Designation: D 3505 – 96 (Reapproved 2000)

Standard Test Method for Density or Relative Density of Pure Liquid Chemicals[1]

This standard is issued under the fixed designation D 3505; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method describes a simplified procedure for the measurement of density or relative density of pure liquid chemicals for which accurate temperature expansion functions are known. It is restricted to liquids having vapor pressures not exceeding 600 mm Hg (0.8 atm) at the equilibration temperature, and having viscosities not exceeding 15 cSt at 20°C (60°F).

1.2 Means are provided for reporting results in the following units:

Density g/cm^3 at 20°C
Density g/ml at 20°C
Relative density 20°C/4°C
Relative density 60°F/60°F (15.56°C/15.56°C)
Commercial density, lb (in air)/U.S. gal at 60°F
Commercial density, lb (in air)/U.K. gal at 60°F.

NOTE 1—This test method is based on the old definition of 1 L = 1.000028 dm^3 (1 mL = 1.000028 cm^3). In 1964 the General Conference on Weights and Measures withdrew this definition of the litre and declared that the word "litre" was a special name for the cubic decimetre, thus making 1 mL = 1 cm^3 exactly.

NOTE 2—An alternative method for determining relative density of pure liquid chemicals is Test Method D 4052.

1.3 The following applies to all specified limits in this test method: for purposes of determining conformance with this test method, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand digit used in expressing the specification limit, in accordance with the rounding-off method of Practice E 29.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific hazard statements are given in 7.1.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water[2]
D 1555 Test Method for Calculation of Volume and Weight of Industrial Aromatic Hydrocarbons[3]
D 3437 Practice for Sampling and Handling Liquid Cyclic Products[3]
D 4052 Test Method for Density and Relative Density of Liquids by Digital Density Meter[4]
E 1 Specification of ASTM Thermometers[5]
E 12 Terminology Relating to Density and Specific Gravity of Solids, Liquids, and Gases[6]
E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[7]

2.2 *Other Document:*

OSHA Regulations, 29 CFR, paragraphs 1910.1000 and 1910.1200[8]

3. Terminology

3.1 *Definitions:*

3.1.1 *density*—the mass of material per unit volume at a given temperature called the "reference temperature." Weight corrected to a standard acceleration of gravity and corrected for the buoyant effect of air is used to measure mass. This method specifies the use of a beam balance to determine weight so that no correction for variation in acceleration of gravity is necessary. When a torsion or spring balance is used, such correction must be applied.

3.1.2 *relative density*—the ratio of the density of the material at reference temperature" t" to the density of pure water, in consistent units, at reference temperature t_2. It is common practice to use reference temperature t_1 equal to t_2.

3.1.2.1 Since the mass of water at 4°C is very close to 1 g/mL or 1 g/cm^3, it is common practice to set the reference temperature t_2 for water at 4°C. When this is done and the density of the material is given in grams per millilitre, or grams per cubic centimetre, the value of density is very nearly

[1] This test method is under the jurisdiction of ASTM Committee D16 on Aromatic Hydrocarbons and Related Chemicals and is the direct responsibility of Subcommittee D16.04 on Instrumental Analysis.

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[2] *Annual Book of ASTM Standards*, Vol 11.01.
[3] *Annual Book of ASTM Standards*, Vol 06.04.
[4] *Annual Book of ASTM Standards*, Vol 05.02.
[5] *Annual Book of ASTM Standards*, Vol 14.03.
[6] Discontinued 1996; see *1995 Annual Book of ASTM Standards*, Vol 15.05.
[7] *Annual Book of ASTM Standards*, Vol 14.02.
[8] Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

identical to the value for relative density. Thus, density at 20°C in g/cm ^{3} or g/mL, is nearly identical with relative density 20°C/4°C.

3.1.3 *commercial density*—weight per unit volume without correcting for the buoyant effect of air and is limited in this document to pounds (in air) per U.S. gallon at 60°F, or pounds in air per U.K. gallon at 60°F. This is the density most commonly used in commercial transactions in the petroleum and coal chemicals industry in the United States and Canada.

3.2 The definitions included in Terminology E 12 are applicable to this test method.

4. Summary of Test Method

NOTE 3—See Appendix for details on the method and derivation of formulas.

4.1 For materials listed in Table 1 the sample is drawn into a weighed and calibrated bicapillary pycnometer. The filler pycnometer is allowed to come to equilibrium at any convenient temperature between 10 and 30°C (50 and 86°F). The equilibrium temperature is measured to the nearest 0.02°C. The weight is determined using a beam balance. The density, relative density, or commercial density at the desired reference temperature is then calculated from the sample weight, a calibration factor proportional to an equal volume of water, and a multiplier which corrects for the buoyancy of air and the change in volume of the pycnometer and the sample due to deviation from the chosen reference temperature.

TABLE I, PART I 20° C Reference Temperature Multiplier, F20, for use in Computing Density, 12.1

CHOOSE A MULTIPLIER FOR THE MATERIAL BEING MEASURED CORRESPONDING TO THE BATH TEMPERATURE AT WHICH THE PYCNOMETER EQUILIBRATED.

