PHYSICAL PROPERTIES OF GLYCERINE AND ITS SOLUTIONS

Physical Properties of Glycerine and Its Solutions

THE extremely wide range of uses for glycerine is due in large measure not to a single property, but to its unique combination of properties.

Nature made glycerol the most widely distributed of the polyhydric alcohols, as combined in fats and other lipids essential to life processes. Derivatives dependent on its chemical structure have now been extended to virtually every field of research and technology, from explosives to emulsifiers.

Glycerine (sometimes *glycerin*) is the term most often applied to the commercial product, which usually contains a small percentage of water. *Glycerol* (chemically, also 1,2,3-*propanetriol*) refers to the chemical compound and content in a formulation. specifically to the trihydric alcohol $C_3H_5(OH)_3$.

But over and above its chemical combinations, pure glycerine offers the formulator a liquid with a fortuitous balance of physical properties, bland, viscous, stable, hygroscopic and widely compatible. In the area of products for personal use it is clear, odorless and recognized as safe. It prevents freezing and promotes long shelf life.

This booklet highlights another distinct advantage of glycerine for the developer of new products. All its properties, even those of seemingly esoteric interest, have been spread on the record by over a century of scientific study. If there is a need to know its dielectric constant, its coefficient of expansion or the rate of sound transmission through glycerine, a handbook reference may save hours of critical measurement.

Our aim in this compilation is to present the more important of the available data on glycerine and its aqueous solutions for ready reference. Other sections dealing with chemical and biological properties are also being made available. The material here condenses and brings up to date information originally compiled by C. S. Miner and N. N. Dalton in GLYCEROL (American Chemical Society Monograph 117) 1953; published and copyrighted by Reinhold Publishing Corp. to whom we are indebted for permission to use many of the tables and charts contained herein.

Table 1. Specific Gravity and Per Cent Glycerol — by Weight

Glycerol (%)	Apparent Specific Gravity				True Specific Gravity			
	15/15°C	15.5/15.5°C	20/20°C	25/25°C	15/15°C	15.5/15.5°C	20/20°C	25/25°C
100	1.26557	1.26532	1.26362	1.26201	1.26526	1.26501	1.26331	1.26170
99	1.26300	1.26275	1.26105	1.25945	1.26270	1.26245	1.26075	1.25910
98	1.26045	1.26020	1.25845	1.25685	1.26010	1.25985	1.25815	1.25655
97	1.25785	1.25760	1.25585	1.25425	1.25755	1.25730	1.25555	1.25395
96	1.25525	1.25500	1.25330	1.25165	1.25495	1.25470	1.25300	1.25140
95	1.25270	1.25245	1.25075	1.24910	1.25240	1.25215	1.25045	1.24880
94	1.25005	1.24980	1.24810	**1.24645**	1.24975	1.24950	1.24780	1.24615
93	1.24740	1.24715	1.24545	**1.24380**	1.24710	1.24685	1.24515	1.24350
92	1.24475	1.24450	1.24280	**1.24115**	1.24445	1.24420	1.24250	1.24085
91	1.24210	1.24185	1.24020	**1.23850**	1.24185	1.24155	1.23985	1.23825
90	1.23950	1.23920	1.23755	1.23585	1.23920	1.23895	1.23725	1.23500
89	1.23680	1.23655	1.23490	1.23320	1.23655	1.23625	1.23460	1.23295
88	1.23415	1.23390	1.23220	1.23055	1.23390	1.23360	1.23195	1.23025
87	1.23150	1.23120	1.22955	1.22790	1.23125	1.23095	1.22930	1.22760
86	1.22885	1.22855	1.22690	1.22520	1.22860	1.22830	1.22660	1.22495
85	1.22620	1.22590	1.22420	1.22255	1.22595	1.22565	1.22395	1.22230
84	1.22355	1.22325	1.22155	1.21990	1.22330	1.22300	1.22130	1.21965
83	1.22090	1.22055	1.21890	1.21720	1.22060	1.22030	1.21865	1.21695
82	1.21820	1.21790	1.21620	1.21455	1.21795	1.21765	1.21595	1.21430
81	1.21555	1.21525	1.21355	1.21190	1.21530	1.21500	1.21330	1.21165
80	1.21290	1.21260	1.21090	1.20925	1.21265	1.21235	1.21065	1.20900
79	1.21015	1.20985	1.20815	1.20655				
78	1.20740	1.20710	1.20540	1.20380				
77	1.20465	1.20440	1.20270	1.20110				
76	1.20190	1.20165	1.19995	1.19840				
75	1.19915	1.19890	1.19720	1.19565	1.19890	1.19865	1.19700	1.19540
74	1.19640	1.19615	1.19450	1.19295				
73	1.19365	1.19340	1.19175	1.19025				
72	1.19090	1.19070	1.18900	1.18755				
71	1.18815	1.18795	1.18630	1.18480				
70	1.18540	1.18520	1.18355	1.18210	1.18515	1.18495	1.18330	1.18185
69	1.18260	1.18240	1.18080	1.17935				
68	1.17985	1.17965	1.17805	1.17660				
67	1.17705	1.17685	1.17530	1.17385				
66	1.17430	1.17410	1.17255	1.17110				
65	1.17155	1.17130	1.16980	1.16835	1.17135	1.17110	1.16960	1.16815
64	1.16875	1.16855	1.16705	1.16560				
63	1.16600	1.16575	1.16430	1.16285				
62	1.16320	1.16300	1.16155	1.16010				
61	1.16045	1.16020	1.15875	1.15735				
60	1.15770	1.15745	1.15605	1.15460	1.15750	1.15725	1.15585	1.15445
59	1.15490	1.15465	1.15325	1.15185				
58	1.15210	1.15190	1.15050	1.14915				
57	1.14935	1.14910	1.14775	1.14640				
56	1.14655	1.14635	1.14500	1.14365				
55	1.14375	1.14355	1.14220	1.14090	1.14360	1.14340	1.14205	1.14075
54	1.14100	1.14080	1.13945	1.13815				
53	1.13820	1.13800	1.13670	1.13540				
52	1.13540	1.13525	1.13395	1.13265				
51	1.13265	1.13245	1.13120	1.12995				

Glycerol (%)	Apparent Specific Gravity				True Specific Gravity			
	15/15°C	15.5/15.5°C	20/20°C	25/25°C	15/15°C	15.5/15.5°C	20/20°C	25/25°C
50	1.12985	1.12970	1.12845	1.12720	1.12970	1.12955	1.12830	1.12705
49	1.12710	1.12695	1.12570	1.12450				
48	1.12440	1.12425	1.12300	1.12185				
47	1.12165	1.12150	1.12030	1.11915				
46	1.11890	1.11880	1.11760	1.11650				
45	1.11620	1.11605	1.11490	1.11380	1.11605	1.11595	1.11475	1.11365
44	1.11345	1.11335	1.11220	1.11115				
43	1.11075	1.11060	1.10950	1.10845				
42	1.10800	1.10790	1.10680	1.10575				
41	1.10525	1.10515	1.10410	1.10310				
40	1.10255	1.10245	1.10135	1.10040	1.10240	1.10235	1.10125	1.10030
39	1.09985	1.09975	1.09870	1.09775				
38	1.09715	1.09705	1.09605	1.09510				
37	1.09445	1.09435	1.09335	1.09245				
36	1.09175	1.09165	1.09070	1.08980				
35	1.08905	1.08895	1.08805	1.08715	1.08895	1.08885	1.08790	1.08705
34	1.08635	1.08625	1.08535	1.08455				
33	1.08365	1.08355	1.08270	1.08190				
32	1.08100	1.08085	1.08005	1.07925				
31	1.07830	1.07815	1.07735	1.07660				
30	1.07560	1.07545	1.07470	1.07395	1.07550	1.07535	1.07460	1.07385
29	1.07295	1.07285	1.07210	1.07135				
28	1.07035	1.07025	1.06950	1.06880				
27	1.06770	1.06760	1.06690	1.06625				
26	1.06510	1.06500	1.06435	1.06370				
25	1.06250	1.06240	1.06175	1.06115	1.06240	1.06230	1.06165	1.06110
24	1.05985	1.05980	1.05915	1.05860				
23	1.05725	1.05715	1.05655	1.05605				
22	1.05460	1.05455	1.05400	1.05350				
21	1.05200	1.05195	1.05140	1.05095				
20	1.04935	1.04935	1.04880	1.04840	1.04930	1.04925	1.04875	1.04830
19	1.04685	1.04680	1.04630	1.04590				
18	1.04435	1.04430	1.04380	1.04345				
17	1.04180	1.04180	1.04135	1.04100				
16	1.03930	1.03925	1.03885	1.03850				
15	1.03675	1.03675	1.03635	1.03605	1.03670	1.03670	1.03630	1.03600
14	1.03425	1.03420	1.03390	1.03360				
13	1.03175	1.03170	1.03140	1.03110				
12	1.02920	1.02920	1.02890	1.02865				
11	1.02670	1.02665	1.02640	1.02620				
10	1.02415	1.02415	1.02395	1.02370	1.02415	1.02410	1.02390	1.02370
9	1.02175	1.02175	1.02155	1.02135				
8	1.01935	1.01930	1.01915	1.01900				
7	1.01690	1.01690	1.01675	1.01660				
6	1.01450	1.01450	1.01435	1.01425				
5	1.01210	1.01205	1.01195	1.01185	1.01205	1.01205	1.01195	1.01185
4	1.00965	1.00965	1.00955	1.00950				
3	1.00725	1.00725	1.00720	1.00710				
2	1.00485	1.00485	1.00480	1.00475				
1	1.00240	1.00240	1.00240	1.00235				

Table 2. Specific Gravity of Aqueous Glycerine Solutions with Glycerol Concentrations between 95-100%

S. G.	0	1	2	3	4	5	6	7	8	9
1.252	94.72	94.76	94.80	94.84	94.88	94.92	94.96	95.00	95.03	95.07
1.253	95.11	95.15	95.19	95.22	95.26	95.30	95.34	95.38	95.42	95.46
1.254	95.49	95.53	95.57	95.61	95.65	95.69	95.73	95.77	95.80	95.84
1.255	95.88	95.92	95.96	96.00	96.04	96.08	96.11	96.15	96.19	96.23
1.256	96.27	96.31	96.35	96.39	96.42	96.46	96.50	96.54	96.58	96.62
1.257	96.66	96.69	96.73	96.77	96.81	96.85	96.89	96.93	96.97	97.00
1.258	97.04	97.08	97.12	97.16	97.20	97.24	97.28	97.32	97.36	97.40
1.259	97.44	97.48	97.52	97.56	97.60	97.64	97.68	97.72	97.76	97.80
1.260	97.84	97.88	97.92	97.96	98.00	98.04	98.07	98.10	98.14	98.18
1.261	98.22	98.26	98.30	98.34	98.38	98.41	98.45	98.49	98.53	98.57
1.262	98.61	98.65	98.69	98.72	98.76	98.80	98.84	98.88	98.92	98.96
1.263	99.00	99.03	99.07	99.11	99.15	99.19	99.23	99.27	99.31	99.34
1.264	99.38	99.42	99.46	99.50	99.54	99.58	99.61	99.65	99.69	99.73
1.265	99.77	99.81	99.85	99.89	99.93	99.96	100.00			

Table 3. Density & Percent of Glycerol

Glycerol (%)	Density at					Glycerol (%)	Density at				
	15°C	15.5°C	20°C	25°C	30°C		15°C	15.5°C	20°C	25°C	30°C
100	1.26415	1.26381	1.26108	1.25802	1.25495	50	1.12870	1.12845	1.12630	1.12375	1.12110
99	1.26160	1.26125	1.25850	1.25545	1.25235	49	1.12600	1.12575	1.12360	1.12110	1.11845
98	1.25900	1.25865	1.25590	1.25290	1.24975	48	1.12325	1.12305	1.12090	1.11840	1.11580
97	1.25645	1.25610	1.25335	1.25030	1.24710	47	1.12055	1.12030	1.11820	1.11575	1.11320
96	1.25385	1.25350	1.25080	1.24770	1.24450	46	1.11780	1.11760	1.11550	1.11310	1.11055
95	1.25130	1.25095	1.24825	1.24515	1.24190	45	1.11510	1.11490	1.11280	1.11040	1.10795
94	1.24865	1.24830	1.24560	1.24250	1.23930	44	1.11235	1.11215	1.11010	1.10775	1.10530
93	1.24600	1.24565	1.24300	1.23985	1.23670	43	1.10960	1.10945	1.10740	1.10510	1.10265
92	1.24340	1.24305	1.24035	1.23725	1.23410	42	1.10690	1.10670	1.10470	1.10240	1.10005
91	1.24075	1.24040	1.23770	1.23460	1.23150	41	1.10415	1.10400	1.10200	1.09975	1.09740
90	1.23810	1.23775	1.23510	1.23200	1.22890	40	1.10145	1.10130	1.09930	1.09710	1.09475
89	1.23545	1.23510	1.23245	1.22935	1.22625	39	1.09875	1.09860	1.09665	1.09445	1.09215
88	1.23280	1.23245	1.22975	1.22665	1.22360	38	1.09605	1.09590	1.09400	1.09180	1.08955
87	1.23015	1.22980	1.22710	1.22400	1.22095	37	1.09340	1.09320	1.09135	1.08915	1.08690
86	1.22750	1.22710	1.22445	1.22135	1.21830	36	1.09070	1.09050	1.08865	1.08655	1.08430
85	1.22485	1.22445	1.22180	1.21870	1.21565	35	1.08800	1.08780	1.08600	1.08390	1.08165
84	1.22220	1.22180	1.21915	1.21605	1.21300	34	1.08530	1.08515	1.08335	1.08125	1.07905
83	1.21955	1.21915	1.21650	1.21340	1.21035	33	1.08265	1.08245	1.08070	1.07860	1.07645
82	1.21690	1.21650	1.21380	1.21075	1.20770	32	1.07995	1.07975	1.07800	1.07600	1.07380
81	1.21425	1.21385	1.21115	1.20810	1.20505	31	1.07725	1.07705	1.07535	1.07335	1.07120
80	1.21160	1.21120	1.20850	1.20545	1.20240	30	1.07455	1.07435	1.07270	1.07070	1.06855
79	1.20885	1.20845	1.20575	1.20275	1.19970	29	1.07195	1.07175	1.07010	1.06815	1.06605
78	1.20610	1.20570	1.20305	1.20005	1.19705	28	1.06935	1.06915	1.06755	1.06560	1.06355
77	1.20335	1.20300	1.20030	1.19735	1.19435	27	1.06670	1.06655	1.06495	1.06305	1.06105
76	1.20060	1.20025	1.19760	1.19465	1.19170	26	1.06410	1.06390	1.06240	1.06055	1.05855
75	1.19785	1.19750	1.19485	1.19195	1.18900	25	1.06150	1.06130	1.05980	1.05800	1.05605
74	1.19510	1.19480	1.19215	1.18925	1.18635	24	1.05885	1.05870	1.05720	1.05545	1.05350
73	1.19235	1.19205	1.18940	1.18650	1.18365	23	1.05625	1.05610	1.05465	1.05290	1.05100
72	1.18965	1.18930	1.18670	1.18380	1.18100	22	1.05365	1.05350	1.05205	1.05035	1.04850
71	1.18690	1.18655	1.18395	1.18110	1.17830	21	1.05100	1.05090	1.04950	1.04780	1.04600
70	1.18415	1.18385	1.18125	1.17840	1.17565	20	1.04840	1.04825	1.04690	1.04525	1.04350
69	1.18135	1.18105	1.17850	1.17565	1.17290	19	1.04590	1.04575	1.04440	1.04280	1.04105
68	1.17860	1.17830	1.17575	1.17295	1.17020	18	1.04335	1.04325	1.04195	1.04035	1.03860
67	1.17585	1.17555	1.17300	1.17020	1.16745	17	1.04085	1.04075	1.03945	1.03790	1.03615
66	1.17305	1.17275	1.17025	1.16745	1.16470	16	1.03835	1.03825	1.03695	1.03545	1.03370
65	1.17030	1.17000	1.16750	1.16475	1.16195	15	1.03580	1.03570	1.03450	1.03300	1.03130
64	1.16755	1.16725	1.16475	1.16200	1.15925	14	1.03330	1.03320	1.03200	1.03055	1.02885
63	1.16480	1.16445	1.16205	1.15925	1.15650	13	1.03080	1.03070	1.02955	1.02805	1.02640
62	1.16200	1.16170	1.15930	1.15655	1.15375	12	1.02830	1.02820	1.02705	1.02560	1.02395
61	1.15925	1.15895	1.15655	1.15380	1.15100	11	1.02575	1.02565	1.02455	1.02315	1.02150
60	1.15650	1.15615	1.15380	1.15105	1.14830	10	1.02325	1.02315	1.02210	1.02070	1.01905
59	1.15370	1.15340	1.15105	1.14835	1.14555	9	1.02085	1.02075	1.01970	1.01835	1.01670
58	1.15095	1.15065	1.14830	1.14560	1.14285	8	1.01840	1.01835	1.01730	1.01600	1.01440
57	1.14815	1.14785	1.14555	1.14285	1.14010	7	1.01600	1.01590	1.01495	1.01360	1.01205
56	1.14535	1.14510	1.14280	1.14015	1.13740	6	1.01360	1.01350	1.01255	1.01125	1.00970
55	1.14260	1.14230	1.14005	1.13740	1.13470	5	1.01120	1.01110	1.01015	1.00890	1.00735
54	1.13980	1.13955	1.13730	1.13465	1.13195	4	1.00875	1.00870	1.00780	1.00655	1.00505
53	1.13705	1.13680	1.13455	1.13195	1.12925	3	1.00635	1.00630	1.00540	1.00415	1.00270
52	1.13425	1.13400	1.13180	1.12920	1.12650	2	1.00395	1.00385	1.00300	1.00180	1.00035
51	1.13150	1.13125	1.12905	1.12650	1.12380	1	1.00155	1.00145	1.00060	0.99945	0.99800
						0	0.99913	0.99905	0.99823	0.99708	0.99568

Specific Gravity:

Measurement of specific gravity is the principal means of determining the glycerol content of distilled glycerine. Specific gravity is best determined with a pycnometer[1]. A Westphal balance or a hydrometer is less satisfactory because of the viscosity of concentrated glycerine.

