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PHYSICAL CONSTANTS

Speed of light in vacuum	**c**	**2.998×10^{8} m s^{-1}**
Elementary charge	e	1.602×10^{-19} C
Avogadro constant	N_A	6.022×10^{23} mol^{-1}
Atomic mass unit	U	1.661×10^{-27} kg
Electron rest mass	m_e	9.100×10^{-31} kg
Proton rest mass	m_p	1.673×10^{-27} kg
Faraday constant	F	9.6485×10^{4} C mol^{-1}
		23,060 cal mol^{-1} eV^{-1}
Planck constant	H	6.626×10^{-34} J s
Rydberg constant	R_∞	1.097×10^{7} m^{-1}
Gas constant	R	8.314 J K^{-1} mol^{-1}
		0.08314 L bar K^{-1} mol^{-1}
		1.987 cal K^{-1} mol^{-1}
		0.082 06 L atm K^{-1} mol^{-1}

NUMERICAL CONSTANTS

π = 3.141 592 65	**2.54 cm inch $^{-1}$**
e = 2.718 281 828	453.6 g lb^{-1}
ln x = log x/log e = 2.302 585 09 log x	4.184 J cal^{-1}
101,325 N m^{-2} atm^{-1}	1.602×10^{-19} J eV^{-1}
10^{5} N m^{-2} bar^{-1}	10^{-3} m^3 L^{-1}
1.01325 bar atm^{-1}	

CONVERSION FACTORS

TO CONVERT	TO	MULTIPLY BY
Acres	Hectares	0.4047
Acres	Square fee	43
Atmospheres	Feet of H_2O	33.8995
Atmospheres	mm of mercury	760
Atmospheres	Inches of mercury	29.9213
Atmospheres	psi	14.6960
Bar	psi	14.5
Bar	Kilopascals	101.3
Bar	Inches of Hg	29.92
Bar	Mm of Hg	760
Barrels (oil, US)	Gallons (US)	42
BTU's	Kilowatt	0.01757
BTU's	Kilogram-calories	0.2520
BTU's	Foot-lbs	777.649
BTU's	Horsepower-hrs	3.92758×10^{-4}
BTU's	Kilogram-meters	107.514
BTU's	Kilowatt-hrs	2.92875×10^{-4}
BTU's	Therms	0.001
BTU/hr	Foot-lbs/sec	0.2162
BTU/min	Horsepower	0.0235
Centimeters	Feet	0.03281
Centimeters	Inches	0.3937
Centimeters/sec	Feet/min	1.9685039
Cubic centimeters	Gallons (US, liq)	2.6417205×10^{-4}
Cubic centimeters/min	ML/min	1
Cubic centimeters/min	Gallons/hr	0.016
Cubic feet	Cubic inches	1728
Cubic feet	Cubic meters	0.028316847
Cubic feet	Cubic yards	0.03704
Cubic feet	Gallons (US, liq)	7.4805195
Cubic feet	Liters	28.316847
Cubic feet/hr	Liters/min	0.472
Cubic feet/min	Liters/min	28.31
Cubic inches	Cubic centimeters	16.387064
Cubic inches	Cubic feet	5.7870370×10^{-4}
Cubic yards	Cubic feet	27
Cubic yards	Cubic inches	46,656
Cubic yards	Gallons (US, liq)	201.97403
Degrees	Min	60
Degrees	Radians	0.017453293
Degrees	Sec	3600
Drams (avdp)	Grains	27.34375
Drams (avdp)	Ounces (avdp)	0.0625
Fathoms	Feet	6
Feet	Centimeters	30.48
Feet	Meters	0.3048
Feet of H_2O	Atmospheres	0.0294

TO CONVERT	TO	MULTIPLY BY
Acres	Hectares	0.4047
Feet of H_2O	Inches of mercury	0.8826
Feet/min	Centimeters/sec	0.508
Feet/min	Miles/hr	0.01136363
Gallons (US, liq)	Cubic centimeters	3785.4118
Gallons (US, liq)	Cubic feet	0.133680555
Gallons (US, liq)	Cubic yards	4.9511317×10^{-3}
Gallons (US, liq)	Liters	3.7854118
Gallons of H_2O in air	Lbs of H_2O	8.33585
Grains	Grams	0.06479891
Grains	Ounces (troy)	2.0833×10^{-3}
Grams	Grains	15.432358
Grams	Ounces (avdp)	0.035273962
Grams	Lbs (avdp)	2.2046226×10^{-3}
Horsepower	BTU/min	42.4356
Horsepower	Kilowatts	0.745700
Horsepower	Watts	745.700
Horsepower (boiler)	BTU (mean)/hr	33445.7
	Cubic meters	0.7646
Gallon (imperial)	Liters	4.546
Horsepower (boiler)	Kilowatts	9.80950
Inches	Centimeters	2.54
Inches of mercury (32°F)	Atmospheres	0.0334211
Inches of mercury (32°F)	Lbs/sq inch	0.4911542
Kilograms	Lbs (avdp)	2.2046226
Kilometer	Miles	0.6214
Kilowatts	BTU/hr	3414.43
Kilowatts	Horsepower	1.34102
Kilowatts	Watts	999.835
Lbs (avdp)	Drams (avdp)	256
Lbs (avdp)	Grains	7000
Lbs (avdp)	Grams	453.59237
Lbs (troy)	Grains	5760
Lbs (troy)	Pennyweights	240
Lbs/sq inch	Atmospheres	0.0680460
Lbs/sq inch	Bars	0.0689476
Lbs/sq inch	Inches of H_2O	27.6807
Lbs/sq inch	Inches of mercury	2.03602
Lbs/sq inch	Kilograms/cm^2	0.070306958
Lbs/sq inch	Kilopascals	6.895
Lbs/sq inch	Milibars	68.9476
Lbs/sq inch	mm of H_2O	703.1
Lbs/sq inch	mm of mercury	51.7149
Lbs/sq inch	Pascals	6,895.0
Liters	Cubic feet	0.035314667
Liters/min	Cubic feet/hr	2.119