TEMP DEGC	BENZENE	TOLUENE	MIXED XYLENES	O-XYLENE	M-XYLENE	P-XYLENE	STYRENE	CYCLO-HEXANE
10.0	0.98822	0.98941	0.99028	0.99052	0.99028	0.99011	0.99029	0.98912
10.2	0.98845	0.98962	0.99047	0.99070	0.99047	0.99030	0.99048	0.98933
10.4	0.98868	0.98983	0.99066	0.99089	0.99066	0.99049	0.99066	0.98953
10.6	0.98891	0.99003	0.99085	0.99107	0.99085	0.99069	0.99085	0.98973
10.8	0.98914	0.99024	0.99104	0.99126	0.99104	0.99088	0.99104	0.98993
11.0	0.98937	0.99045	0.99123	0.99144	0.99123	0.99107	0.99123	0.99013
11.2	0.98960	0.99066	0.99142	0.99163	0.99142	0.99126	0.99142	0.99034
11.4	0.98982	0.99086	0.99161	0.99181	0.99161	0.99146	0.99161	0.99054
11.6	0.99005	0.99107	0.99179	0.99200	0.99179	0.99165	0.99180	0.99075
11.8	0.99028	0.99128	0.99198	0.99218	0.99198	0.99184	0.99199	0.99095
12.0	0.99051	0.99148	0.99217	0.99237	0.99217	0.99204	0.99218	0.99116
12.2	0.99074	0.99169	0.99236	0.99255	0.99236	0.99223	0.99237	0.99136
12.4	0.99097	0.99190	0.99255	0.99274	0.99255	0.99242	0.99256	0.99157
12.6	0.99120	0.99211	0.99274	0.99292	0.99274	0.99262	0.99275	0.99178
12.8	0.99144	0.99231	0.99293	0.99311	0.99293	0.99281	0.99294	0.99199
13.0	0.99167	0.99252	0.99312	0.99329	0.99312	0.99300	0.99313	0.99220
13.2	0.99190	0.99273	0.99331	0.99348	0.99331	0.99320	0.99332	0.99240
13.4	0.99213	0.99294	0.99350	0.99367	0.99350	0.99339	0.99351	0.99261
13.6	0.99236	0.99315	0.99369	0.99385	0.99369	0.99358	0.99370	0.99282
13.8	0.99259	0.99335	0.99389	0.99404	0.99389	0.99378	0.99390	0.99303
14.0	0.99282	0.99356	0.99408	0.99422	0.99408	0.99397	0.99409	0.99325
14.2	0.99305	0.99377	0.99427	0.99441	0.99427	0.99417	0.99428	0.99346
14.4	0.99329	0.99398	0.99446	0.99460	0.99446	0.99436	0.99447	0.99367
14.6	0.99352	0.99419	0.99465	0.99478	0.99465	0.99456	0.99466	0.99388
14.8	0.99375	0.99440	0.99484	0.99497	0.99484	0.99475	0.99485	0.99410
15.0	0.99398	0.99461	0.99503	0.99516	0.99503	0.99495	0.99504	0.99431
15.2	0.99421	0.99481	0.99522	0.99534	0.99522	0.99514	0.99523	0.99452
15.4	0.99445	0.99502	0.99541	0.99553	0.99541	0.99534	0.99542	0.99474
15.6	0.99468	0.99523	0.99561	0.99572	0.99561	0.99553	0.99562	0.99496
15.8	0.99491	0.99544	0.99580	0.99590	0.99580	0.99573	0.99581	0.99517
16.0	0.99515	0.99565	0.99599	0.99609	0.99599	0.99592	0.99600	0.99539
16.2	0.99538	0.99586	0.99618	0.99628	0.99618	0.99612	0.99619	0.99561
16.4	0.99561	0.99607	0.99637	0.99646	0.99637	0.99631	0.99638	0.99582
16.6	0.99585	0.99628	0.99657	0.99665	0.99657	0.99651	0.99658	0.99604
16.8	0.99608	0.99649	0.99676	0.99684	0.99676	0.99670	0.99677	0.99626
17.0	0.99632	0.99670	0.99695	0.99703	0.99695	0.99690	0.99696	0.99648
17.2	0.99655	0.99691	0.99714	0.99721	0.99714	0.99710	0.99715	0.99670
17.4	0.99679	0.99712	0.99734	0.99740	0.99734	0.99729	0.99734	0.99692
17.6	0.99702	0.99733	0.99753	0.99759	0.99753	0.99749	0.99754	0.99715
17.8	0.99726	0.99754	0.99772	0.99778	0.99772	0.99768	0.99773	0.99737
18.0	0.99749	0.99775	0.99791	0.99797	0.99791	0.99788	0.99792	0.99759
18.2	0.99773	0.99796	0.99811	0.99815	0.99811	0.99808	0.99811	0.99781
18.4	0.99796	0.99817	0.99830	0.99834	0.99830	0.99827	0.99831	0.99804
18.6	0.99820	0.99838	0.99849	0.99853	0.99849	0.99847	0.99850	0.99826
18.8	0.99843	0.99859	0.99869	0.99872	0.99869	0.99867	0.99869	0.99849
19.0	0.99867	0.99880	0.99888	0.99891	0.99888	0.99886	0.99888	0.99871
19.2	0.99890	0.99901	0.99907	0.99910	0.99907	0.99906	0.99908	0.99894
19.4	0.99914	0.99922	0.99927	0.99928	0.99927	0.99926	0.99927	0.99917
19.6	0.99938	0.99943	0.99946	0.99947	0.99946	0.99946	0.99946	0.99939
19.8	0.99961	0.99964	0.99966	0.99966	0.99966	0.99965	0.99966	0.99962
20.0	0.99985	0.99985	0.99985	0.99985	0.99985	0.99985	0.99985	0.99985

TABLE I, PART I *Continued*

CHOOSE A MULTIPLIER FOR THE MATERIAL BEING MEASURED CORRESPONDING TO THE BATH TEMPERATURE AT WHICH THE PYCNOMETER EQUILIBRATED.

TEMP DEGC	BENZENE	TOLUENE	MIXED XYLENES	O-XYLENE	M-XYLENE	P-XYLENE	STYRENE	CYCLO-HEXANE
20.0	0.99985	0.99985	0.99985	0.99985	0.99985	0.99985	0.99985	0.99985
20.2	1.00009	1.00006	1.00004	1.00004	1.00004	1.00005	1.00004	1.00008
20.4	1.00032	1.00027	1.00024	1.00023	1.00024	1.00025	1.00024	1.00031
20.6	1.00056	1.00048	1.00043	1.00042	1.00043	1.00044	1.00043	1.00054
20.8	1.00080	1.00069	1.00063	1.00061	1.00063	1.00064	1.00062	1.00077
21.0	1.00104	1.00091	1.00082	1.00080	1.00082	1.00084	1.00082	1.00100
21.2	1.00128	1.00112	1.00102	1.00099	1.00102	1.00104	1.00101	1.00124
21.4	1.00151	1.00133	1.00121	1.00118	1.00121	1.00124	1.00121	1.00147
21.6	1.00175	1.00154	1.00141	1.00137	1.00141	1.00143	1.00140	1.00170
21.8	1.00199	1.00175	1.00160	1.00156	1.00160	1.00163	1.00159	1.00194
22.0	1.00223	1.00196	1.00180	1.00175	1.00180	1.00183	1.00179	1.00217
22.2	1.00247	1.00218	1.00199	1.00194	1.00199	1.00203	1.00198	1.00241
22.4	1.00271	1.00239	1.00219	1.00213	1.00219	1.00223	1.00218	1.00264
22.6	1.00295	1.00260	1.00238	1.00232	1.00238	1.00243	1.00237	1.00288
22.8	1.00319	1.00281	1.00258	1.00251	1.00258	1.00263	1.00257	1.00312
23.0	1.00342	1.00302	1.00278	1.00270	1.00278	1.00283	1.00276	1.00336
23.2	1.00366	1.00324	1.00297	1.00289	1.00297	1.00303	1.00296	1.00360
23.4	1.00390	1.00345	1.00317	1.00308	1.00317	1.00322	1.00315	1.00383
23.6	1.00414	1.00366	1.00336	1.00327	1.00336	1.00342	1.00335	1.00408
23.8	1.00438	1.00387	1.00356	1.00346	1.00356	1.00362	1.00354	1.00432
24.0	1.00462	1.00409	1.00376	1.00365	1.00376	1.00382	1.00374	1.00456
24.2	1.00487	1.00430	1.00395	1.00384	1.00395	1.00402	1.00393	1.00480
24.4	1.00511	1.00451	1.00415	1.00403	1.00415	1.00422	1.00413	1.00504
24.6	1.00535	1.00473	1.00435	1.00422	1.00435	1.00442	1.00432	1.00529
24.8	1.00559	1.00494	1.00454	1.00442	1.00454	1.00462	1.00452	1.00553
25.0	1.00583	1.00515	1.00474	1.00461	1.00474	1.00482	1.00471	1.00577
25.2	1.00607	1.00537	1.00494	1.00480	1.00494	1.00502	1.00491	1.00602
25.4	1.00631	1.00558	1.00514	1.00499	1.00514	1.00522	1.00511	1.00627
25.6	1.00656	1.00579	1.00533	1.00518	1.00533	1.00542	1.00530	1.00651
25.8	1.00680	1.00601	1.00553	1.00537	1.00553	1.00563	1.00550	1.00676
26.0	1.00704	1.00622	1.00573	1.00557	1.00573	1.00583	1.00569	1.00701
26.2	1.00728	1.00643	1.00593	1.00576	1.00593	1.00603	1.00589	1.00726
26.4	1.00753	1.00665	1.00612	1.00595	1.00612	1.00623	1.00609	1.00751
26.6	1.00777	1.00686	1.00632	1.00614	1.00632	1.00643	1.00628	1.00776
26.8	1.00801	1.00707	1.00652	1.00634	1.00652	1.00663	1.00648	1.00801
27.0	1.00825	1.00729	1.00672	1.00653	1.00672	1.00683	1.00667	1.00826
27.2	1.00850	1.00750	1.00692	1.00672	1.00692	1.00703	1.00687	1.00851
27.4	1.00874	1.00772	1.00711	1.00691	1.00711	1.00724	1.00707	1.00876
27.6	1.00899	1.00793	1.00731	1.00711	1.00731	1.00744	1.00726	1.00902
27.8	1.00923	1.00815	1.00751	1.00730	1.00751	1.00764	1.00746	1.00927
28.0	1.00947	1.00836	1.00771	1.00749	1.00771	1.00784	1.00766	1.00953
28.2	1.00972	1.00858	1.00791	1.00769	1.00791	1.00804	1.00786	1.00978
28.4	1.00996	1.00879	1.00811	1.00788	1.00811	1.00825	1.00805	1.01004
28.6	1.01021	1.00901	1.00831	1.00807	1.00831	1.00845	1.00825	1.01029
28.8	1.01045	1.00922	1.00851	1.00827	1.00851	1.00865	1.00845	1.01055
29.0	1.01070	1.00944	1.00871	1.00846	1.00871	1.00885	1.00864	1.01081
29.2	1.01094	1.00965	1.00891	1.00866	1.00891	1.00906	1.00884	1.01107
29.4	1.01119	1.00987	1.00911	1.00885	1.00911	1.00926	1.00904	1.011[illegible]
29.6	1.01143	1.01008	1.00931	1.00904	1.00931	1.00946	1.00924	1.0115[illegible]
29.8	1.01168	1.01030	1.00951	1.00924	1.00951	1.00966	1.00944	1.01185
30.0	1.01192	1.01051	1.00971	1.00943	1.00971	1.00987	1.00963	1.01211

