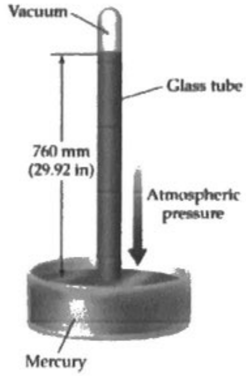
AP CHEM NOTES: GAS LAWS

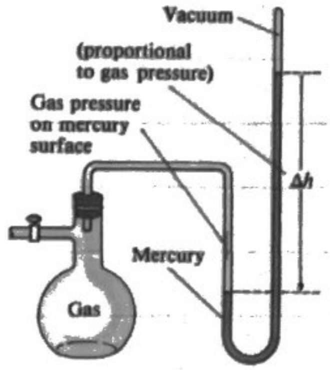
General Properties:

- uniformly fills any container
- easily compressed
- mixes completely with any other gas
- exerts pressure on its surroundings

Devices to Measure Pressure

- barometer
- manometer





Pressure Units:

- SI base unit: pascal (Pa)
- Standard Pressures: 760 mmHg, 76 cmHg, 760 torr, 1 atm, 29.92 inHg, 14.7 psi, 101.325 kPa

Kinetic Molecular Theory (an attempt to describe an ideal gas)

- The particles are so small compared with the distances between them that the volume of the individual particles can be assumed to be negligible (zero volume).
- The particles are in constant motion. The collisions of the particles with the walls of the container are the cause of the pressure exerted by the gas. Furthermore, the collisions between gas particles are perfectly elastic—there is no net loss of kinetic energy over a period of time.
- The particles are assumed to exert no forces on each other.
- The average kinetic energy of a collection of gas particles is assumed to be directly proportional to the Kelvin temperature of the gas.

Dalton's Law of Partial Pressure:

- partial pressure → the pressure a gas in a mixture of gases would exert if it were in the container by itself
- $\boxed{P_{total} = P_1 + P_2 + P_3 + \dots}$

Boyle's Law:

- states the volume of a gas is inversely proportional to its pressure at constant temperature and moles
- $V \propto \frac{1}{P} \Rightarrow PV = k \qquad P_1V_1 = k$ and $P_2V_2 = k \Rightarrow \boxed{P_1V_1 = P_2V_2}$

Charles' Law:

- states the volume of a gas is directly proportional to its Kelvin temperature at constant pressure and moles
- $V \propto T \Rightarrow \frac{V}{T} = k \qquad \frac{V_1}{T_1} = k$ and $\frac{V_2}{T_2} = k \Rightarrow \boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2}}$

Combined Gas Law:

- just as the name implies, this is a combination of both Boyle's and Charles' laws at constant moles
- $V \propto \frac{T}{P} \Rightarrow \frac{PV}{T} = k \Rightarrow \boxed{\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}}$

Ideal Gas Law:

- Since: $\left.\begin{array}{l} V \propto T \\ V \propto \frac{1}{P} \\ V \propto n \end{array}\right\} \Rightarrow \left.\begin{array}{l} \frac{V}{T} = k_1 \\ PV = k_2 \\ \frac{V}{n} = k_3 \end{array}\right\} \Rightarrow V = R\left(\frac{Tn}{P}\right)$ where R is the combined constants called the **ideal gas law constant**
- the value of R: $R = 0.08206 \frac{L \cdot atm}{K \cdot mol}$ This means that volume must be in L and pressure must be in atm.
- ideal gas law equation → $\boxed{PV = nRT}$
- Since $mol = \frac{g}{MM}$, then another form of this equation could be: $\boxed{PV = \frac{gRT}{MM}}$
- This equation is good anytime you know the variables needed at just one situation for a gas sample.
- Problem: Determine the volume of a 20.0 g sample of O_2 gas at 745.0 torr and 127.0°C.

