A New Computer for Calculating the Water Content of Gases

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A new computer designed to reduce the labor in computing the water content of gases is described, and details of construction and use are given. The computer is of the circular slide-rule type with an accuracy of about that of a 10-inch slide rule. The computer consists of three disks with appropriate circular scales, which automatically correct for all deviations from ideality. It is a completely new design of an earlier model, and it is based on newly determined values for the corrections. The primary function of the computer is to calculate the water content and dewpoint of gases at pressures up to 6,000 pounds per square inch quickly, accurately, and with a minimum of effort, but it may be used for many other computations. Attention should be called to the fact that deviations from ideality are not dependent on methods of measurement and that they affect many measurements and computations in which they are usually ignored.

1. Introduction

Determining the water content of gases by the Weaver-electrical method [1, 2, 3] [1] involves the solution of the general equation

$$W_x = W_s \frac{P_w P_c (1 - KP_c + K'P_c^2)}{P_s(1 - KP_s + K'P_s^2)P_x(1 - KP_x + K'P_x^2)} \quad (1)$$

where W_x is the unknown concentration (weight per unit volume) of water vapor in the gas being tested, W_s is the concentration of water in the comparison gas at pressure P_s (usually W_s is the concentration of water vapor in equilibrium with liquid water or with ice, and P_s is the pressure of saturation), P_c is the absolute pressure of the comparison gas at which the fugacity of its water vapor is equal to that of the unknown gas at pressure P_x, P_w is the pressure at which W_x is to be expressed—usually 1 atm, and K and K' are constants, the values of which were determined experimentally [4] to be $K = 1.9 \times 10^{-4}$, $K' = 1.4 \times 10^{-8}$ for air and other gases (like oxygen and nitrogen) that behave similarly. All pressures in this equation are expressed in pounds per square inch absolute.

To solve the equation by longhand takes much more time than to make the measurements needed for a determination. To reduce the labor in making the necessary computations, a simple computer designed for the purpose may be used. The principle of the computer is not new; but it is a completely new design of an earlier model described by Weaver and Riley [1]. The computer is a circular slide rule consisting of three disks with appropriate circular scales inscribed on them. The several multiplications and divisions required for the solution of eq (1) are made by adding and subtracting angles proportional to the logarithms of the numbers indicated by the scales. Although the primary function of the computer is to solve the general equation for W_x quickly, accurately, and with a minimum of effort, it may also be used for many other computations. The devia-

[1] Figures in brackets indicate the literature references at the end of this paper.

tion from ideality that makes necessary the corrections involving K and K' is, of course, a natural phenomenon that should not be ignored in work at high pressures, whatever the method of determining water vapor.

2. General Arrangement of the Computer

The computer consists of a base disk and two rotating disks with protruding tabs. Circular scales are arranged on the three disks in such a way that the general equation can be solved for W_x with a minimum of manipulation. The computer is shown in figure 1.

3. Base Disk

The base disk (fig. 2) contains two scales, a logarithmic scale near its outer rim and a temperature scale near its center. Concentrations of water vapor are marked in milligrams per liter on the outer scale. Because this scale is a logarithmic scale like that of the ordinary slide rule, it can be used for a variety of computations involving, particularly, conversions from one unit to another. Data used in constructing the scale, and other details, are given in table 1.

On a relatively small circle on the base disk is a scale of Fahrenheit temperature, covering the range of $-30°$ to $+120°$ F. This scale is read through windows in the two upper disks. On it, angles are proportional to the logarithm of the vapor pressure of water at saturation at the temperatures marked on the scale. The arrangement of the temperature scale in relation to the outside scale and the markings on the latter require explanation.