TABLE I, PART II 60° F Reference Temperature Multiplier, F60, for use in Computing Density, 12.1

CHOOSE A MULTIPLIER FOR THE MATERIAL BEING MEASURED CORRESPONDING TO THE BATH TEMPERATURE AT WHICH THE PYCNOMETER EQUILIBRATED.

TEMP DEGC	BENZENE	TOLUENE	MIXED XYLENES	O-XYLENE	M-XYLENE	P-XYLENE	STYRENE	CYCLO-HEXANE
10.0	0.99341	0.99405	0.99454	0.99467	0.99454	0.99444	0.99454	0.99403
10.2	0.99364	0.99426	0.99473	0.99485	0.99473	0.99464	0.99473	0.99424
10.4	0.99387	0.99446	0.99492	0.99504	0.99492	0.99483	0.99492	0.99444
10.6	0.99410	0.99467	0.99511	0.99523	0.99511	0.99502	0.99511	0.99464
10.8	0.99433	0.99488	0.99530	0.99541	0.99530	0.99522	0.99530	0.99485
11.0	0.99456	0.99509	0.99549	0.99560	0.99549	0.99541	0.99549	0.99505
11.2	0.99479	0.99530	0.99568	0.99578	0.99568	0.99560	0.99568	0.99525
11.4	0.99502	0.99550	0.99587	0.99597	0.99587	0.99580	0.99587	0.99546
11.6	0.99525	0.99571	0.99606	0.99615	0.99606	0.99599	0.99606	0.99567
11.8	0.99548	0.99592	0.99625	0.99634	0.99625	0.99619	0.99625	0.99587
12.0	0.99571	0.99613	0.99644	0.99653	0.99644	0.99638	0.99644	0.99608
12.2	0.99594	0.99634	0.99663	0.99671	0.99663	0.99657	0.99663	0.99629
12.4	0.99617	0.99655	0.99682	0.99690	0.99682	0.99677	0.99682	0.99649
12.6	0.99640	0.99675	0.99701	0.99708	0.99701	0.99696	0.99701	0.99670
12.8	0.99664	0.99696	0.99721	0.99727	0.99721	0.99716	0.99721	0.99691
13.0	0.99687	0.99717	0.99740	0.99746	0.99740	0.99735	0.99740	0.99712
13.2	0.99710	0.99738	0.99759	0.99764	0.99759	0.99755	0.99759	0.99733
13.4	0.99733	0.99759	0.99778	0.99783	0.99778	0.99774	0.99778	0.99754
13.6	0.99756	0.99780	0.99797	0.99802	0.99797	0.99794	0.99797	0.99775
13.8	0.99780	0.99801	0.99816	0.99820	0.99816	0.99813	0.99816	0.99796
14.0	0.99803	0.99822	0.99835	0.99839	0.99835	0.99833	0.99835	0.99818
14.2	0.99826	0.99843	0.99854	0.99858	0.99854	0.99852	0.99855	0.99839
14.4	0.99850	0.99863	0.99874	0.99876	0.99874	0.99872	0.99874	0.99860
14.6	0.99873	0.99884	0.99893	0.99895	0.99893	0.99891	0.99893	0.99882
14.8	0.99896	0.99905	0.99912	0.99914	0.99912	0.99911	0.99912	0.99903
15.0	0.99920	0.99926	0.99931	0.99933	0.99931	0.99930	0.99931	0.99925
15.2	0.99943	0.99947	0.99950	0.99951	0.99950	0.99950	0.99950	0.99946
15.4	0.99966	0.99968	0.99970	0.99970	0.99970	0.99969	0.99970	0.99968
15.6	0.99990	0.99989	0.99989	0.99989	0.99989	0.99989	0.99989	0.99989
15.8	1.00013	1.00010	1.00008	1.00008	1.00008	1.00009	1.00008	1.00011
16.0	1.00037	1.00031	1.00027	1.00026	1.00027	1.00028	1.00027	1.00033
16.2	1.00060	1.00052	1.00047	1.00045	1.00047	1.00048	1.00047	1.00055
16.4	1.00084	1.00073	1.00066	1.00064	1.00066	1.00067	1.00066	1.00077
16.6	1.00107	1.00094	1.00085	1.00083	1.00085	1.00087	1.00085	1.00099
16.8	1.00131	1.00115	1.00105	1.00102	1.00105	1.00107	1.00105	1.00121
17.0	1.00154	1.00136	1.00124	1.00120	1.00124	1.00126	1.00124	1.00143
17.2	1.00178	1.00158	1.00143	1.00139	1.00143	1.00146	1.00143	1.00165
17.4	1.00201	1.00179	1.00163	1.00158	1.00163	1.00166	1.00162	1.00187
17.6	1.00225	1.00200	1.00182	1.00177	1.00182	1.00186	1.00182	1.00210
17.8	1.00249	1.00221	1.00201	1.00196	1.00201	1.00205	1.00201	1.00232
18.0	1.00272	1.00242	1.00221	1.00215	1.00221	1.00225	1.00220	1.00254
18.2	1.00296	1.00263	1.00240	1.00234	1.00240	1.00245	1.00240	1.00277
18.4	1.00319	1.00284	1.00259	1.00252	1.00259	1.00264	1.00259	1.00299
18.6	1.00343	1.00305	1.00279	1.00271	1.00279	1.00284	1.00278	1.00322
18.8	1.00367	1.00326	1.00298	1.00290	1.00298	1.00304	1.00296	1.00344
19.0	1.00391	1.00348	1.00318	1.00309	1.00318	1.00324	1.00317	1.00367
19.2	1.00414	1.00369	1.00337	1.00328	1.00337	1.00344	1.00337	1.00390
19.4	1.00438	1.00390	1.00357	1.00347	1.00357	1.00363	1.00356	1.00413
19.6	1.00462	1.00411	1.00376	1.00366	1.00376	1.00383	1.00375	1.00435
19.8	1.00486	1.00432	1.00396	1.00385	1.00396	1.00403	1.00395	1.00458
20.0	1.00509	1.00453	1.00415	1.00404	1.00415	1.00423	1.00414	1.00481