V = ?

g = 20.0 g

$P = 745.0 \text{ torr} \left(\frac{1 \text{ atm}}{760 \text{ torr}}\right) = 0.9803 \text{ atm}$

T = 127.0°C = 400.2 K

$$PV = \frac{gRT}{MM}$$

$$V = \frac{gRT}{P(MM)} = \frac{(20.0 \text{ g})(0.08206 \frac{L \cdot atm}{K \cdot mol})(400.2 \text{ K})}{(0.9803 \text{ atm})(32.00 \frac{g}{mol})} = \boxed{20.9 \text{ L}}$$

STP:

- standard temperature and pressure
- standard temperature → 0°C or 273.15 K
  - to convert between K and °C ⇒ $\boxed{K = {}^\circ C + 273.15}$
- standard pressures already given

Velocity and Temperature

The idea that temperature is a measure of the ______________________________ of a gas is of critical importance.

Per mole of gas molecules → KE = 3/2 RT where $R = 8.314\ J\ K^{-1}\ mol^{-1}$ $1\ J = 1 kg\ m^2\ s^{-2}$

Per molecule → KE = ½ mv^2 (m=mass, v=velocity)

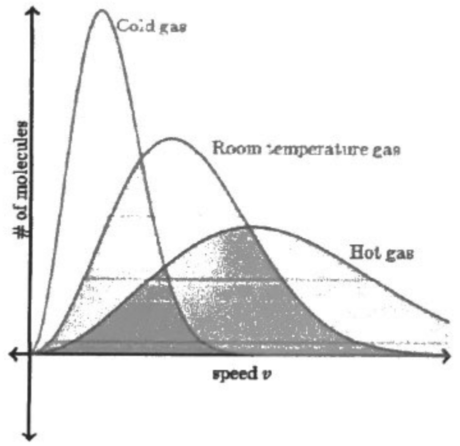
So, ½ mv^2 = 3/2 RT This means that ________________ (as indicated by the random motion of the particles of a gas) increases with higher ______________________.

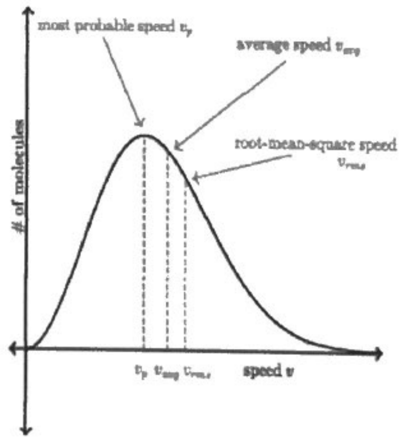
Root Mean Square Velocity – This is an expression dealing with the average velocity of gas particles. $\upsilon_{rms} = \sqrt{3RT/M}$ $R = 8.314\ J\ K^{-1}\ mol^{-1}$

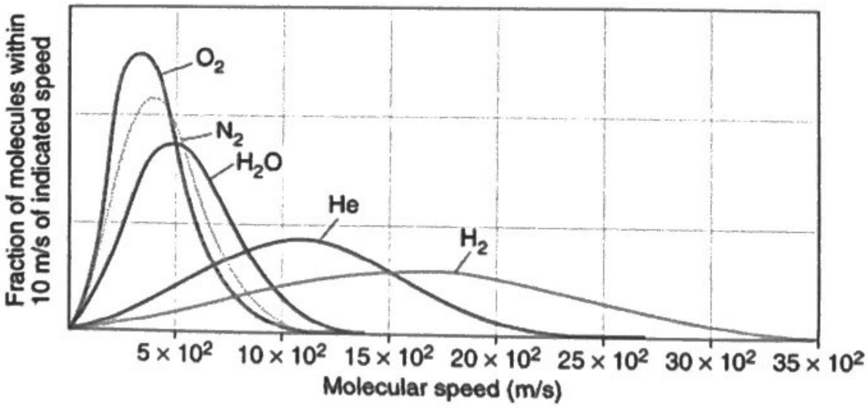
M = molar mass in ____________________

Example: Calculate the root mean square velocity for the atoms in a sample of oxygen gas at A.) 0.0°C and B.) 300.0°C.

