSTRUCTIONS

1. Answer ALL QUESTIONS in Section A and ANY TWO (2) questions in Section B
2. Each question carries 25 marks
3. Use of calculators is permissible

MARK ALLOCATION

QUESTION	MARKS
A1.	25
A2.	25
B1.	25
B2.	25
B3.	25
B4.	25
TOTAL ATTAINABLE MARKS	100

Page 1 of 8

SECTION A

Answer all questions

QUESTION A1

- a. Draw and label a P-T diagram for a pure fluid. [5]
- b. i. What is a system? [1]
- ii. List and describe the three types of systems. [6]
- c. You have been asked to measure the rate at which waste gases are being discharged from a stack. The gases entering contain 2.1 % carbon dioxide. Pure carbon dioxide is introduced into the bottom of the stack at a measured rate of 4.0 lb per minute. You measure the discharge of gases leaving the stack and find the concentration of carbon dioxide is 3.2 %. Calculate the rate of flow, in lb mol/minute, of the entering waste gases. [7].
- d. Calcium carbonate is a naturally occurring white solid used in the manufacture of lime and cement. Calculate the number of lb mols of calcium carbonate in:
- i. 50 g mol of CaCO_3 . [2]
- ii. 150 kg of CaCO_3 . [2]
- iii. 100 lb of CaCO_3 . [2]

QUESTION A2

- a. Wine making involves a series of very complex reactions most of which are performed by microorganisms. The starting concentration of sugars determines the final alcohol content and sweetness of the wine. The specific gravity of the starting stock is therefore adjusted to achieve desired quality of wine. A starting stock solution has a specific gravity of 1.075 and contains 12.7 wt% sugar. If all the sugar is assumed to be $\text{C}_{12}\text{H}_{22}\text{O}_{11}$, determine
- i. kg sugar/kg H_2O [2]
- ii. lb solution/ft³ solution [2]
- iii. g sugar/L solution. [2]
- b. FeS can be roasted in O_2 to form FeO:
- $$2\text{FeS} + 3\text{O}_2 \rightarrow 2\text{FeO} + 2\text{SO}_2$$

If the slag (solid product) contains 80% FeO and 20% FeS, and the exit gas is 100% SO₂, determine the extent of the reaction and the initial number of moles of FeS. Use 100 g or 100 lb as the basis.

[4]

b. TiCl₄ can be formed by reacting titanium dioxide (TiO₂) with hydrochloric acid. TiO₂ is available as an ore containing 78 % TiO₂ and 22 % inerts. The HCl is available as a 45 wt% solution (the balance is water). The per-pass conversion of TiO₂ is 75 %. The HCl is fed into the reactor in 20 % excess based on the reaction. Pure unreacted TiO₂ is recycled back to mix with the TiO₂ feed.



For 1 kg of TiCl₄ produced, determine:

i. the kg of TiO₂ ore fed. [6]

ii. the kg of 45 wt % HCl solution fed. [4]

iii. the ratio of recycle stream to fresh TiO₂ ore (in kg). [5]

(MW : TiO₂ = 79.9; HCl = 36.47; TiCl₄ = 189.7)

SECTION B

Answer any 2 questions

QUESTION B1

a. Gas at 15°C and 105 kPa is flowing through an irregular duct. To determine the rate of flow of the gas, CO₂ from a tank is steadily passed into the gas stream. The flowing gas, just before mixing with the CO₂, analyses 1.2% CO₂ by volume. Downstream, after mixing, the flowing gas analyses 3.4% CO₂ by volume. As the CO₂ that was injected exited the tank, it was passed through a rotameter and found to flow at the rate of 0.0917 m³/min at 7°C and 131 kPa. What was the rate of flow of the entering gas in the duct in cubic meters per minute? [6]

