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

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 $C_{12}H_{22}O_{11}$, determine

i. kg sugar/kg H_2O [2]

ii. lb solution/ft^3 solution [2]

iii. g sugar/L solution. [2]

b. b. FeS can be roasted in O_2 to form FeO:

$2FeS + 3O_2 \rightarrow 2FeO + 2SO_2$

If the slag (solid product) contains 80% FeO and 20% FeS, and the exit gas is 100% SO_2, 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. $TiCl_4$ can be formed by reacting titanium dioxide (TiO_2) with hydrochloric acid. TiO_2 is available as an ore containing 78 % TiO_2 and 22 % inerts. The HCl is available as a 45 wt% solution (the balance is water). The per-pass conversion of TiO_2 is 75 %. The HCl is fed into the reactor in 20 % excess based on the reaction. Pure unreacted TiO_2 is recycled back to mix with the TiO_2 feed.

$$TiO_2 + 4\,HCl \text{ -----> } TiCl_4 + 2H_2O$$

For 1 kg of $TiCl_4$ produced, determine:

i. the kg of TiO_2 ore fed. [6]

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

iii. the ratio of recycle stream to fresh TiO_2 ore (in kg). [5]

(MW : TiO_2 = 79.9; HCl = 36.47; $TiCl_4$ = 189.7)

SECTION B

Answer any 2 questions

QUESTION B1

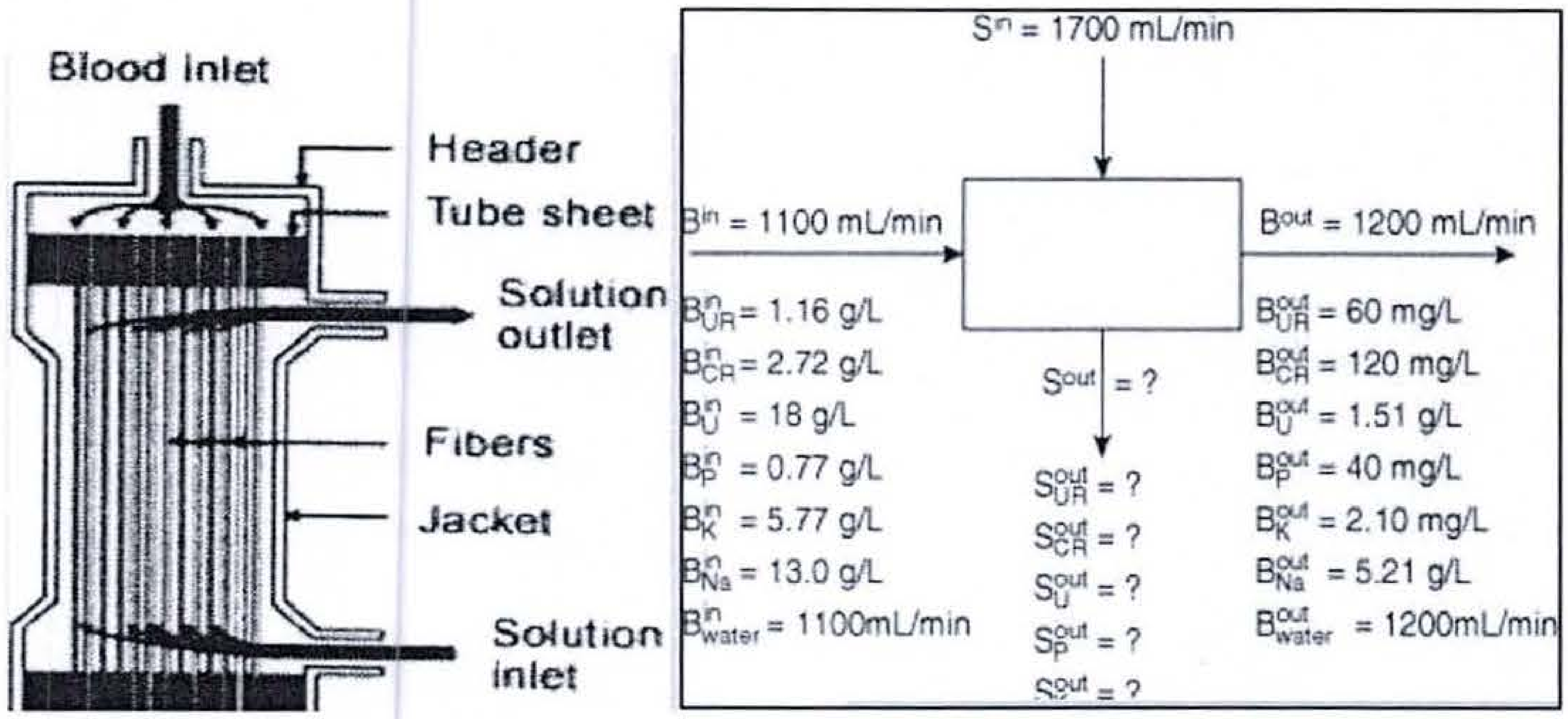
a. Gas at 15°C and 105 kPa is flowing through an irregular duct. To determine the rate of flow of the gas, CO_2 from a tank is steadily passed into the gas stream. The flowing gas, just before mixing with the CO_2, analyses 1.2% CO_2 by volume. Downstream, after mixing, the flowing gas analyses 3.4% CO_2 by volume. As the CO_2 that was injected exited the tank, it was passed through a rotameter and found to flow at the rate of 0.0917 m^3/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 $CaCO_3$ 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]