Many determinations of the specific gravity of glycerol and its water solutions have been published[2]. Some of these are of questionable accuracy because the glycerol then available contained impurities such as polyglycerol or trimethylene glycol.

In 1927, Bosart and Snoddy[3] published their determination of the specific gravity of glycerol solutions, as measured under carefully controlled conditions at 15/15, 15.5/15.5, 20/20 and 25/25 $\pm$ 0.1° C. These figures for apparent specific gravity, and the calculated figures for true specific gravities (in vacuum) are given in Table 1. They have been widely used in the industry.

Another set of specific gravity determinations which has been employed in the industry are those determined by Timmermans[4] which show slight differences in the fourth and fifth decimal places. For 100% concentration at 15/4° C., the following true specific gravities were found:

Bosart & Snoddy 1.26415
Timmermans 1.26443

Table 2 has been calculated from Timmermans results, corrected to apparent specific gravity at 60/60° F. = 1.26560. It shows concentrations corresponding to tabulated values of specific gravity at 60° F.

Density:

The density of glycerol solutions at various concentrations and temperatures was calculated from their specific gravity data by Bosart and Snoddy[5], and are shown in Table 3. In a subsequent discussion[1] of these density values versus those appearing in the International Critical Tables[6], it is suggested that the latter are unsatisfactory where accuracy in the fourth decimal place is necessary, particularly at or above 20° C.

A practical table of glycerol-water densities covering a wider temperature range, has been compiled from six different sources and is shown in Table 4[7].

The densities of glycerol solutions at temperatures below 0° C. were determined by Green and Park[8] and are shown in Table 5. Changes in density of glycerol when subjected to high pressures are shown in Table 36.

Densities of mixtures of glycerol with methanol and water; with ethanol and water, and with ethylene glycol and water have been determined are available in GLYCEROL by Miner and Dalton[1].

Table 4. Density of Glycerol-Water Solutions

%w Glycerine	Density, grams/ml (in vacuo)									
Temp, °C:	90	80	70	60	50	40	30	20	10	0
0	1.24683	1.21962	1.19200	1.16349	1.13486	1.10667	1.07892	1.05161	1.02517	0.99987
10	1.24124	1.21440	1.18701	1.15909	1.13101	1.10336	1.07623	1.04951	1.02414	0.99973
20	1.23510	1.20850	1.18125	1.15380	1.12630	1.09930	1.07270	1.04690	1.02210	0.99823
30	1.22865	1.20231	1.17519	1.14822	1.12096	1.09452	1.06856	1.04347	1.01916	0.99567
40	1.22214	1.19606	1.16920	1.14247	1.11534	1.08924	1.06371	1.03945	1.01552	0.99224
50	1.2158	1.18999	1.16338	1.13655	1.10945	1.00380	1.05849	1.03505	1.01131	0.98807
60	1.20922	1.18352	1.15683	1.13015	1.1034	1.07800	1.05291	1.02958	1.00625	0.98324
70	1.20269	1.17679	1.15036	1.12382	1.09723	1.07184	1.04729	1.02386	1.00065	0.97781
80	1.19611	1.16990	1.14384	11.1745	1.09079	1.06564	1.04093	1.01752	0.99463	0.97183
90	1.18961	1.16332	1.13730	1.11094	1.08423	1.05901	1.0343	1.01097	0.98840	0.96534
100	1.18273	1.15604	1.3018	1.10388	1.07733	1.05217	1.02735	1.00392	0.98187	0.95838
dens. at bp	1.15479	1.14004	1.12030	1.09763	1.07295	1.04947	1.02539	1.00277	0.98121	0.95838
bp	138	121	113.3	109	106	104	102.8	101.8	100.9	100

100% GLYCEROL

Temp, °C	Density, grams/ml	Temp, °C	Density, grams/ml	Temp, °C	Density, grams/ml
0	1.27269	75.5	1.2256	180	1.14864
10	1.26699	99.5	1.2097	200	1.13178
15	1.26443	110	1.20178	220	1.11493
20	1.26134	120	1.19446	240	1.09857
30	1.25512	130	1.18721	260	1.08268
40	1.24896	140	1.17951	280	1.06725
54	1.2397	160	1.16440	290	1.05969

Table 5. Density and Per Cent of Glycerol at Low Temperatures

Glycerol (%)	F.p. (°C)	Temperature				
		−5°	−10°	−20°	−30°	−40°
10	−1.6	—	—	—	—	
20	−4.8	—	—	—	—	—
30	−9.5	1.0810		—	—	—
40	−15.4	1.1096	1.1109	—	—	—
50	−23.0	1.1387	1.1407	1.1450		
60	−34.7	1.1663	1.1685	1.1732	1.1787	—
66.7	−46.5	1.1860	1.1889	1.1945	1.1985	1.2034
70	−38.5	1.1954	1.1993	1.2038	1.2079	—
80	−20.3	1.2210	1.2255	1.2305	—	—
90	−1.6	—	—	—	—	—

Contraction by Solution:

When water and glycerol are mixed, there is a slight rise in temperature as well as contraction in volume. This contraction was measured by Gerlach and is shown in Table 7 and in Figure B.

Fig. A. Aqueous Density of Glycerine from 0°C to 130°C.*

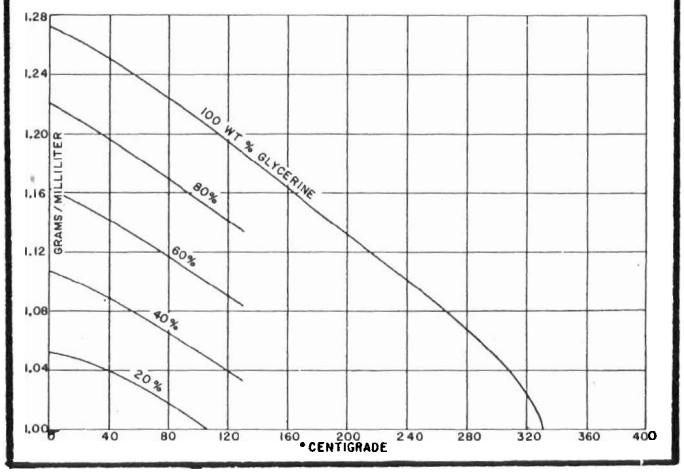


Table 6. Comparison of Composition of Glycerol Solutions by Weight and by Volume

% by Wt of Pure Glycerol	Equivalent % by Wt of Aqueous Glycerol of Given Concentration				Equivalent % by Vol of Aqueous Glycerol of Given Concentration				
	99% by Wt	95% by Wt	75% by Wt	60% by Wt	100% by Wt	99% by Wt	95% by Wt	75% by Wt	60% by Wt
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00	5.05	5.26	6.67	8.33	4.00	4.05	4.25	5.63	7.28
10.00	10.10	10.53	13.33	16.67	8.10	8.19	8.61	11.38	14.74
15.00	15.15	15.79	20.00	25.00	12.29	12.40	13.07	17.29	22.38
20.00	20.20	21.05	26.67	33.33	16.58	16.78	17.63	23.34	30.21
25.00	25.25	26.31	33.33	41.67	20.98	21.24	22.31	29.53	38.23
30.00	30.30	31.58	40.00	50.00	25.49	25.80	27.10	35.88	46.45
35.00	35.35	36.84	46.67	58.33	30.11	30.48	32.02	42.38	54.87
40.00	40.40	42.10	53.33	66.67	34.84	35.26	37.04	49.03	63.49
45.00	45.45	47.36	60.00	75.00	39.67	40.16	42.18	55.85	72.31
50.00	50.50	52.63	66.67	83.33	44.63	45.17	47.45	62.81	81.32
55.00	55.55	57.89	73.33	91.67	49.68	50.30	52.83	69.94	90.56
60.00	60.60	63.16	80.00	100.00	54.86	55.54	58.34	77.23	100.00
65.00	65.65	68.42	86.67		60.16	60.89	63.97	84.67	
66.67	67.34	70.21	88.89		61.95	62.71	65.88	87.18	
70.00	70.70	73.68	93.33		65.56	66.35	69.71	92.25	
75.00	75.75	78.95	100.00		71.07	71.92	75.57	100.00	
80.00	80.80	84.21			76.69	77.59	81.55		
85.00	85.85	89.47			82.39	83.34	87.61		
90.00	90.90	94.74			88.20	89.20	93.78		
95.00	95.95	100.00			94.05	95.16	100.00		
98.00	98.98				97.60	98.78			
99.00	100.00				98.81	100.00			
100.00					100.00				

"By Weight" vs. "By Volume":

Correlation of the composition of glycerol solutions to achieve a definite percentage by weight of pure glycerol has been calculated and is given in Table 6.

The dilution of glycerol to a specific concentration from a solution of a given percentage (by weight or by volume) can be calculated from the following formula[9]:

$$x = 100(a - b)/b \quad (1)$$

$$y = 100[(a - b)/b]\, D_t^t \quad (2)$$

$$K = 100 - [V(D_t^t - 1) + 100\, d_t^t] \quad (3)$$

in which

x = parts by wt. of water to be added to 100 parts of glycerol

y = parts by vol. of water to be added to 100 vol. of glycerol

K = % contraction based on the final volume

a = % (wt. or vol.) of glycerol in the original material

b = % (wt. or vol.) of glycerol in the desired concentration

D_t^t = density of the original material

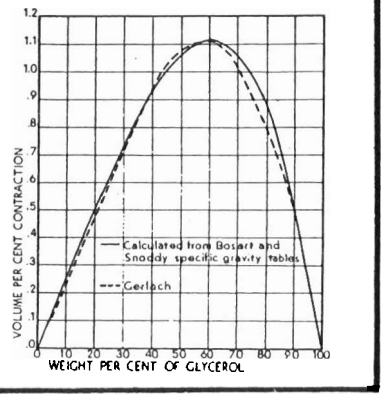
d_t^t = density of the desired concentration

V = vol. of the original material

Table 7. Volumetric Contraction of Glycerol and Water when Mixed at 20°C (Gerlach)

100 Parts by wt of solution contains		Average hypothetical vol of solution $\frac{A}{1.262} + B$	Actual vol of solution $\frac{100}{\text{Sp. gr.}}$	$\frac{D \times 100}{C}$	100 − E
Glycerol	Water				
A	B	C	D	E	F
100	0	79.240	79.240	100	0.
90	10	81.315	80.906	99.497	0.503
80	20	83.392	82.713	99.186	0.814
70	30	85.468	84.603	98.987	1.013
60	40	87.544	86.580	98.899	1.101
50	50	89.620	88.652	98.920	1.080
40	60	91.696	90.826	99.052	0.948
30	70	93.772	93.110	99.294	0.705
20	80	95.885	95.420	99.515	0.485
10	90	97.924	97.704	99.775	0.225
0	100	100.	100.	100.	0.

Fig. B. Contraction of Glycerol & Water when mixed



Boiling Point:

The boiling point of pure glycerol at atmospheric pressure (760 mm) is 290° C., based on determinations by a number of investigators[12]. Gerlach's values for the boiling point of glycerol solutions (along with related constants) are shown in Table 9.

Boiling points under reduced pressures were calculated by von Rechenberg[13] and are shown in Table 8. A more detailed calculation of the increase in boiling point of glycerol-water solutions, including such solutions saturated with salt, at reduced pressures, has been drawn up[14]. It was found that Duhrings rule applies to these solutions, enabling boiling points to be calculated from the equation:

$$\frac{T_1}{t_1} - \frac{T_2}{t_2} = K$$

Where T_1 is the boiling point of a given substance at pressure P_1; T_2 is its boiling point at another pressure P_2 and t_1 and t_2 are boiling points of a second similar liquid at the same pressures. K is a constant. The boiling points of glycerol-water solutions as calculated by this rule are given in Table 10.

Table 8.
Boiling Points of Pure Glycerol at Various Pressures

mm Hg	°C	mm Hg	°C
800	292.01	60	208.40
760	290.00	50	203.62
700	286.79	40	197.96
600	280.91	30	190.87
500	274.23	20	181.34
400	266.20	15	174.86
300	256.32	10	166.11
200	243.16	8	161.49
100	222.41	6	155.69
90	219.44	5	152.03
80	216.17	4	147.87
70	212.52		

Table 9. Some Physical Properties of Glycerol Solutions

Parts by Wt of Glycerol in 100 Parts of Solution	Parts by Wt of Glycerol with 100 Parts of Water	Specific Wt of Glycerol Solution		B.p. at 760 mm (°C)	Vapor Pressure of Glycerol Solution at 100°C (mm)
		at 15°C, Water at 15°C = 1	at 20°C, Water at 20°C = 1		
100	Glycerol	1.2653	1.2620	290	64
99	9900	1.2628	1.2594	239	87
98	4900	1.2602	1.2568	208	107
97	3233.333	1.2577	1.2542	188	126
96	2400	1.2552	1.2516	175	144
95	1900	1.2526	1.2490	164	162
94	1566.666	1.2501	1.2464	156	180
93	1328.571	1.2476	1.2438	150	198
92	1150	1.2451	1.2412	145	215
91	1011.111	1.2425	1.2386	141	231
90	900	1.2400	1.2360	138	247
89	809.090	1.2373	1.2333	135	263
88	733.333	1.2346	1.2306	132.5	279
87	669.231	1.2319	1.2279	130.5	295
86	614.286	1.2292	1.2252	129	311
85	566.666	1.2265	1.2225	127.5	326
84	525	1.2238	1.2198	126	340
83	488.235	1.2211	1.2171	124.5	355
82	455.555	1.2184	1.2144	123	370
81	426.316	1.2157	1.2117	122	384
80	400	1.2130	1.2090	121	396
79	376.190	1.2102	1.2063	120	408
78	354.500	1.2074	1.2036	119	419
77	334.782	1.2046	1.2009	118.2	430
76	316.666	1.2018	1.1982	117.4	440
75	300	1.1990	1.1955	116.7	450
74	284.615	1.1962	1.1928	116	460
73	270.370	1.1934	1.1901	115.4	470
72	257.143	1.1906	1.1874	114.8	480
71	244.828	1.1878	1.1847	114.2	489
70	233.333	1.1850	1.1820	113.6	496
65	185.714	1.1710	1.1685	111.3	553
60	150	1.1570	1.1550	109	565
55	122.222	1.1430	1.1415	107.5	593
50	100	1.1290	1.1280	106	618
45	81.818	1.1155	1.1145	105	639
40	66.666	1.1020	1.1010	104	657
35	53.846	1.0885	1.0875	103.4	675
30	42.857	1.0750	1.0740	102.8	690
25	33.333	1.0620	1.0610	102.3	704
20	25	1.0490	1.0480	101.8	717
10	11.111	1.0245	1.0235	100.9	740
0	0	1.0000	1.0000	100	760

Table 10. Boiling Points of Glycerol-Water Solutions (Calculated from Dühring Lines)

Pressure (Mm)	Boiling point of water (°C)	(Boiling Points °C)									
		Water (%) 90 Glycerol (%) 10	80 20	70 30	60 40	50 50	40 60	30 70	20 80	10 90	4.36 95.64
760.00	100	100.7	101.6	102.9	104.5	106.7	109.6	114.0	121.5	139.8	175.8
525.80	90	90.6	91.5	92.8	94.2	96.3	99.3	103.5	110.3	127.8	161.1
355.10	80	80.5	81.4	82.6	84.0	86.0	88.8	92.8	99.3	116.0	146.5
233.53	70	70.4	71.2	72.4	73.7	75.6	78.5	82.2	88.3	104.0	132.1
149.19	60	60.3	61.0	62.2	63.5	65.5	68.1	71.5	77.3	92.0	117.6
92.30	50	50.2	50.9	52.1	53.4	55.2	57.6	61.0	66.2	80.1	103.1

Vapor Pressure:

Glycerol has a lower vapor pressure than would be expected from its molecular weight, as a result of the molecular association characteristic of alcohols. Many of the important uses of glycerine are dependent on its relative non-volatibility. Consequently, there have been a number of determinations of its vapor pressure and its partial pressure in glycerol solutions.