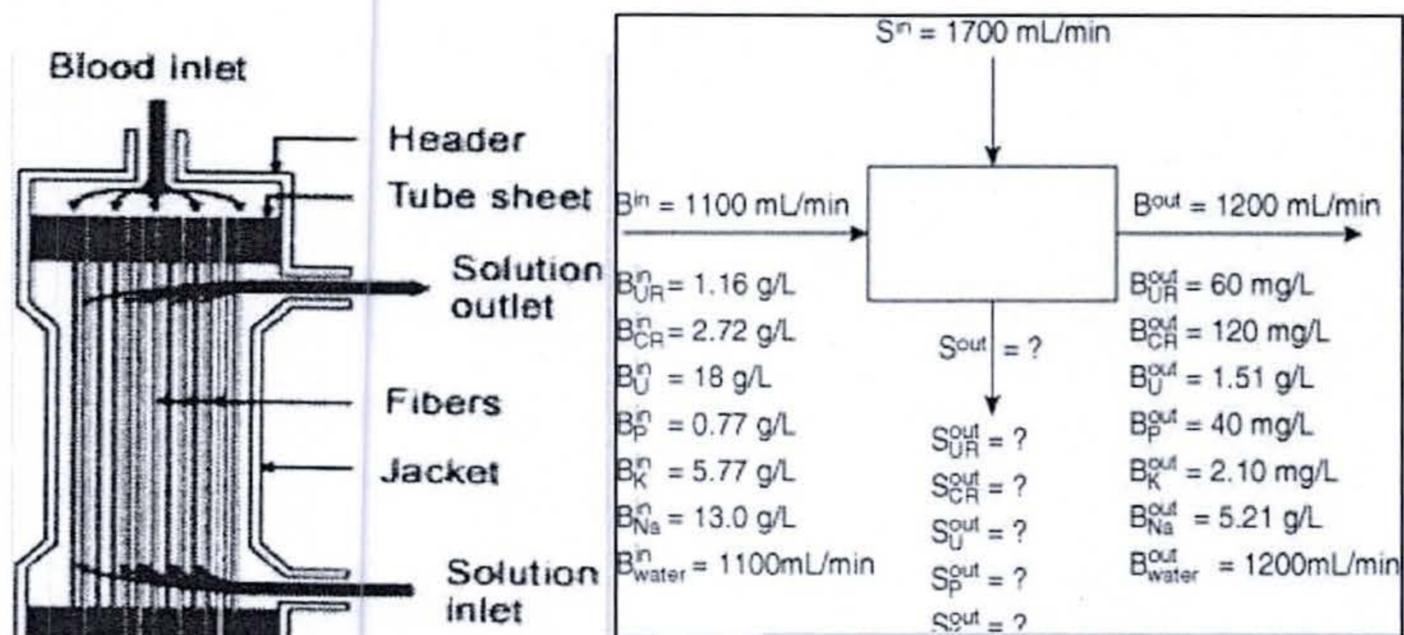
b. How much heat is required when 10 000 kg of CaCO₃ is heated at atmospheric pressure from 323.15 to 1153.15 K (50°C to 880°C)? [4]

c. Define i. Atmospheric pressure. ii. Absolute pressure. [2]

d. Hemodialysis is the most common method used to treat advanced and permanent kidney failure. When your kidneys fail, harmful wastes build up in your body, your blood pressure may

rise, and your body may retain excess fluid and may not make enough red blood cells. In hemodialysis, your blood flows through a device with a special filter that removes urea and preserves the water balance and the serum proteins in the blood.

The dialyzer itself (refer to Figure B1) is a large canister containing thousands of small fibres through which the blood passes.