TO CONVERT	TO	MULTIPLY BY
Acres	Hectares	0.4047
Liters/min	Cubic feet/min	0.0353
Liters	Cubic inches	61.023744
Liters	Gallons (US, liq)	0.26417205
Meters	Inches	39.370079
Meters	Feet	3.281
Meters	Yards	1.094
Miles (statute)	Feet	5280
Miles (statute)	Kilometers	1.609344
Miles (statute)	Yards	1760
Miles (national)	Feet	6080
Miles/hr	Feet/sec	1.4666666
Miles/hr	Kilometers/hr	1.609344
Miles/hr	Knots (Intl)	0.86897624
mm	Inches	0.039370079
mm of mercury	Atmospheres	0.0013
Ounces (avdp)	Grains	437.5
Ounces (avdp)	Grams	28.349523
Ounces (avdp)	Lbs (avdp)	0.0625
Pascals	Inches of mercury	0.000295
Pascals	mm of mercury	0.0075
ppm	Grains/gallon (US)	0.05841620
ppm	Grains/gallon (G.B.)	0.07015488
Radians	Degrees	57.295779
Radians	Min	3437.7468
Sq centimeters	Sq feet	1.0763867×10^{-3}
Sq centimeters	Sq inches	0.15500031
Sq feet	Acres	2.295684×10^{-5}
Sq feet	Sq inches	144
Sq feet	Sq miles	3.5870064×10^{-8}
Sq inches	Sq centimeters	6.4516
Sq inches	Sq feet	0.0069444
Sq kilometers	Acres	247.10538
Sq miles	Acres	640
Sq miles	Sq yards	3.0976×10^{6}
Sq yards	Acres	2.0661157×10^{-4}
Sq yards	Sq meters	0.83612736
Therms	BTU’s	100,000
Sq meter	Sq feet	10.76
Sq feet	Sq meters	0.0929
Sq meters	Sq yards	1.196
Sq miles	Sq kilometers	2.59
Pound	Grams	453.6
Pound	Grains	7000
Pound	Ounces	16
Torr	Pascal	133.322
Tons	Pounds	2000
Tons (metric)	Kilograms	1016

SUMMARY OF UNITS

MULTIPLICATION FACTOR	**PREFIX**	**SYMBOL**
$1{,}000{,}000{,}000{,}000{,}000{,}000 = 10^{18}$	exa	E
$1{,}000{,}000{,}000{,}000{,}000 = 10^{15}$	peta	P
$1{,}000{,}000{,}000{,}000 = 10^{12}$	tera	T
$1{,}000{,}000{,}000 = 10^{9}$	giga	G
$1{,}000{,}000 = 10^{6}$	mega	M
$1{,}000 = 10^{3}$	kilo	k
$100 = 10^{2}$	hecto	h
$10 = 10^{1}$	deka	da
$0.1 = 10^{-1}$	deci	d
$0.01 = 10^{-2}$	centi	c
$0.001 = 10^{-3}$	milli	m
$0.000\ 001 = 10^{-6}$	micro	μ
$0.000\ 000\ 001 = 10^{-9}$	nano	n
$0.000\ 000\ 000\ 001 = 10^{-12}$	pico	p
$0.000\ 000\ 000\ 000\ 001 = 10^{-15}$	femto	f
$0.000\ 000\ 000\ 000\ 000\ 001 = 10^{-18}$	atto	a

MLI routinely analyzes ambient air to the parts-per-million (ppm), parts-per-billion (ppb), and even parts-per-trillion (ppt) level. To understand the sensitivity of these measurements, consider the following:

- One part per million is the equivalent of about one ounce of contamination in a typical 10,000-gallon railroad tank car, full of water.
- One part per billion is the equivalent of about one drop of contamination in the same 10,000-gallon railroad tank car.
- One part per trillion is the equivalent of about one drop of contamination in one thousand, 10,000-gallon railroad tank cars.

FORCE (MLT^{-2}) OR (F)

Multiply by to obtain	**Newton Joules per meter**	**Grams**	**Kilograms**	**Pounds**	**Poundals**
Newton Joules per meter	1	9.807×10^{-3}	9.807	4.448	0.1383
Grams	102.0	1	1000	453.6	14.10
Kilograms	0.1020	0.001	1	0.4536	1.410×10^{-2}
Pounds	0.2248	2.205×10^{-3}	2.205	1	3.108×10^{-2}
Poundals	7.233	7.093×10^{-2}	70.93	32.17	1

ENERGY, WORK AND HEAT (ML^2T^{-2}) OR (FL)

Multiply by to obtain	British thermal units	Centi meter – grams	Foot – pounds	Horse power – hours	Joules watt – second	Kilowatt – hours	Meter – kilograms	Watt - hours
British thermal units	1	9.297×10^{-8}	1.285×10^{-3}	2545	9.480×10^{-4}	3413	9.297×10^{-3}	3.413
Centimeter – grams	1.076×10^{7}	1	1.383×10^{4}	2.737×10^{10}	1.020×10^{4}	3.671×10^{10}	10^{5}	3.671×10^{7}
Foot – pounds	778	7.233×10^{-5}	1	1.98×10^{4}	0.7376	2.655×10^{6}	7.233	2655
Horse-power – hours	3.929×10^{-4}	3.654×10^{-11}	5.050×10^{-7}	1	3.722×10^{-7}	1.341	3.653×10^{-6}	1.341×10^{-3}
Joules watt – second	1054.8	9.807×10^{-5}	1.356	2.684×10^{6}	1	3.6×10^{6}	9.807	3600
Kilowatt – hours	2.930×10^{-4}	2.724×10^{-11}	3.756×10^{-7}	0.7457	2.778×10^{-7}	1	2.724×10^{-6}	0.001
Meter – kilograms	107.6	10^{-5}	0.1383	2.737×10^{5}	0.1020	3.671×10^{5}	1	367.1
Watt – hours	0.2930	2.724×10^{-8}	3.766×10^{-4}	745.7	2.778×10^{-4}	1000	2.724×10^{-3}	1

