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Soil quality — Determination of dry bulk density

Qualité du sol — Détermination de la masse volumique apparente sèche

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Foreword

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This document was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 3, *Chemical methods and soil characteristics*.

This second edition cancels and replaces the first edition (ISO 11272:1998), which has been technically revised.

Introduction

The dry bulk density is used together with the particle density (see ISO 11508) for the calculation of the solids content and porosity of soil for the evaluation of soil structure and conversion of concentrations of substances in soil from mass/volume to mass/mass and vice versa.

Soil quality — Determination of dry bulk density

1 Scope

This document specifies three methods for the determination of dry bulk density of soils calculated from the mass and the volume of a soil sample. The methods involve drying and weighing a soil sample, the volume of which is either known [core method (see 4.1)] or determined [excavation method (see 4.2) and clod method (see 4.4)].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ASTM D1556, *Standard test method for density and unit weight of soil in place by sand-cone method*

ASTM D2167, *Standard test method for density and unit weight of soil in place by the rubber balloon method*

ASTM D4914, *Standard test methods for density of soil and rock in place by the sand replacement method in a test pit*

ASTM D5030, *Standard test methods for density of soil and rock in place by the water replacement method in a test pit*

DIN 18125-2, *Soil investigation and testing — Determination of density of soil — Part 2: Field tests*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
dry bulk density
ratio of the oven-dry mass of the solids to the volume of the soil

Note 1 to entry: The bulk volume includes the volume of the solids and of the pore space.

Note 2 to entry: The preferred SI unit of measurement is kilograms per cubic metre ($kg \cdot m^{-3}$), but grams per cubic centimetre ($g \cdot cm^{-3}$) is also very common. Note that $x\ g \cdot cm^{-3} = 1\ 000\ x\ kg \cdot m^{-3}$.

4 Test procedures

4.1 Core method

4.1.1 Principle

This method is applicable to stoneless and slightly stony soils. Core samples of known volume are taken with a metal sampling tool. The sample is dried in an oven and weighed, and the dry bulk density is calculated.

4.1.2 Apparatus

4.1.2.1 Core sample holders, thin-walled metal cylinders with a volume of 100 cm^3 to 400 cm^3, a steel cap for driving into the soil, and a driver.

4.1.2.2 Oven, heated and ventilated, capable of maintaining a temperature of (105 ± 2) °C.

4.1.2.3 Desiccator, sealed chamber in which the air is kept dry with the aid of silica gel or other desiccant.

4.1.2.4 Laboratory balance, capable of weighing to an accuracy of 1/1 000 of the measured value.

4.1.3 Sampling and drying

Press or drive a core sample holder (4.1.2.1) of known volume without deflection and compaction into either a vertical or horizontal soil surface far enough to fill the sampler. Carefully remove the sample holder and its contents to preserve the natural structure, and trim the soil extending beyond each end of the sample holder with a straight-edged knife or sharp spatula. The soil sample volume is thus equal to the volume of the sample holder. Take at least six core samples from each soil layer. Place the holders containing the samples in an oven (4.1.2.2) at 105 °C until constant mass is reached.

NOTE 1 In most cases, constant mass is reached after 48 h drying.

Remove the samples from the oven and allow them to cool in the desiccator (4.1.2.3). Weigh the samples on the balance (4.1.2.4) immediately after removal from the desiccator (m_t). Control mass is reached when the differences in successive weighings of the cooled sample, at intervals of 4 h, do not exceed 0,01 % of the original mass of the sample.

Swell/shrink soils (especially clays, muds and peats) change their bulk density with changing water content. Such soils should be sampled first in a moist state (i.e. field capacity); in addition, they should be sampled in a wetter state (water saturation) and in a drier state (i.e. wilting point). If the dry soil is too hard to be sampled, the bulk density of the soil can be determined according to 4.3, and the total soil volume according to 4.2.3.

NOTE 2 If bulk density (and water content) is the only parameter of interest, it is not necessary to keep the samples in their holders when taking them back to the laboratory. After the sample has been obtained and trimmed, the soil can be extracted from the holder, without loss, in order to be stored for transportation either in a metal box or in a heat-resistant plastic bag.

It is normally worthwhile to combine a measurement of the water content with a measurement of the bulk density; in that case it is necessary to transport the samples without allowing loss of water by evaporation, and to begin the laboratory operations by weighing the fresh sample.

4.1.4 Calculation

The dry bulk density is calculated using Formula (1) and Formula (2):

$$\rho_{b,s} = \frac{m_d}{V} \quad (1)$$

$$m_d = m_t - m_s \quad (2)$$

where

$\rho_{b,s}$	is the bulk density, dry, in grams per cubic centimetre, g/cm^3;
m_d	is the mass of the sample dried at 105 °C, in grams, g;
V	is the volume of the sample holder, in cubic centimetres, cm^3;
m_s	is the mass of the empty sample holder, in grams, g;
m_t	is the mass of the sample holder together with the soil sample dried at 105 °C, in grams, g.