Dialysis solution, the cleansing solution, is pumped around these fibres. The fibres allow wastes and extra fluids to pass from your blood into the solution that carries them away. This example focuses on the plasma components in streams S (solvent) and B (blood): water, uric acid (UR), creatinine (CR), urea (U), P, K, and Na. You can ignore the initial filling of the dialyzer because the treatment lasts for an interval of two or three hours. Given the measurements obtained from one treatment, as shown in Figure B1, calculate the grams per litre of each component of the plasma in the outlet solution. [10]

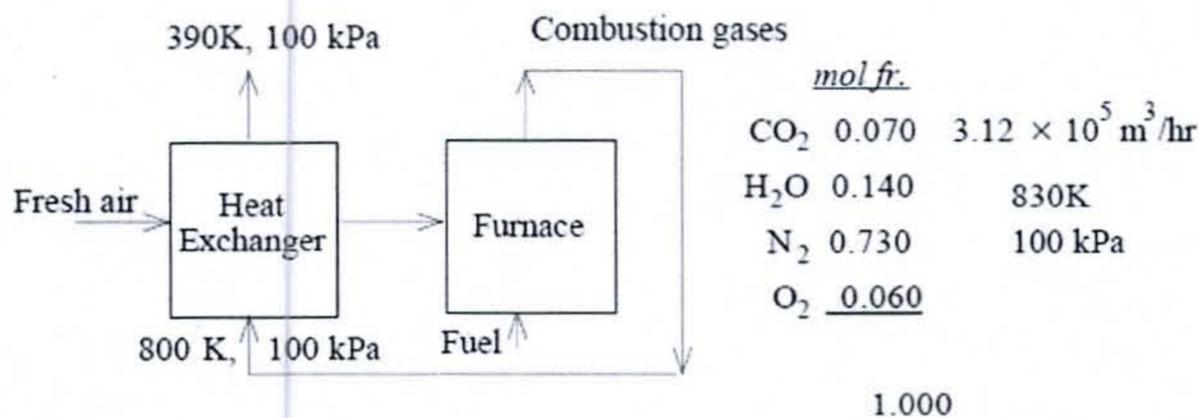
e. If 1 L of ethyl alcohol is mixed with 1 L of water, how many kilograms of solution result and litres result? [3]

QUESTION B2

a. A manufacturer blends lubricating oil by mixing 300 kg/min of No. 10 oil with 100 kg/min of No. 40 oil in a tank. The oil is well mixed and is withdrawn at the rate of 380 kg/min. Assume the tank contains no oil at the start of the blending process. How much oil remains in the tank after 1 hr? [5]

b. Chlorine gas containing 2.4 % O₂ is flowing through an earthenware pipe. The gas flow rate is measured by introducing air into it at the rate of 115 m³/min. Further down the line, after mixing is complete, the gas is found to contain 10.85 % O₂. How much m³ of the initial gas was flowing per minute through the pipe? [8]

c. Energy can be saved by passing the combustion gases from a furnace or boiler through a heat exchanger in which the air entering the furnace is preheated. Examine the figure B2. The air does not contact the combustion gases directly in the heat exchanger; tube walls separate the streams. Calculate the enthalpy change in kJ that occurs for the combustion gases on passing through the heat exchanger. [8]



d. The heat capacity of sulphuric acid in a handbook has the units J/(gmol)(°C) and is given the relation

$$\text{Heat capacity} = 139.1 + 1.56 \times 10^{-1} T$$

where T is expressed in °C. Modify the formula so that the resulting expression has the associated units of Btu/(lbmol)(°R) and T is in °R. [4]

QUESTION B3

a. Saturated steam at 400°C is used to heat a counter-currently flowing stream of methanol from 65°C to 250°C in an adiabatic heat exchanger. The flow rate of the alcohol is 5600 L/min (STP) and the steam condenses and leaves the heat exchanger as water at 85 °C.

i. Evaluate the rate of heat transfer from the water to the methanol (kW) [7]

ii. Calculate the required flow rate of the entering steam in m^3/min [7]

b. Argon gas in an insulated plasma deposition chamber with a volume of 2 L is to be heated by an electric resistance heater. Initially the gas, which can be treated as an ideal gas, is at 1.5 Pa and 300 K. The 1000-ohm heater draws current at 40 V for 5 min (i.e., 480 J of work is done on the system by the surroundings). What are the final gas temperature and pressure in the chamber? The mass of the heater is 12 g and its heat capacity is 0.35 J/(g)(K). Assume that the heat transfer through the walls of the chamber from the gas at this low pressure and in the short time period involved is negligible. [8]

c. Indicate whether the following statements are true or false:

i. Purge is used to maintain a concentration of a minor component of a process stream below some set point so that it does not accumulate in the process.