It is the purpose of the computer to solve problems involving the compositions of gas mixtures (relative quantities of water vapor and of other gases), and it is convenient to express all compositions in terms of the weight of water in the quantity of mixture that would occupy unit volume under some standard condition, in this case 1 atm and 70° F. If p_{70} represents the vapor pressure of water at 70° F, W_{70} its density, and p_t and W_t the vapor pressure
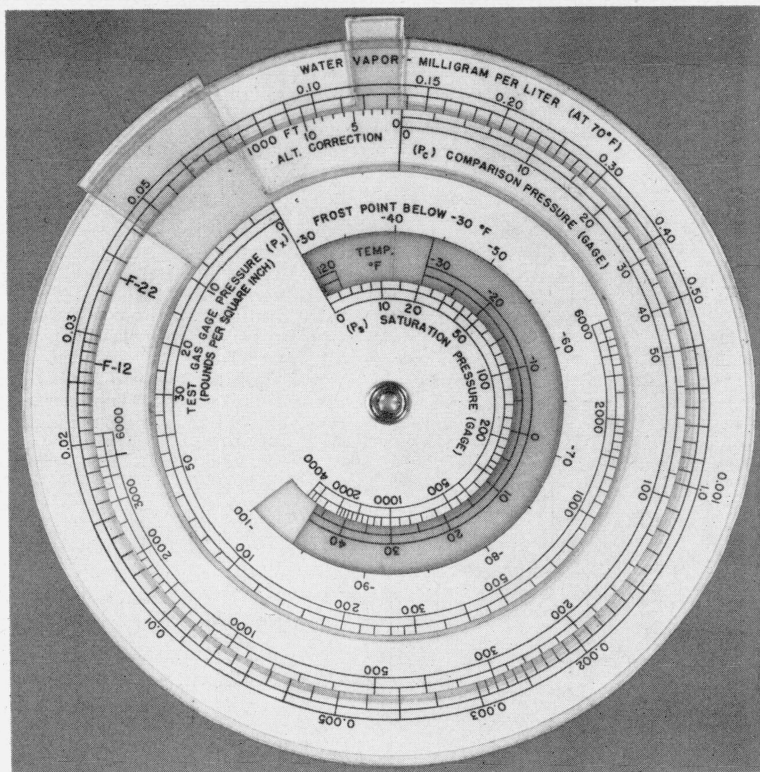
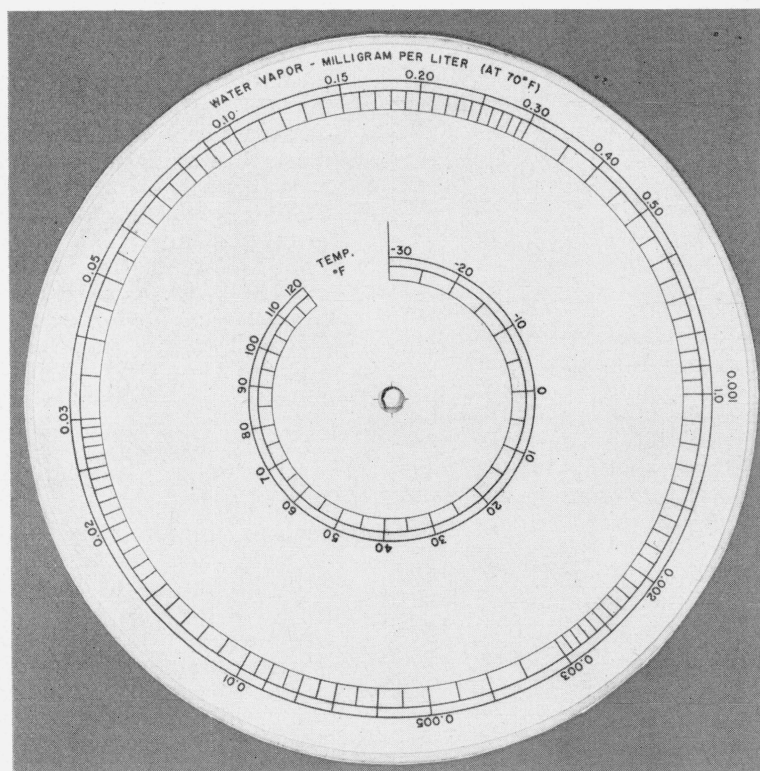FIGURE 1. *Assembled computer (approximately full size).*

FIGURE 2. *Base disk.*

TABLE 1. *Data for outer logarithmic scale on base disk*

(The scale is marked in milligrams of water vapor per liter at 70° F.)

No.	Logarithm	1st cycle Angle [a]	1st cycle Label	2d cycle Angle	2d cycle Label	3d cycle Angle	3d cycle Label on scale
		deg		*deg*		*deg*	
1.0	0.0000	0.0	1.0, 0.001 [b]	120.0	0.01	240.0	0.10
1.1	.0414	5.0	----------	125.0	----------	245.0	----------
1.2	.0792	9.5	----------	129.5	----------	249.5	----------
1.3	.1139	13.7	----------	133.7	----------	253.7	----------
1.4	.1461	17.5	----------	137.5	----------	257.5	----------
1.5	.1761	21.1	----------	141.1	----------	261.1	0.15
1.6	.2041	24.5	----------	144.5	----------	264.5	----------
1.7	.2304	27.6	----------	147.6	----------	267.6	----------
1.8	.2553	30.6	----------	150.6	----------	270.6	----------
1.9	.2788	33.4	----------	153.4	----------	273.4	----------
2.0	.3010	36.1	0.002	156.1	0.02	276.1	0.20
2.1	.3222	38.7	----------	158.7	----------	278.7	----------
2.2	.3424	41.1	----------	161.1	----------	281.1	----------
2.3	.3617	43.4	----------	163.4	----------	283.4	----------
2.4	.3802	45.6	----------	165.6	----------	285.6	----------
2.5	.3979	47.7	----------	167.7	----------	287.7	----------
2.6	.4150	49.8	----------	169.8	----------	289.8	----------
2.7	.4314	51.8	----------	171.8	----------	291.8	----------
2.8	.4472	53.7	----------	173.7	----------	293.7	----------
2.9	.4624	55.5	----------	175.5	----------	295.5	----------
3.0	.4771	57.2	0.003	177.2	0.03	297.2	0.30
3.5	.5441	65.3	----------	185.3	----------	305.3	----------
4.0	.6021	72.2	----------	192.2	----------	312.2	----------
4.5	6532	78.4	----------	198.4	----------	318.4	----------
5.0	.6990	83.9	0.005	203.9	0.05	323.9	0.50
5.5	.7404	88.8	----------	208.8	----------	328.8	----------
6.0	.7782	93.4	----------	213.4	----------	333.4	----------
6.5	.8129	97.5	----------	217.5	----------	337.5	----------
7.0	.8451	101.4	----------	221.4	----------	341.4	----------
7.5	.8751	105.0	----------	225.0	----------	345.0	----------
8.0	.9031	108.4	----------	228.4	----------	348.4	----------
8.5	.9294	111.5	----------	231.5	----------	351.5	----------
9.0	.9542	114.5	----------	234.5	----------	354.5	----------
9.5	.9777	117.3	----------	237.3	----------	357.3	----------
10.0	1.0000	120.0	0.01	240.0	0.10	360.0	1.0, 0.001 [b]

[a] The angles for the three cycles were calculated as follows:
For the 1st cycle: Angle=120×log of each number.
For the 2d cycle: Angle=angle used in 1st cycle plus 120.
For the 3d cycle: Angle=angle used in 1st cycle plus 240.
[b] There are two labels on this mark.

and density at temperature t, and if the water vapor at this low pressure behaves as an ideal gas,

$$\frac{W_t}{W_{70}} = \frac{p_t}{p_{70}} \frac{70+460}{t+460}. \qquad (2)$$

However, we are concerned not with the density (or concentration) of the water vapor at temperature t but with its concentration, W_x, in the gas mixture at 70° F if the temperature is changed without gain or loss of vapor.