FORCE PER UNIT AREA ($ML^{-1}T^{-2}$) OR (FL^{-2})

Multiply by to obtain	**Atmospheres**	**cm. of mercury @ 0°C**	**in. of mercury @ 0°C**	**in. of water @ 4°C**	**ft. of water @ 4°C**	**Kilograms per square meter**	**Pounds per square inch**	**Pascal**
Atmospheres	1	1.316×10^{-2}	3.342×10^{-2}	2.458×10^{-3}	2.950×10^{-2}	9.678×10^{-5}	6.804×10^{-2}	0.9869×10^{-5}
cm. of mercury @ 0°C	76.00	1	2.540	0.1868	2.232	7.356×10^{-3}	5.171	7.501×10^{-4}
in. of mercury @ 0°C	29.92	0.3937	1	7.355×10^{-2}	0.8826	2.896×10^{-3}	2.036	2.952×10^{-4}
in. of water @ 4°C	406.8	5.354	13.6	1	12	3.937×10^{-2}	27.68	4.015×10^{-3}
ft. of water @ 4°C	33.90	0.4460	1.133	8.333×10^{-2}	1	3.281×10^{-3}	2.307	3.345×10^{-4}
Kilograms per square meter	1.033×10^{4}	136.0	345.3	25.40	304.8	1	703.1	1.0197×10^{-1}
Pounds per square inch	14.70	0.1934	0.4912	3.613×10^{-2}	0.4335	1.422×10^{-3}	1	1.45×10^{-4}
Pascal	$1.013\,25 \times 10^{5}$	1333	3386.4	249.082	2989	9.80665	6894.757	1

POWER OR RATE OF DOING WORK (ML^2T^{-3}) OR (FLT^{-}

Multiply by to obtain	BTU per minute	Foot-pounds per minute	Foot-pounds per second	Horse-power	Kilo-watts	Watts
BTU per minute	1	1.285×10^{-3}	7.712×10^{-2}	42.41	56.89	5.689×10^{-2}
Foot-pounds per minute	778	1	60	3.3×10^{4}	4.426×10^{4}	44.26
Foot-pounds per second	12.97	1.667×10^{-2}	1	550	737.6	0.7376
Horsepower	2.357×10^{-2}	3.030×10^{-5}	1.818×10^{-3}	1	1.341	1.341×10^{-3}
Kilowatts	1.758×10^{-2}	2.260×10^{-5}	1.356×10^{-3}	0.7457	1	10^{-3}
Watts	17.5725	2.2597×10^{-2}	1.356	745.7	1000	1

ENGLISH/METRIC CONVERSION

Inches		Millimeters	Feet		Meters
0.039	1	25.40	3.281	1	0.305
0.079	2	50.80	6.562	2	0.610
0.118	3	76.20	9.843	3	0.914
0.157	4	101.60	13.123	4	1.219
0.197	5	127.00	16.404	5	1.524
Yards		**Meters**	**Miles**		**Kilometers**
1.094	1	0.914	0.621	1	1.609
2.187	2	1.829	1.243	2	3.219
3.281	3	2.743	1.864	3	4.828
4.375	4	3.658	2.485	4	6.437
5.468	5	4.572	3.107	5	8.047
Sq Feet		**Sq Meters**	**Sq Yards**		**Sq Meters**
10.794	1	0.093	1.196	1	0.836
21.528	2	0.186	2.392	2	1.672
32.292	3	0.279	3.588	3	2.508
43.056	4	0.372	4.784	4	3.345
53.819	5	0.465	5.980	5	4.181
Cu Feet		**Cu Meters**	**Cu Yards**		**Cu Meters**
35.315	1	0.028	1.308	1	0.765
70.629	2	0.057	2.616	2	1.529
105.943	3	0.085	3.924	3	2.294
141.258	4	0.113	5.232	4	3.058
176.572	5	0.142	6.540	5	3.823
Ounces		**Grams**	**Pounds**		**Kilograms**
0.035	1	28.350	2.205	1	0.454
0.071	2	56.699	4.409	2	0.907
0.106	3	85.049	6.614	3	1.361
0.141	4	113.398	8.819	4	1.814
0.176	5	141.748	11.023	5	2.268

MOLECULAR WEIGHTS OF SELECTED GASES

Gas	Formula	Molecular Weight
Acetylene	C_2H_2	26.04
Ammonia	NH_3	17.03
Argon	Ar	29.944
Arsine	ArH_3	77.93
Butane	C_4H_{10}	58.12
Butene – 1	C_4H_8	56.10
Carbon Dioxide	CO_2	44.01
Carbon disulfide	CS_2	76.14
Carbon Monoxide	CO	28.01
Chlorine	CI_2	70.91
Ethane	C_2H_6	30.07
Fluorine	F_2	38.00
Formaldehyde	HCHO	30.03
Helium	He	4.003
Hydrogen Chloride	HCl	36.47
Hydrogen	H_2	2.016
Hydrogen Fluoride	HF	20.01
Hydrogen Sulfide	H_2S	34.08
Krypton	Kr	83.7
Methane	CH_4	16.04
Neon	Ne	20.18
Nitric Oxide	N_2O	30.01
Nitrogen	N_2	28.02
Nitrogen Dioxide	NO_2	46.01
Nitrous Oxide	N_2O	44.02
Oxygen	O_2	32.00
Ozone	O_3	48.00
Propane	C_3H_8	44.09
Sulfur Dioxide	SO_2	64.07
Sulfur Trioxide	SO_3	80.07
Xenon	Xe	131.3