The vapor pressure of 100% glycerol is below 0.001 (mm. Hg.) at room temperature, and below 0.2 mm. at 100° C. Figure C gives these vapor pressures at the lower range of temperatures. Early determinations made by Gerlach[11] are apparently in error for anhydrous glycerol. Vapor pressures of pure glycerol calculated by extrapolating from partial pressures of solutions to the point where the partial pressure equals the total pressure are estimated to be accurate to about 1%[16]. They are shown in Table 11 (page 8). Another set of determinations (250° F. to 572° F.) is plotted in Figure D.

More interest has centered on the vapor pressure of aqueous solutions of glycerine. Glycerol causes a greater reduction in the vapor pressure of the water than can be accounted for by its molar concentration, due to the formation of hydrates. This effect was measured at 70° C. by Perman and Price[17] and expressed in terms of apparent molecular weight: i.e., a 45% glycerine solution has a "vapor pressure-lowering" effect on water equivalent to a compound having an 86.9 molecular weight. Table 12 (page 8) gives the effect at other concentrations.

Vapor pressures for aqueous glycerol solutions can be calculated according to Duhrings rule. This rule states that if a solution and water have the same vapor pressure, p_1, at the temperatures t_1 and t_2, respectively and have vapor pressure, p_2, at the temperatures t_3 and t_4 respectively, then:

$$(t_1 - t_3) / (t_2 - t_4) = K.$$

Values of K (Duhrings constant) have been calculated for several glycerol concentrations and the relative vapor pressures are given in Table 14. Measurements made by a manometer technique by Campbell[18] give comparable values at 70° C. Table 13.

The vapor pressure of water over glycerine solutions of various concentrations may be read from the nomograph shown in Figure E.

A liquid evaporates into a vacuum at a rate equal to that predicted by kinetic theory multiplied by x — called the evaporation coefficient. A new technique has been developed to measure x and with pure glycerol it was found to be equal to 0.05[20].

Fig. C. Vapor Pressure of Glycerine (60°F to 250°C)

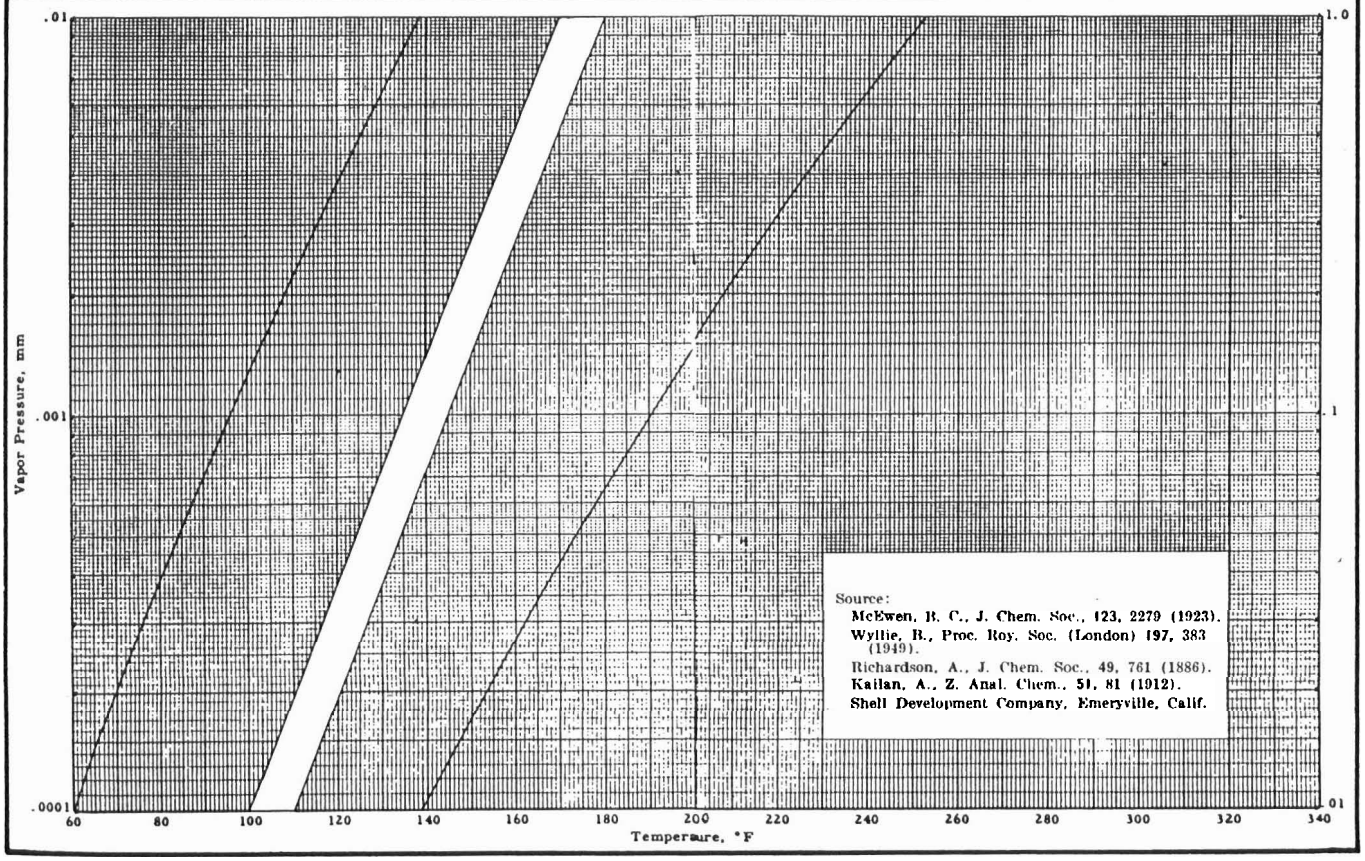


Table 11. Vapor Pressure of Pure Glycerol

Temp. (°C).....	200	190	180	170	160	150	140	130	120	110
V. p. (mm Hg)..	46.0	30.3	19.3	12.1	7.4	4.30	2.43	1.35	0.74	0.385
Temp. (°C).....	100	90	80	70	60	50				
V. p. (mm Hg)..	0.195	0.093	0.041	0.017	0.0067	0.0025				

Table 12. Vapor Pressure of Glycerol-Water Solutions at 70°C and Apparent Molecular Weight of the Glycerol

Moles Glycerol / Moles Water	% Wt. of Glycerol	Apparent Mol. Wt.	Vapor Pressure mm Hg
0.0259	11.69	189.6	230.9
0.0266	11.97	126.3	229.3
0.0540	21.63	96.4	222.3
0.1602	45.02	86.9	199.9
0.3079	61.15	81.4	173.4
0.6694	77.38	74.7	128.1
1.4390	88.03	71.0	79.8

Table 13. Vapor Pressure of Water in Contact with Glycerol at 70°C

% Wt Water	Mole Fraction	Observed Pressure (mm)	Ratio. Observed Pressure to Pressure of Pure Water
12.10	0.410	79.8	0.341
25.11	0.599	128.1	0.548
38.75	0.764	173.4	0.741
54.97	0.862	199.9	0.855
88.00	0.974	229.3	0.980
89.26	0.977	230.9	0.987
100.00	1.000	233.8	1.000

Fig. E. Vapor Pressure of Water over Glycerol Solutions

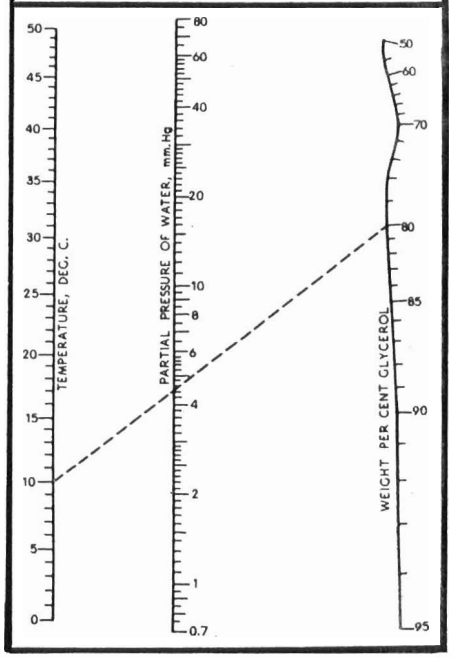


Fig. D Vapor Pressure of Glycerine (252°F to 572°F)

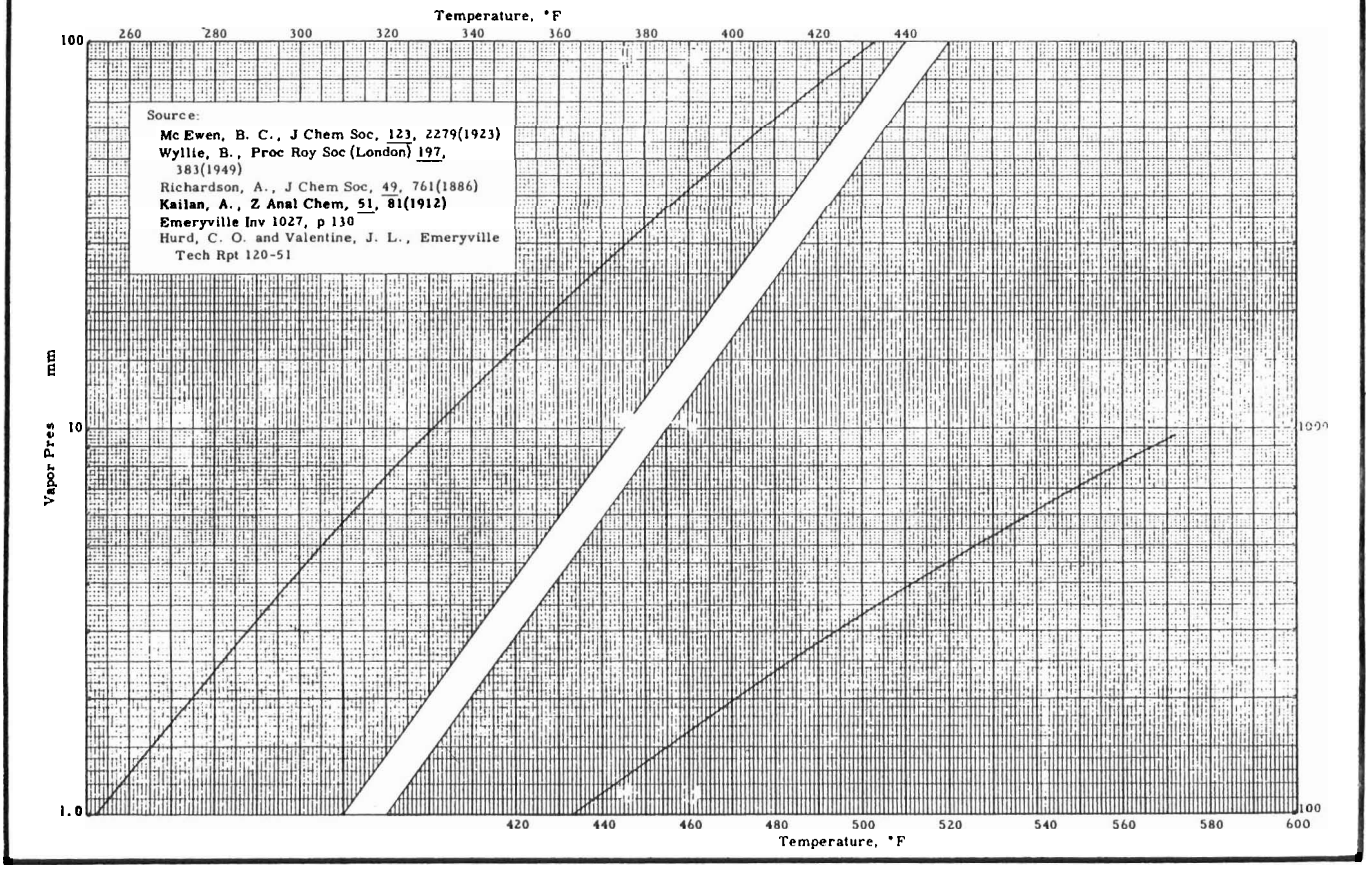


Table 14. Dühring's Constants and Calculated Relative Vapor Pressure* of Glycerol Solutions from 0 to 70°C

Glycerol (%)	Dühring's constant	Relative vapor pressure			
		(0°)	(20°)	(40°)	(70°)
90	1.194	0.324	0.320	0.309	0.303
80	1.106	0.496	0.517	0.509	0.505
60	1.040	0.700	0.738	0.738	0.744
40	1.022	0.822	0.865	0.866	0.862
20	1.014	0.900	0.942	0.939	0.931

* Relative Vapor Pressure = $\frac{\text{vapor pressure of solution}}{\text{vapor pressure of water}}$

Hygroscopicity:

Anhydrous glycerol has a very high affinity for water, a property responsible for its uses as a drying agent for gases, for the preparation of anhydrous alcohol, etc.

The ability to attract moisture from the air and hold it is one of the most valuable properties of glycerol. It is the basis for its use as a humectant, and also for its use as a conditioning agent where both the glycerol itself and the water it holds act as plasticizers.

Glycerol solutions, at any concentration, will gain or supply moisture until a concentration is reached which is in equilibrium with the moisture of the air. A number of determinations have been made of the relative humidity maintained over glycerol solutions[21], and they furnish the basis for the curve shown in Figure H (page 12). Temperature change within normal atmospheric limits has little effect on the equilibrium concentration, so long as relative humidity is constant.

The application of the chart is quite simple. Suppose we have an open dish containing a solution of 80 grams of glycerol and 20 grams of water. If the relative humidity of the room is 40%, then water will evaporate out of solution until it has become concentrated to 86% glycerol. No further water loss will take place. If we had placed our dish in a 55% relative humidity atmosphere, our solution would gain moisture until it reached a 77% glycerol concentration. In other words, the total amount of liquid would stabilize itself at about 103.8 grams (80 grams glycerol – 23.8 grams water) having attracted 3.8 grams of moisture from the air.

Of course, somewhat different conditions prevail if the solution is exposed in a cabinet or other enclosure which limits the total amount of water to be absorbed. Here, glycerine of a specific concentration will produce atmospheres of known relative humidity, and this has been applied in laboratory humidity control cabinets as an alternative to humectant solutions of sulfuric acid or certain saturated salts[22]. The relative humidities obtainable from various glycerol concentrations are shown in Table 15. (It should be kept in mind that it will be necessary to add glycerine to restore the desired concentration if appreciable amounts of water are picked up from moisture from products within the enclosure. The specific gravity measurements are useful here.)

