VALTRONICS

Application Note A12:

Measurement of gas levels at different altitudes & temperatures

This note was created to show how the gas laws effect volumetric gas monitors.
The % change column represents an effect on the SPAN (up scale) reading and not on ZERO.

A question that sometimes is asked: If you calibrate one of our gas sensors at sea level would it read accurately at 6000 feet? Since all **NDIR** (**N**on-**D**ispersive **I**nfra-**R**ed) gas sensors are based on a volumetric measurement, the gas law effects the unit's calibration. The following charts assume **gas calibration was done at sea level and 75°F (23.9°C)**. If you gas calibrate at a different altitude and temperature the charts would be revised to indicate a new **0.0%** change point at that altitude and temperature.

Altitude in Feet from sea level	Pressure in Millimeters of Mercury	% change from sea level
-1,000	787.9	3.7%
0	**760.0**	0.0%
1,000	732.9	-3.6%
2,000	706.6	-7.0%
3,000	681.1	-10.4%
4,000	656.3	-13.6%
5,000	632.3	-16.8%
6,000	609.0	-19.9%
7,000	586.4	-22.8%
8,000	564.4	-25.7%
9,000	543.2	-28.5%
10,000	522.6	-31.2%
15,000	428.8	-43.6%
20,000	349.1	-54.1%
25,000	281.9	-62.9%
30,000	225.6	-70.3%
35,000	178.7	-76.5%
40,000	140.7	-81.5%
45,000	110.8	-85.4%
50,000	87.3	-88.5%

Density of Carbon Dioxide at 1 atmosphere			
Temperature ℃	Temperature ℉	Density mg/cc	% change from 75°F
-1.1	30	1.987	9.2%
1.7	35	1.968	8.1%
4.4	40	1.950	7.1%
7.2	45	1.931	6.1%
10.0	50	1.913	5.1%
12.8	55	1.894	4.1%
15.6	60	1.876	3.1%
18.3	65	1.857	2.0%
21.1	70	1.839	1.0%
23.9	**75**	**1.820**	**0.0%**
26.7	80	1.801	-1.0%
29.4	85	1.783	-2.0%
32.2	90	1.764	-3.1%
35.0	95	1.746	-4.1%
37.8	100	1.727	-5.1%
40.6	105	1.709	-6.1%
43.3	110	1.690	-7.1%
46.1	115	1.672	-8.1%
48.9	120	1.653	-9.2%

Temperature Testing Note:
Temperature testing of any measurement device assumes that their are **no temperature gradients** or unstable temperature conditions when response data is recorded. In other words, the data is recorded during a steady state condition . This requires a **soak period** of time after a temperature change of more than 2°C for the instrument to reach a temperature equilibrium

The basic gas equilibrium equation of $P_1V_1/T_1 = P_2V_2/T_2$ describes most of the significant factors. P designates the pressure, V is the volume of space the gas occupies, and T is the temperature of the gas. Take the case of a given mass (number of molecules) of CO_2, like our 1000 ppm (0.1%) calibration gas (99.9% N_2) occupying a volume such as our sample cell. The number of molecules that will occupy the space between the infrared source (emitter) and the infrared bandpass filter / detector depends on how far apart the molecules are. The average distance between molecules depends on pressure and temperature since the volume is constant. The number of molecules of CO_2 in the optical path will determine how much infrared energy at the specific CO_2 wavelength is absorbed. See page 2 for a generalized chart that shows the effect of temperature on the number of molecules in the gas cell for all gases.

Typical atmospheric pressure at sea level is 760 mm of mercury (Hg.). At 6000 feet (1829 meters) the pressure is 609 mm Hg. (a 20% decrease in pressure). If you operate an infrared gas monitor at 6000 feet elevation, you need to calibrate it at that elevation to make it more accurate. If you know the altitude, like Denver at about 5300 ft, you can **specify that on your purchase order** and we will correct the gas calibration for that altitude when we calibrate it at an additional cost. CO_2 in air will decrease in density a little more than 3% per 1000 feet increase in elevation. That approximation works to about 10,000 feet (see the attached chart).