SPECIFIC GRAVITIES OF GASES

Gas	Formula	Specific Gravity
Acetylene	C_2H_2	0.897
Air		1.000
Ammonia	NH_3	0.587
Argon	A	1.378
Butane-N	C_4H_{10}	2.390
Butane-Iso	$(CH)_3)_2CHCH_3$	1.990
Carbon Dioxide	CO_2	1.517
Carbon Monoxide	CO	0.966
Chlorine	CL_2	2.452
Ethane	C_2H_{10}	1.035
Ethylene	C_2H_4	0.977
Helium	He	0.138
Hydrogen	H_2	0.070
Hydrogen Sulfide	H_2S	1.187
Methane	CH_4	0.553
Natural Gas		0.665 (Appox. Avg.)
Nitric Oxide	NO	1.035
Nitrogen	N_2	0.966
Nitrogen Dioxide	NO_2	1.602
Nitrogen Oxide	N_2O	1.518
Oxygen	O_2	1.103
Propane	C_3H_8	1.550
Sulfur Dioxide	SO_2	2.209

ALTITUDE PRESSURE TABLE

Mercury at 0°C (32°F)

Altitude in Feet	Inches of Hg.	Millimeter's of Mercury
-1000	31.02	787.9
0	29.921	760.0
1000	28.86	732.9
2000	27.82	706.6
3000	26.81	681.1
4000	25.84	656.3
5000	24.89	632.3
6000	23.98	609.0
7000	23.09	586.4
8000	22.22	564.4
9000	21.38	543.2
10,000	20.58	522.6
15,000	16.88	458.8
20,000	13.75	349.1
25,000	11.10	281.9
30,000	8.88	225.6
35,000	7.04	178.7
40,000	50.54	140.7
45,000	4.36	110.8
50,000	3.436	87.30

DENSITY OF AIR

Standard air density is normally taken as 0.075 lb per cu ft under average conditions of temperature, humidity and barometric pressure. The approximate density may be determined from the following equation:

$$d = \frac{1.325\ b}{T}$$

where b is the barometric pressure in inches of mercury and T is the absolute temperature in degrees Fahrenheit

Altitude Feet	Barometric pressure inches of Hg	Density pound per cubic feet	Altitude Feet	Barometric pressure inches of Hg	Density pound per cubic feet
0	29.92	.07495	3000	26.81	.0672
200	29.70	.0744	3500	26.32	.0659
400	29.50	.0739	4000	25.84	.0647
600	29.29	.0734	4500	25.84	.0635
800	29.07	.0728	5000	25.36	.0623
1000	28.86	.0723	5500	24.89	.0612
1200	28.65	.0718	6000	24.43	.0601
1400	28.45	.0713	6500	23.98	.0589
1600	28.24	.0707	7000	23.09	.0578
1800	28.03	.0702	7500	22.65	.0567
2000	27.82	.0697	8000	22.22	.0557
2500	27.31	.0684	8500	21.80	.546
			9000	21.38	.0536

DENSITY OF AIR
Change with Temperature – Pressure Constant at 29.92 inches Hg

Temperature °F	Density pound per cubic foot	Temperature °F	Density pound per cubic foot
0	.0864	200	.0602
10	.845	225	.0582
20	.828	250	.0559
30	.0811	275	.0540
40	.795	300	.0522
50	.0779	325	.0506
60	.0764	350	.0490
70	.07495	375	.0475
80	.0735	400	.0462
90	.0722	450	.0436
100	.0709	500	.0414
110	.0697	550	.0393
120	.0685	600	.0374
130	.0673	650	.0358
140	.0662	700	.0342
150	.0651	750	.0328
160	.0640	800	.0315
170	.0630	850	.0303
180	.0620	900	.0292
190	.0611	950	.0282
		1000	.0272

DENSITY OF GASES AT 60°F AND 30 INCHES OF MERCURY

Gas	Molecular Formula	Molecular Weight	Specific Gravity Air = 1.0	Weight pound per cubic foot	Volume cubic foot per pound
Air		28.9	1.000	0.07655	13.063
Oxygen	O_2	32.00	1.105	0.08461	11.819
Hydrogen	H_2	2.02	0.070	0.00533	187.723
Nitrogen (atmospheric)	N_2	28.02	0.972	0.07439	13.443
Carbon Monoxide	CO	28.01	0.967	0.07404	13.506
Carbon Dioxide	CO_2	44.01	1.528	0.1170	8.548
Methane	CH_4	16.04	0.554	0.04243	23.565
Acetylene	C_2H_2	26.04	0.911	0.06971	14.344
Ethylene	C_2H_4	28.05	0.974	0.07456	13.412
Ethane	C_2H_6	30.07	1.049	0.08029	12.455
Sulfur Dioxide	SO_2	64.06	2.264	0.1733	5.770
Hydrogen Sulfide	H_2S	34.08	1.190	0.09109	10.979

Approximate Percentage Composition of Air

	By Weight	By Volume
Nitrogen	76.8	79.0
Oxygen	23.2	21.0

MEAN SPECIFIC HEAT OF GASES AT CONSTANT PRESSURE
from 32°F to t F in BTU per pound per F