In comparing humectants for product conditioning, the concept of *Humectant range* has been introduced[23]. This is defined as the change in moisture level taking place when a solution is transferred from one equilibrium point to another. Sorbitol, for example, holds less water than glycerol at a particular humidity level, and has a narrower humectant range. In relation to its water-holding *capacity*, however, glycerol shows a smaller ratio between initial and final equilibrium water content percentages as shown by the following example:

	% Water Held by Glycerol Solution	% Water Held by Sorbitol Solution
Initial Rel. Humidity – 40%	15%	9%
Final Rel. Humidity – 80%	48%	36%

How soon equilibrium between glycerine and the surrounding atmosphere is attained depends in large measure on the character of the exposed surface or product in which the humectant is incorporated – its area, viscosity, gel structure and other factors affecting the rate of migration of water within the product – as well as the relative humidity of the surrounding atmosphere.

Some data indicate a slower rate of change for polyols of narrower humectant range[21]. A method of testing changes in water content which recognizes the surface-area factors involved is based on the weight of glass cloth on which a thin film of humectant solution has been deposited[23]. The rate of change shows little variation between humectants.

Table 15. Relative Humidity Over Glycerol-Water Mixtures at 25°C

Relative humidity	Glycerol (by weight)	Specific gravity
%	%	
10	95	1.245
20	92	1.237
30	89	1.229
40	84	1.216
50	79	1.203
60	72	1.184
70	64	1.162
80	51	1.127
90	33	1.079

Viscosity:

Many measurements of the viscosity of glycerol and glycerol solutions have been made, using different types of viscometers. Consequently, there is some disagreement in data from various sources. Precise work done by Sheeley covers the entire range of concentration in more than 100 measurements, and has been commended as suitable for the calibration of viscosimeters in the 20° C. to 30° C. temperature range[43].. A more general determination covering 0-100% concentration and 0 to 100° C. temperature was made by Segar and Oberstar,[44] and is given in Table 17. The chart shown in Figure G, is based on this and other data, as converted to degrees Fahrenheit.

The viscosity of glycerol solutions below 0° C. was determined by Green and Parke[8], who used Ostwald viscometers except with 66.7% glycerol at –40° C., in which case a falling ball viscometer was used. Values are shown in Table 19. Viscosities of supercooled glycerine have also been determined by the falling ball viscometer down to –40° C. and are given in Table 16. At –89° C., glycerine becomes hard, its viscosity having been calculated as 10^{13} poises[45].

Table 16. Viscosity of Supercooled Glycerol

Glycerol + 0.5 % Water (°C)	(Poises)	Glycerol, Anhydrous (°C)	(Poises)
–40.9	45000	–42.0	67100
–37.0	22000	–41.8	63000
–34.0	10600	–36.3	21700
–34.0	10800	–36.0	20500
–30.0	5220	–28.9	5360
–26.0	2830	–25.0	2600
–13.9	407	–25.0	2640
–13.9	405	–20.0	1340
–6.1	142	–19.5	1230
–6.1	144	–15.4	665
–6.0	137	–10.8	357
+2.0	53.8	–10.8	352
+1.8	56.5	–4.2	148
+1.7	62.4	–4.2	149
+6.3	34.4		
+6.3	35.7		
+9.1	26.7		
+9.2	26.0		
+12.8	18.4		
+12.8	18.3		

Table 17. Viscosity of Aqueous Glycerol Solutions Centipoises

Glyc. % Wt.	Temperature (°C)										
	0	10	20	30	40	50	60	70	80	90	100
0*	1.792	1.308	1.005	0.8007	0.6560	0.5494	0.4688	0.4061	0.3565	0.3165	0.2838
10	2.44	1.74	1.31	1.03	0.826	0.680	0.575	0.500	—	—	—
20	3.44	2.41	1.76	1.35	1.07	0.879	0.731	0.635	—	—	—
30	5.14	3.49	2.50	1.87	1.46	1.16	0.956	0.816	0.690	—	—
40	8.25	5.37	3.72	2.72	2.07	1.62	1.30	1.09	0.918	0.763	0.668
50	14.6	9.01	6.00	4.21	3.10	2.37	1.86	1.53	1.25	1.05	0.910
60	29.9	17.4	10.8	7.19	5.08	3.76	2.85	2.29	1.84	1.52	1.28
65	45.7	25.3	15.2	9.85	6.80	4.89	3.66	2.91	2.28	1.86	1.55
67	55.5	29.9	17.7	11.3	7.73	5.50	4.09	3.23	2.50	2.03	1.68
70	76	38.8	22.5	14.1	9.40	6.61	4.86	3.78	2.90	2.34	1.93
75	132	65.2	35.5	21.2	13.6	9.25	6.61	5.01	3.80	3.00	2.43
80	255	116	60.1	33.9	20.8	13.6	9.42	6.94	5.13	4.03	3.18
85	540	223	109	58	33.5	21.2	14.2	10.0	7.28	5.52	4.24
90	1310	498	219	109	60.0	35.5	22.5	15.5	11.0	7.93	6.00
91	1590	592	259	127	68.1	39.8	25.1	17.1	11.9	8.62	6.40
92	1950	729	310	147	78.3	44.8	28.0	19.0	13.1	9.46	6.82
93	2400	860	367	172	89	51.5	31.6	21.2	14.4	10.3	7.54
94	2930	1040	437	202	105	58.4	35.4	23.6	15.8	11.2	8.19
95	3690	1270	523	237	121	67.0	39.9	26.4	17.5	12.4	9.08
96	4600	1580	624	281	142	77.8	45.4	29.7	19.6	13.6	10.1
97	5770	1950	765	340	166	88.9	51.9	33.6	21.9	15.1	10.9
98	7370	2460	939	409	196	104	59.8	38.5	24.8	17.0	12.2
99	9420	3090	1150	500	235	122	69.1	43.6	27.8	19.0	13.3
100	12070	3900	1410	612	284	142	81.3	50.6	31.9	21.3	14.8

* Viscosity of water taken from "Properties of Ordinary Water-Substance," N. E. Dorsey, p. 184. New York (1940)

Table 18. Viscosity of Mixtures of Glycerol with Methyl Alcohol and with Ethyl Alcohol Centipoises

Methyl Alcohol (% Wt.)	25°C	45°C	Ethyl Alcohol (% Wt)	25°C	45°C
0	875	311	0	875	311
9.8	375	149	9.9	504	187.1
24.8	97.7	46.55	24.8	167	77.6
49.4	14.38	9.77	49.1	24.58	21.8
74.3	2.75	2.53	73.6	6.17	4.76
87.8	1.23	1.22	100.0	1.23	1.25
100	0.63	0.71			

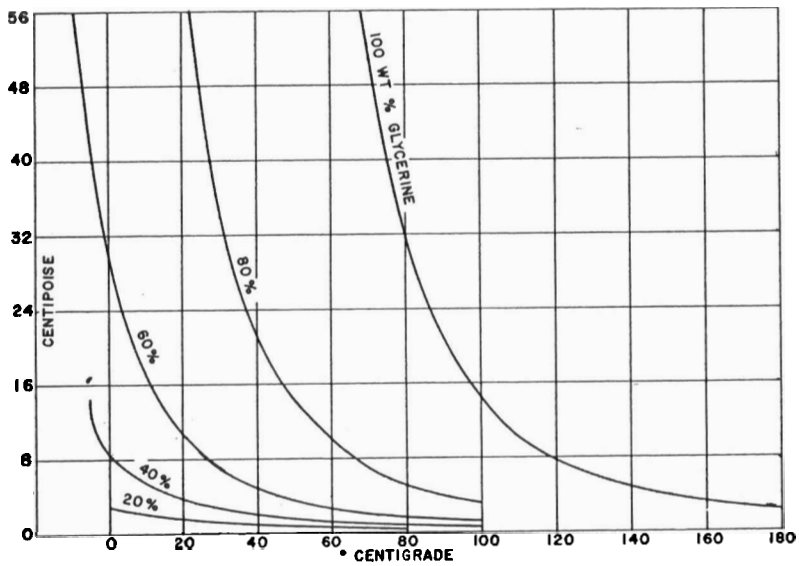
Table 19. Viscosity of Glycerol-Water Solutions at Low Temperatures in Centipoises

Glycerol % wt	Temp. F.p.°C	–5°C	–10°C	–20°C	–30°C	–40°C
10	–1.6	—	—	—	—	—
20	–4.8	—	—	—	—	—
30	–9.5	6.5	—	—	—	—
40	–15.4	10.3	14.4	—	—	—
50	–23.0	18.8	24.4	48.1	—	—
60	–34.7	41.6	59.1	108.0	244.0	—
66.7	–46.5	74.7	113.0	289.0	631.0	1398.0
70	–38.5	110.0	151.0	394.0	1046.0	—
80	–20.3	419.0	683.0	1600.0	—	—
90	–1.6	—	—	—	—	—

Table 20. The Viscosity of 100 Per Cent Glycerol at High Temperatures

°C.....	80	90	100	110	120	130	140
Centipoise.....	32.18	21.20	14.60	10.48	7.797	5.986	4.726
°C.....	150	158	167				
Centipoise.....	3.823	3.282	2.806				

Fig. F. Aqueous Viscosity of Glycerine from 0°C to 100°C.*

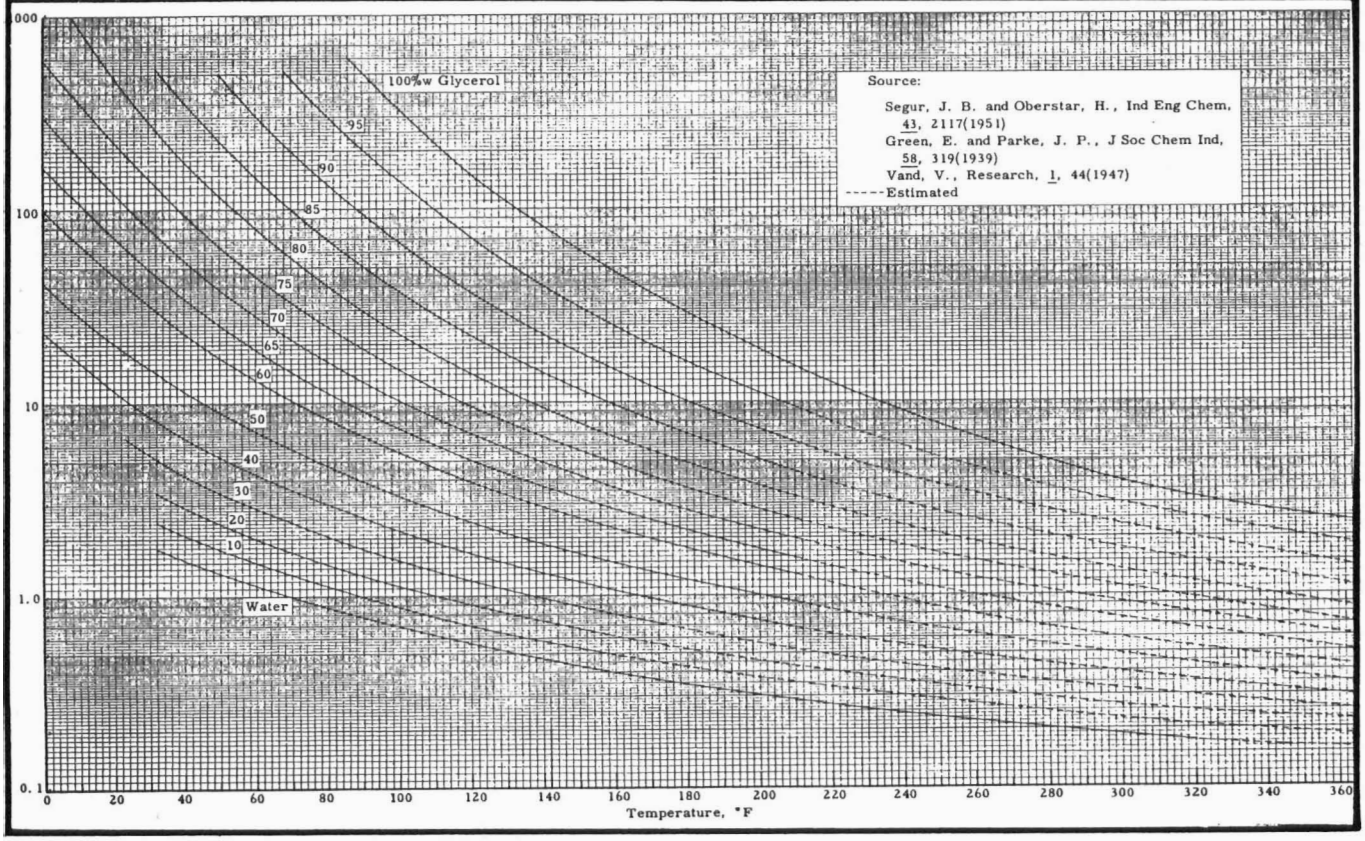


The viscosity of glycerol at high temperature 80° - 167° C. has also been derived and is given in Table 20[46].

Viscosity of glycerol rises with increasing pressure[47]. Generally, electrolytes dissolved in glycerol increase its viscosity, but a few have the opposite effect. Ammonium bromide, and iodide, rubidium chloride, bromide and iodide and cesium chloride and nitrate belong to this group[48 & 49]. Potassium iodide also reduces the viscosity of glycerol[50].

Mixtures of glycerol-alcohol, glycerol-alcohol-water, and sugar solutions in glycerol have been studied with respect to viscosity[51]. Viscosities of glycerol-alcohol mixtures are shown in Table 18

Fig. G. Liquid Viscosities of Glycerol-Water Solutions



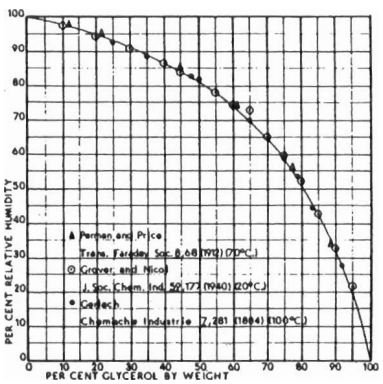
Glycerine as a Softener:

Glycerine has been used as a softener and to maintain flexibility in films, packaging materials and the like for years. Recently research has been done which has led to a new interpretation of cellulose softener interaction in terms of hydrogen-bond energies.

The basic action of the softener seems to be its interruption or breaking of interchain hydrogen bonds. In this respect, glycerine is twice as effective as water. Measurements have been made of the elastic modulus of viscous flow and delayed elasticity. The inelastic deformation was found to be a linear function of the heat of vaporization of the softener, which is related to hydrogen bonding energy[24].

A special apparatus for determining the elastic modulus and measurement of the softener and moisture content at various levels of relative humidity has been developed. It has been shown that the softening action of glycerine is not caused by a simple increase in the moisture content from the presence of the glycerine, but largely by the direct effect of the glycerol molecules on the cellulose structure. This softening action of glycerine will be maintained even at low levels of relative humidity. This test method makes it easier to calculate the amounts of glycerol needed for a particular elastic modulus at a given relative humidity[25].

Fig. H. Relative Humidity over Aqueous Glycerol (20-100° C)



Freezing Point:

The freezing point of pure glycerol has been variously reported at values distributed closely around 18° C., with 18.17° C. as perhaps the most precise. Glycerol is seldom seen in its crystallized state, because of its tendency to supercool, and the pronounced effect of small amounts of water in depressing the freezing point.

Measurements of the freezing points of glycerol solutions have been determined by the U.S. Bureau of Standards[26] and others, and the freezing point curve developed by Lane[27] is in general use (See Figure I). Other values between 10% and 60% glycerol are shown in Table 22.

Glycerol 66.7% (by weight) and 33.3% water form a eutetic mixture which has a freezing point generally reported as –46.5° C., although Ross[28] gives the figure of –43.5° in a more recent study.

Because of its use as an antifreeze, Olsen et al.[29] determined the "flow point" of glycerol solutions – as the point at which a glycerol solution containing ice crystals would flow freely through a ¼ inch orifice. These values are shown in Table 21.

Studies have been made of the freezing points of glycerol-alcohol-water systems and glycerine-ethylene glycol-water systems because of their application to antifreeze and to refrigeration systems[30].