$$\frac{W_x}{W_t} = \frac{t+460}{70+460}, \qquad (3)$$

combining eq (2) and (3)

$$\frac{W_x}{W_{70}} = \frac{p_t}{p_{70}} \frac{70+460}{t+460} \frac{t+460}{70+460} = \frac{p_t}{p_{70}}. \qquad (4)$$

Because of this direct proportionality, it is only necessary to arrange the two scales so that the logarithm of vapor pressure at 70° F is on the same radius as the logarithm of the concentration of water vapor at that temperature multiplied by a convenient power of 10, and any other concentration "reduced"

to 70° will then be found on the same radius as its corresponding temperature. Because familiarity with the ideal gas law might make the reduction to 70° easier to follow, that law was assumed in the derivation given. Actually, the result would have been the same had any other relation been assumed between temperature and gas density because, in the two steps of the reduction, the temperature factors cancel out. The reduction to 70° only puts all measurements on the basis of a common unit of composition; it does not imply that gas saturated at a higher temperature can be cooled to 70° without condensing some of the water.

Because the concentrations to be read in practice cover 5 or 6 orders of magnitude, whereas the circle is divided into only three decades, only values of the concentration (reduced to 70° F) below 1 mg/liter (at about 0° F) are marked with their correct decimals. Above 1 mg/liter the values of concentration opposite a given temperature are to be multiplied by 1,000.

Detailed directions for laying off the temperature scale are given in table 2. The number 1.017 in the fifth column is that by which vapor pressure in millimeters of mercury at 70° F must be divided to obtain concentration in milligrams per liter.

TABLE 2. *Data for inner scale on base disk*

Temperature ° F. The scale is marked with the temperatures at which saturated vapors, after reducing to 70° F, have the density marked at the same radius as the outer scale. See table 1.

Temperature		Vapor pressure[a]	Log vapor pressure[b]	Conversion factor	Log conversion factor	Log mg/liter at 70° F[c]	Angle	Label on scale
° F	° C	mm					deg	
−30.0	−34.4	0.180	2.2553	1.017	0.0073	2.2480	269.8	−30
−25.0	−31.7	.240	2.3802	--------	--------	2.3729	284.7	--------
−20.0	−28.9	.320	2.5052	--------	--------	2.4979	299.7	−20
−15.0	−26.1	.426	2.6294	--------	--------	2.6221	314.6	--------
−10.0	−23.3	.563	2.7505	--------	--------	2.7432	329.2	−10
−5.0	−20.5	.740	2.8692	--------	--------	2.8619	343.4	--------
0	−17.7	.966	2.9850	--------	--------	2.9777	357.3	0
5.0	−15.0	1.241	0.0938	--------	--------	0.0865	10.4	--------
10.0	−12.2	1.602	.2047	--------	--------	.1974	23.7	10
15.0	−9.5	2.039	.3094	--------	--------	.3021	36.2	--------
20.0	−6.7	2.603	.4155	--------	--------	.4082	49.0	20
25.0	−3.9	3.308	.5196	--------	--------	.5123	61.5	--------
30.0	−1.1	4.182	.6214	--------	--------	.6141	73.7	30
35.0	1.7	5.181	.7144	--------	--------	.7071	84.8	--------
40.0	4.4	6.274	.7975	--------	--------	.7902	94.8	40
45.0	7.2	7.617	.8817	--------	--------	.8744	104.9	--------
50.0	10.0	9.209	.9642	--------	--------	.9569	114.8	50
55.0	12.8	11.08	1.0445	--------	--------	1.0372	124.5	--------
60.0	15.6	13.29	1.1135	--------	--------	1.1062	132.7	60
65.0	18.4	15.87	1.2006	--------	--------	1.1933	143.2	--------
70.0	21.1	18.76	1.2732	--------	--------	1.2659	151.9	70
75.0	23.9	22.24	1.3471	--------	--------	1.3398	160.8	--------
80.0	26.6	26.12	1.4170	--------	--------	1.4097	169.2	80
85.0	29.4	30.74	1.4877	--------	--------	1.4804	177.6	--------
90.0	32.2	36.07	1.5572	--------	--------	1.5499	186.0	90
95.0	35.0	42.18	1.6251	--------	--------	1.6178	194.1	--------
100.0	37.8	49.16	1.6916	--------	--------	1.6343	202.1	100
105.0	40.6	57.11	1.7567	--------	--------	1.7494	209.9	--------
110.0	43.3	65.82	1.8184	--------	--------	1.8111	217.3	110
115.0	46.1	76.04	1.8810	--------	--------	1.8737	224.8	--------
120.0	48.9	87.58	1.9424	--------	--------	1.9351	232.2	120

[a] Obtained from International Critical Tables, vol. 3, p. 210–12 (1926 ed.).
[b] In the first 7 entries 3.0000 was added to the logarithm for easier mathematical handling.
[c] Log milligrams per liter at 70° F = log vapor pressure minus log conversion factor.

4. Middle Disk

The middle disk is shown in figure 3. On the outer rim of the disk are located a pressure scale, an altitude scale, and two marks labeled F-12 and F-22. The pressure scale, which is marked Comparison Pressure (P_c), extends about three-quarters of the way around the disk. Intervals of this scale are proportional to the effect of a gage pressure on the fugacity [2] of water in the gas, and include corrections for the reduction of the fugacity of water vapor in the gas phase at high pressure and for the differences between gage pressure and absolute pressure. The scale was constructed by laying off angles corresponding to the logarithms of the adjusted absolute pressures, i. e., $P(1-KP+K'P^2)$ instead of P. Each point is marked with the corresponding gage pressure (absolute pressure minus 14.7 psi). Data used in the construction of the pressure scale and other details are given in table 3.