Temperature °F	100	300	500	1000	1500	2000
Air	0.240	0.241	0.243	0.249	0.257	0.263
Oxygen - O_2	0.218	0.222	0.225	0.235	0.243	0.249
Nitrogen – N_2	0.248	0.249	0.251	0.256	0.262	0.270
Hydrogen – H_2	3.41	3.14	3.45	3.47	3.51	3.55
Water Vapor – H_2O	0.444	0.449	0.454	0.472	0.493	0.516
Carbon Monoxide – CO	0.248	0.249	0.251	0.258	0.265	0.273
Carbon Dioxide – CO_2	0.200	0.213	0.224	0.246	0.262	0.274
Typical Flue Gas of average Bituminous Coal. Based on 20% Excess Air and 5% H_2O	0.243	0.247	0.250	0.260	0.269	0.277

The volume of 1 pound of a gas at any given temperature and pressure may be found from

$$V = \frac{t+460}{W \times P \times 35.38}$$

Where V = Volume in cubic feet
t = Temperature F
W = Weight of gas in lb per cubic foot
P = Absolute Pressure in lb per square inch

STANDARD AMBIENT AIR COMPOSITION (DRY AIR)

	% by Volume	ppm by Volume
N_2	78.084	-
O_2	20.946	-
CO_2	0.033	330
Ar	0.934	9,340
Ne	-	18.18
He	-	5.24
Kr	-	1.14
Xe	-	0.087
H_2	-	0.5
CH_4	-	2
N_2O	-	0.5

FLOW EQUIVALENTS

1 Cu. Ft./Hr.	**1 Cu. Ft./Min**
0.0166 Cu. Ft./Min	60 Cu. Ft./Hr.
0.4719 LPM	28.316 LPM
28.316 LPH	1699 LPH
471.947 CC/Min.	28317 CC/Min.
28317 CC/Hr.	1699011 CC/Hr.
0.1247 Gal./Min.	7.481 Gal./Min.
7.448 Gal./Hr.	448.831 Gal./Hr.

1 LPM	**1 LPH**
60 LPH	0.166 LPM
0.035 Cu. Ft./Min.	0.00059 Cu. Ft./Min.
2.1189 Cu. Ft./Hr.	0.35 Cu. Ft./Hr.
1000 CC/Min.	16.667 CC/Min.
60002 CC/Hr.	1000 CC/Hr.
0.264 Gal./Min.	0.004 Gal./Min.
15.851 Gal. Hr.	0.264 Gal./Hr.

1 CC/Min	**1 CC/Hr**
60 CC/Hr.	0.167 CC/Min.
0.000035 Cu. Ft./Min.	0.0000005 Cu. Ft./Min.
0.0021 Cu. Ft.Min.	0.00003 Cu. Ft./Hr.
0.001 LPM	0.000017 LPM
0.06 LPH	0.001 LPH
0.00026 Gal./Min.	0.000004 Gal./Min.
0.0159 Gal./Hr.	0.00026 Gal./Hr.

CORRECTIONS FOR GAS ANALYSIS

1. **Excess air correction:**
   O_2 correction
   Corrected value = measured value x
   $$\frac{21\text{-}O_2 \text{ ref. value (in\%)}}{21\text{-}O_2 \text{ measured value (in\%)}}$$

2. **Wet to dry results**
   Dry value = measured wet value x
   $$\frac{100}{100\text{-}H_2O \text{ measured concentration (in\%)}}$$

3. **Temperature correction**
   Corrected value = measured value x
   $$\frac{\text{Temp. measured value (°K)}}{273\ (°K)}$$

4. **Pressure correction**
   Corrected value = measured value x
   $$\frac{\text{measured value x 101.3 (Kpa)}}{\text{measured pressure(Kpa)}}$$

CONVERSION OF UNITS

To convert from ppm to mg/m^3

Conc (mg/m^3) =

$$\frac{\text{Concentration (ppm) x Molecular weight (g)}}{\text{Molar volume (at given temperature)}}$$

i.e.

$$\frac{100\text{ppm CO}}{22.4} = 100 \times 28 = 125\ mg/m^3 \text{ (at 0°C)}$$

Molar volume is the volume occupied by one gram mole of a gas at a specific temperature and pressure. See table below.

MOLAR VOLUMES

Temperature °C	Molar Volume (dm^3)	Temperature °C	Molar Volume (dm^3)
-20	20.76	+5	22.81
-15	21.17	+10	23.22
-10	21.58	+15	23.63
-5	21.99	+20	24.04
0	22.40	+25	24.45
		+30	24.86

Conversion of Units cont.

Average Density 1.222 kg/m^3 .0763 lb/ft^3

$$\text{Conc (ppm)} = \frac{mg\backslash m^3 \times 22.4}{MW}$$

ppm to mg/m^3 at °C and 1 atmosphere

Gas	ppm $\rightarrow$ mg/m^3
SO_2	2.86
NO	1.34
NO_2	2.05
HCl	1.64
CO	1.25
CO_2	1.96

TABLE OF MOISTURE CONTENT VS. DEW-POINT TEMPERATURE

Moisture content of saturated air or Other Gas at Various Temperatures (Dew-Points) and at 1 Atmosphere Absolute Pressure (14.7 PSIA)

Dew Point Temperature		**Moisture Per Cent by Volume***
°F	°C	
212	100	100.00
205	96.1	86.90
200	93.3	78.45
195	90.6	70.69
190	87.8	63.57
185	85.0	57.06
180	82.2	51.13
175	79.4	45.72
170	76.7	40.80
165	73.9	36.33
160	71.1	32.28
155	68.3	28.62
150	65.6	25.32
145	62.8	22.35
140	60.0	19.67
135	57.2	17.28
130	54.4	15.14
125	51.7	13.23
120	48.9	11.53
115	46.1	10.02
110	43.3	8.69
105	40.6	7.51
104	40.0	7.30
102	38.9	6.90
100	37.8	6.50
98	26.7	6.10
96	35.6	5.75
94	34.4	5.40
92	33.3	5.05
90	32.2	4.75
88	31.1	4.46
86	30.0	4.18
84	28.9	3.92
82	27.8	3.68
80	26.7	3.44
78	25.6	3.22
76	24.4	3.02
74	23.3	2.84
72	22.2	2.65
70	21.1	2.47