TABLE I, PART II *Continued*

CHOOSE A MULTIPLIER FOR THE MATERIAL BEING MEASURED CORRESPONDING TO THE BATH TEMPERATURE AT WHICH THE PYCNOMETER EQUILIBRATED.

TEMP DEGC	BENZENE	TOLUENE	MIXED XYLENES	O-XYLENE	M-XYLENE	P-XYLENE	STYRENE	CYCLO-HEXANE
20.0	1.00509	1.00453	1.00415	1.00404	1.00415	1.00423	1.00414	1.00481
20.2	1.00533	1.00474	1.00435	1.00423	1.00435	1.00443	1.00434	1.00504
20.4	1.00557	1.00496	1.00454	1.00442	1.00454	1.00463	1.00453	1.00527
20.6	1.00581	1.00517	1.00474	1.00461	1.00474	1.00482	1.00472	1.00551
20.8	1.00605	1.00538	1.00493	1.00480	1.00493	1.00502	1.00492	1.00574
21.0	1.00629	1.00559	1.00513	1.00499	1.00513	1.00522	1.00511	1.00597
21.2	1.00653	1.00581	1.00532	1.00518	1.00532	1.00542	1.00531	1.00621
21.4	1.00677	1.00602	1.00552	1.00537	1.00552	1.00562	1.00550	1.00644
21.6	1.00701	1.00623	1.00572	1.00556	1.00572	1.00582	1.00570	1.00668
21.8	1.00725	1.00644	1.00591	1.00575	1.00591	1.00602	1.00589	1.00691
22.0	1.00749	1.00666	1.00611	1.00594	1.00611	1.00622	1.00609	1.00715
22.2	1.00773	1.00687	1.00630	1.00613	1.00630	1.00642	1.00628	1.00738
22.4	1.00797	1.00708	1.00650	1.00632	1.00650	1.00662	1.00648	1.00762
22.6	1.00821	1.00730	1.00670	1.00652	1.00670	1.00682	1.00667	1.00786
22.8	1.00845	1.00751	1.00689	1.00671	1.00689	1.00702	1.00687	1.00810
23.0	1.00869	1.00772	1.00709	1.00690	1.00709	1.00722	1.00707	1.00834
23.2	1.00893	1.00794	1.00729	1.00709	1.00729	1.00742	1.00726	1.00858
23.4	1.00917	1.00815	1.00748	1.00728	1.00748	1.00762	1.00746	1.00882
23.6	1.00941	1.00836	1.00768	1.00747	1.00768	1.00782	1.00765	1.00906
23.8	1.00965	1.00858	1.00788	1.00767	1.00788	1.00802	1.00785	1.00930
24.0	1.00990	1.00879	1.00808	1.00786	1.00808	1.00822	1.00805	1.00954
24.2	1.01014	1.00900	1.00827	1.00805	1.00827	1.00842	1.00824	1.00979
24.4	1.01038	1.00922	1.00847	1.00824	1.00847	1.00862	1.00844	1.01003
24.6	1.01062	1.00943	1.00867	1.00843	1.00867	1.00882	1.00863	1.01028
24.8	1.01086	1.00965	1.00887	1.00863	1.00887	1.00902	1.00883	1.01052
25.0	1.01111	1.00986	1.00906	1.00882	1.00906	1.00922	1.00903	1.01077
25.2	1.01135	1.01007	1.00926	1.00901	1.00926	1.00943	1.00922	1.01101
25.4	1.01159	1.01029	1.00946	1.00920	1.00946	1.00963	1.00942	1.01126
25.6	1.01184	1.01050	1.00966	1.00940	1.00966	1.00983	1.00962	1.01151
25.8	1.01208	1.01072	1.00986	1.00959	1.00986	1.01003	1.00981	1.01176
26.0	1.01232	1.01093	1.01006	1.00978	1.01006	1.01023	1.01001	1.01201
26.2	1.01257	1.01115	1.01025	1.00997	1.01025	1.01043	1.01021	1.01226
26.4	1.01281	1.01136	1.01045	1.01017	1.01045	1.01064	1.01040	1.01251
26.6	1.01305	1.01158	1.01065	1.01036	1.01065	1.01084	1.01060	1.01276
26.8	1.01330	1.01179	1.01085	1.01055	1.01085	1.01104	1.01080	1.01301
27.0	1.01354	1.01201	1.01105	1.01075	1.01105	1.01124	1.01099	1.01326
27.2	1.01379	1.01222	1.01125	1.01094	1.01125	1.01144	1.01119	1.01352
27.4	1.01403	1.01244	1.01145	1.01113	1.01145	1.01165	1.01139	1.01377
27.6	1.01428	1.01265	1.01165	1.01133	1.01165	1.01185	1.01159	1.01402
27.8	1.01452	1.01287	1.01185	1.01152	1.01185	1.01205	1.01178	1.01428
28.0	1.01477	1.01308	1.01205	1.01172	1.01205	1.01225	1.01198	1.01454
28.2	1.01501	1.01330	1.01225	1.01191	1.01225	1.01246	1.01218	1.01479
28.4	1.01526	1.01352	1.01245	1.01210	1.01245	1.01266	1.01238	1.01505
28.6	1.01551	1.01373	1.01265	1.01230	1.01265	1.01286	1.01258	1.01531
28.8	1.01575	1.01395	1.01285	1.01249	1.01285	1.01307	1.01278	1.01557
29.0	1.01600	1.01416	1.01305	1.01269	1.01305	1.01327	1.01297	1.01583
29.2	1.01624	1.01438	1.01325	1.01288	1.01325	1.01347	1.01317	1.01609
29.4	1.01649	1.01460	1.01345	1.01308	1.01345	1.01368	1.01337	1.01635
29.6	1.01674	1.01481	1.01365	1.01327	1.01365	1.01388	1.01357	1.01661
29.8	1.01699	1.01503	1.01385	1.01347	1.01385	1.01408	1.01377	1.01687
30.0	1.01723	1.01524	1.01405	1.01366	1.01405	1.01429	1.01397	1.01714

4.2 For liquids not listed in Table 1, the sample is equilibrated at the desired reference temperature, usually 20°C or 60°F (15.56°C), the density, relative density, or commercial density is then calculated from the sample weight, a calibration factor proportional to an equal volume of water and a term which corrects for the buoyancy of air. In the case of volatile liquids such as pentane, the time between reading of volume at the equilibrium temperature and weighing must not be prolonged, otherwise weight loss through evaporation may result in errors.[9]