The altitude scale is used to correct the value of W_x when P_c is atmospheric pressure at a high altitude and is not directly measured. The correction is accomplished by subtracting an angle that corresponds nearly to the logarithm of the ratio of atmospheric pressure at the elevated altitude to atmospheric pressure at sea level. The construction and use of the scale will be explained more fully later.

The two marks labeled F-12 and F-22 are used in connection with moisture determinations in Freon-12 and in Freon-22. Their use is explained in section 8, dealing with conversion of units.

5. Small Disk

The small disk (fig. 4) contains two pressure scales, indentical in angular intervals with the comparison pressure scale on the middle disk. The inner, or saturation pressure (P_s), scale is adjacent to the temperature scale on the base disk. The outer, or test gas pressure (P_x), scale is arranged for convenient use in connection with the comparison pressure scale on the middle disk, but the sequence of numbers and their logarithms runs in the opposite direction. Each scale is the reciprocal of the other; that is, an angular displacement in the direction of increasing readings of one scale produces multiplication, and angular displacement in the direction of increasing numbers of the other scale results in division. The small disk also carries a scale of temperatures from −30° to −100° F marked Frost Point below −30° F. It is, in effect, an extension of the temperature scale on the base disk and is used

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[2] For the water vapor in two phases to be in equilibrium, it must have the same fugacity in each. For ideal gases fugacity is proportional to partial pressure.
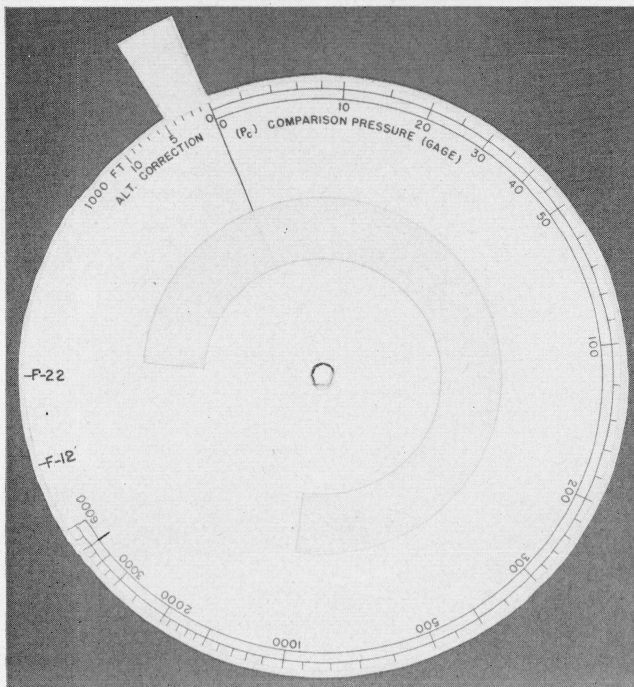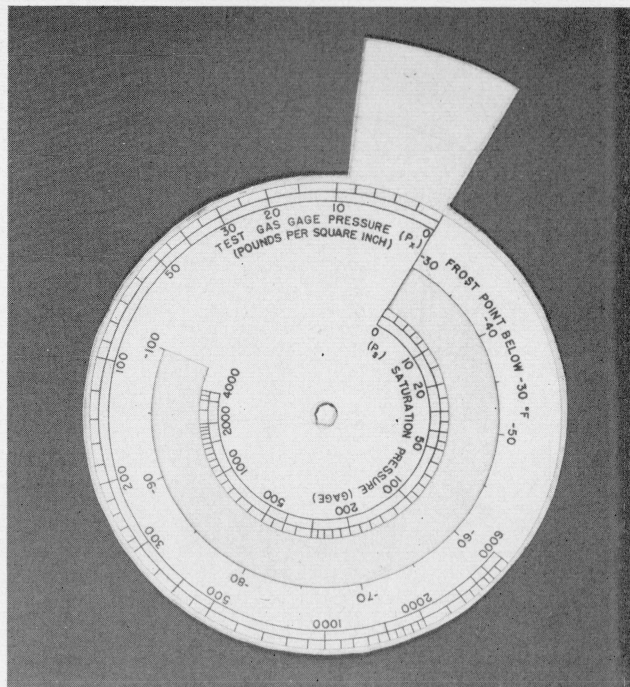
FIGURE 3.   *Middle disk.*

FIGURE 4.   *Upper (small) disk.*

by setting the temperature of interest at the -30 mark of the temperature scale and reading the -30 mark of the frost point scale. Data and other details for the three scales of the small disk are given in table 4.

6. Mathematical Operations

The actual mathematical operations involved in solving eq (1) for W_x with the computer are (a) divide W_s by P_s by subtracting the angle corresponding to the logarithm of P_s from the angle corresponding to the logarithm of W_s, (b) multiply by P_w/P_x by adding the angle corresponding to the difference between the logarithm of 14.7 (if P_w is atmospheric pressure) and the logarithm of P_x, and, (c) multiply by P_c by adding the angle corresponding to the logarithm of P_c. (All pressures involved in this operation are the adjusted pressures obtained by multiplying the absolute pressure in pounds per square inch by the factor $[1-KP+K'P^2]$.) When P_w is greater than atmospheric pressure, multiply by $P_w/14.7$ by adding the angle corresponding to the difference between the logarithms of P_w (not adjusted)[3] and 14.7.

Problem 1 will serve to illustrate the most common use of the computer.