Dew Point Temperature		Moisture Per Cent by Volume*
68	20.0	2.31
66	18.9	2.16
64	17.8	2.02
62	16.7	1.88
60	15.6	1.75
58	14.4	1.63
56	13.3	1.51
54	12.2	1.40
52	11.1	1.30
50	10.0	1.21
48	8.9	1.12
46	7.8	1.04
44	6.7	0.966
42	5.6	.894
40	4.4	.827
38	3.3	.765
36	2.2	.707
34	1.1	.653
32	0.0	.602
30	-1.1	.553
28	-2.2	.511
26	-3.3	.475
24	-4.4	.434
22	-5.6	.398
20	-6.7	.367
18	-7.8	.337
16	-8.9	.308
14	-10.0	.282
12	-11.1	.258
10	-12.2	.236
8	-13.3	.216
6	-14.4	.198
4	-15.6	.180
2	-16.7	.165
0	-17.8	.150
-2	-18.9	.136
-4	-20.0	.124
-6	-21.1	.113
-8	-22.2	.102
-10	-23.3	.093
-12	-24.4	.084
-14	-25.6	.076
-16	-26.7	.0685
-18	-27.8	.0619
-20	-28.9	.0558
-22	-30.0	.0503
-24	-31.1	.0452

Dew Point Temperature		Moisture Per Cent by Volume*
-26	-32.2	.0407
-28	-33.3	.0364
-30	-34.4	.0328

- *At sea level pressure
- For other atm pressures:

$$\% H_2O = \frac{\% H_2O \text{ (table)}}{\text{atm pressure}} * \text{atm press at sea level}$$

Water at 62°F (16.7°C)

1 cubic foot = 62.3 lbs
1 pound = 0.01604 cubic feet
1 gallon = 8.33 pounds

Water at 39.2°F (4°C)
Maximum Density

1 cubic foot = 62.4 pounds
1 cubic meter = 1,000 kilograms
1 pound = 0.01602 cubic foot
1 liter = 1.0 kilograms
1 kg per cubic meter = 1 gram per liter = 1 part per thousand
1 gram per cubic meter = 1 milligram per liter = 1 part per million

COMMON EQUATIONS

Humidity

Relative Humidity (as % RH)$RH = \frac{e}{e_s} \times 100 = \frac{D}{D_s} \times 100$

Absolute Humidity (as g/m^3)

$$D = \frac{804}{1\text{-}0.00366t} \times \frac{e}{P_o} = \frac{RH}{100} \times \frac{804}{1\text{-}0.00366t} \times \frac{e}{P_o}$$

RH = relative humidity (% RH)
e = water steam pressure (mm Hg)
e_s = saturated water steam pressure (mm Hg)
D = absolute humidity (g/m_3)
D_s = absolute humidity in saturation (g/m^3)
t = temperature (°C)
P_0 = standard air pressure (mm Hg)

Temperature

°F = (1.8 x °C) = 32
°C = 0.5555556 (°F-32)

STACK (OR DUCT) VOLUME FLOW RATE CALCULATIONS

Stack (or duct) gas velocity (feet per second) =

$$85.49 \times C_P \times (\sqrt{\Delta P})avg \times \left[\frac{(T_{s(avg)}+460)}{M_s \times P_s} \right]^{1\backslash 2}$$

C_P = Pitot tube coefficient (0.99 for most standard pitots or 0.84 for most S-type pitots)
ΔP = Velocity head of stack gas, in inches H_2O
$T_{S(avg)}$ = Temperature, in °F stack (or duct)
M_S = Molecular weight of stack gas, wet basis in lb/lb-mole (~ 29 for most emission sources gases)
P_S = Absolute stack gas pressure, in inches of mercury (~ 30 for most emission sources gases)
ACFM (stack gas dry volumetric flow rate in actual cubic feet per minute)
= Gas velocity (feet per second) x area (of stack or duct in sq ft) x 60 (seconds per min)
DSCFM (stack gas dry volumetric flow rate, at standard conditions)

$$= 17.647 \text{ °R/inch Hg} \times ACFM \times \frac{P_s}{(460+_{s(avg)})} \times (1\text{-}B_{ws})$$

B_{ws} = Fractional moisture content of stack gas (~0.02 for most ambient air)

CONVERSION OF PPM TO LBS/HR FOR A POLLUTANT IN AIR

$lbs/hr = ppmv \times mw \times DSCFM \times (1.554 \times 10^{-2})$
lbs/hr = lbs/hr emission of pollutant
ppmv = Concentration of pollutant in gas, parts per million (volume/volume basis)
mw = Molecular weight of pollutant in gas (lbs/lbs mole)
DSCFM = Stack gas dry volumetric flow rate, at standard conditions (cubic ft/min)

Ideal Gas Law
PV = n RT, where
- P = absolute pressure
- V = volume
- n = number of moles
- R = gas constant
- T = absolute temperature

Beers Law
$I/Io = 10^{-acl}$,where
- I = intensity of light detected after passing through a measurement cavity of length "l", containing a gas of concentration "c" and having an absorption coefficient "a".
- Io = intensity of light detected after passing through a measurement cavity containing no gases of interest.