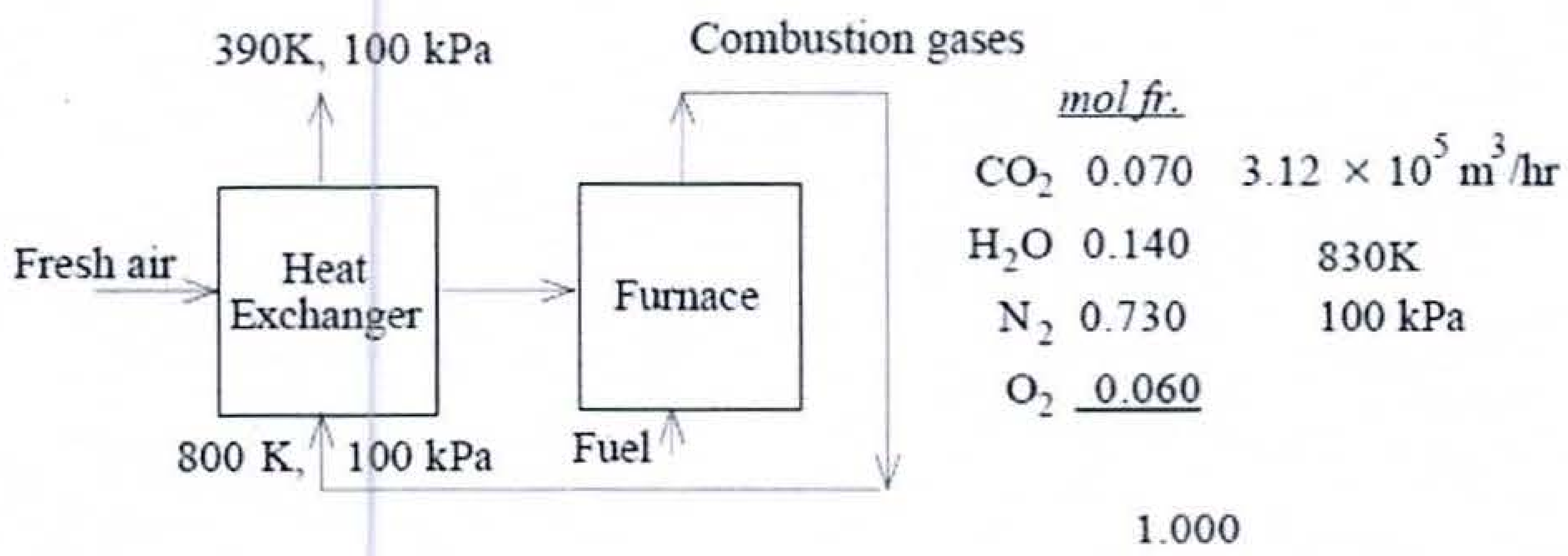
e. If 1 L of ethyl alcohol is mixed with 1 L of water, how many kilograms of solution result and litres result? [3]

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 % O_2 is flowing through an earthenware pipe. The gas flow rate is measured by introducing air into it at the rate of 115 m^3/min. Further down the line, after mixing is complete, the gas is found to contain 10.85 % O_2. How much m^3 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