Problem 1: A high-pressure test gas containing an unknown amount of water (W_x) is matched with a comparison gas that is saturated at a pressure of 1,000

psig [4] (P_s) and at a temperature of 60° F (T_s). Identical readings of the indicator show that the two gases have the same fugacity, that is, each is in equilibrium with the same third phase, when the test gas is at a pressure of 6,000 psig (P_x) and the gas from the saturator is at a comparison pressure of 40 psig (P_c). What is the water content (W_x) of the test gas when expanded to one atmosphere at 70° F? *Solution:* Opposite the saturation temperature (T_s) of 60° F set the saturation pressure (P_s) of 1,000 psig. Without disturbing the previous setting, set the 0 of the comparison pressure scale (P_c) opposite the test gas pressure (P_x) of 6,000 psig. Opposite the comparison pressure (P_c) of 40 psig read the water content (W_x) of 0.0058 mg/liter at 70° F. A second use of the computer is in the determination of temperatures of condensation (dewpoints or frost points), as will be illustrated by problems 2 and 3:

Problem 2: What is the frost point of the gas considered in problem 1 when (a) discharged at atmospheric pressure, (b) reduced to a pressure of 100 psig? *Solution:* (a) Bring the right-hand edge of the wide tab to the water content at atmospheric pressure and 70° F, 0.0058 mg/liter. Opposite $-30°$ on the temperature scale, read $-81°$ on the scale indicating "frost point below $-30°$ F." (b) Bring the zero of the P_c scale (the right-hand edge of the narrow tab) to 0.0058 mg/liter. Bring the right-hand edge of the wide tab to 100 psig on the P_c scale. Opposite $-30°$ of the temperature scale

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[3] Fugacity does not enter the correction of density for pressure, and the change can usually be assumed to be ideal. When dewpoints are calculated, the effect of gas pressure on fugacity must be considered, and P_w is to be "adjusted" like the other pressures [4].

[4] Psig is the abbreviation for pounds per square inch gage i. e., above barometric pressure.

TABLE 3. *Data for comparison pressure scale on middle disk*

The scale is proportional to the logarithms of the absolute pressures corrected for deviations from the ideal gas laws, but is marked with uncorrected gage pressures when the barometric pressure is 14.7 psi.

Pressure		$P^2 \times 10^{-8}$	KP $(1.9 \times 10^{-4}P)$	$(1-KP)$	$K'P^2$ $(1.4 \times 10^{-8}P^2)$	$(1-KP+K'P^2)$	Adjusted pressure	Log of adjusted pressure −1.0000	Angle	Label on scale
psig	*psia*						*psia*		°	
0	14.7	0.00000216	0.0028	0.9972	0	0.9972	14.7	0.1673	20.1	0
2	16.7	.00000279	.0032	.9968	0	.9968	16.6	.2201	26.4	--------
4	18.7	.00000350	.0036	.9964	0	.9964	18.6	.2695	32.3	--------
6	20.7	.00000428	.0039	.9961	0	.9961	20.6	.3139	37.7	--------
8	22.7	.00000515	.0043	.9957	0	.9957	22.6	.3541	42.5	--------
10	24.7	.00000610	.0047	.9953	0	.9953	24.6	.3909	46.9	10
15	29.7	.00000882	.0056	.9944	0	.9944	29.5	.4698	56.4	--------
20	34.7	.0000120	.0066	.9934	0	.9934	34.5	.5378	64.5	20
25	39.7	.0000158	.0075	.9925	0	.9925	39.4	.5955	71.5	--------
30	44.7	.0000200	.0085	.9915	0	.9915	44.3	.6464	77.6	30
35	49.7	.0000247	.0094	.9906	0	.9906	49.2	.6920	83.0	--------
40	54.7	.0000299	.0104	.9896	0	.9896	54.1	.7332	88.0	40
45	59.7	.0000356	.0113	.9887	0	.9887	59.0	.7708	92.5	--------
50	64.7	.0000419	.0123	.9877	0	.9877	63.9	.8055	96.7	50
60	74.7	.0000558	.0142	.9858	0	.9858	73.6	.8669	104.0	--------
70	84.7	.0000717	.0161	.9839	0	.9839	83.3	.9206	110.5	--------
80	94.7	.0000897	.0180	.9820	0.0001	.9821	93.0	.9685	116.2	--------
90	104.7	.000110	.0199	.9801	.0002	.9803	102.6	1.0112	121.3	--------
100	114.7	.000132	.0218	.9782	.0002	.9786	112.2	1.0500	126.0	100
120	134.7	.000181	.0256	.9744	.0002	.9746	131.2	1.1179	134.1	--------
140	154.7	.000239	.0294	.9706	.0003	.9709	150.2	1.1767	141.2	--------
160	174.7	.000305	.0332	.9668	.0004	.9672	169.0	1.2279	147.3	--------
180	194.7	.000379	.0370	.9630	.0005	.9635	187.6	1.2732	152.8	--------
200	214.7	.000461	.0408	.9592	.0006	.9598	206.1	1.3141	157.7	200
220	234.7	.000574	.0446	.9554	.0008	.9562	224.4	1.3510	162.1	--------
240	254.7	.000648	.0484	.9516	.0009	.9525	242.6	1.3849	166.2	--------
260	274.7	.000755	.0522	.9478	.0011	.9489	260.7	1.4161	169.9	--------
280	294.7	.000868	.0560	.9440	.0012	.9452	278.6	1.4450	173.4	--------
300	314.7	.000990	.0598	.9402	.0014	.9416	296.3	1.4717	176.6	300
350	364.7	.00133	.0693	.9307	.0019	.9326	340.1	1.5316	183.8	--------
400	414.7	.00172	.0788	.9212	.0024	.9236	383.0	1.5832	190.0	--------
450	464.7	.00216	.0883	.9117	.0030	.9147	425.1	1.6285	195.4	--------
500	514.7	.00265	.0978	.9022	.0037	.9059	466.4	1.6687	200.2	500
600	614.7	.00378	.1168	.8832	.0053	.8885	546.2	1.7374	208.5	--------
700	714.7	.00511	.1358	.8642	.0072	.8714	622.8	1.7944	215.3	--------
800	814.7	.00664	.1548	.8452	.0093	.8545	696.2	1.8427	221.1	--------
900	914.7	.00837	.1738	.8262	.0117	.8379	766.8	1.8847	226.2	--------
1000	1015	.01030	.1928	.8072	.0144	.8216	833.9	1.9211	230.5	1000
1100	1115	.01243	.2118	.7882	.0174	.8056	898.2	1.9534	234.4	--------
1200	1215	.01476	.2308	.7692	.0207	.7899	959.8	1.9822	237.9	--------
1300	1315	.01729	.2498	.7502	.0242	.7744	1018	2.0078	240.9	--------
1400	1415	.02002	.2688	.7312	.0280	.7592	1074	2.0310	243.7	--------
1500	1515	.02295	.2878	.7122	.0321	.7443	1128	2.0523	246.3	--------
1600	1615	.02608	.3068	.6934	.0365	.7299	1179	2.0715	248.6	--------
1700	1715	.02941	.3258	.6742	.0412	.7154	1227	2.0888	250.6	--------
1800	1815	.03294	.3448	.6552	.0461	.7013	1273	2.1048	252.6	--------
1900	1915	.03667	.3638	.6362	.0513	.6875	1317	2.1196	254.4	--------
2000	2015	.04060	.3828	.6172	.0568	.6740	1358	2.1329	255.9	2000
2500	2515	.06325	.4778	.5222	.0886	.6108	1536	2.1864	262.4	--------
3000	3015	.09090	.5728	.4272	.1273	.5545	1672	2.2232	266.8	3000
3500	3515	.1236	.6678	.3322	.1730	.5052	1776	2.2494	269.9	--------
4000	4015	.1612	.7628	.2372	.2257	.4629	1858	2.2690	272.3	--------
4500	4515	.2038	.8578	.1422	.2853	.4275	1930	2.2856	274.3	--------
5000	5015	.2515	.9528	.0472	.3521	.3993	2002	2.3015	276.2	--------
5500	5515	.3042	1.0478	−.0478	.4259	.3781	2085	2.3191	278.3	--------
6000	6015	.3618	1.1428	−.1428	.5065	.3637	2188	2.3400	280.8	6000