Fig. I. Freezing Points of Glycerol-Water Solutions

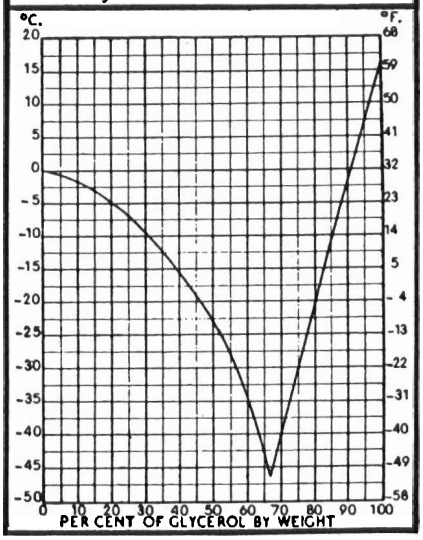


Table 21. Freezing and Flow Points of Glycerol-Water Solutions

Composition				Freezing Point		Flow Point	
% by wt		% by vol					
96.5°	100°	96.5°	60°	(°C)	(°F)	(°C)	(°F)
10	9.65	8.14	14.23	–2.2	28.0	–3.0	26.6
20	19.30	16.62	29.09	–5.3	22.46	–9.0	15.8
30	28.95	25.46	44.65	–8.8	16.3	–15.8	3.5
35	33.78	30.03	52.71	–12.4	9.5	–18.0	–2.0
40	38.60	34.70	60.96	–17.2	1.04	–19.5	–3.1
45	43.43	39.47	69.40	–18.0	0.4	–20.5	–4.9
50	48.25	44.36	78.03	–21.4	–6.5	–28.0	–18.4
55	53.08	49.35	86.91	–27.5	–17.5	–35.9	–32.6
60	57.90	54.46	95.98	–34.0	–29.2	–41.9	–43.6
70	67.55	65.03		–41.5	–42.7		

* The per cent weight concentration of the glycerol on which the indicated compositions are based.

Table 22. Freezing Points of Glycerol-Water Solutions (°C)					
% by Wt of Glycerol	Lane	Bureau of Standards	Olsen, Brunjes, and Olsen	Feldman and Dahlstrom	Spangler and Davis
10	−1.6	−1.7	−2.3	−1.9	−1.99
20	−4.8	−4.8	−5.5	−5.4	−5.21
30	−9.5	−9.4	−9.8	−9.7	−9.92
35	−12.2	−12.3	−12.4	....	−12.65
40	−15.4	−15.6	−15.7	−15.6	−15.93
45	−18.8	−19.4	−18.6	....	−19.90
50	−23.0	−25.8	−28.8	−23.6	−24.55
55	−28.2	....	....	....	−30.10
60	−34.7	....	−37.2	−35.5	−37.90

Refractive Index:

The refractive index of 100% glycerol is ($N^{20}/_{D}$) 1.47399. Being easily measured and sensitive to dilution with water it may be used as a measure of concentration. However, these results are not quite as precise as those obtained from specific gravity.

Determinations of the refractive index of glycerol solutions have been made by a number of investigators including Hoyt[62] who prepared samples from 5 to 100% concentration as determined by Bossart and Snoddy. Refractive index values at 20 ± 0.1° C. were plotted against concentration and found to fall along a curve which could be divided into three sections: a curve from 0 to 44%, a straight line from 45 to 79% and a curve from 80-100% concentration. The equations for these lines are:

(1) Curve from 0 to 44% glycerol
$$y = 1.3303 + 0.001124x + 0.00000605x^2 - 0.000000555x^2$$

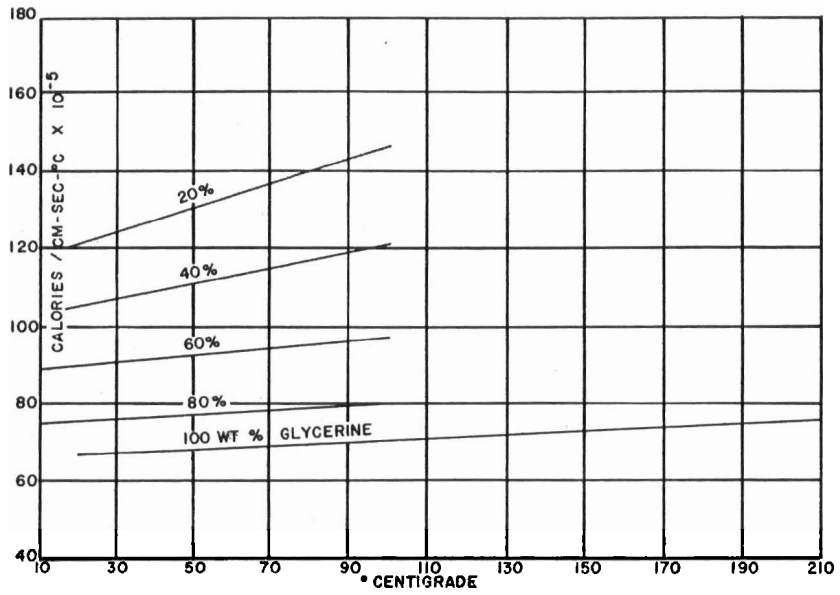
(2) Straight line from 45 to 79%
$$y = 0.00149x + 1.32359$$

(3) Curve from 80 to 100%
$$y = 0.90799 + 0.0154x - 0.000155x^2 + 0.000000576x^3$$

With these equations refractive indices shown in Table 23 were calculated. These calculated values deviated from the observed values only by 0.00011 and make possible the determination of glycerol concentration with an accuracy of at least 0.1 percent.

Table 23. Refractive Index of Glycerol-Water Solutions at 20.0°C					
Glycerol % by weight	Refractive Index n_D^{20}	Difference for 1%	Glycerol % by weight	Refractive Index n_D^{20}	Difference for 1%
100	1.47399	0.00165	50	1.39809	0.00149
99	1.47234	0.00163	49	1.39660	0.00147
98	1.47071	0.00161	48	1.39513	0.00145
97	1.46909	0.00157	47	1.39368	0.00141
96	1.46752	0.00156	46	1.39227	0.00138
95	1.46597	0.00154	45	1.39089	0.00136
94	1.46443	0.00153	44	1.38953	0.00135
93	1.46290	0.00151	43	1.38818	0.00135
92	1.46139	0.00150	42	1.38683	0.00135
91	1.45989	0.00150	41	1.38548	0.00135
90	1.45839	0.00150	40	1.38413	0.00135
89	1.45689	0.00150	39	1.38278	0.00135
88	1.45539	0.00150	38	1.38143	0.00135
87	1.45389	0.00152	37	1.38008	0.00134
86	1.45237	0.00152	36	1.37874	0.00134
85	1.45085	0.00155	35	1.37740	0.00134
84	1.44930	0.00156	34	1.37606	0.00134
83	1.44770	0.00160	33	1.37472	0.00134
82	1.44612	0.00162	32	1.37338	0.00134
81	1.44450	0.00160	31	1.37204	0.00134
80	1.44290	0.00155	30	1.37070	0.00134
79	1.44135	0.00153	29	1.36936	0.00134
78	1.43982	0.00150	28	1.36802	0.00133
77	1.43832	0.00149	27	1.36669	0.00133
76	1.43683	0.00149	26	1.36536	0.00132
75	1.43534	0.00149	25	1.36404	0.00132
74	1.43385	0.00149	24	1.36272	0.00131
73	1.43236	0.00149	23	1.36141	0.00131
72	1.43087	0.00149	22	1.36010	0.00131
71	1.42938	0.00149	21	1.35879	0.00130
70	1.42789	0.00149	20	1.35749	0.00130
69	1.42640	0.00149	19	1.35619	0.00129
68	1.42491	0.00149	18	1.35490	0.00129
67	1.42342	0.00149	17	1.35361	0.00128
66	1.42193	0.00149	16	1.35233	0.00127
65	1.42044	0.00149	15	1.35106	0.00126
64	1.41895	0.00149	14	1.34980	0.00126
63	1.41746	0.00149	13	1.34854	0.00125
62	1.41597	0.00149	12	1.34729	0.00125
61	1.41448	0.00149	11	1.34604	0.00123
60	1.41299	0.00149	10	1.34481	0.00122
59	1.41150	0.00149	9	1.34359	0.00121
58	1.41001	0.00149	8	1.34238	0.00120
57	1.40852	0.00149	7	1.34118	0.00119
56	1.40703	0.00149	6	1.33999	0.00119
55	1.40554	0.00149	5	1.33880	0.00118
54	1.40405	0.00149	4	1.33762	0.00117
53	1.40256	0.00149	3	1.33645	0.00115
52	1.40107	0.00149	2	1.33530	0.00114
51	1.39958	0.00149	1	1.33416	0.00113
			0	1.33303	—

Fig. J. Aqueous Thermal Conductivity for Glycerine from 10°C to 100°C.*



Thermal Conductivity:

The thermal conductivity of glycerol solutions increases as their water content increases. It also increases with rising temperature, the rate of change being linear. Hence the average coefficient of thermal conductivity over a temperature range is equal to the true coefficient at the average temperature.

Eucken and Englert[67] found the thermal conductivity of liquid glycerol at 0° C. to be 0.000691 cal/cm-/deg/sec and of vitreous glycerol at −78° C. to be 0.000760×10^{-6} cal/cm/deg/sec. The figures in Table 24 were obtained from curves plotted from experimentally determined values for coefficient of thermal conductivity and solution concentrations,[68] as was the data in Figure J.

Table 24. True Coefficient of Thermal Conductivity of Glycerol-Water Solutions

Water % by weight	Glycerol % by weight	Values of K_t 10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	α_{20} %, $C^{\circ -1}$	Equations for True Coefficient of Thermal Conductivity
		Gram calories, second^{-1}, cm.$^{-1}$, °C^{-1}, cm.°									
100	(Pure water)	0.00138	0.00141	0.00145	0.00149	0.00152	0.00156	0.00160	0.00163	0.26	$K_t = 0.00134 + 0.00000367\ (t)$
95	5	0.00133	0.00137	0.00140	0.00144	0.00147	0.00151	0.00154	0.00158	0.25	$K_t = 0.00130 + 0.00000342\ (t)$
90	10	0.00130	0.00133	0.00137	0.00140	0.00143	0.00146	0.00149	0.00152	0.24	$K_t = 0.00127 + 0.00000317\ (t)$
85	15	0.00125	0.00128	0.00131	0.00134	0.00137	0.00140	0.00143	0.00146	0.23	$K_t = 0.00122 + 0.00000300\ (t)$
80	20	0.00121	0.00124	0.00127	0.00129	0.00132	0.00135	0.00138	0.00141	0.23	$K_t = 0.00118 + 0.00000284\ (t)$
75	25	0.00117	0.00119	0.00122	0.00125	0.00127	0.00130	0.00132	0.00135	0.22	$K_t = 0.00114 + 0.00000263\ (t)$
70	30	0.00112	0.00115	0.00117	0.00120	0.00122	0.00124	0.00126	0.00129	0.20	$K_t = 0.00110 + 0.00000234\ (t)$
65	35	0.00109	0.00111	0.00114	0.00116	0.00118	0.00120	0.00122	0.00124	0.20	$K_t = 0.00107 + 0.00000217\ (t)$
60	40	0.00105	0.00107	0.00108	0.00110	0.00112	0.00114	0.00116	0.00118	0.17	$K_t = 0.00103 + 0.00000183\ (t)$
55	45	0.00102	0.00103	0.00105	0.00106	0.00108	0.00110	0.00111	0.00113	0.15	$K_t = 0.00100 + 0.00000159\ (t)$
50	50	0.00097	0.00099	0.00100	0.00101	0.00103	0.00104	0.00105	0.00107	0.13	$K_t = 0.00096 + 0.00000133\ (t)$
45	55	0.00094	0.00095	0.00096	0.00098	0.00099	0.00100	0.00101	0.00102	0.12	$K_t = 0.00093 + 0.00000116\ (t)$
40	60	0.00090	0.00091	0.00091	0.00092	0.00093	0.00094	0.00095	0.00096	0.10	$K_t = 0.00089 + 0.00000090\ (t)$
35	65	0.00086	0.00087	0.00088	0.00089	0.00089	0.00090	0.00091	0.00091	0.08	$K_t = 0.00086 + 0.00000067\ (t)$
30	70	0.00084	0.00084	0.00085	0.00085	0.00086	0.00086	0.00087	0.00087	0.06	$K_t = 0.00083 + 0.00000050\ (t)$
25	75	0.00080	0.00081	0.00081	0.00081	0.00082	0.00082	0.00082	0.00082	0.04	$K_t = 0.00080 + 0.00000030\ (t)$
20	80	0.00077	0.00078	0.00078	0.00078	0.00079	0.00079	0.00079	0.00079	0.04	$K_t = 0.00077 + 0.00000030\ (t)$
15	85	0.00074	0.00074	0.00074	0.00074	0.00074	0.00074	0.00075	0.00075	0.01	$K_t = 0.00074 + 0.00000008\ (t)$
10	90	0.00072	0.00072	0.00072	0.00072	0.00072	0.00072	0.00072	0.00073	0.0+	$K_t = 0.00072$
5	95	0.00070	0.00070	0.00070	0.00070	0.00070	0.00070	0.00070	0.00070	—	$K_t = 0.00070$
(Pure glycerol)	100	0.00068	0.00068	0.00068	0.00068	0.00068	0.00068	0.00068	0.00068	—	$K_t = 0.00068$

* K_t(cal., sec.$^{-1}$, cm^{-2}, °C^{-}, cm.) 2900 = K_t(B.t.u., hr.$^{-1}$, ft.$^{-2}$, °F^{-1} inch). C.g.s. system English system

† α_{20} as defined by $K_t = K_{20}[1 + \alpha_{20}(t - 20)]$.

Heat of Solution:

When glycerol is dissolved in water there is a slight rise in temperature which reaches a maximum of about 5° C. when 58% by weight of glycerol is used. The results of these experiments made by Gerlach[11] are given in Figure K.

The maximum amount of heat (though not the greatest rise in temperature) is obtained when the glycerol is dissolved in a large excess of water. If the glycerol is not anhydrous some of its heat of solution will have been dissipated and so correspondingly smaller amounts of heat will be produced by further dilution. Such measurements made by Fricke[59] are given in Table 25.

Glycerol has a negative heat of solution in methyl alcohol and ethyl alcohol. The following molar values were reported by Kolossowsky.[79]

Methyl alcohol, 1:50 moles −370 cal.
Water+methyl alcohol, 1:(43+43) moles −417 cal.
Water+ethyl alcohol, 1:(200+128) moles −337 cal.
Water+ethyl alcohol, 1:(150+25) moles ±0 cal.