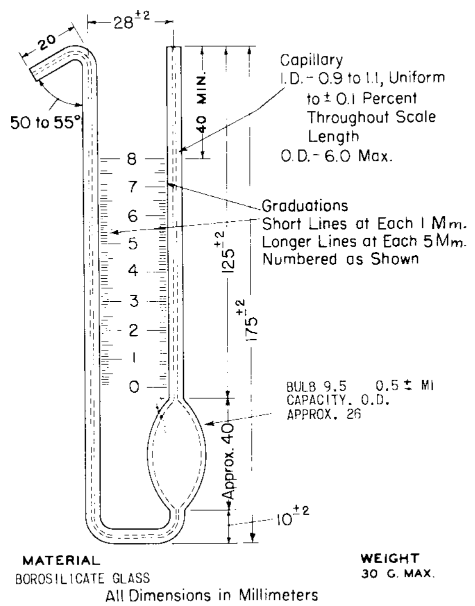
5. Significance and Use

5.1 This test method is suitable for setting specification, for use as an internal quality control tool, and for use in development or research work on industrial aromatic hydrocarbons and related materials. In addition to the pure liquid chemicals for which expansion functions are known, it may also be used for liquids for which temperature expansion data are not available, or for impure liquid chemicals if certain limitations are observed. Information derived from this test can be used to describe the relationship between weight and volume.

6. Apparatus

6.1 *Pycnometer*, 9 to 10-mL capacity, conforming to the dimensions given in Fig. 1, constructed of borosilicate glass, and having a total weight not exceeding 30 g.

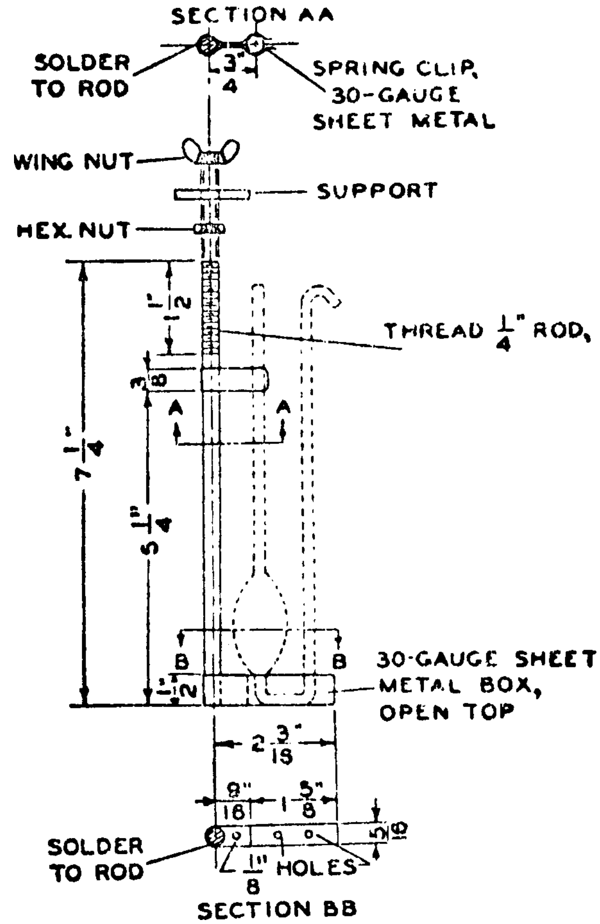
6.2 *Bath*, having a depth of at least 300 mm, capable of being maintained constant to ±0.02°C at any convenient temperature between 10°C (50°F) and 30°C (86°F). Provide a support for the pycnometer (see Fig. 2) constructed of any suitable noncorrosive metal.



NOTE 1—The graduation lines shall extend around the entire circumference of the pycnometer at the integral numbers 0, 1, 2 cm, etc., half way around at the half divisions 0.5, 1.5, etc., and shorter lines for the intermediate subdivisions.

FIG. 1 Pycnometer

NOTE 4—If the laboratory air temperature does not vary more than 0.02°C during temperature equilibration a special bath is not needed.



NOTE 1—All dimensions are in inches.

FIG. 2 Pycnometer Holder

6.3 *Bath Thermometer*, An ASTM Precision Thermometer, having a range from −8 to +32°C and conforming to the requirements for Thermometer 63C as prescribed in Specification E 1.

7. Hazards

7.1 Consult current OSHA regulations, supplier's Material Safety Data Sheets, and local regulations, for all materials used in this test method.

8. Sampling

8.1 Sample the material in accordance with Practice D 3437.

9. Preparation of Apparatus

9.1 *Acid Cleaning*, for use when the pycnometer is to be calibrated or when liquid fails to drain cleanly from the walls of the pycnometer or its capillary. Thoroughly clean with hot chromic acid solution and rinse well with reagent water conforming to Type III of Specification D 1193. Other suitable cleaning procedures may be used. Dry at 105 to 110°C for at least 1 h, preferably with a slow current of filtered air passing through the pycnometer.

9.2 *Solvent Cleaning*, for use between determinations. Rinse with toluene and then with anhydrous acetone, drying with a filtered stream of dry air.

[9] For a more complete discussion on the use of this design pycnometer, see Lipken, Davidson, Harvey and Kurtz, *Industrial Engineering Chemistry, Analytical Edition;* Vol 16, 1944, p. 55.

10. Calibration of Apparatus

10.1 Using the procedure described in Section 11, determine the weight of freshly boiled reagent water conforming to Type III of Specification D 1193 held by the pycnometer with the water level at each of three different scale points on the graduated arms. Two of these water levels must be at opposite ends of the scale. Make all weighings on the same day, using the same balance and weights.

10.2 Calculate the volume, $V_T{}^p$, at each scale point tested by means of the following equation; carry all calculations in 6 non-zero digits and round to 4 decimal places:

$$\text{Pycnometer capacity, } V_T{}^p\text{, mL} = A \times (W^w/d_t{}^w) + B(T - t) \quad (1)$$

where:

A = air buoyancy coefficient, a constant for the temperature range involved = 1.001064
$V_T{}^p$ = volume of pycnometer at reference temperature, T
W^w = weight of water in air, contained in the pycnometer, g
$d_t{}^w$ = density of water at t (see Table 2)
t = test temperature, °C
T = reference temperature, 20°C or 15.56°C, and
B = volumetric coefficient of expansion of 9.5 mL of a borosilicate glass pycnometer, 9.26276×10^{-5} mL/°C.

10.3 Prepare a calibration curve by plotting apparent volume, V_A, that is, the sum of the scale readings on the two arms of the pycnometer against the corresponding calculated volume, $V_T{}^p$. If a straight line cannot be drawn through the three points, discard the data and determine three additional points so that a straight calibration line can be drawn such that no data point lies more than 0.0002-mL units from the line. If neither set of data meets the condition, the diameters of the graduated capillary arms are not sufficiently uniform, and the pycnometer should be discarded.

10.4 From the curve obtained, prepare a table of apparent volume, V_A, (sum of scale readings of both arms), as *apparent volume* against corresponding calculated volumes, $V_T{}^p$, in increments of 0.0001 mL. Label this table with the reference temperature to which it applies.

11. Procedure

11.1 Weigh the clean, dry pycnometer to 0.1 mg and record the weight.

11.2 With the sample at approximately the test temperature, fill the pycnometer by holding it in an upright position and placing the hooked tip in the sample; the liquid will then be drawn over the bend in the capillary by surface tension. Allow the pycnometer to fill by siphoning (about 1 min) and break the siphon when the liquid level in the bulb arm of the pycnometer reaches the lowest graduation mark.