ᵃ 1.0000 was subtracted from the logarithm for easier mathematical handling.

read −52° on the scale indicating "frost point below −30° F."

Problem 3: Gas at a pressure of 100 psig is saturated with water vapor at 90° F. What will be its dewpoint if expanded to 4 psig? *Solution:* Set 100 psig of the saturation pressure scale opposite 90° of the Temperature scale. Opposite 4 psig on the saturation pressure Scale, read 40° F, the dewpoint of the gas at 4 psig.

In a problem like those above, the test gas can be air, oxygen, nitrogen, or even Freon-12 at a pressure nearly up to its point of liquefaction, and the comparison gas can be any of the first three gases. These four gases have negligibly different properties insofar as they affect moisture determinations. Further, the test gas can also be Freon-22, which does not behave like the others except at low pressures, provided certain restrictions are observed. For Freon-22 at pressures up to 30 psig, the computer will give moisture readings directly with negligible error. Above 30 psig, the readings become progressively erroneous with increase of pressure, but they can be corrected for any single pressure, as explained below in the section on conversion of units.

TABLE 4. *Data for scales on the small disk*

Saturation Pressure, P_s, Scale

The saturation pressure, P_s, scale is the same as the comparison pressure, P_c, scale except that it reads only to 4,000 psi, and some of the labels are omitted.
Labels: 0, 10, 20, 50, 100, 200, 500, 1000, 2000, 4000.

Test Gas Pressure, P_x, Scale

The test gas pressure, P_x, scale is the reverse of the P_c and P_s scales. The P_x scale starts at the same point as the P_s scale (20.1°) but it is laid out counterclockwise. Some labels are omitted.
Labels: 0, 10, 20, 30, 50, 100, 200, 300, 500, 1000, 2000, 6000.

Frost Point Below −30° F Scale

The scale is a continuation of the temperature scale arranged for convenient subtraction of angles from the point −30° F of that scale.

Temperature		Vapor pressure	Log vapor pressure[a]	Conversion factor	Log conversion factor	Log mg per liter[b]	Angle A	Angle B[c]	Label on scale
−°F	−°C	mm Hg					deg	deg	
30	34.5	0.1777	2.2497	1.02	0.0086	2.2411	269	21	−30
35	37.2	.1323	2.1216	------	--------	2.1130	254	36	------
40	40.0	.0966	1.9850	------	--------	1.9764	237	53	−40
45	42.8	.0682	1.8338	------	--------	1.8252	219	71	------
50	45.6	.0497	1.6964	------	--------	1.6878	202	88	−50
55	48.4	.0360	1.5563	------	--------	1.5477	186	104	------
60	51.1	.0258	1.4116	------	--------	1.4030	167	123	−60
65	53.9	.0180	1.2553	------	--------	1.2467	150	140	------
70	56.8	.0124	1.0934	------	--------	1.0848	130	160	−70
75	59.4	.0087	0.9395	------	--------	0.9309	112	178	------
80	62.2	.0059	.7708	------	--------	.7622	92	198	−80
85	65.0	.0040	.6021	------	--------	.5935	71	219	------
90	67.7	.0027	.4314	------	--------	.4228	51	239	−90
95	70.5	.0018	.2553	------	--------	.2467	30	260	------
100	73.2	.0012	.0792	------	--------	.0706	8	282	−100

a 3.000 was added to logarithm for easier mathematical handling.
b Log milligrams per liter =log vapor pressure −log conversion factor.
c The angles in this column are oriented with respect to the −30 mark on the temperature scale on the base disk. Angle B=290°−angle A.