An increase in temperature causes approximately a -0.37% (decrease) in CO_2 density per degree C or about -0.2% per degree F. These factors could easily be corrected in software if you are using a microcomputer or PC to process the data. There are other factors like specific gravity of the gases in a mixture that can affect their density at different altitudes and temperatures but at low concentrations of CO_2 this should not be significant. The specific gravity of CO_2 is 1.517, N2 is 0.966, and of course air that consists mostly of N_2 and O_2 is 1.000 at 68°F and 1 atmosphere (14.7 psia).

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Amedeo Avogadro (1776-1856), Italian chemist and physicist, determined in **1811** that all gases occupying equal volumes at the same temperature and pressure contain equal numbers of molecules. **Avogadros's number** is <u>**6.023 x 10^{23}**</u> molecules per gram molecular weight. A molar volume, **22.4 liters** at 0°C and 76 cm mercury (Hg) pressure, is the volume occupied by a gram molecular weight (mole) of gas (any gas). One of our gas cells has a volume of 3.61 mL. It will contain 9.71 x 10^{19} molecules at 0°C and 76 cm Hg. Of those only 5% will be methane molecules when 5% CH_4 is in the cell. This means that there will be 4.855 x 10^{18} molecules of CH_4 in the cell at 0°C and 76 cm Hg. The chart below shows how the number of molecules and therefore the percent absorption (scale response) changes as a function of ambient and gas cell temperature. The percentage change in gas **density** can be applied to all gases. This chart assumes **steady state** temperature and pressure conditions at each point on the chart (see Note on page 1 about Temperature Testing a Measurement Instrument).

Effect of temperature on the number of molecules in the gas cell for all gases.
Gas calibration is assumed at **0°C**, **32°F**, or **273.2°K** (absolute).

°C	°F	% change
-55	-67.0	**20.13%**
-54	-65.2	**19.76%**
-53	-63.4	**19.40%**
-52	-61.6	**19.03%**
-51	-59.8	**18.66%**
-50	-58.0	**18.30%**
-49	-56.2	**17.93%**
-48	-54.4	**17.57%**
-47	-52.6	**17.20%**
-46	-50.8	**16.83%**
-45	-49.0	**16.47%**
-44	-47.2	**16.10%**
-43	-45.4	**15.74%**
-42	-43.6	**15.37%**
-41	-41.8	**15.00%**
-40	-40.0	**14.64%**
-39	-38.2	**14.27%**
-38	-36.4	**13.91%**
-37	-34.6	**13.54%**
-36	-32.8	**13.17%**
-35	-31.0	**12.81%**
-34	-29.2	**12.44%**
-33	-27.4	**12.08%**
-32	-25.6	**11.71%**
-31	-23.8	**11.34%**
-30	-22.0	**10.98%**
-29	-20.2	**10.61%**
-28	-18.4	**10.25%**
-27	-16.6	**9.88%**
-26	-14.8	**9.51%**
-25	-13.0	**9.15%**
-24	-11.2	**8.78%**
-23	-9.4	**8.42%**
-22	-7.6	**8.05%**
-21	-5.8	**7.68%**
-20	-4.0	**7.32%**
-19	-2.2	**6.95%**
-18	-0.4	**6.59%**
-17	1.4	**6.22%**
-16	3.2	**5.85%**
-15	5.0	**5.49%**
-14	6.8	**5.12%**
-13	8.6	**4.76%**
-12	10.4	**4.39%**
-11	12.2	**4.02%**
-10	14.0	**3.66%**
-9	15.8	**3.29%**
-8	17.6	**2.93%**
-7	19.4	**2.56%**
-6	21.2	**2.19%**
-5	23.0	**1.83%**
-4	24.8	**1.46%**
-3	26.6	**1.10%**
-2	28.4	**0.73%**
-1	30.2	**0.36%**
0	**32.0**	**0.00%**
1	33.8	**-0.37%**
2	35.6	**-0.73%**
3	37.4	**-1.10%**
4	39.2	**-1.47%**
5	41.0	**-1.83%**
6	42.8	**-2.20%**
7	44.6	**-2.56%**
8	46.4	**-2.93%**
9	48.2	**-3.30%**
10	50.0	**-3.66%**
11	51.8	**-4.03%**
12	53.6	**-4.39%**
13	55.4	**-4.76%**
14	57.2	**-5.13%**
15	59.0	**-5.49%**
16	60.8	**-5.86%**
17	62.6	**-6.22%**
18	64.4	**-6.59%**
19	66.2	**-6.96%**
20	68.0	**-7.32%**
21	69.8	**-7.69%**
22	71.6	**-8.05%**
23	73.4	**-8.42%**
24	75.2	**-8.79%**
25	77.0	**-9.15%**
26	78.8	**-9.52%**
27	80.6	**-9.88%**
28	82.4	**-10.25%**
29	84.2	**-10.62%**
30	86.0	**-10.98%**
31	87.8	**-11.35%**
32	89.6	**-11.71%**
33	91.4	**-12.08%**
34	93.2	**-12.45%**
35	95.0	**-12.81%**
36	96.8	**-13.18%**
37	98.6	**-13.54%**
38	100.4	**-13.91%**
39	102.2	**-14.28%**
40	104.0	**-14.64%**
41	105.8	**-15.01%**
42	107.6	**-15.37%**
43	109.4	**-15.74%**
44	111.2	**-16.11%**
45	113.0	**-16.47%**
46	114.8	**-16.84%**
47	116.6	**-17.20%**
48	118.4	**-17.57%**
49	120.2	**-17.94%**
50	122.0	**-18.30%**
51	123.8	**-18.67%**
52	125.6	**-19.03%**
53	127.4	**-19.40%**
54	129.2	**-19.77%**
55	131.0	**-20.13%**
56	132.8	**-20.50%**
57	134.6	**-20.86%**
58	136.4	**-21.23%**
59	138.2	**-21.60%**
60	140.0	**-21.96%**
61	141.8	**-22.33%**
62	143.6	**-22.69%**
63	145.4	**-23.06%**
64	147.2	**-23.43%**
65	149.0	**-23.79%**
66	150.8	**-24.16%**
67	152.6	**-24.52%**
68	154.4	**-24.89%**
69	156.2	**-25.26%**
70	158.0	**-25.62%**