Fig. K. Temperature Rise on Mixing Glycerol and Water

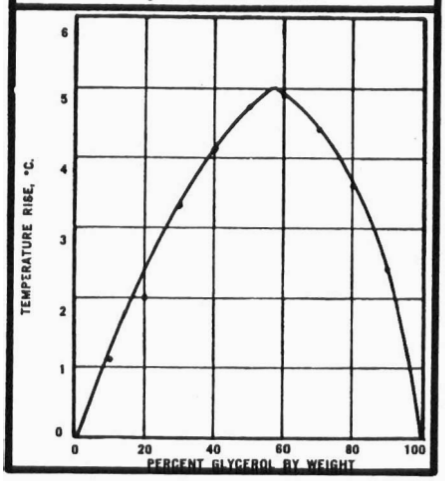


Table 25. Molar Heat of Solution of Glycerol

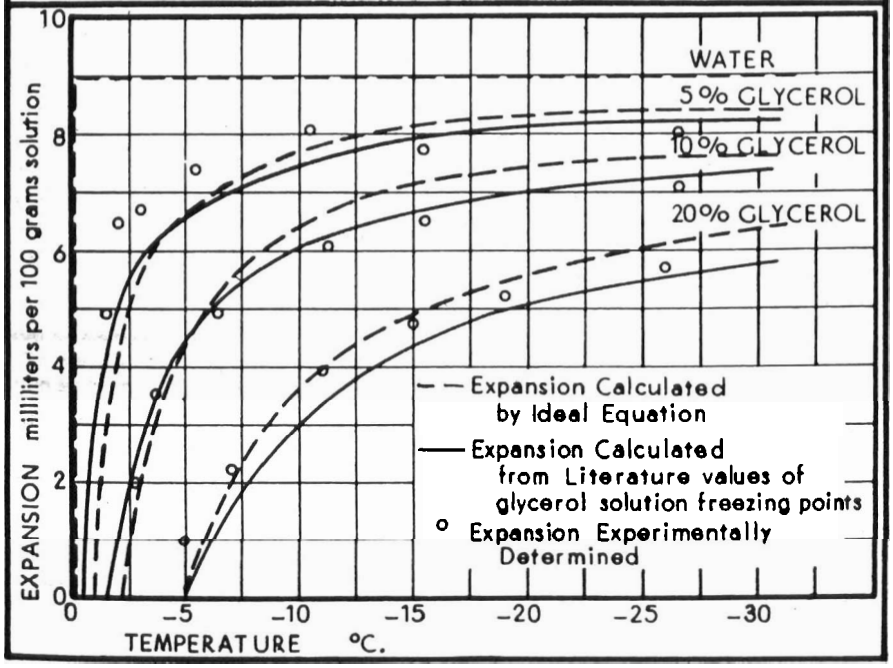
Moles H_2O per Mole Glycerol	% H_2O	Molar Heat of Solution Cal
0.000	0.00	1381
0.164	3.11	1329
0.304	5.62	1261
0.684	11.81	1140
1.633	24.21	962
2.866	35.93	788
3.711	42.07	705
4.564	47.17	615

Diffusion:

Theoretically the diffusion of a non-electrolyte into a solvent should be inversely proportional to the viscosity of the solvent. However, when glycerol is the diffusing substance, the values obtained in water and alcohols are not constant. The values obtained with water are considerably higher than others. The diffusion constant of water into glycerol is 1.33 x 10^{-7} cm^2/sec at 20.08° C.[52]. The abnormal rapidity of the diffusion indicated the water molecules move independently of the glycerol molecules.

According to some more recent work[53] the diffusion coefficient is independent of concentration up to 70% glycerol, after which it rises. The increased mobility at very high glycerol concentrations is attributed to a decreased hydration of the glycerol molecules under these conditions.

Fig. L. Cubical Expansion of Glycerol-Water Solutions when Partially Frozen



Cubical Expansion — Heat of Fusion:

The cubical expansion of glycerol-water solutions, as determined by Guiteras and Reich[32] is shown in Figure L. The heat of fusion is reported as 47.5 cal per gm and 47.9 cal per gm[33 & 34].

Heat of Vaporization:

The heat of vaporization of glycerol is 21,060 cal/mol at 55° and 18,170 at 195° C. The intermediate figures have been determined by Stedman[16].

Specific Heat:

The specific heat of pure glycerol has been determined by several investigators with values in the range of 0.575 to 0.5795 cal per ° C. per gm at 26° C.[33 & 37]. The specific heat of glycerol-water mixtures is higher. Because of its refrigerant properties, the heat capacity of glycerol and glycerol solutions have been thoroughly explored at low temperatures. Figure O shows values for pure glycerol in different states as determined by Gibson and Giauque[33].

The specific heat of glycerol-water mixtures at temperatures from 0° to −31° C. was thoroughly explored by Gucker and Marsh[38], and is given in Table 26 and Figure M. The total heat capacity of the glycerol-water mixture was derived by including both the liquid and ice phases, the heat of fusion of ice, heat of solution of water, etc., in the calculations.

By using Table 26, the most efficient mixture to act as a coolant or thermal-buffer at a given temperature range can be selected. For example, if a temperature of about 0° F. (−17.8° C.) is to be maintained, a 40 per cent solution will have the highest specific heat (2.4). The amount of heat absorbed by a unit amount of solution in warming from −20° F. to 0° F., for example, is found by subtracting the value at 0° F. from that at −20° F. in any given column. By comparing differences in the adjacent columns, it is found that the greatest heat capacity is provided by the 40 per cent solution. These values can also be derived from Figure N.

Table 26. Specific Heats of Glycerol-Water Mixtures

°F	°C	Specific Heats, Cal/G/°C or BTU/Lb/°F — Glycerol 25%	30%	35%	40%	45%	50%	55%	60%	65%
35	1.7	0.88	0.87	0.86	0.84	0.82	0.80	0.77	0.74	0.71
30	−1.1	0.88	0.86	0.85	0.83	0.81	0.79	0.76	0.73	0.70
25	−3.9	0.87	0.86	0.84	0.82	0.80	0.78	0.75	0.72	0.69
20	−6.7	0.86	0.85	0.83	0.82	0.79	0.77	0.74	0.71	0.68
19.0[a]	−7.2	6.8[a]	..	..	..	..	..	..	..	..
15[a]	−9.4	4.1	4.8[a]	0.82	0.80	0.78	0.76	0.73	0.70	0.67
10.4[a]	−12.0	..	..	3.7[a]	..	..	..	..	..	..
10	−12.2	2.7	3.2	3.6	0.80	0.78	0.75	0.72	0.69	0.66
5	−15.0	2.1	2.4	2.7	0.79	0.77	0.74	0.71	0.67	.0.65
4.6[a]	−15.2	..	..	..	2.9[a]	..	..	..	..	..
0	−17.8	1.7	1.9	2.1	2.4	0.76	0.73	0.70	0.66	0.63
−1.8[a]	−18.8	..	..	..	..	2.4[a]	..	..	..	..
−5	−20.6	1.4	1.6	1.8	2.0	2.2	0.72	0.69	0.65	0.62
−9.6[a]	−23.1	..	..	..	..	..	2.0[a]	..	..	..
−10	−23.3	1.2	1.4	1.6	1.7	1.9	2.0	0.68	0.64	0.61
−15	−26.1	1.1	1.2	1.3	1.5	1.6	1.7	0.67	0.63	0.60
−18.9[a]	−28.3	..	..	..	..	..	..	1.7[a]	..	..
−20	−28.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	0.62	0.59
−25	−31.7	0.9	1.0	1.1	1.2	1.25	1.3	1.4	0.61	0.58

[a]Estimated freezing point, and maximum specific heat for mixture of this composition. The horizontal lines in each column mark the lower limit of the one-phase systems.

Fig. M. Specific Heats of Glycerol-Water Mixtures at Various Temperatures

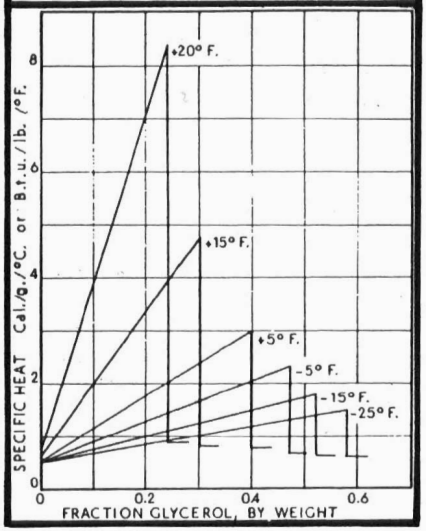


Fig. N. Specific Heats of Glycerol-Water Mixtures of Various Compositions

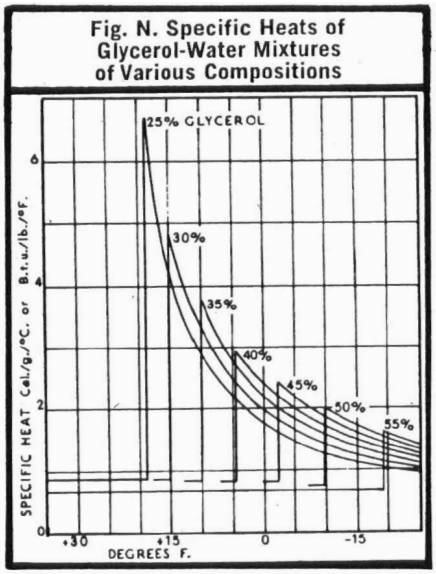


Fig. O. Heat Capacity of Glycerol

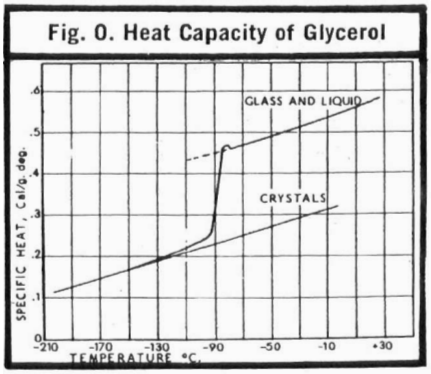
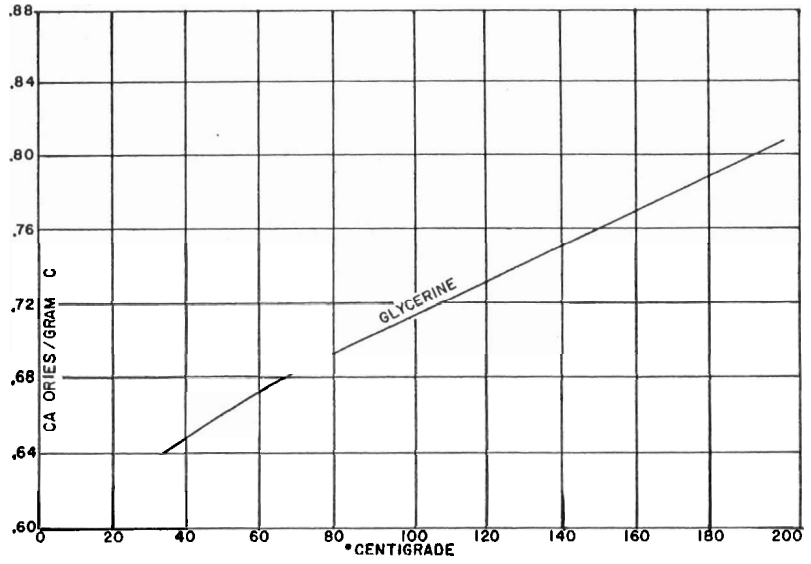


Fig. P. Liquid Heat Capacity of Glycerine from 20°C to 200°C.*



* Hydrocarbon Processing, Vol. 46, No. 5 (1967), p. 201 to 215.

Vitreous Glycerol:

When glycerol is supercooled, its viscosity gradually increases, and then a more rapid change from viscous liquid to a rigid glassy state occurs at a temperature range of −70 to −110° C. When in the vitreous state, its physical constants lie nearer those of crystalline glycerol than liquid glycerol. For example, the specific heat diminishes abruptly with change in state at about −83° C. For an extended discussion of the vitreous state, see "The Nature of the Glassy State and Behavior of Liquids at Low Temperature" by Kauzmann[36]. Experiments with supercooled glycerol are generally carried on with glycerol containing 0.5% water.

Dielectric Constant:

The dielectric constant of glycerol-water solutions at 25° C. was determined by Albright.[60] The measurements were made with a current having a frequency of 0.57×10^6 cycles/second. Table 27.

At high frequencies (247,000 cycles/second) at 0° C. but not at 30° C. glycerine shows an anomalous behavior in that the dielectric constant, which first increases with pressure, reaches a maximum of 55.6 at about 4290 atmospheres and thereafter decreases. The effect is attributed to the increased viscosity of the glycerol. The dielectric constant of anhydrous glycerol is increased by increasing the pressure.

The effect of temperature on the dielectric constant of pure glycerol and also glycerol-water solutions within the range of 20 to 100° C. is given in Table 28. These measurements were made by the resonance method at a wave length of 150 meters, which corresponds to a frequency of 2×10^6 cyles/second.[61]

Dielectric constants of water-ethanol-glycerine systems have been experimentally determined[74]. The measured values were found to differ from values calculated according to simplification of the Onsager-Kirkwood equation, regardless of whether composition of the various solutions was expressed on the basis of weight percentage or volume percentage.

Table 27. Dielectric Constant, e, of Glycerol-Water Solutions at 25°C. Current Frequency = 0.57×10^6 Cycles/Sec

Glyc. % Wt.		Glyc. % Wt.	
0.00	78.48	60.15	62.38
9.88	75.98	70.00	58.52
20.33	73.86	79.86	54.08
30.19	71.44	90.42	48.66
39.67	68.93	100.00	42.48
50.23	65.72		

Table 28. Dielectric Constant, e, of Glycerol-Water Solutions Current Frequency = 2×10^6 Cycles/Sec

Glycerol % Wt	20°C	25°C	40°C	60°C	80°C	100°C
0	80.37	78.5	73.12	66.62	60.58	55.10
10	77.55	75.7	70.41	63.98	58.31	—
20	74.72	72.9	67.70	61.56	56.01	—
30	71.77	70.0	64.87	58.97	53.65	—
40	68.76	67.1	62.03	56.24	51.17	—
50	65.63	64.0	59.55	53.36	48.52	—
60	62.03	60.0	55.48	50.17	45.39	41.08
70	57.06	55.6	51.41	46.33	41.90	38.07
80	52.27	50.6	46.92	42.32	38.30	34.70
90	46.98	45.5	42.26	38.19	34.47	31.34
100	41.14	40.1	37.30	33.82	30.63	27.88

Note: The data for 25°C were obtained by interpolation.

Adiabatic Expansion:

The change in temperature by adiabatic expansion of glycerol was determined by Pushin and Grebenshchikov.[61] Their data are shown in Table 29.

Table 29. Adiabatic Expansion of Glycerol and Water

Pressure, p*	dt/dp†						
	1	500	1000	1500	2000	2500	3000
Water at 0°C	−.00130	−.00020	.0064	.00116	.00150	.00173	.00189
Water at 80°C	.00492	.00468	.00445	.00423	.00406	.00392	.00382
Glycerol at 25°C	.00437	.00407	.00380	.00352	.00327	.00308	.00294
Glycerol at 98.2°C	.00625	.00570	.00520	.00475	.00441	—	—

* Pressure = kg/cm².
† dt/dp = change of temp./change of pressure of 1 kg/cm² at a pressure p.

Solubility and Solvent Power:

Because of its hydroxyl groups glycerol has solubility characteristics similar to those of water and the simple aliphatic alcohols. It is completely miscible with water, methyl alcohol, ethyl alcohol, n-propyl alcoloh, isopropyl alcohol, n-butyl alcohol, isobutyl alcohol, sec.-butyl alcohol, tertiary amyl alcohol, ethylene glycol, propylene glycol, trimethylene glycol and phenol. It is soluble to the extent of 5% by weight in acetone at ordinary temperatures. Nine parts of glycerol are soluble in 100 parts of ethyl acetate. It also has limited solubility in dioxane, and ethyl ether. It is practically insoluble in higher alcohols, in fatty oils and the hydrocarbons and chlorinated solvents such as chlorhexane, chlorbenzene and chloroform. It is completely miscible with ethylene glycol monoethyl ether but is miscible with only a limted amount of ethylene glycol monobutyl ether.

The introduction of hydroxyl and amine groups into aliphatic and aromatic hydrocarbons increases their miscibility with glycerol while the introduction of alkyl groups decreases their miscibility. Heterocylic compounds which contain a nitrogen atom in the ring are generally miscible with glycerol[54]. Miscibility data for a number of compounds with glycerol are given in Tables 30 and 31.

The solubility of gases in glycerol as in all liquids depends on both temperature and pressure. The solubility of hydrogen and nitrogen in aqueous glycerol solutions at 25° C. was measured by Drucker and Moles[57]. Solubilities of nitrogen and carbon dioxide at 15° C. were determined by Hamel[58]. These data are combined in Table 32 (page 19).

Because of the importance of glycerol as a solvent in pharmaceutical preparations and flavor extracts, considerable work has been done on the solubility of a number of substances in glycerol. Table 34 gives the solubility of many of these compounds.

The miscibility of ternary mixtures such as glycerol-benzene-ethanol; glycerol-phenol-water; glycerol-carbon tetrachloride-ethanol, has been determined[55]. The solubility and salt hydrate data of glycerol, water and such salts as sodium carbonate, sodium phosphate, copper sulfate and zinc sulfate have been plotted[56]. Although glycerol is completely miscible with either water or tertiary amyl alcohol, a mixture of the three substances will form two liquid phases.