7. Correction for Altitude (or Abnormal Barometric Pressure)

The various pressure scales involve the reduction of gage pressures to absolute pressures and are correct only when the barometric pressures is 14.7 psia, the normal pressure at sea level. When the barometer differs significantly from normal, a correct result can be obtained by adding the barometric pressure to each pressure reading, subtracting 14.7 psi, and using the corrected pressures instead of the observed ones on the computer.

As an example of this correction and at the same time of the convenient use of the outside scale as a slide rule, assume that the gage readings of problem 1 were obtained when the barometer reading was 600 mm of mercury instead of the normal 760. The instrument will first be used as a slide rule to convert the pressure in millimeters of mercury to pounds per square inch. Set an edge of one of the tabs as a marker over 760 (multiplied by any convenient power of 10) and an edge of the other disk over 600. Rotate the two disks together until the first marker reads 14.7. The second marker reads 11.6, the barometric pressure in pounds per square inch. The difference between 14.7 and 11.6 is 3.1 and is to be subtracted from each gage reading. P_s becomes 996.9 psig, P_x becomes 5,996.9 psig, and P_c becomes 36.9 psig. When these corrected pressures are used and the setting otherwise made as before, the reading obtained is 0.0053 mg/liter. In this case the correction of P_c is the only significant one; the others are outside the limit of accuracy of gages or computer.

The ordinary variations of the barometer at any one place can usually be neglected. Often the difference between the prevailing pressure at a testing station and sea level cannot. Corrections to sea-level conditions can always be made by the method described above, but this takes too much time when routine tests for compliance with a specification are being made. In the most convenient procedure for testing the dryness of compressed gases, the "comparison" gas is saturated at about 500 psig and is passed over the detector at or only slightly above atmospheric pressure to obtain P_c. The sample is then passed over the detector and its pressure, P_x, is adjusted until the galvanometer reading is the same as that of the comparison gas at P_c.

Substantially all Government and many commercial specifications limit the water content of "dry" gases to 0.02 mg (20 µg) per liter after expansion to 1 atm at 70° F. A scale, marked Alt. Correction, has been added at the lower end of the P_c scale by the use of which a gas that just meets the requirement of 0.02 mg/liter will show the same analysis under average pressures at each altitude. The scale was obtained by comparing, for various altitudes, the concentration of water corresponding to the same set of gage readings when reduced to absolute pressures and entered in the general eq (1). For example, when a gas containing 0.02 mg/liter at 1 atm and 70° F is measured by the procedure described when the barometric pressure is normal for sea level and the temperature is 70° F, the gage readings

TABLE 5. *Altitude-correction scale*

Angles are measured to left of 0 of scale.

Altitude, A	Barometric pressure[5]	Ratio of pressures	Ratio R	Log R+1	Angle	Label on scale
ft	*mm Hg*				*deg*	
0	760	1.000	1.000	------	0	0
1,000	732.9	0.964	0.966	0.985	1.8	------
2,000	706.6	.930	.933	.970	3.6	------
3,000	681.1	.896	.901	.955	5.4	------
4,000	656.3	.864	.871	.940	7.2	------
5,000	632.3	.832	.841	.925	9.0	5
6,000	609.0	.801	.811	.909	10.92	------
7,000	586.4	.771	.782	.893	12.84	------
8,000	564.4	.743	.754	.877	14.76	------
9,000	543.2	.715	.727	.862	16.56	------
10,000	522.6	.688	.701	.846	18.48	10

TABLE 6. *Corrected and uncorrected water content, W, of gases producing selected sets of gage readings at 10,000 feet and a temperature of 70° F*

Observed gage readings			Computed value of W (µg/liter)		
P_c	P_s	P_x	Uncorrected for altitude	Corrected by "Alt" scale	Corrected by equation
psig	*psig*	*psig*			
0	500	301	28.58	20.00	20.00
0	500	450	20.08	14.07	13.90
0	500	3,100	4.951	3.47	3.43
0	500	160	50.21	35.10	35.57
0	3,500	100	20.08	14.07	14.34
32.5	500	2,000	19.82	13.89	18.11
500	500	2,000	198.0	138.7	198.5

are $P_s=500$ psig, $P_x=445$ psig, $P_c=0$ psig. The normal barometric pressure at an altitude of 10,000 ft is 10.1 psig instead of the normal 14.7 psig at sea level. By substituting corrected absolute pressures for the same gage readings in eq (1), we obtain, for sea level,

$$(W_x)_0 = \frac{W_s(14.7)(14.7)}{514.7(1-515K+26523K')(459.7)(1-460K+21160K')},$$

and for 10,000 ft,

$$(W_x)_0 = \frac{W_s(10.1)(14.7)}{510.1(1-510K+26010K')(455.1)(1-455K+20703K')},$$

from which

$$\frac{(W_x)_{10000}}{(W_x)_0} = 0.701.$$

Hence, the 10,000-ft mark of the altitude correction is placed at an angle below the zero of the correction scale corresponding to the logarithm of 1/0.701. Table 5 shows the water contents corresponding to identical sets of gage pressures expressed as fractions of the water content at sea level computed in this manner. The alt. correction scale can be used with sufficient accuracy for most purposes if the comparison pressure is kept near atmospheric. However, when the comparison pressure is large, the alt. correction scale should not be used, but the gage pressures should be corrected for the abnormal barometric pressure, as described in the illustrative problem.

Table 6 shows the errors that result from failure to correct for altitude and from the use of the alt. correction scale in a number of typical cases. The last column in the table shows the correct result, computed from the basic eq (1).

8. Conversion of Units

The quantity of water in a gas is designated at various times and for several reasons by a variety of systems and units. It is often necessary or convenient to convert from one system to another.