Maxwell-Boltzmann Distribution







Graham's Law of Effusion

____________________ - scattering of gas molecules due to their random motion

____________________ - when gas molecules in a container pass through a small hole

The rate of diffusion (effusion) varies directly as the velocity of the molecules.

At the same ____________________, molecules of small mass diffuse ____________ than molecules of large mass. ($KE = \frac{1}{2} mv^2$)

If two substances are at the same temperature, their ____________________________ must be the same.

$$KE_1 = KE_2 \qquad KE = \tfrac{1}{2} mv^2$$

$$\tfrac{1}{2} M_1 v_1^2 = \tfrac{1}{2} M_2 v_2^2$$

$$M_1 v_1^2 = M_2 v_2^2$$

$$\frac{v_1^2}{v_2^2} = \frac{M_2}{M_1}$$

$$\frac{v_1}{v_2} = \sqrt{M2/M1}$$

Graham's Law of Effusion

Mixtures of Gases

If a mixture of gases in a container behaves ideally, each gas acts as though it were the only gas in the container. Therefore:

- Each gas occupies the entire container
- Each gas exerts its own pressure (called partial pressure)
- The total pressure is the sum of the individual partial pressures (Dalton's Law of Partial Pressures)

Since each component obeys the ideal gas law (PV=nRT) and has the same T and V, it follows that the partial pressure of each gas in the container is directly proportional to its moles.

$$\frac{P_1V_1 = n_1R_1T_1}{P_2V_2 = n_2R_2T_2}$$

$$\frac{P_1}{P_2} = \frac{n_1}{n_2} \qquad \frac{P_i}{P_T} = \frac{n_i}{n_T}$$

rearrange

$$P_i = \frac{n_i}{n_T} \times P_T$$

substitute

$$P_i = X \times P_T$$

Mole fraction (chi)

VAPOR PRESSURE OF WATER BELOW 100°C (mm Hg)

Pressure of aqueous vapor over water in mm of Hg for temperatures from −15.8 to 100°C. Values for fractional degrees between 50 and 89 were obtained by interpolation.

Temp. °C	0.0	0.2	0.4	0.6	0.8	Temp. °C	0.0	0.2	0.4	0.6	0.8
−15	1.436	1.414	1.390	1.368	1.345	−5	3.163	3.115	3.069	3.022	2.976
−14	1.560	1.534	1.511	1.485	1.460	−4	3.410	3.359	3.309	3.259	3.211
−13	1.691	1.665	1.637	1.611	1.585	−3	3.673	3.620	3.567	3.514	3.461
−12	1.834	1.804	1.776	1.748	1.720	−2	3.956	3.898	3.841	3.785	3.730
−11	1.987	1.955	1.924	1.893	1.863	−1	4.258	4.196	4.135	4.075	4.016
−10	2.149	2.116	2.084	2.050	2.018	−0	4.579	4.513	4.448	4.385	4.320
−9	2.326	2.289	2.254	2.219	2.184	0	4.579	4.647	4.715	4.785	4.855
−8	2.514	2.475	2.437	2.399	2.362	1	4.926	4.998	5.070	5.144	5.219
−7	2.715	2.674	2.633	2.593	2.553	2	5.294	5.370	5.447	5.525	5.605
−6	2.931	2.887	2.843	2.800	2.757	3	5.685	5.766	5.848	5.931	6.015

VAPOR PRESSURE OF WATER BELOW 100°C (continued) (mm Hg)