ii. Bypassing means that a process stream enters the process in advance of the feed to the process.

ii. A trace component in a stream or produced in a reactor will have negligible effect on the overall material balance when recycle occurs. [3]

(END OF EXAMINATION PAPER)

Conversion Factor Table

Multiply	by	To Get						
inch	2.54	cm	hp	2544.5	Btu / hr	m / s	3.60	km / h
This can also be written as: 1 inch = 2.54 cm			hp	745.70	W (watt)	m / s	3.2808	ft / s
A acre	43,560	ft ²	hp	0.74570	kW	m / s	2.237	mi / h (mph)
ampere-hr (A-h)	3,600	coulomb (C)	hp	33,000	ft-lbf / min	m / s ²	3.2808	ft / s ²
ångström (Å)	1x10 ⁻¹⁰	m	hp	550	ft-lbf / sec	metric ton	1000	kg
atm (atmosphere)	1.01325	bar	hp-hr	2544	Btu	mil	0.001	in
atm, std	76.0	cm of Hg	hp-hr	1.98x10 ⁶	ft-lbf	mi (mile)	5280	ft
atm, std	760	mm of Hg at 0°C	hp-hr	2.68x10 ⁶	J	mi	1.6093	km
atm, std	33.90	ft of water	in	2.54*	cm	mi ² (square mile)	640	acres
atm, std	29.92	in of Hg at 30°F	in of Hg	0.0334	atm	mph (mile/hour)	1.6093	km / hr
atm, std	14.696	lbf/in ² abs (psia)	in of Hg	13.60	in of water	mph	88.0	ft / min (fpm)
atm, std	101.325	kPa	in of Hg	3.387	kPa	mph	1.467	ft / s
atm, std	1.013x10 ⁵	Pa	in of water	0.0736	in of Hg	mph	0.4470	m / s
atm, std	1.03323	kgf / cm ²	in of water	0.0361	lbf / in ² (psi)	micron	1x10 ⁻⁶	m
atm, std	14.696	psia	in of water	0.002458	atm	mm of Hg	1.316x10 ⁻³	atm
B bar	0.9869	atm, std	J	9.4782x10 ⁻⁴	Btu	mm of Hg	0.1333	kPa
bar	1x10 ⁵	Pa	J	6.2415x10 ¹⁸	eV	mm of water	9.678x10 ⁻⁵	atm
Btu	778.169	ft-lbf	J	0.73756	ft-lbf	N (newton)	1	kg-m / s ²
Btu	1055.056	J	J	1	N-m	N	1x10 ⁵	dyne
Btu	5.40395	psia-ft ³	J / s	1x10 ⁷	ergs	μN (microN)	0.1	dyne
Btu	2.928x10 ⁻⁴	kWh	K	1	W	N	0.22481	lbf
Btu	1x10 ⁻⁵	therm	kg (kilogram)	2.2046226	lbf (pound mass)	N-m	0.7376	ft-lbf
Btu / hr	1.055056	kJ / hr	kg	0.068522	slug	N-m	1	J
Btu / hr	0.216	ft-lbf / sec	kg / m ³	0.062428	metric ton	P Pa (pascal)	1	N / m ²
Btu / hr	3.929x10 ⁻⁴	hp	kgf	9.80665	lbf / ft ³	Pa	1.4504x10 ⁻⁴	lbf / in ² (psia)
Btu / hr	0.2931	W	kip	1000	newton (N)	Pa	0.020886	lbf / ft ²
Btu / lbm	2.326*	kJ / kg	kip	4448	lbf	Pa	9.869x10 ⁻⁶	atm
Btu / lbm	25.037	ft ² / s ²	kJ	1	N	Pa-s	10	poise
Btu / lbm-R	4.1868	kJ / kg-K	kJ	1000	1 kPa-m ³	psi (pounds per square inch) — see lbf / in ²		
Btu / lbm-°F	4.1868	kJ / kg-°C	kJ	0.94782	N-m	R radian	180/π	degree
Btu / lbmol-R	4.1868	kJ / kmol-K	kJ	737.56	Btu	S short ton	2000	lbm
C cal (g-calorie)	3.968x10 ⁻³	Btu	kJ / kg	1000	ft-lbf	short ton	907.1847	kg
cal	1.560x10 ⁻⁶	hp-hr	kJ / kg	0.42992	m ² / s ²	slug	32.174	lbm
cal (IT calorie)	4.1868	J	kJ / kg-K	0.23885	Btu / lbm	slug	14.5939	kg