11.3 Thoroughly dry the wet tip. Wipe the body of the pycnometer with a chemically clean, lint-free cloth slightly damp with water (Note 4) and weigh the filled pycnometer to the nearest 0.1 mg.

NOTE 5—In atmospheres below 60 % relative humidity, drying the pycnometer by rubbing with a dry cotton cloth will induce static charges equivalent to a loss of about 1 mg or more in the weight of the pycnometer. This charge may not be completely dissipated in less than ½, and can be detected by touching the pycnometer to the wire hook in the balance and then drawing it away slowly. If the pycnometer exhibits an attraction for the wire hook, it may be considered to have a static charge.

11.4 Place the pycnometer in the holder in a constant-temperature bath held at any convenient temperature 10 and 30°C within ±0.02°C; for materials not listed in Table 1, hold the bath exactly at the desired reference temperature, usually 15.56°C or 20°C. When the liquid level has reached temperature equilibrium (usually in about 10 min) and while still in the bath, read the scale to the nearest 0.2 small division at the liquid level in each arm.

12. Calculation

12.1 *Table 1 Materials*—Compute the density or relative density, or both, by means of the following equations:

$$\text{Density, g/mL at } 60°F = \frac{W^s}{V_{60}{}^p} \times F_{60} + 0.00121 \quad (2)$$

$$\text{Density, g/mL at } 20°C = \frac{W^s}{V_{20}{}^p} \times F_{20} + 0.00121 \quad (3)$$

TABLE 2 Density of Water[A], g/ml

t,° C		0.0	0.1	0.2	0.3	0.4	0.5	0.56	0.6	0.7	0.8	0.9
15	0.999	13	11	10	08	07	05	04	04	02	00	*99
16	0.998	97	96	94	92	91	89		87	86	84	82
17		80	79	77	75	73	72		70	68	66	64
18		62	61	59	57	55	53		51	49	47	45
19		43	42	40	38	36	34		32	30	27	25
20		23	21	19	17	15	13		11	09	07	04
21		02	00	*98	*96	*93	*91		*89	*87	*85	*82
22	0.997	80	78	75	73	71	69		66	64	62	59
23		57	54	52	50	47	45		42	40	38	35
24		33	30	28	25	23	20		18	15	13	10
25		08	05	02	00	*97	*95		*92	*89	*87	*84
26	0.996	81	79	76	73	71	68		65	63	60	57
27		54	52	49	46	43	41		38	35	32	29
28		26	24	21	18	15	12		09	06	03	00
29	0.995	98	95	92	89	86	83		80	77	74	72
30		68	65	62	59	56	53		50	46	43	40

[A] Abstracted from Tilton and Taylor, U.S. National Bureau of Standards Research Paper 971, NBS *Journal of Research* Vol 18, 1917, p. 213. This paper is a statistical analysis of the data of Chappuis, *Travaux Et Memoires du Bureau International de Poid et Mesures*, Vol 13, 1907, p. D39.

TABLE 3 Air Buoyancy Correction (Section 12.2)

W/V	C	W/V	C	W/V	C
0.70	0.00036	0.80	0.00024	0.90	0.00012
0.71	0.00035	0.81	0.00023	0.91	0.00011
0.72	0.00033	0.82	0.00022	0.92	0.00010
0.73	0.00032	0.83	0.00020	0.93	0.00009
0.74	0.00031	0.84	0.00019	0.94	0.00007
0.75	0.00030	0.85	0.00018	0.95	0.00006
0.76	0.00029	0.86	0.00017	0.96	0.00005
0.77	0.00028	0.87	0.00016	0.97	0.00004
0.78	0.00026	0.88	0.00014	0.98	0.00003
0.79	0.00025	0.89	0.00013	0.99	0.00001

$$\text{Density, g/cm}^3 \text{ at } 20°C = \left[\frac{W^s}{V_{20}{}^p} F_{20} + 0.00121\right] 0.99997 \quad (4)$$

$$\text{Relative density } 60/60°F = \left[\frac{W^s}{V_{60}{}^p} \times F_{60} + 0.00121\right] 1.00096 \quad (5)$$

where:

W^s = observed weight of sample, corrected for variation of weights, g,

$W_{20}{}^p$, $V_{60}{}^p$ = calculated volume, $V_T{}^p$, of sample at 20°C or 60°F, millilitres, obtained from the pycnometer calibration table (Note 5),

F_{20}, F_{60} = constants taken from Table 1. Corresponding to the test temperature, t°C

NOTE 6—For frequently examined products it should prove convenient to combine Table 1 with the calibration table described in 10.2.

12.2 *General Method*—Compute the density or relative density, or both, by means of the following equations:

$$\text{Density, g/mL at } 20°C = \frac{W^s}{V_{20}{}^p} + C \quad (6)$$

$$\text{Density, g/cm}^3 \text{ at } 20°C = \left[\frac{W^s}{V_{20}{}^p} + C\right] 0.99997 \quad (7)$$

$$\text{Relative density } 60/60°F = \left[\frac{W^s}{V_{60}{}^p} + C\right] 1.00096 \quad (8)$$

where:

W^s = observed weight of sample, corrected for variation of weights, g,

$V_{20}{}^p$, $V_{60}{}^p$ = calculated volume, $V_T{}^p$, of sample at 20°C or 60°F obtained from the pycnometer calibration table, and

C = air buoyancy correction factor from Table 3.

12.3 *Pounds per Gallon*—Compute the commercial density, pounds (in air) per U.S. gallon and U.K. gallon as follows:

12.3.1 *From Pycnometer Data*:

$$\text{lb/}U.S.\text{ gal (in air) at } 60°F = W^s/V_{60}{}^p \times F_{60} \times 8.3464 \quad (9)$$

$$\text{lb/U.K. gal (in air) at } 60°F = W^s/V_{60}{}^p \times F_{60} \times 10.0236 \quad (10)$$

12.3.2 *Converted from* d_{60}*, g/mL*:

$$\text{lb/U.S. gal (in air) at } 60°F = \text{g/mL} \times 8.3464 - 0.0100 \quad (11)$$

$$\text{lb/U.K. gal (in air) at } 60°C = \text{g/mL} \times 10.0236 - 0.0121 \quad (12)$$

13. Precision and Bias [10]

13.1 The following data should be used for judging the acceptability of results (95 % probability) for the materials of Table 1:

13.1.1 *Repeatability*—Duplicate results by the same operator should not be considered suspect unless they differ by more than the following amounts:

0.0002 g/mL

13.1.2 *Reproducibility*—The results submitted by one laboratory should not be considered suspect unless it differs from that of another laboratory by more than the following amounts:

0.0003 g/mL

14. Keywords

14.1 correction for temperature expansion; density; pure liquid chemicals; relative density

[10] Source of precision data: The Coal Tar Research Association, Oxford Road, Gomersal, Checkheaton, Yorks, U.K., Standardization of Tar Products, Test Committee, Document No. 0763, Serial No. GPI-67.