Temp. °C	0.0	0.2	0.4	0.6	0.8	Temp. °C	0.0	0.2	0.4	0.6	0.8
4	6.101	6.187	6.274	6.363	6.453	53	107.20	108.2	109.3	110.4	111.4
5	6.543	6.635	6.728	6.822	6.917	54	112.51	113.6	114.7	115.8	116.9
6	7.013	7.111	7.209	7.309	7.411	55	118.04	119.1	120.3	121.5	122.6
7	7.513	7.617	7.722	7.828	7.936	56	123.80	125.0	126.2	127.4	128.6
8	8.045	8.155	8.267	8.380	8.494	57	129.82	131.0	132.3	133.5	134.7
9	8.609	8.727	8.845	8.965	9.086	58	136.08	137.3	138.5	139.9	141.2
10	9.209	9.333	9.458	9.585	9.714	59	142.60	143.9	145.2	146.6	148.0
11	9.844	9.976	10.109	10.244	10.380	60	149.38	150.7	152.1	153.5	155.0
12	10.518	10.658	10.799	10.941	11.085	61	156.43	157.8	159.3	160.8	162.3
13	11.231	11.379	11.528	11.680	11.833	62	163.77	165.2	166.8	168.3	169.8
14	11.987	12.144	12.302	12.462	12.624	63	171.38	172.9	174.5	176.1	177.7
15	12.788	12.953	13.121	13.290	13.461	64	179.31	180.9	182.5	184.2	185.8
16	13.634	13.809	13.987	14.166	14.347	65	187.54	189.2	190.9	192.6	194.3
17	14.530	14.715	14.903	15.092	15.284	66	196.09	197.8	199.5	201.3	203.1
18	15.477	15.673	15.871	16.071	16.272	67	204.96	206.8	208.6	210.5	212.3
19	16.477	16.685	16.894	17.105	17.319	68	214.17	216.0	218.0	219.9	221.8
20	17.535	17.753	17.974	18.197	18.422	69	223.73	225.7	227.7	229.7	231.7
21	18.650	18.880	19.113	19.349	19.587	70	233.7	235.7	237.7	239.7	241.8
22	19.827	20.070	20.316	20.565	20.815	71	243.9	246.0	248.2	250.3	252.4
23	21.068	21.324	21.583	21.845	22.110	72	254.6	256.8	259.0	261.2	263.4
24	22.377	22.648	22.922	23.198	23.476	73	265.7	268.0	270.2	272.6	274.8
25	23.756	24.039	24.326	24.617	24.912	74	277.2	279.4	281.8	284.2	286.6
26	25.209	25.509	25.812	26.117	26.426	75	289.1	291.5	294.0	296.4	298.8
27	26.739	27.055	27.374	27.696	28.021	76	301.4	303.8	306.4	308.9	311.4
28	28.349	28.680	29.015	29.354	29.697	77	314.1	316.6	319.2	322.0	324.6
29	30.043	30.392	30.745	31.102	31.461	78	327.3	330.0	332.8	335.6	338.2
30	31.824	32.191	32.561	32.934	33.312	79	341.0	343.8	346.6	349.4	352.2
31	33.695	34.082	34.471	34.864	35.261	80	355.1	358.0	361.0	363.8	366.8
32	35.663	36.068	36.477	36.891	37.308	81	369.7	372.6	375.6	378.8	381.8
33	37.729	38.155	38.584	39.018	39.457	82	384.9	388.0	391.2	394.4	397.4
34	39.898	40.344	40.796	41.251	41.710	83	400.6	403.8	407.0	410.2	413.6
35	42.175	42.644	43.117	43.595	44.078	84	416.8	420.2	423.6	426.8	430.2
36	44.563	45.054	45.549	46.050	46.556	85	433.6	437.0	440.4	444.0	447.5
37	47.067	47.582	48.102	48.627	49.157	86	450.9	454.4	458.0	461.6	465.2
38	49.692	50.231	50.774	51.323	51.879	87	468.7	472.4	476.0	479.8	483.4
39	52.442	53.009	53.580	54.156	54.737	88	487.1	491.0	494.7	498.5	502.2
40	55.324	55.91	56.51	57.11	57.72	89	506.1	510.0	513.9	517.8	521.8
41	58.34	58.96	59.58	60.22	60.86	90	525.76	529.77	533.80	537.86	541.95
42	61.50	62.14	62.80	63.46	64.12	91	546.05	550.18	554.35	558.53	562.75
43	64.80	65.48	66.16	66.86	67.56	92	566.99	571.26	575.55	579.87	584.22
44	68.26	68.97	69.69	70.41	71.14	93	588.60	593.00	597.43	601.89	606.38
45	71.88	72.62	73.36	74.12	74.88	94	610.90	615.44	620.01	624.61	629.24
46	75.65	76.43	77.21	78.00	78.80	95	633.90	638.59	643.30	648.05	652.82
47	79.60	80.41	81.23	82.05	82.87	96	657.62	662.45	667.31	672.20	677.12
48	83.71	84.56	85.42	86.28	87.14	97	682.07	687.04	692.05	697.10	702.17
49	88.02	88.90	89.79	90.69	91.59	98	707.27	712.40	717.56	722.75	727.98
50	92.51	93.5	94.4	95.3	96.3	99	733.24	738.53	743.85	749.20	754.58
51	97.20	98.2	99.1	100.1	101.1	100	760.00	765.45	770.93	776.44	782.00
52	102.09	103.1	104.1	105.1	106.2	101	787.57	793.18	798.82	804.50	810.21