Solubility parameters for glycerol in terms of dispersion component (δ_d), a polar component (δ_p) and the hydrogen bonding forces (δ_h) have been calculated as follows:

δ_d=8.46 δ_p=5.9 δ_h=14.13

These parameters determine how the solvents interact with various organic and inorganic materials.[78]

Table 30. Miscibility of Organic Solvents with Glycerol

Acetone I	Diethylenetriamine M	α-Methylbenzylamine M
Isoamyl acetate I	Diethyl formamide M	α-Methylbenzyldiethanolamine M
n-Amyl cyanide I	Di(2-ethylhexyl)amine I	α-Methylbenzyldimethylamine I
Anisaldehyde I	Diisopropylamine M	α-Methylbenzylethanolamine M
Benzene I	Di-n-propyl aniline I	2-Methyl-5-ethylpyridine M
Benzyl ether I	Ethyl alcohol M	Methyl isopropyl ketone I
Chloroform I	Ethyl chloracetate I	4-Methyl-n-valeric acid I
Cinnamaldehyde I	Ethyl cinnamate I	o-Phenetidine I
o-Cresol M	Ethyl Ether I	2-Phenylethylamine M
Di-n-amylamine S	Ethyl phenylacetate I	Isopropanolamine M
Di-n-butylamine S	3-Heptanol I	Pyridine M
Diisobutyl ketone I	n-Heptyl acetate I	Salicylaldehyde I
Diethyl acetic acid I	n-Hexyl ether I	Tetradecanol I
2, 6, 8, Trimethyl 4-nonanone I	Triethylenetetramine M	Tri-n-butyl phosphate I

M = Miscible I = Immiscible S = Partially miscible

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Table 31. Miscibility of Various Substances with Glycerol of $n_D^{24.8} = 1.4634$

Acetone		m-Toluidine		Acetophenone		Methyl Ethyl Ketone		Isoamyl Alcohol	
% Wt*	°C†	% Wt*	°C†	% Wt*	°C†	% Wt*	°C†	% Wt*	°C†
89.61	40.0	83.23	89.0	97.13	90.5	92.14	55.5	84.26	12.5
86.93	58.5	79.23	102.0	95.30	113.5	86.55	118.5	76.21	36.8
76.96	81.3	71.58	113.5	83.42	162.5	74.78	150.0	62.40	61.4
67.42	91.7	64.30	119.4	75.07	175.5	67.14	161.5	54.41	69.3
64.47	93.5	58.68	120.5	61.90	183.6	60.25	164.5	46.16	73.0
57.25	95.5	53.10	120.2	53.32	185.5	53.84	164.5	36.79	74.1
56.59	95.5	45.68	119.5	51.13	185.4	41.27	163.2	31.90	74.2
55.34	95.6	36.87	117.5	42.00	185.0	36.17	162.5	27.62	73.7
53.07	95.7	17.71	88.5	34.62	184.0	26.75	155.5	19.20	71.5
51.28	95.6			21.14	174.5	13.21	128.5	13.97	66.5
48.43	95.5	83.62	33.4	15.88	164.0	10.73	116.5	10.35	58.0
46.31	95.3	66.04	7.8	8.86	136.5	4.00	37.5	5.05	21.5
45.75	95.3	62.86	7.0	4.38	97.5				
44.67	95.2	48.80	6.7						
34.74	90.9	40.99	8.2						
29.24	85.3	31.40	9.2						
26.58	81.3	21.68	14.2						
20.44	66.6	18.72	16.8						
15.77	44.8	13.99	23 and 69						
10.90	9.5	10.96	No separation						

Line separates upper and lower miscibility limits

Benzadehyde		Salicylaldehyde		o-Toluidine		Anisole		Monomethylaniline	
% Wt*	°C†	% Wt*	°C†	% Wt*	°C†	% Wt*	°C†	% Wt*	°C
97.02	85.5	95.60	106.5	92.20	100.0	90.12	230.5	89.50	197.5
94.54	107.5	91.38	143.5	86.14	130.0	78.80	263.5	73.50	220.0
90.10	127.5	77.02	170.5	73.42	150.0	69.46	273.5	66.42	223.0
77.13	152.5	58.67	176.5	63.28	154.0	53.41	275.5	59.48	224.5
62.30	159.5	52.22	176.6	52.53	154.4	44.02	274.5	51.56	223.5
55.29	160.7	48.32	176.5	46.59	154.0	27.68	250.5	40.60	222.5
49.22	160.3	41.82	175.5	40.97	153.0	11.29	185.5	30.26	219.0
26.63	144.5	26.54	165.5	32.04	150.0	6.07	161.5	14.60	190.5
23.87	140.0	18.30	148.5	20.96	137.0				
12.42	123.5	5.36	91.5	12.42	99.2				
7.74	103.5								
4.53	67.5								

* Per cent weight of the non-glycerol component in total mixture.
† Temperature at which the mixture becomes miscible.

Dimethylaniline		Pyrocatechol Monoethyl Ether		o-Anisidine	
% Wt*	°C†	% Wt*	°C†	% Wt*	°C†
92.40	197.5	79.37	183.0	73.09	142.5
86.00	245.0	63.71	192.0	61.25	145.0
68.02	282.0	48.68	192.8	51.69	144.5
58.54	286.0	44.42	192.9	43.57	143.0
50.06	287.0	35.30	191.0	34.25	141.0
35.68	284.0	20.05	172.5		
21.71	273.0				
9.18	218.5				

Table 32. Solubility of Some Gases in Aqueous Glycerol

Drucker and Moles				Hammel			
Glycerol % Wt	Hydrogen λ 25°C	Glycerol % Wt	Nitrogen λ 25°C	Glycerol % Wt	Nitrogen λ 15°C	Glycerol % Wt	CO_2 λ 15°C
4.0	0.0186	16.0	0.0103	0.0	0.01801	0.0	1.064
10.5	0.0178	29.7	0.0068	15.7	0.01478	26.11	0.829
22.0	0.0154	48.9	0.0051	29.9	0.01147	27.69	0.845
49.8	0.0099	74.5	0.0025	46.6	0.00886	43.72	0.675
50.5	0.0097	84.1	0.0024	57.6	0.00736	46.59	0.655
52.6	0.0090			67.1	0.00670	62.14	0.540
67.0	0.0067			72.8	0.00582	73.36	0.474
80.0	0.0051			74.7	0.00630	77.75	0.454
82.0	0.0051			77.0	0.00556	87.74	0.446
88.0	0.0044			85.1	0.00508	90.75	0.427
95.0	0.0034			87.3	0.00519	96.64	0.438
				88.5	0.00565	99.26	0.438
				99.25	0.00553		

Solubility, $\lambda = \frac{\text{volume of absorbed gas}}{\text{volume of liquid}}$*

Table 33. Binary Systems Containing Glycerol Azeotropic and Nonazeotropic

Second Component			Azeotropic Data	
Formula	Name	B.P. (°C)	B.P. (°C)	Wt. % Glycerol
H_2O	Water	100	Nonazeotropic	
$C_6H_4Br_2$	*p*-Dibromobenzene	220.25	217.1	10
$C_6H_5NO_2$	**Nitrobenzene**	**210.75**	**Nonazeotropic**	
$C_6H_6O_2$	Pyrocatechol	232.9	Nonazeotropic	
$C_6H_6O_2$	Resorcinol	281.4	Nonazeotropic	
$C_7H_7NO_2$	*m*-Nitrotoluene	230.8	229.5	32
$C_7H_7NO_2$	*o*-Nitrotoluene	221.85	220.8	8
$C_7H_7NO_2$	*p*-Nitrotoluene	239.0	235.7	17
C_7H_8	Toluene	110.75	Nonazeotropic	
C_7H_8O	***o*-Cresol**	**191.1**	**Nonazeotropic**	
C_7H_8O	***p*-Cresol**	**201.7**	**Nonazeotropic**	
C_8H_8	Styrene	145.8	Nonazeotropic	
$C_8H_8O_2$	Benzyl formate	202.3	Nonazeotropic	
$C_8H_8O_2$	Methyl benzoate	199.45	Nonazeotropic	
$C_8H_8O_3$	Methyl salicylate	222.35	221.4	7.5
C_8H_{10}	*m*-Xylene	139.0	Nonazeotropic	
C_8H_{10}	*o*-Xylene	143.6	Nonazeotropic	
$C_8H_{10}O$	Phenethyl alcohol	219.4	Nonazeotropic	
$C_8H_{10}O_2$	*m*-Dimethoxybenzene	214.7	212.5	7
$C_9H_{10}O$	*p*-Methylacetophenone	226.35	Nonazeotropic	
$C_9H_{10}O_2$	Benzyl acetate	214.9	Nonazeotropic	
$C_9H_{10}O_2$	Ethyl benzoate	212.6	Nonazeotropic	
$C_9H_{10}O_3$	Ethyl salicylate	233.7	230.5	10.3
C_9H_{12}	Mesitylene	164.6	Nonazeotropic	
C_9H_{12}	Propyl benzene	158.8	Nonazeotropic	
$C_{10}H_8$	Naphthalene	218.05	215.2	10
$C_{10}H_{10}O_2$	Isosafrole	252.0	243.8	16
$C_{10}H_{10}O_2$	Safrole	235.9	231.3	14.5
$C_{10}H_{12}O$	Estragole	215.6	213.5	7.5
$C_{10}H_{12}O_2$	Ethyl α-toluate	228.75	228.6	7
$C_{10}H_{12}O_2$	Propyl benzoate	230.85	228.8	8
$C_{10}H_{12}O_2$	Eugenol	252.7	251.0	14
$C_{10}H_{14}O$	Carvone	231.0	230.85	3
$C_{10}H_{14}O$	Thymol	232.8	Nonazeotropic	
$C_{10}H_{14}O_2$	*m*-Diethoxybenzene	235.4	231.0	13
$C_{10}H_{16}$	Camphene	159.6	Nonazeotropic	
$C_{10}H_{16}$	*d*-Limonene	177.8	177.7	1
$C_{10}H_{16}$	α-Pinene	155.8	Nonazeotropic	
$C_{10}H_{16}$	Thymene	179.7	179.6	1
$C_{11}H_{10}$	1-Methylnaphthalene	244.9	237.25	18
$C_{11}H_{10}$	2-Methylnaphthalene	241.15	233.7	16.5
$C_{11}H_{14}O_2$	1-Allyl-3,4-dimethoxybenzene	255.0	248.3	18
$C_{11}H_{14}O_2$	1,2-Dimethoxy-4-propenylbenzene	270.5	258.4	25
$C_{11}H_{14}O_2$	Butyl benzoate	249.8	243.0	17
$C_{11}H_{14}O_2$	Isobutyl benzoate	241.9	237.4	14
$C_{11}H_{20}O$	Methyl α-terpineol ether	216.2	214.0	8
$C_{12}H_{10}$	Acenaphthene	277.9	259.1	29
$C_{12}H_{10}$	Biphenyl	254.9	243.8	55
$C_{12}H_{10}O$	Phenyl ether	257.7	246.3	22
$C_{12}H_{16}O_2$	Isoamyl benzoate	262.05	251.6	22
$C_{12}H_{16}O_3$	Isoamyl salicylate	279.0	267.0	—
$C_{12}H_{18}$	1,3,5-Triethylbenzene	215.5	212.9	8
$C_{12}H_{20}O_2$	Bornyl acetate	227.7	226.0	10
$C_{13}H_{10}O_2$	Phenyl benzoate	315.0	279.0	55
$C_{13}H_{12}$	Diphenyl methane	265.6	250.8	27
$C_{14}H_{12}O_2$	Benzyl benzoate	324.0	282.5	—
$C_{14}H_{14}$	1,2-Diphenylethane	284.0	261.3	32

Binary and Ternary Mixtures:

The boiling points of various glycerol mixtures, both azeotropic and non-azeotropic, has been compiled and is shown in Table 33. In the system ethyl alcohol-water-glycerol, the affinity of the glycerol for the water prevents the distillation of an alcohol-water azeotrope, and anhydrous alcohol can be distilled from the mixture. This is the basis of certain processes for making absolute alcohol. The addition of certain hygroscopic salts, such as potassium carbonate, makes the process more efficient. The dehydration is best carried out in a rectifying column in which glycerol flows countercurrent to the alcohol vapors[15].

Crystalline Glycerol:

In spite of the tendency of glycerol to supercool, it can be crystallized by the use of seed crystals, or by cooling to −50° C. or below and then slowly warming to about 0° C. Approximately one day is required for crystallization to be completed. The crystals are orthorhombic and very deliquescent.

Purification of glycerol by crystallization from a solvent has been explored[35] and l-butanol was found to be the preferred solvent.

The crystal structure of glycerol has been determined by X-ray analysis, with the aid of a direct method.[75] Out of six possible staggered conformations of glycerol the structural investigation leads to the symmetrical XX-conformation.

Table 34. Solubility of Various Compounds in Glycerine

Substance	Glycerol Concentration % Weight	Temp. (°C)	Sol. in Parts per 100 Parts of Solvent	Ref.†
Alum	*	15	40	6
Ammonium carbonate	*	15	20	8
	99.04	20	19.8	9
	87.27	20	13.7	9
Ammonium chloride	*	15	20.06	8
Anisic aldehyde	*	15	0.1	1
Arsenic acid	*	15	20	6
Arsenious acid	*	15	20	6
Atropine	*	15	3	5
Atropine sulfate	99.04	20	45.2	9
	87.27	20	45.8	9
Barium chloride	*	15	9.73	8
Benzoic acid	**98.5**	—	**2**	**4**
	95.1	23	2.01	—
	90	23	1.74	—
	86.5	—	1.18	4
	75	23	1.02	—
	50	23	0.60	—
Benzyl acetate	*	15	0.1	1
Boric acid	98.5	20	24.80	4
	86.5	20	13.79	4
Brucine	*	15	2.25	5
Calcium hydroxide	35	25	1.3	2
Calcium hypophosphite	**99.04**	**20**	**2.5**	**9**
	87.27	20	3.2	9
Calcium oleate	**45**	**15**	**1.18**	**6**
Calcium sulfate	*	15	5.17	8
Calcium sulfide	*	15	5	6
Cinchonine	*	15	0.30	5
Cinchonine sulfate	*	15	6.70	5
Cinnamic aldehyde	*	15	0.1	1
Codeine hydrochloride	99.04	20	11.1	9
	87.27	20	4.7	9
Copper acetate	*	**15**	**10**	**6**
Copper sulfate	*	15	30	6
Ethyl acetate	99.04	20	1.9	9
	87.27	20	1.8	9
Ethyl ether	99.04	20	0.65	9
	87.27	20	0.38	9
Eugenol	*	15	0.1	1
Ferrous sulfate	*	15	25	6
Guaiacol	99.04	20	13.1	9
	87.27	20	9.05	9
Guaiacol carbonate	99.04	20	0.043	9
	87.27	20	0.039	9
Iodine	*	15	2	8
Iodoform	95	15	0.12	3
Iron and potassium tartrate	*	15	8	5
Iron lactate	*	**15**	**16**	**5**
Iron oleate	45	15	0.71	8
Lead acetate	*	15	10	8
	98.5	—	143	4
	86.5	—	129.3	4
Lead sulfate	*	15	30.3	8
Magnesium oleate	45	15	0.94	6
Mercuric chloride	*	15	8	8
Mercurous chloride	*	15	7.5	5
Mercurous cyanide	*	15	27	5
Morphine	*	15	0.45	5
Morphine acetate	*	15	20	5
Morphine hydrochloride	*	15	20	5
Novacaine	99.04	20	11.2	9
	87.27	20	7.8	9
Oxalic acid	*	15	15.1	6
Pentaerythritol	100	100	9.3	Anon.
Phenacetin	99.04	20	0.47	9
	87.27	20	0.3	9
Phenol	99.04	20	276.4	9
	87.27	20	361.8	9
Phenylethyl alcohol	*	15	1.5	1
Phosphorus	*	**15**	**ca. 0.25**	**8**
Potassium arsenate	*	15	50.13	8
Potassium bromide	*	15	25	6
	98.5	—	**17.15**	**4**
	86.5	—	20.59	4
Potassium chlorate	*	15	3.54	8
	98.5	—	1.03	4
	86.5	—	1.32	4
Potassium chloride	*	15	3.72	8
Potassium cyanide	*	15	31.84	8
Potassium iodate	*	15	1.9	5
Potassium iodide	*	15	39.72	8
	98.5	—	50.70	4
	86.5	—	58.27	4
Quinine	*	15	0.47	8
Quinine sulfate	98.5	—	1.32	4
	86.5	—	0.72	4
Quinine tannate	*	15	0.25	5
	99.04	20	2.8	9
	87.27	20	2.45	9
Salicin	*	15	12.5	5
Salicylic acid	98.5	—	1.63	4
	86.4	—	0.985	4
Santonin	*	15	6	5
Sodium arsenate	*	15	50	8
	99.04	20	64	9
	87.27	20	44	9
Sodium bi-borate	98.5	—	111.15	4
	86.5	—	89.36	4
Sodium bicarbonate	*	15	8.06	8
Sodium tetraborate (borax)		15	60	8
Sodium carbonate (crystals)	*	15	98.3	8
Sodium chlorate	*	15	20	5
Sodium hypophosphite	99.04	20	32.7	9
	87.27	20	42.2	9
Sodium pyrophosphate	87.27	20	9.6	9
Sodium sulfate·12H_2O	100	25	8.1	10
Stearic acid	99.04	20	0.089	9
	87.27	20	0.066	9
Strychnine	*	**15**	**0.25**	**5**
Strychnine nitrate	*	15	4	5
Strychnine sulfate	*	15	22.5	5
Sulfur	*	15	ca. 0.1	8
Tannic acid	*	15	48.8	6
Tannin	*	15	48.83	8
Tartar emetic	*	15	5.5	5
Theobromine	99.04	20	0.028	9
	87.27	20	0.017	9
Urea	*	15	50	5
Zinc chloride	*	**15**	**49.87**	**8**
Zinc iodide	*	15	39.78	8
Zinc sulfate	*	15	35.18	8
Zinc valerate	99.04	20	0.336	9
	87.27	20	0.382	9

*Glycerol concentration not specified, probably 95 to 100 per cent.