The computer is designed to facilitate, particularly, interconversions among the following:

1. Weight of water per unit volume of gas at a standard temperature:
   a. Milligrams per liter at 70° F (almost identical with ounces per 1,000 cubic feet).
   b. Pounds per 10,000 cubic feet.
2. Weight of water per weight of gas:
   a. Parts per thousand when the gas is air.
   b. Parts per thousand when the gas is Freon-12.
   c. Parts per thousand when the gas is Freon-22.
3. Vapor pressure of water.
4. Dewpoint (frost point below 32° F).
5. Relative humidity.
6. Percentage by volume of vapor in gas.

The angular width of the large tab, on the small disk, is such that when the right edge (the 0 of the P_s and P_x scales) reads milligrams per liter, the left edge reads pounds per 10,000 cubic feet of gas on the outer scale of the base disk. The angular width is 24.7°, which is the angle corresponding to the logarithm of the factor for the conversion (see table 6).

The angular width of the narrow tab, on the middle disk, is such (9.5°) that when the right edge (the 0 of the P_c scale) reads milligrams per liter of air, the left edge reads parts per thousand parts by weight of air.

The narrow tab can also be used for reading milligrams of water per liter of gas at a definite pressure when the gas is Freon-22. The angular width of the narrow tab is such that when the right edge reads the apparent water content in milligrams per liter at a pressure of 120 psig, the left edge reads the correct water content in the same units at the same pressure in Freon-22. This is an empirical relation discovered when using the computer for determining water in the refrigerant in question. Not contemplated in the design, it is nevertheless useful when working with this particular material. For pressures up to 30 psig, as mentioned above, the computer will give directly a close approximation to the correct moisture readings for Freon-22. When the zero of the comparison pressure scale indicates

TABLE 7. *Data for tabs and for window slots*

Middle Disk

Narrow Tab:
Converts milligrams per liter to parts per thousand by weight, if the gas is air. The conversion is accomplished by dividing milligrams per liter by 1.20.

Conversion factor	1.20 (based on density)
Log Conv. factor	0.0792
Angle	9.5°
Width of tab	9.5°
Right edge	20.1°
Left edge	10.6°

Slot:

Length	280°
From	10°
To	290°

F–12 mark:
Converts milligrams per liter to parts per thousand by weight when the gas is Freon–12.

Conversion factor	197 (based on specific volume)
Log conv. factor	2.2945
Angle	275°

F–22 mark:
Converts milligrams per liter to parts per thousand by weight when the gas is Freon–22.

Conversion factor	274 (based on specific volume)
Log conv. factor	2.4378
Angle	293°

Small Disk

Wide Tab:
Converts milligrams per liter to pounds per 10,000 cubic feet, if the gas is air. The conversion is accomplished by dividing milligrams per liter by 1.6.

Conversion factor	1.60
Log conv. factor	0.2041
Angle	34.5°
Width of tab	24.5°
Right edge	20.1°
Left edge	355.6°

Slot:

Length	261.9°
From	20.1°
To	282.0°

milligrams per liter at 70° F, the 5,000 mark of the same scale (elongated to aid the memory) indicates percentage of water vapor by volume. This is another fortuitous coincidence.

The two marks labeled F-12 and F-22 are used to convert milligrams per liter to parts per thousand by weight (and parts per million, by moving the decimal point mentally) when the gas is Freon-12 or Freon-22. The angular distance between each labeled mark and the 0 mark of the comparison pressure scale corresponds to the logarithm of the factor of conversion. When the 0 mark reads milligrams per liter, the appropriate labeled mark reads parts per thousand by weight.

The vapor pressure of water in millimeters of mercury is numerically equal to 1.017 times the number of milligrams of water per liter at 70° F. The difference between this factor and unity is readable on the computer, but is so small it can be neglected in many cases, and the outer scale read directly as vapor pressure.

If the water content is less than 1 mg/liter, the dewpoint is read directly on the temperature scale under milligrams per liter on the outer scale. If the water content is more than 1 mg/liter (at about 0° F), the numbers on the outer scale must be multiplied by 1,000 to correspond to the dewpoint (frost point below 32° F) on the adjacent temperature scale. If the right edge of the wide tab, on the upper disk, is brought to the water content in milligrams per liter on the outer scale, the frost point is read on the scale marked "Frost point below −30° F" at the lowest point (−30° F) on the temperature scale. The decimal point must be watched carefully in this operation; it is not taken care of automatically. Compare with problems 2 and 3.

The relative amount of water in gases under two conditions is ascertained by finding an angle between the points representing concentrations under each condition. This angle can be set readily as that between the edges of the two protruding tabs. Then, if the middle disk is rotated, the small disk is carried along without disturbing the angle until one tab is above 1.0 of the outer scale on the base disk. The other tab then reads directly the ratio of concentration of water in the two cases. If one of the two conditions represents saturation, the ratio found is "relative humidity" as the term is ordinarily used.

Data for constructing the two tabs and the slots through which the temperature scale on the base disk is read, and for laying off the two marks labeled F-12 and F-22, are given in table 7.

9. Construction of Computer

The initial step in constructing the computer involves the making of large-sized ink drawings of each disk of the computer. These drawings are reduced photographically to the desired size, and the negatives are used to prepare stencils for use in an offset-printing press. The sections are printed on heavy white bond paper, and are permitted to dry overnight. The dry prints are cut out and trimmed with the aid of a special cutting tool similar to a beam compass, but with a sharp cutting edge instead of a drawing point. The cutouts are sandwiched

between two layers of plastic for better wearability and easy handling. The sandwiching is performed on a laminating press, which uses heat and pressure to effect the bonding. The laminated sections are cut out and trimmed with the special cutting tool. The center holes are drilled on a drill press, care being taken to center the holes accurately. The three disks are assembled and a metal rivet is used to hold them together.

10. References

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