VAPOR PRESSURE OF WATER ABOVE 100°C.

Based on values given by Keyes in the International Critical Tables.

Temp. °C	Pressure mm	Pressure Pounds per sq. in.	Temp. °F
100	760.	14.696	212.0
101	787.51	15.228	213.8
102	815.86	15.776	215.6
103	845.12	16.342	217.4
104	875.06	16.921	219.2
105	906.07	17.521	221.0
106	937.92	18.136	222.8
107	970.60	18.768	224.6
108	1004.42	19.422	226.4
109	1038.92	20.089	228.2
110	1074.56	20.779	230.0
111	1111.20	21.487	231.8
112	1148.74	22.213	233.6
113	1187.42	22.961	235.4
114	1227.25	23.731	237.2
115	1267.98	24.519	239.0
116	1309.94	25.330	240.8
117	1352.95	26.167	242.6

Temp. °C	Pressure mm	Pressure Pounds per sq. in.	Temp. °F
127	1850.83	35.789	260.6
128	1907.83	36.891	262.4
129	1966.35	38.023	264.2
130	2026.10	39.180	266.0
131	2087.42	40.364	267.8
132	2150.42	41.582	269.6
133	2214.64	42.824	271.4
134	2280.76	44.103	273.2
135	2347.26	45.389	275.0
136	2416.34	46.724	276.8
137	2488.16	48.113	278.6
138	2560.67	49.515	280.4
139	2634.84	50.950	282.2
140	2710.92	52.421	284.0
141	2788.44	53.920	285.8
142	2867.48	55.448	287.6
143	2948.80	57.020	289.4
[illegible]	[illegible]	[illegible]	[illegible]

Temp. °C	Pressure mm	Pressure Pounds per sq. in.	Temp. °F
154	3970.24	76.772	309.2
155	4075.88	78.815	311.0
156	4183.80	80.901	312.8
157	4293.24	83.018	314.6
158	4404.96	85.178	316.4
159	4519.72	87.397	318.2
160	4636.00	89.646	320.0
161	4755.32	91.953	321.8
162	4876.92	94.304	323.6
163	5000.04	96.685	325.4
164	5126.96	99.139	327.2
165	5256.16	101.638	329.0
166	5386.88	104.165	330.8
167	5521.40	106.766	332.6
168	5658.20	109.412	334.4
169	5798.04	112.116	336.2
170	5940.92	114.879	338.0

Temp. °C	Pressure mm	Pressure Pounds per sq. in.	Temp. °F
181	7694.24	148.782	357.8
182	7872.08	152.221	359.6
183	8052.96	155.719	361.4
184	8236.88	159.275	363.2
185	8423.84	162.890	365.0
186	8616.12	166.609	366.8
187	8809.92	170.356	368.6
188	9007.52	174.177	370.4
189	9208.16	178.057	372.2
190	9413.36	182.025	374.0
191	9620.08	186.022	375.8
192	9831.36	190.107	377.6
193	10047.20	194.281	379.4
194	10265.32	198.499	381.2
195	10488.76	202.819	383.0
196	10715.24	207.199	384.8
197	10944.76	211.637	386.6