Sonic Velocity Through a Critical Orifice

$Vc = (K^* P/D)^{0.5}$, where
- Vc = sonic velocity in m/sec
- K = isentropic ratio of 1:4
- P = absolute pressure in pascals
- D = gas density in kg/m^3

Sonic velocity of dry air at 0°C is 1064 ft/sec

F – FACTOR REFERENCE TABLE

Fuel		F-factor (dscf/mmBTU)	F_c-factor (scf CO_2/mmBTU)	F_w-factor (wscf/mmBTU)
Coal	Anthracite	10,100	1,970	10,540
	Bituminous (or Sub-bituminous	9,780	1,800	10,640
	Lignite	9,860	1,910	11,950
Oil		9,190	1,420	10,320
Gas	Natural Gas	8,710	1,040	10,610
	Propane	8,710	1,190	10,200
	Butane	8,710	1,250	10,390
Wood	Bark	9,600	1,920	-
	Wood Residue	9,240	1,830	-

COMBUSTION CALCULATIONS

% H_2O = 100 (1-Bws), where % H_2O is percent moisture in stack effluent

$$Bws = \left(1- \frac{\%O_{2w}}{20.9} \right) - \frac{F_c}{Fw} \left[(1-Bwa) - \frac{\%O_{2w}}{20.9} \right]$$

where % O_{2w} is percent oxygen wet bases and Bwa is fractional content of moisture in combustion air inlet, default value is 0.027.

$$\%CO_{2w} = \frac{4.785\ Fc}{Fw} \left[20.9\ (1-Bwa) - \%\ O_{2w} \right]$$

$$\%O_{2w} = \left[20.9\ (1-Bwa) - \left(\frac{20.9}{100} \right) \left(\frac{Fw}{Fc} \right) \%CO_{2w} \right.$$

$$\%\ O_{2D} = 20.9 \left[1 - \left(\frac{F_D}{F_C} \right) \left(\frac{\%CO_{2D}}{100} \right) \right]$$

EMMISSION RATE (LBS/MMBTU) CALCULATIONS

$E = K\ C_D\ F_D\ (\frac{20.9}{20.9-\%O_2})$, for dry basis measurements

$K = 1.194 \times 10^{-7}$ for NO_x, reported as NO_2

$= 1.660 \times 10^{-7}$ for SO_2

C_D is dry basis concentration of pollutant in ppm

$E = K\ C_W\ F_W\ [\ \frac{20.9}{20.9(1-Bwa)-\%O_{2w}}\ ]$, for wet basis measurements

$E = K\ C_W\ F_D\ [\ \frac{20.9}{.209(100-\%H_2O)-\%O_{2w}}\ ]$, for wet basis measurements with stack moisture

$E = K\ C\ F_C\ (\frac{100}{\%CO_2})$, for dry or wet basis measurements as long as C and $\%CO_2$ are both the same basis

MASS EMISSION RATE (LBS/HR) CALCULATIONS

$E = K\ C_W\ Q$, for wet basis measurements, where C_W is wet basis concentration of pollutant in ppm

Q is stack gas flow rate in SCFH

$E = E\ (\frac{lbs}{mmbtn})\ *\ HI\ (\frac{mmbtu}{hr})$

HEAT INPUT RATE ($\frac{\mathbf{mmbtu}}{\mathbf{hr}}$) FORMULAS

$HI = Q\ \frac{\%CO_{2W}}{100\ F_C}$, for wet basis measurements, where

Q is stack gas flow rate in SCFH

$HI = Q * \frac{1}{F_W} * \frac{[.209(100-\%H_2O)-\%O_{2W}]}{20.9}$, for wet basis measurements with stack moisture.

40 CFR 60

Subparts Cb through WWW are New Standards of Performance for various classes of Industrial Sources.

EPA SOURCE EMISSION TEST METHODS
Title 40, Code of Federal Regulations

PART 60 APPENDIX A

Method	Description
1	Selection of traverse points
1A	Selection of traverse points, small stacks or ducts
2	Flow rate – type S pitot
2A	Flow rate in small ducts – vol.meters
2B	Flow rate – stoichiometry
2C	Flow rate in small ducts – standard pitot
2D	Flow rate in small ducts – rate meters
2E proposed	Flow rate from landfill wells
3	Molecular weight
3A	Instrumental method for O_2 (oxygen) and CO_2 (carbon dioxide)
3B	Orsat for correction factors and excess air
3C proposed	Gas composition from landfill gases
4	Moisture
5	PM (particulate matter)
5A	PM from asphalt roofing (Prop. as M-26)
5B	Nonsulfuric acid PM
5C tentative	PM from small ducts
5D	PM from baghouses – without stacks
5E	PM from fiberglass plants
5F	Nonsulfate PM from FCCU (fluidized catalytic cracking units)
5G	PM from wood heaters – dilution tunnel
5H	PM from wood heaters – stack
6	SO_2 (sulfur dioxide)
6A	SO_2/CO_2
6B	Auto SO_2/CP_2
6C	Instrumental method for SO_2
7	NO_X (nitrogen oxides)
7A	IC (ion chromatograph) NO_X analysis
7B	UV (ultra violet) NO_X analysis for nitric acid plants
7C	Alkaline permanganate/colorimetric for NO_X
7D	Alkaline permanganate/IC for NO_X
7E	Instrumental method for NO_X
8	H_2SO_4 (sulfuric acid) mist and SO_2
9	Opacity via smoke reader
9A	Lidar opacity;called Alternative 1
10	CO (carbon monoxide)
10A	Colorimetric method for CO (used with PS-4)
10B	CO by GC (gas chromatograph), used with PS-4
11	H_2S (hydrogen sulfide)
12	Pb (lead)

EPA SOURCE EMISSION TEST METHODS
Title 40, Code of Federal Regulations

PART 60 APPENDIX A (cont.)