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

https://www.vertex42.com/ExcelTemplates/education.html

	Multiply	**by**	**To Get**
	inch	**2.54**	**cm**
	This can also be written as: 1 inch = 2.54 cm		
A	acre	43,560	ft^2
	ampere·hr (A·h)	3,600	coulomb (C)
	ångström (Å)	1x10^{-10}	m
	atm (atmosphere)	1.01325	bar
	atm, std	76.0	cm of Hg
	atm, std	760	mm of Hg at 0ºC
	atm, std	33.90	ft of water
	atm, std	29.92	in of Hg at 30ºF
	atm, std	14.696	lbf/in^2 abs (psia)
	atm, std	101.325	kPa
	atm, std	1.013x10^5	Pa
	atm, std	1.03323	kgf / cm^2
	atm, std	14.696	psia
B	bar	0.9869	atm, std
	bar	1x10^5	Pa
	Btu	778.169	ft·lbf
	Btu	1055.056	J
	Btu	5.40395	psia·ft^3
	Btu	2.928x10^{-4}	kWh
	Btu	1x10^{-5}	therm
	Btu / hr	1.055056	kJ / hr
	Btu / hr	0.216	ft·lbf / sec
	Btu / hr	3.929x10^{-4}	hp
	Btu / hr	0.2931	W
	Btu / lbm	2.326*	kJ / kg
	Btu / lbm	25,037	ft^2 / s^2
	Btu / lbm·R	4.1868	kJ / kg·K
	Btu / lbm·ºF	4.1868	kJ / kg·ºC
	Btu / lbmol·R	4.1868	kJ / kmol·K
C	cal (g-calorie)	3.968x10^{-3}	Btu
	cal	1.560x10^{-6}	hp·hr
	cal (IT calorie)	4.1868	J
	Calorie (Cal)	4.1868	kJ
	cal / sec	4.1868	W (watt)
	cm (centimeter)	0.03281	ft
	cm	0.3937	in
	cP (centipoise)	0.001	Pa·sec
	cSt (centistokes)	1x10^{-6}	m^2 / sec
D	degree	π/180	radian
	dyne	10	µN (micronewton)
E	eV (electronvolt)	1.602x10^{-19}	J
	erg	1x10^{-7}	J
F	ft (feet)	0.3048*	m
	ft	30.48	cm
	ft^2	2.2957x10^{-5}	acre
	ft^2	144	in^2
	ft^2	0.09290304*	m^2
	ft^3	7.481	gal (U.S.)
	ft^3	0.02832	m^3
	ft^3	28.317	L
	ft^3 / lbm	0.062428	m^3 / kg
	ft·lbf	1.285x10^{-3}	Btu
	ft·lbf	1.35582	J
	ft·lbf	3.766x10^{-7}	kWh
	ft·lbf	1.35582	N·m
	ft·lbf	0.324	calorie (g-cal)
	ft·lbf / sec	1.818x10^{-3}	hp
	ft / s^2	0.3048*	m / s^2
G	U.S. gallon (gal)	0.13368	ft^3
	gal	3.7854	L
	gal	3.7854x10^{-3}	m^3
	gal	231	in^3
	gal (U.K.)	1.201	gal (U.S.)
	gal (U.K.)	277.4	in^3
	gal / min (gpm)	0.002228	ft^3 / sec
	gamma (γ,Γ)	1x10^{-9}	tesla (T)
	gauss	1x10^{-4}	T
	gram (g)	2.205x10^{-3}	lbm
	g / cm^3	1	1 kg / L
	g / cm^3	1000	kg / m^3
	g / cm^3	62.428	lbm / ft^3
	g / cm^3	1.940	slug / ft^3
	g / cm^3	0.036127	lbm / in^3
H	hectare	1x10^4	m^2
	hectare	2.47104	acres
	hp (horsepower)	42.41	Btu / min
	hp	0.7068	Btu / sec
	hp	2544.5	Btu / hr
	hp	745.70	W (watt)
	hp	0.74570	kW
	hp	33,000	ft·lbf / min
	hp	550	ft·lbf / sec
	hp·hr	2544	Btu
	hp·hr	1.98x10^6	ft·lbf
	hp·hr	2.68x10^6	J
	in	2.54*	cm
	in of Hg	0.0334	atm
	in of Hg	13.60	in of water
	in of Hg	3.387	kPa
	in of water	0.0736	in of Hg
	in of water	0.0361	lbf / in^2 (psi)
	in of water	0.002458	atm
J	J (joule)	9.4782x10^{-4}	Btu
	J	6.2415x10^{18}	eV
	J	0.73756	ft·lbf
	J	1	N·m
	J	1x10^7	ergs
	J / s	1	W
K	kg (kilogram)	2.2046226	lbm (pound mass)
	kg	0.068522	slug
	kg	1x10^{-3}	metric ton
	kg / m^3	0.062428	lbm / ft^3
	kgf	9.80665	newton (N)
	kip	1000	lbf
	kip	4448	N
	kJ	1	1 kPa·m^3
	kJ	1000	N·m
	kJ	0.94782	Btu
	kJ	737.56	ft·lbf