APPENDIX

(Nonmandatory Information)

X1. METHOD AND FORMULA DETAILS

X1.1 Introduction

X1.1.1 The manipulative simplicity of this test method is possible, for the materials listed in Table 1, because accurate temperature-density functions have been developed by computer curve fitting for these materials. Moreover, it is known for the purity range of the commercially produced materials of Table 1, that they parallel the temperature-density function of the pure materials. Refer to Method D 1555. Also, the temperature coefficient of expansion of borosilicate laboratory glassware is constant and accurately known. Thus, it is possible, within certain limits, to weigh a calibrated, temperature equilibrated pycnometer containing a substance of known temperature density function and then calculate the density at any other temperature, taking into account the change in volume of both the substance and the pycnometer.[11]

X1.2 Basic Data

X1.2.1 The temperature-density functions of the several products of Table 1, except for styrene, are based on data developed by API Research Project 44, but contain one more significant figure than the values published in "Selected Values of Hydrocarbons and Related Compounds" by American Petroleum Institute Research Project 44. Data for styrene were obtained from Dow Chemical Co.

X1.2.2 The respective temperature-density functions of the materials of Table 1 are based on computer curve fitting of the data to a power series equation of the form:

$$D_t^s = d_0 + \alpha t + \beta t^2 + \gamma t^3 + ...$$

D_t^s = density of substance at temperature, t
d_0 = density of substance at 0°C
t = temperature,° C α, β, γ, ...-power series coefficient[11]

X1.2.3 The values of d_0, α, β, and γ for the products of Table 1 of this test method are tabulated in Table X1.1.

X1.2.4 The value of D at the two most commonly used reference temperatures, 60°F (15.56°C) and 20°C, are given as follows:

Substance	$D^s_{20°C}$	$D^s_{60°F}$
Benzene	0.879 010 1	0.883 658 6
Toluene	0.866 960 0	0.871 058 1
Mixed xylenes		
o-Xylene	0.880 178 4	0.883 904 9
m-Xylene	0.864 170 0	0.867 925 3
p-Xylene	0.861 055 6	0.864 863 2
Styrene	0.906 235 2	0.910 164 1
Cyclohexane	0.778 274 3	0.782 171 1

X1.2.5 To enable the user of this test method to extend it to materials not listed in Table 1 for which temperature density data are available, derivations of the formulas used are provided in Sections X1.3 and X1.4.

X1.3 Density Definition

X1.3.1 Density is defined as follows:

$$D_T^s = M^s/V_T^s \quad \text{(X1.1)}$$

where:
D_T^s = density of a substance, g/mL at reference temperature T,
M^s = mass of substance, and
V_T^s = volume of substance, mL, at "reference" temperature T.

X1.3.2 Mass is determined by correcting the weight W^s of a certain volume of the substance contained in a pycnometer, for the buoyancy of air and variation in local acceleration of gravity. When a beam balance is used no correction is necessary for acceleration of gravity.

X1.3.3 The volume, V_T^s, of the substance at the chosen reference temperature, T, is obtained by making two corrections to the apparent volume observed in the pycnometer.

X1.3.3.1 The first correction is to obtain the true volume of the pycnometer, V_t^p, at the test temperature, t°C. The volume of the pycnometer, V_T^p, is known by calibration at the reference temperature, T. Its volume at the test temperature, V_t^p, is calculated from a knowledge of the cubical coefficient of expansion of the glass and the measured deviation of the test temperature from the reference temperature. The volume of the substance, V_t^s, and the volume of the pycnometer are identical at the test temperature.

X1.3.3.2 The second correction is to correct the true sample volume at the test temperature, V_t^s, to the volume it would occupy at the reference temperature, V_t^s.

X1.4 Pycnometer Calibration, Section 10 of this Test Method

X1.4.1 The pycnometer volume at the reference temperature is calculated from the mass and density of water contained in the pycnometer at the calibration temperature, t, °C, using the equation:

$$V_T^p = \frac{AW^w}{d_t^w} + B(T - t) \quad \text{(X1.2)}$$

where:
V_T^p = pycnometer volume at the reference temperature, mL,
W^w = weight of water in the pycnometer using a beam balance and calibrated brass weights,
d_t^w = density of pure water, g/mL, at the calibration test temperature,
t = calibration test temperature,° C,
T = reference temperature,° C,
A = constant for correcting the observed weight of water to mass, and

[11] For a complete description of the development of these coefficients refer to "Annual Report of Committee D16," *Proceedings*, American Society for Testing and Materials, Vol 63, 1963.

TABLE X1.1 Values for d_0, α, β, and γ.

Benzene	0.899 726 1	−1.021 458	E-03	−7.172 6	E-07	...	
Toluene	0.885 420 0	−9.230 00	E-04	...		...	
Mixed xylenes	0.880 956 7	−8.310 26	E-04	−4.154 8	E-07	...	
o-Xylene	0.896 902 5	−8.335 07	E-04	−5.180	E-08	−4.155 6	E-09
m-Xylene	0.880 956 7	−8.310 26	E-04	−4.154 8	E-07	...	
p-Xylene	0.878 103 7	−8.457 83	E-04	−3.310 6	E-07	...	
Styrene	0.923 892 7	−8.802 93	E-04	−1.290 4	E-07	...	
Cyclohexane	0.794 423 5	−7.226 22	E-04	−3.894 82	E-06	−1.735 57	E-08

B = cubical coefficient of expansion of 9.5-mL pycnometer of borosilicate glass, mL/mL·°C.

NOTE X1.1—The first terms of Eq X1.2 gives the true volume of water at the calibration temperature; that is, the true volume of the pycnometer at the calibration test temperature, t.

The second term corrects this volume to the volume of the pycnometer at the reference temperature; in other words, the volume that the pycnometer would contain if it were at the reference temperature with the liquid level at the same two marks.

X1.4.2 Constant A, Correcting W^w to Mass, M^w:

$$M^w = W^w \left(1 + \frac{d_a}{d_t{}^w} - \frac{d_a}{d_b}\right) = AW^w \quad \text{(X1.3)}$$

where:

M^w = mass of the water in the pycnometer, g,
W^w = weight of the water in the pycnometer, g,
$2d_a$ = average density of air, g/mL (= 0.00121) within the calibration temperature range
d_b = average density of brass weights within the calibration temperature range, g/ml (= 8.100), and
$d_t{}^w$ = defined above.

NOTE X1.2—For the buoyancy correction it is adequate to use the average density of water[12] within the test temperature range, as follows:

t	d_t^w
10	0.999 700 1
15	0.999 128 6
20	0.998 233 6
25	0.997 075 1
30	0.995 678 3
35	0.994 035 6
Mean	0.997 308 55

NOTE X1.3—At t = 15.56°C, $d_t{}^w$ = 0.999 042 3

$$A = \left(1 + \frac{0.001\ 21}{0.997\ 308\ 55} - \frac{0.001\ 21}{8.1}\right) = 1.001\ 064 \quad \text{(X1.4)}$$

X1.4.3 Constant B, volume expansion factor for 9.5-mL pycnometer, mL/°C

B = 9.5 C = 9.5 × 3 × C' × 1.000028
C = volumetrical temperature coefficient of expansion of borosilicate glass = 9.7 50273 × 10^{-6} mL/mL·°C
C' = linear coefficient of expansion of borosilicate glass = 3.25 × 10^{-6} cm/cm·°C

NOTE X1.4—Two manufacturers of low expansion borosilicate glass list their coefficients as 3.2 and 3.3 × 10^{-6}, respectively.