13A	F (fluoride) – colorimetric method
13B	F – SIE (specific ion electrode) method
14	F – from roof monitors
15	TRS (total reduced sulfur) from petroleum refineries
15A	TRS from petroleum refineries alternative (by oxidation)
16	TRS from kraft pulp mills
16A	TRS alternative (by oxidation)
16B	TRS alternative/GC (gas chromatograph) analysis of SO_2 (sulfur dioxide)
16B	TRS alternative/GC (gas chromatograph) analysis of SO_2 (sulfur dioxide)
17	PM (particulate matter) in-stack
18	VOC (volatile organic compounds), general GC method
19	F – factor, coal sampling
20	NO_X (nitrogen oxides)from gas turbines
21	VOC leaks
22	Fugitive VE (visible emissions)
23	Dioxin/dibenzofuran
24	Solvent in surface coatings
24A	Solvent in ink
25	TGNMO (total gaseous non-methane organics)
25A	TOC/FIA (total organic carbon/flame ionization analyzer)
25B	TOC/NDIR (total organic carbon/nondispersive infrared analyzer)
25C	VOC (volatile organic compounds) from landfills
25D	VO from TSDF (treatment storage disposal facility) – purge procedure
25E	VO from TSDF – vapor pressure procedure
26	HCl (hydrogen chloride)
26A	Isokinetic HCl and halogens
27	Tank truck leaks
28	Wood heater certification
28A	Air-to-fuel ratio
29	Multiple metals
30 tentative	TE (total enclosure) criteria
30A tentative	VOC content in liquid streams
30B tentative	VOC emissions in captured gas streams
30C tentative	VOC emissions in captured gas streams-dilution technique
30D tentative	VOC emissions in fugitive gas streams in TE (total enclosure)
30E tentative	VOC emissions in fugitive gas streams in building enclosures
30F tentative	VOC content in liquid input

PART 60 APPENDIX B – CEM PERFORMANCE SPECIFICATIONS

Method	Description
PS-1	Opacity
PS-2	SO_2 (sulfur dioxide) and NO_X (nitrogen oxide)
PS-3	CO_2 (carbon dioxide) and O_2 (oxygen)
PS-4	CO (carbon monoxide)
PS-4A	CO in MWC (municipal waste combustors)
PS-5	TRS (total reduced sulfur)
PS-6	Velocity and mass emission rate
PS-7	H_2S (hydrogen sulfide)
PS-8	VOC CEMS
PS-9	GC CEMS

PART 60 APPENDIX F – CEM PERFORMANCE SPECIFICATIONS

Method	Description
Proc 1	Quality assurance for CEMS (continuous emissions monitoring systems)

PART 61 NESHAPS APPENDIX B – TEST METHODS

Method	Description
101	Hg (mercury) in air streams
101A	Hg in sewage sludge incinerators
102	Hg in H_2 (hydrogen) streams
103	Be (beryllium) screening method
104	Be
105	Hg in sewage sludge
106	VC (vinyl chloride)
107	VC in process streams
107A	VC in process streams
108	Inorganic arsenic
108A	Arsenic in ore samples
108B	Arsenic in ore alternative
108C	Arsenic in ore alternative
111	Polonium – 210
114	Monitoring of radionuclides
115	Radon – 222

PART 51 APPENDIX M

Method	Description
201	PM – 10 (particulate matter less than 10 microns), EGR (exhaust gas recycle) procedure
201A	PM – 10, CSR (constant sampling rate) procedure
202	Condensible PM
203 proposed	Transmissometer for opacity compliance
203A tentative	M – 9 revision – 2-6 minute average
203B tentative	M – 9 revision – time exception
203C tentative	M – 9 revision – instantaneous

PART 63 NESHAPS FOR SOURCE CATEGORIES APPENDIX A

Method	Description
301	Data validation protocol
302 tentative	Generic GC/MS (gas chromatograph/mass spectrometry) procedure
303	By – product coke oven battery, VE (visible emissions)
303A	Non – recovery coke oven battery, VE
304A-B	Biodegradation rate
305	Compound specific liquid waste
306A-B	Hexavalent chromium
307	Halogenated solvent vapor cleaning machines

PART 63 NESHAPS FOR SOURCE CATEGORIES APPENDIX A (cont.)

308	Methanol
310A-B-C	Residual hexame
311	HAPS by direct GC injection
312	
313	

PART 64 COMPLIANCE ASSURANCE MONITORING (CAMS)

PART 70 STACK OPERATING PERMIT PROGRAMS

PART 75 (CEMS FOR ACID RAIN INSTALLATIONS)

Method	Description
Appendix A	Specs & test procedures
Appendix B	QA/QC procedures

PART 76 ACID RAIN NO_X EMISSION REDUCTION

NO_X BUDGET PROGRAM

AMBIENT AIR – REGULATIONS

Part	Description
40CFR50	National primary and secondary ambient air quality standards
40CFR53	Ambient air monitoring reference and equivalent methods
40CFR58	Ambient air quality surveillance

AMBIENT AIR STANDARDS (NAAGS)

	Primary	Secondary
SO_2	0.003 ppm annual avg 0.14 ppm 24-hr avg with only one exceedance/year	
	0.5 ppm 3-hr avg with only one exceedance/year	same
PM_{10}	150 mg/m^3 24-hr avg with only one exceedance/year	same
	50 mg/m^3 annual avg	same
$PM_{2.5}$	15 mg/m^3 annual avg	same
	65 mg/m^3 24-hr avg	same
CO	9ppm 8-hr avg with only one exceedance/year	none
	35 ppm 1-hr avg with only one exceedance/year	
0_3	0.12 ppm 1-hr avg with only one exceedance/year	same
	0.08 ppm 8-hr avg with 4^{th} highest max 8-hr avg less than 0.08 in a year	same
NO_X	0.053 ppm annual avg	same
Pb (lead)	1.5 mg/m^3 max arithmetic mean averaged over a calendar quarter	same