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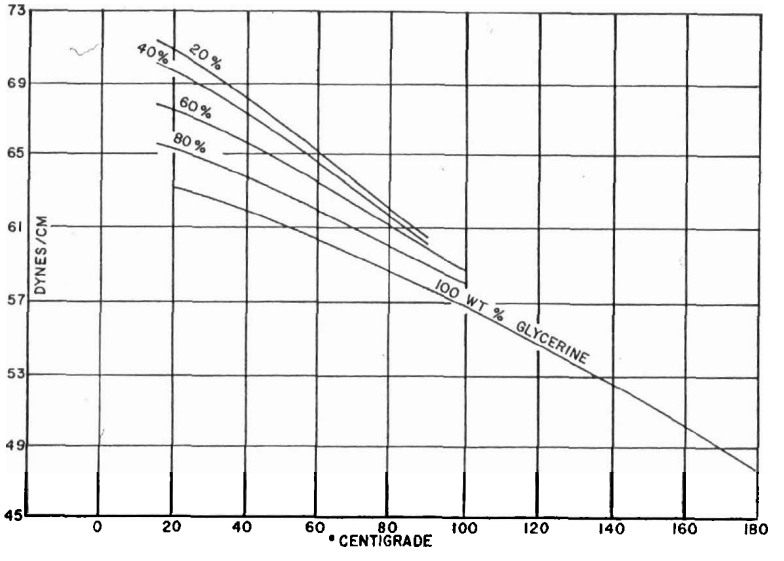
Table 35. Surface Tension of Glycerol in Dynes/cm

Temp. (°C)	Glycerol % by Wt.					
	99.19	81.98	61.44	39.31	20.29	0.0
17		65.41	—	—	—	—
18	62.47	—	—	69.86	71.13	—
20	—	65.26	67.64	—	70.93	71.68
30	62.08	64.66	66.68	68.42	69.49	70.25
40	61.53	63.93	65.71	67.18	68.02	68.68
50	61.05	63.05	64.67	65.86	66.79	67.05
60	60.34	62.11	63.59	64.55	65.23	65.50
70	59.36	61.11	62.39	63.09	63.73	63.94
80	58.72	60.07	61.21	61.62	62.01	62.16
90	57.85	59.02	59.92	60.13	60.48	60.51

Fig. Q. Aqueous Surface Tension for Glycerine from 20°C to 100°C.*



Surface Tension and Surface Energy:

The surface tension of glycerol is less than that of water, though higher than the majority of organic liquids, and diminishes with increasing temperature. It is raised slightly by the addition of water, but sharply diminished by the addition of ethyl alcohol.

The surface tension of aqueous glycerol at temperatures from 17 to 90° C. were determined by Muller[65]. Table 35.

Surface tension figures for 100% glycerol are:

63.4 dynes/cm (20° C.)
58.6 dynes/cm (90°)
51.9 dynes/cm (150°)

Surface tension of aqueous glycerine solutions from 20° to 100° C have also been determined and are plotted in Figure Q.[76]

Compressibility:

Glycerol is one of the least compressible of liquids, being only one half as compressible as water and having a compressibility of 21.10 x 10^{-6} cc per atm. per cm^2 at 28.5° C. Of eighteen organic liquids tested, using pressures up to 12,000 Kg/cm^2 at 0, 50 and 95° C. glycerol was the least compressible. Data on the relative volumes of water and pure glycerol under pressure are given in Table 36.[63]

Table 36. Compressibility of Water and Glycerol

Pressure kg/cm^2	Relative Volumes						
	Water			Pure Glycerol			50% Glycerol
	0°C	50°C	95°C	0°C	50°C	95°C	30°C
0	1.0000	—	—	1.0000	1.0266	—	1.0000
500	.9771	—	—	.9900	1.0136	—	—
1000	.9567	.9741	.9984	.9806	1.0025	1.0240	.9674
1500	.9396	.9582	.9812	.9721	.9930	1.0125	—
2000	.9248	.9439	.9661	.9641	.9843	1.0024	.9416
3000	.8996	.9201	.9409	.9501	.9688	.9853	.9199
4000	.8795	.8997	.9194	.9373	.9548	.9700	.9007
5000	.8626	.8824	.9009	.9264	.9423	.9565	.8842
6000	—	.8668	.8849	.9157	.9310	.9447	.8701
7000	—	.8530	.8705	.9057	.9211	.9342	.8566
8000	—	.8407	.8577	.8958	.9121	—	.8447
9000	—	.8296	.8461	.8867	.9036	—	.8342
10000	—	.8192	.8352	.8783	.8955	—	.8241
11000	—	—	.8256	.8712	.8879	—	.8149
12000	—	—	—	.8648	.8800	—	—

Magnetic Susceptibility:

The unit of magnetic susceptibility of glycerol ($Hx10^6$) at 22° C. is –0.64.[41]

Dissociation Constant:

The dissociation constant of glycerol as a weak acid is $0.07x10^{-13}$.[42]

Conductivity:

At ordinary temperatures the conductivity of glycerol is $5x10^{-8}$ reciprocal ohms[49]. The specific conductivity of glycerol at temperatures from 0 to 21° C. is given in Table 37.[66]

The electrical conductivity of glycerine has recently been determined for solutions of from 1 to 94% glycerol, as shown in Table 38. The maximum conductivity was obtained at a glycerol content of 18%.[77]

Flash and Fire Points, Auto Ignition Temperature:

The flash and fire point of 99% glycerol are 350° F. (177° C.) and 400° F. (204° C.) respectively when determined in a Cleveland open cup, using the procedure described in Test D 92-33 of the American Society for Testing Materials[39]. When aqueous glycerol is tested it will not flash until enough water has evaporated to bring the glycerol concentration to about 97.5% by weight. It will then flash at 375° F. (190° C.). This higher flash point may be due to the water vapor accompanying the glycerol vapor. Continuation of the test to the fire point results in further concentration of the glycerol to about 98.6% by weight. At this point the 400° F. is reached.

The auto ignition temperature of glycerol is 523° C. on platinum or 429° C. on glass.[40]

Table 37. Specific Conductivity, N, of Glycerol

°C	0.0	5.9	11.7	14.8	16.0	17.6	20.0	21.3
$N \times 10^8$	2.2	3.6	5.6	7.8	8.4	9.6	10.0	12.3

Table 38. Electrical Conductivity of Glycerol-Water Solutions

Glycerol Content, Weight %	× $.10^5$ ohm^{-1} cm^{-1}	Glycerol Content, Weight %	× $.10^5$ ohm^{-1} cm^{-1}	Glycerol Content, Weight %	× $.10^5$ ohm^{-1} cm^{-1}	Glycerol Content, Weight %	× $.10^5$ ohm^{-1} cm^{-1}
1	10.30	25	13.75	49	11.65	73	6.40
2	10.55	26	13.70	50	11.50	74	6.10
3	10.80	27	13.60	51	11.40	75	5.80
4	11.05	28	13.53	52	11.30	76	5.50
5	11.30	29	13.47	53	11.20	77	5.20
6	11.55	30	13.40	54	11.05	78	4.90
7	11.80	31	13.35	55	10.82	79	4.55
8	12.05	32	13.30	56	10.70	80	4.25
9	12.30	33	13.25	57	10.50	81	4.00
10	12.55	34	13.20	58	10.30	82	3.75
11	12.80	35	13.10	59	10.15	83	3.50
12	13.05	36	13.00	60	10.00	84	3.25
13	13.30	37	12.85	61	9.75	85	3.00
14	13.50	38	12.75	62	9.50	86	2.75
15	13.70	39	12.65	63	9.25	87	2.50
16	13.90	40	12.60	64	9.00	88	2.25
17	14.05	41	12.50	65	8.75	89	2.00
18	14.10	42	12.40	66	8.50	90	1.80
19	14.05	43	12.30	67	8.25	91	1.60
20	14.00	44	12.20	68	8.00	92	1.40
21	13.95	45	12.10	69	7.65	93	1.20
22	13.90	46	12.00	70	7.30	94	1.00
23	13.85	47	11.90	71	7.00		
24	13.80	48	11.80	72	6.70		

Thermal Expansion:

The expansion of glycerol with increasing temperature may be measured by its change in volume or change in density. Comey and Backus[10] determined these values at temperature intervals above 15.5° C. as shown in Table 41. Values calculated by Bosart and Snoddy are given in Table 42. Gerlach[11] made direct expansion measurements with a dilatometer to show how volume increases with temperature up to the boiling point, Table 43.

Heat of Formation and Combustion:

The heat of combustion at 15° C. is 397.0 k cal per mole[69] and the calculated heat of formation is 159.80 k cal[70].

Taste:

The taste of glycerine is predominantly sweet though somewhat less sweet than sucrose[71].

Sound Transmission:

The velocity of sound in pure glycerol has been studied by a number of researchers, using different methods of determination. Results vary but the most generally accepted figure is 1.92 x 10^5 cm/sec at 20° C.[72] for pure glycerol. Figures for velocities at varying temperatures and concentrations are given in Table 44[73].

Cryoscopic Constant:

The cryoscopic constant is defined as the freezing point depression per mol of solute (water) in 1000 grams of solvent (glycerol). This was determined by Pushin and Glagoleva[31] and their results are given in Table 45.

Table 45. Cryoscopic Constant of Glycerol

Glycerol (g)	Water (g)	$\triangle t$	K
11.4474	0.0435	0.690°	3.27
10.7008	0.0610	1.116°	3.52
11.4474	0.1297	2.326°	3.69

$\triangle t$ is the depression of the freezing point.

K is the cryoscopic constant; the freezing point depression per mole of solute (water) in 1000 grams of solvent (glycerol).

Table 41. Coefficient of Expansion (Gravimetric) of High Gravity Glycerol of Sp. Gr. 1.254 to 1.264 at 15.5/15.5°C

Temp. Interval	Coefficient
15.5–20	0.000612
15.5–25	0.000617
15.5–30	0.000622

Table 42. Coefficient of Thermal Expansion (Gravimetric) of Mixtures of Glycerol and Water

Glycerol (%)	Change in Specific Gravity per Degree		
	15–20°C	15–25°C	20–25°C
100	0.000615	0.000615	0.000610
97.5	0.000620	0.000615	0.000605
95	0.000615	0.000615	0.000615
90	0.000610	0.000615	0.000620
80	0.000620	0.000615	0.000610
70	0.000580	0.000570	0.000565
60	0.000540	0.000545	0.000550
50	0.000485	0.000495	0.000510
40	0.000430	0.000435	0.000445
30	0.000370	0.000385	0.000400
20	0.000300	0.000315	0.000325
10	0.000230	0.000255	0.000280
Water	0.000180	0.000205	0.000230

Table 43. Thermal Expansion of Pure Glycerol

(°C)	Vol	(°C)	Vol	(°C)	Vol
0	= 10,000	100	= 10,530	200	= 11,245
10	= 10,045	110	= 10,590	210	= 11,330
20	= 10,090	120	= 10,655	220	= 11,415
30	= 10,140	130	= 10,720	230	= 11,500
40	= 10,190	140	= 10,790	240	= 11,585
50	= 10,240	150	= 10,860	250	= 11,670
60	= 10,295	160	= 10,930	260	= 11,755
70	= 10,350	170	= 11,005	270	= 11,840
80	= 10,410	180	= 11,080	280	= 11,925
90	= 10,470	190	= 11,160	290	= 12,010

Table 44. Adiabatic Compressibility of Glycerol; Velocity of Sound in Glycerol

Temp. °C	Bhagavantum and Joga Rao			Freyer et al.		
	Density	Vel. of Sound m/sec	Compress. per atm. per cc × 10^{-6}	Density	Vel. of Sound m/sec.	Compress. per atm. per cc × 10^{-6}
10	—	—	—	1.2671	1941.5	21.2
20	—	—	—	1.2613	1923	21.7
28.5	1.2562	1957	21.1	—	—	—
30	—	—	—	1.2553	1905	22.3
40	1.2490	1926	21.9	1.2491	1886.5	22.8
50	1.2426	1895	22.7	1.2427	1868.5	23.4
60	1.2360	1862	23.6	—		—
70	1.2292	1840	24.3	—	—	—

Glycerine Grades and Definitions

Refined glycerine is sold by American producers on individual product specifications which differ in minor respects from company to company.

Glycerine for a particular field of use — say for cellophane or alkyd resins — may be designated as such by the producer in meeting special tests of the consuming industry.

The following information as to commercial grades has been obtained from Federal and other published data. However, it does not represent Association classification, nor does the Association warrant that glycerine so designated will meet these specifications.

"Glycerine" is the most widely used commercial name, but is frequently spelled "glycerin." Glycerol (1,2,3-propanetriol) refers to the chemical compound and anhydrous content in a formulation. Concentration of commercial grades given below is by weight, normally obtained by conversion from specific gravity measurements made at either 15°/15°C or 25°/25°C as designated.

U.S.P. Glycerin(e), often referred to as C.P. (chemically pure) glycerine. It is a water-white product for uses requiring glycerine of high purity with taste and odor characteristics desirable for pharmaceutical and food purposes. Its glycerol content is "not less than 95%" (as defined by a specific gravity of not less than 1.249 at 25°/25°C), and it is normally shipped at 96% concentration. See U.S. Pharmacopoeia XVII. Glycerine originating either from fats or from propylene is now offered meeting U.S.P. specifications.

99% C.P. Glycerine is generally the same quality as U.S.P. but is offered at a higher concentration, typically not less than 99.0% glycerol (Specific Gravity 1.2595 minimum at 25°/25°C).

High Gravity Glycerine is a designation for a commercial grade of glycerine close to white in color, and conforming to Federal Specification O-G-491b (amended). This product also conforms to ASTM specification D 1257-55 "High Gravity Glycerine for Alkyd Resins," which must contain not less than 98.7% glycerol based on specific gravity at 1.2587 minimum at 25°/25°C. It is now commonly supplied at not less than 99.0% concentration (Specific Gravity minimum 1.2595 at 25°/25°C).

Glycerine from propylene, referred to as "synthetic glycerine," conforms to Federal Specifications for High Gravity Glycerine and to the ASTM specification. It is offered as U.S.P. both as a 96% material and as a 99.5% minimum product. The glycerol content of the regular grade is 99.5% minimum.

Dynamite Glycerine meets all regular High Gravity Specifications except color, but will not be darker than the Federal Color Standard for OG491b-(amended).

Saponification (88%) and Soap Lye (80%) Crude. These are grades of natural glycerine as purchased for refining. Saponification crude is a concentrate of "sweetwater" from fat hydrolysis or "splitting." It has limited industrial use as such. Soap lye crude is the product of the spent lye of the soap kettle, after being concentrated in a desalting evaporator. Although an important article of commerce, it is almost never used without refining.

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