	kJ / kg	1000	m^2 / s^2
	kJ / kg	0.42992	Btu / lbm
	kJ / kg·K	0.23885	Btu / lbm·ºR
	kJ / kg·ºC	1	kJ / kg·K
	kJ / kg·ºC	1	J / g·ºC
	kJ / kg·ºC	0.23885	Btu / lbm·ºF
	kJ / kg·ºC	0.23885	Btu / lbm·R
	km	3280.8	ft
	km	0.6214	mi
	km/hr	0.6214	mi / hr (mph)
	km/hr	0.2778	m/s
	km/hr	0.9113	ft/s
	kPa (kilopascal)	9.8693x10^{-3}	atm
	kPa	0.14504	lbf / in^2 (psi)
	kW	3412.14	Btu / hr
	kW	0.9478	Btu / sec
	kW	737.56	lbf·ft / sec
	kW	1.341	hp
	kWh (kW-hour)	3412.14	Btu
	kWh	1.341	hp·hr
	kWh	3600	kJ
L	L (liter)	0.03531	ft^3
	L	61.02	in^3
	L	0.2642	gal (U.S.)
	L	0.001	m^3
	L / s	2.119	ft^3 / min (cfm)
	L / s	15.85	gal / min (gpm)
	lbf (pound force)	32.174	lbm·ft / s^2
	lbf	4.44822	N
	lbf	32.17	poundals
	lbf / in^2 (psi)	0.06805	atm
	lbf / in^2	2.307	ft water
	lbf / in^2	2.036	in Hg
	lbf / in^2	6894.757	Pa
	lbm	0.45359237*	kg
	lbm	0.031081	slug
	lbm / in^3	1728	lbm / ft^3
	lbm / ft^3	0.016018	g / cm^3
	lbm / ft^3	16.018	kg / m^3
M	m (meter)	3.28083	ft
	m	1.0926	yard
	m	39.370	in
	m^2	1550	in^2
	m^2	10.764	ft^2
	m^3	1x10^6	cm^3 (cc)
	m^3	35.315	ft^3
	m^3	264.17	gal (U.S.)
	m^3	1000	L
	m^3 / kg	16.02	ft^3 / lbm
	m / s	196.8	ft / min
	m / s	3.60	km / h
	m / s	3.2808	ft / s
	m / s	2.237	mi / h (mph)
	m / s^2	3.2808	ft / s^2
	metric ton	1000	kg
	mil	0.001	in
	mi (mile)	5280	ft
	mi	1.6093	km
	mi^2 (square mile)	640	acres
	mph (mile/hour)	1.6093	km / hr
	mph	88.0	ft / min (fpm)
	mph	1.467	ft / s
	mph	0.4470	m / s
	micron	1x10^{-6}	m
	mm of Hg	1.316x10^{-3}	atm
	mm of Hg	0.1333	kPa
	mm of water	9.678x10^{-5}	atm
N	N (newton)	1	kg·m / s^2
	N	1x10^5	dyne
	µN (microN)	0.1	dyne
	N	0.22481	lbf
	N·m	0.7376	ft·lbf
	N·m	1	J
P	Pa (pascal)	1	N / m^2
	Pa	1.4504x10^{-4}	lbf / in^2 (psia)
	Pa	0.020886	lbf / ft^2
	Pa	9.869x10^{-6}	atm
	Pa·s	10	poise
	psi (pounds per square inch) --- see lbf / in^2		
R	radian	180/π	degree
S	short ton	2000	lbm
	short ton	907.1847	kg
	slug	32.174	lbm
	slug	14.5939	kg
	slug / ft^3	0.5154	g / cm^3
	stokes	1x10^{-4}	m^2 / s
T	therm	1x10^5	Btu
	ton of refrigeration	200	Btu / min
W	W (watt)	3.4121	Btu / hr
	W	0.7376	ft·lbf / sec
	W	1.341x10^{-3}	hp
	W	1	J / s
	W / cm^2	1x10^4	W / m^2
	W / cm^3	1x10^6	W / m^3
	W / m^2	0.3171	Btu / (h·ft^2)
	W / m^3	0.09665	Btu / (h·ft^3)
	W / m·ºC	1	W / m·K
	W / m·ºC	0.57782	Btu / (h·ft·ºF)
	W / (m^2·ºC)	1	W / (m^2·K)
	W / (m^2·ºC)	0.17612	Btu / (h·ft^2·ºF)
	weber / m^2	10,000	gauss

* The exact conversion between metric and English.

TEMPERATURE

T(K) = T(ºC) + 273.15
T(R) = T(ºF) + 459.67
T(ºF) = 1.8 T(ºC) + 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 (10^1), hecto (10^2), kilo (10^3), mega (10^6), giga (10^9), tera (10^{12}), peta (10^{15}), exa (10^{18}), zetta (10^{21}), yotta (10^{24})

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/AtWt/
masses for 107-111 from C&EN, March 13, 1995, p. 35
112 from http://www.gsi.de/z112e.html