$$B = 9.5 \times 1.000028 \times 3 \times 3.25 \times 10^{-6} = 9.262759 \times 10^{-5}\ \text{m}L/°C$$

therefore:

$$V_t{}^p = 1.001064 \times \frac{W^w}{d_t^w} + 0.00009263\ (T - t) \quad \text{(X1.5)}$$

when T = 20°C; $d_t{}^w$ = 0.9982336
when T = 60°F; $d_t{}^w$ = 0.9990423

$$V^p_{20°C} = W^w \times 1.002835 + 0.00009262\ (20 - t) \quad \text{(X1.6)}$$

$$V^p_{60°C} = W^w \times 1.002024 + 0.00009262\ (15.56 - t) \quad \text{(X1.7)}$$

X1.4.3.1 Error introduced by using average single value for the pycnometer rather than true pycnometer volume.
Average deviation± 0.5 mL
Maximum expansion factor error for a 20°C range

$$B\ \text{(error)} = 0.5 \times 0.00000975 \times 20 = \pm 0.0000975\ \text{m}L$$

X1.4.4 Development of Factor F and the constant 0.00121 (Section 12 and Table 1) of the test method.

$$D_T{}^s,\ \text{g/mL} = \frac{W^s}{V_T^p} \times F_T + 0.00121\ \text{(see 12.1)}$$

X1.4.5 The factor F contains the following corrections: It corrects the pycnometer volume, $V_T{}^p$, as read from the pycnometer calibration table, ($V_a$versus $V_T{}^p$, 10.3) to the actual sample volume at the test temperature, $V_t{}^s$.

X1.4.6 Corrects the actual sample volume $V_t{}^s$ to the volume it would occupy at the reference temperature, $V_T{}^s$.

X1.4.7 Converts the observed sample weight (in air) to mass.

NOTE X1.5—If a torsion or spring balance is used, a correction for local acceleration of gravity must also be applied to the observed sample weight.

X1.4.7.1

$$V_t^s = V_T{}^p\left(\frac{1 + Ct}{1 + CT}\right) \quad \text{(X1.8)}$$

$$V_t^p = V_t{}^s = V' + V'C(t - t')$$

$$V_T{}^p = V' + V'C(T - t')$$

where:

V' = volume of the pycnometer at t' = 0°C; and
C = defined above.

$$V_t^s = V'\ (1 + Ct)$$

$$V_T{}^p = V'\ (1 + CT)$$

$$\frac{V_t^s}{V_T^p} = \frac{1 + Ct}{1 + CT}$$

X1.4.7.2

$$V_T{}^s = V_t^s\left(\frac{d_t^s}{d_T{}^s}\right) + V_t^s = V_T{}^s\left(\frac{d_T{}^s}{D_t{}^s}\right) \quad \text{(X1.9)}$$

X1.4.7.3

$$M^s = W^s\left(1 + \frac{0.00121}{d_t^s} - \frac{0.00121}{8.1}\right) \quad \text{(X1.10)}$$

To solve Eq X1.10 it is necessary to know the density of the substance, $d_t{}^s$, at the test temperature. Instead of this value, it is adequate for the buoyancy correction to use an approximate density calculated from the observed weight $W^s$and the corrected sample volume $V_t{}^s$, thus:

$$M^s = W^s\left(1 + \frac{0.00121}{W^s/V_t^s} - \frac{0.00121}{8.1}\right) \quad \text{(X1.11)}$$

X1.4.8 Combining Eq X1.1, Eq X1.8, Eq X1.9, and Eq X1.11 to arrive at equation for factor F:

[12] Water density obtained from: Tilton & Taylor, National Bureau of Standards Research Paper RP971, *Journal of Research* of the NIST, Vol 18, February 1937.

$$D_T^{\,s} = \frac{M^s}{V_T^{\,s}}$$

$$V_t^{\,s} = V_T^{\,p}\left(\frac{1 + Ct}{1 + CT}\right)$$

$$V_t^{\,s} = V_T^{\,s}\left(\frac{d_T^{\,s}}{d_t^{\,s}}\right); \qquad V_T^{\,s} = V_t^{\,s}\left(\frac{d_t^{\,s}}{d_T^{\,s}}\right)$$

$$M^s = W^s\left(1 + \frac{d_a}{W^s/V_t^{\,s}} - \frac{d_a}{d_b}\right)$$

or

simplified

$$M^s = W^s\left(1 - \frac{d_a}{d_b}\right) + d_a V_t^{\,s} \tag{X1.12}$$

combining Eq X1.1, Eq X1.11, and Eq X1.9:

$$D_T^{\,s} = \frac{W^s\left(1 - \frac{d_a}{d_a}\right) + d_a V_t^{\,s}}{V_t^{\,s}\ \frac{d_t^{\,s}}{d_T^{\,s}}} \tag{X1.13}$$

Simplifying:

$$D_T^{\,s} = \frac{W^s}{V_t^{\,s}}\left(1 - \frac{d_a}{d_b}\right)\frac{d_T^{\,s}}{d_t^{\,s}} + d_a\frac{d_T^{\,s}}{d_t^{\,s}} \tag{X1.14}$$

Substituting for V_t^s from Eq X1.8.

$$D_T^{\,s} = \frac{d_T^{\,s}}{d_t^{\,s}} = \left[\frac{W^s\left(1 - \frac{d_a}{d_b}\right)}{V_T^{\,p}\left(\frac{1 + Ct}{1 + CT}\right)} + d_a\right] \tag{X1.15}$$

$$D_T^{\,s} = \frac{d_T^{\,s}}{d_t^{\,s}}\left[\frac{W^s}{V_T^{\,p}}\left(\frac{1 + CT}{1 + Ct}\right)\left(1 - \frac{d_a}{d_b}\right)\right] + d_a\frac{d_T^{\,s}}{d_t^{\,s}} \tag{X1.16}$$

$$D_T^{\,s} = \frac{W^s}{V_T^{\,p}}\left[\frac{d_T^{\,s}}{d_t^{\,s}}\left(\frac{1 + CT}{1 + Ct}\right)\left(1 - \frac{d_a}{d_b}\right)\right] + d_a\frac{d_T^{\,s}}{d_t^{\,s}} \tag{X1.17}$$

The last term varies between 0.001196 and 0.001232 for the temperature range, 10 to 30°C, of the test and can be rounded to 0.00121.

Also,

$$\frac{d_T^{\,s}}{d_t^{\,s}} = \frac{d_0 + \alpha T + \beta T^2 + \gamma T^3 \ldots\ldots}{d_0 + \alpha t + \beta t^2 + \gamma t^3 \ldots\ldots}$$

from Eq X1.1 of the basic data.

Thus, Eq X1.4 reduces to:

$$D_T^{\,s} = \frac{W^s}{V_T^{\,p}} F_T + 0.00121$$

where:

$$F_T = \frac{d_0 + \alpha T + \beta T^2 + \gamma T^3}{d_0 + \alpha t + \beta t^2 + \gamma t^3}\left(\frac{1 + CT}{1 + Ct}\right)\left(1 - \frac{d_a}{d_b}\right)$$

F_{20} values given in Table 1, Part I, are the solution to the preceding equation when $T = 20$°C and t is any 0.2°C value from 10 to 30°C.

F_{60} values given in Table 1, Part II, are the solutions to the above equation when T is 15.56°C (60°F) and t is any 0.2° value from 10 to 30°C.