Calorie (Cal)	4.1868	kJ	kJ / kg-°C	1	Btu / lbm-°R	slug / ft ³	0.5154	g / cm ³
cal / sec	4.1868	W (watt)	kJ / kg-°C	1	kJ / kg-K	stokes	1x10 ⁻⁴	m ² / s
cm (centimeter)	0.03281	ft	kJ / kg-°C	0.23885	J / g-°C	T therm	1x10 ⁵	Btu
cm	0.3937	in	kJ / kg-°C	0.23885	Btu / lbm-°F	ton of refrigeration	200	Btu / min
cP (centipoise)	0.001	Pa-sec	km	3280.8	Btu / lbm-R	W (watt)	3.4121	Btu / hr
cSt (centistokes)	1x10 ⁻⁶	m ² / sec	km	0.6214	ft	W	0.7376	ft-lbf / sec
D degree	π/180	radian	km/hr	0.6214	mi	W	1.341x10 ⁻³	hp
dyne	10	μN (micronewton)	km/hr	0.2778	m/s	W	1	J / s
E eV (electronvolt)	1.602x10 ⁻¹⁹	J	km/hr	0.9113	ft/s	W / cm ²	1x10 ⁴	W / m ²
erg	1x10 ⁻⁷	J	kPa (kilopascal)	9.8693x10 ⁻³	atm	W / cm ³	1x10 ⁶	W / m ³
F ft (feet)	0.3048*	m	kPa	0.14504	lbf / in ² (psi)	W / m ²	0.3171	Btu / (h-ft ²)
ft	30.48	cm	kW	3412.14	Btu / hr	W / m ³	0.09665	Btu / (h-ft ³)
ft ²	2.2957x10 ⁻⁵	acre	kW	0.9478	Btu / sec	W / m-°C	1	W / m-K
ft ²	144	in ²	kW	737.56	lbf-ft / sec	W / m-°C	0.57782	Btu / (h-ft-°F)
ft ²	0.09290304*	m ²	kWh (kW-hour)	3412.14	hp	W / (m ² -°C)	1	W / (m ² -K)
ft ³	7.481	gal (U.S.)	kWh	1.341	Btu	W / (m ² -°C)	0.17612	Btu / (h-ft ² -°F)
ft ³	0.02832	m ³	kWh	3600	hp-hr	weber / m ²	10,000	gauss
ft ³	28.317	L	L (liter)	0.03531	kJ			
ft ³ / lbm	0.062428	m ³ / kg	L	61.02	ft ³			
ft-lbf	1.285x10 ⁻³	Btu	L	0.2642	in ³			
ft-lbf	1.35582	J	L	0.001	gal (U.S.)			
ft-lbf	3.766x10 ⁻⁷	kWh	L / s	2.119	m ³			
ft-lbf	1.35582	N-m	L / s	15.85	ft ³ / min (cfm)			
ft-lbf	0.324	calorie (g-cal)	lbf (pound force)	32.174	gal / min (gpm)			
ft-lbf / sec	1.818x10 ⁻³	hp	lbf	4.44822	lbm-ft / s ²			
ft / s ²	0.3048*	m / s ²	lbf	32.17	N			
G U.S. gallon (gal)	0.13368	ft ³	lbf / in ² (psi)	0.06805	poundals			
gal	3.7854	L	lbf / in ²	2.307	atm			
gal	3.7854x10 ⁻³	m ³	lbf / in ²	2.036	ft water			
gal	231	in ³	lbf / in ²	6894.757	in Hg			
gal (U.K.)	1.201	gal (U.S.)	lbm	0.45359237*	Pa			
gal (U.K.)	277.4	in ³	lbm	0.031081	kg			
gal / min (gpm)	0.002228	ft ³ / sec	lbm / in ³	1728	slug			
gamma (γ, Γ)	1x10 ⁻⁹	tesla (T)	lbm / ft ³	0.016018	lbm / ft ³			
gauss	1x10 ⁻⁴	T	lbm / ft ³	16.018	g / cm ³			
gram (g)	2.205x10 ⁻³	lbm	M m (meter)	3.28083	kg / m ³			
g / cm ³	1	1 kg / L	m	1.0926	ft			
g / cm ³	1000	kg / m ³	m	39.370	yard			
g / cm ³	62.428	lbm / ft ³	m	0.001	in			
g / cm ³	1.940	slug / ft ³	m ²	1550	in ²			
g / cm ³	0.036127	lbm / in ³	m ²	10.764	ft ²			
H hectare	1x10 ⁴	m ²	m ³	1x10 ⁶	cm ³ (cc)			
hectare	2.47104	acres	m ³	35.315	ft ³			
hp (horsepower)	42.41	Btu / min	m ³	264.17	gal (U.S.)			
hp	0.7068	Btu / sec	m ³ / kg	1000	L			
			m / s	16.02	ft ³ / lbm			
				196.8	ft / min			