5% Methane (CH_4)

Temperature in			# of CH4	% change
°K	*°C*	*°F*	molecules	molecules
210	-63.2	-81.76	5.98E+18	23.13%
215	-58.2	-72.76	5.89E+18	21.30%
220	-53.2	-63.76	5.80E+18	19.47%
225	-48.2	-54.76	5.71E+18	17.64%
230	-43.2	-45.76	5.62E+18	15.81%
235	-38.2	-36.76	5.53E+18	13.98%
240	-33.2	-27.76	5.44E+18	12.15%
245	-28.2	-18.76	5.36E+18	10.32%
250	-23.2	-9.76	5.27E+18	8.49%
255	-18.2	-0.76	5.18E+18	6.66%
260	-13.2	8.24	5.09E+18	4.83%
265	-8.2	17.24	5.00E+18	3.00%
270	-3.2	26.24	4.91E+18	1.17%
273.2	**0.0**	**32.00**	4.86E+18	**0.00%**
275	1.8	35.24	4.82E+18	-0.66%
280	6.8	44.24	4.73E+18	-2.49%
285	11.8	53.24	4.65E+18	-4.32%
290	16.8	62.24	4.56E+18	-6.15%
295	21.8	71.24	4.47E+18	-7.98%
300	26.8	80.24	4.38E+18	-9.81%
305	31.8	89.24	4.29E+18	-11.64%
310	36.8	98.24	4.20E+18	-13.47%
315	41.8	107.24	4.11E+18	-15.30%
320	46.8	116.24	4.02E+18	-17.13%
325	51.8	125.24	3.93E+18	-18.96%
330	56.8	134.24	3.85E+18	-20.79%
335	61.8	143.24	3.76E+18	-22.62%
340	66.8	152.24	3.67E+18	-24.45%
345	71.8	161.24	3.58E+18	-26.28%

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