* The exact conversion between metric and English.

TEMPERATURE
 $T(K) = T(°C) + 273.15$
 $T(R) = T(°F) + 459.67$
 $T(°F) = 1.8 T(°C) + 32$

SOME IMPORTANT CONSTANTS

Atomic Mass Unit (u)	=	1.66054x10 ⁻²⁷ kg
Avogadro's number (N _A)	=	6.02213x10 ²³ particles/mol
Boltzmann's constant (k _B)	=	1.38065x10 ⁻²³ J / K
electron charge (e)	=	-1.6022x10 ⁻¹⁹ C
electron mass (m _e)	=	9.10939x10 ⁻³¹ kg
proton mass (m _p)	=	1.6726x10 ⁻²⁷ kg
Gas Constant (R)	=	8314 J / kmol-K
Gravitational Constant (G)	=	6.672x10 ⁻¹¹ N-m ² / kg ²
Gravity (mean)	=	9.8067 (9.81) m / s ²
Planck's constant (h)	=	6.6260x10 ⁻³⁴ J-s
Speed of Light (c)	=	2.99792458x10 ⁸ m/s (exact)

SI PREFIXES

yocto (10⁻²⁴), zepto (10⁻²¹), atto (10⁻¹⁸), femto (10⁻¹⁵), pico (10⁻¹²), nano (10⁻⁹), micro (10⁻⁶), milli (10⁻³), centi (10⁻²), deci (10⁻¹), deka (10¹), hecto (10²), kilo (10³), mega (10⁶), giga (10⁹), tera (10¹²), peta (10¹⁵), exa (10¹⁸), zetta (10²¹), yotta (10²⁴)

The Periodic Table of the Elements

1 H Hydrogen 1.00794																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				

58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

1995 IUPAC masses and Approved Names from <http://www.chem.qmw.ac.uk/iupac/AtW/>
 masses for 107-111 from C&EN, March 13, 1995, p. 35
 112 from <http://www.gsi.de/z112e.html>