4.2 Excavation method

4.2.1 Principle

Bulk density is determined by excavating a quantity of soil, drying and weighing it, and determining the volume of the excavation by filling it with sand. This procedure is applicable to soils containing gravel and/or stones.

4.2.2 Apparatus

4.2.2.1 Earth-digging equipment, such as a spade, with a long sharp-edged straight blade.

4.2.2.2 Sampling equipment, flat-bladed spade, knife (for hard or stony soil), pick, spade chisel, hammer.

4.2.2.3 Equipment for collecting and cleaning, such as plastic sheet, brush, heat-resistant plastic bags or canisters.

4.2.2.4 Plastic film, thin, flexible, but stable.

4.2.2.5 Equipment for spreading sand, including funnel with a gauging rod (the falling height beneath the funnel mouth should be 5 cm), graduated cylinder of 1 dm^3 capacity.

4.2.2.6 Dry, graded sand of known volume, with a particle diameter between 500 µm and 700 µm.

4.2.2.7 Balance, capable of weighing to an accuracy of 0,1 g.

4.2.2.8 Oven, heated and ventilated, capable of maintaining a temperature of (105 ± 2) °C.

4.2.2.9 Vacuum desiccator with self-indicating desiccant.

4.2.2.10 Sieve, with 2 mm apertures.

4.2.2.11 Straight metal blade.

4.2.3 Field procedure

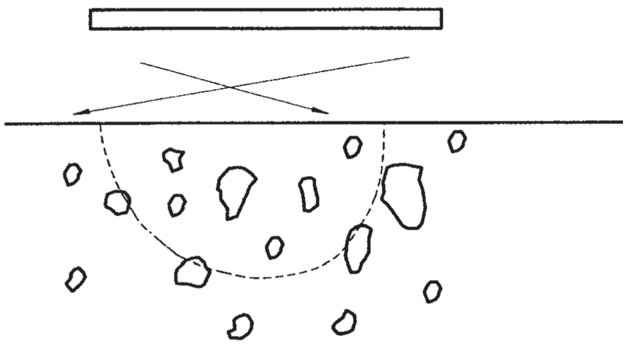
Level off the soil surface with the straight metal blade (4.2.2.11) [Figure 1 a)]. Dig a hole in the levelled soil having a representative content of larger gravel and stones according to visual inspection. Avoid compaction of the soil on the sides [Figure 1 b)]. Put the excavated soil in bags (4.2.2.3) for laboratory analysis. Large nonporous stones such as granite pieces may be separated in the field, cleaned with a stiff brush, putting the fine material into the bags. Weigh the large nonporous stone(s) on a field balance and include it in the mass of gravel and stones.

Line the hole with the plastic film (4.2.2.4). Using the funnel (4.2.2.5), fill the hole to excess with a known volume of sand (4.2.2.6) from a height of 5 cm [Figure 1 c)]; then, level the surface with the blade without packing down. Replace the excess sand into the graduated measuring cylinder (4.2.2.5), and read the volume [Figure 1 d)]; the difference from the initial volume of sand is the volume V of the hole.

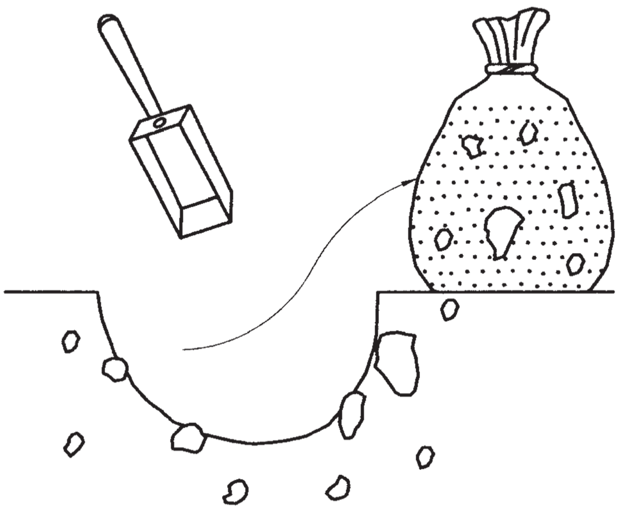
4.2.4 Laboratory procedure

Determine the mass, in grams, of the moist excavated soil with a balance (4.2.2.7) (m_{pw}). Separate the stones and gravel from the fine soil with the sieve (4.2.2.10) (clean any dirty pieces with a cloth or a stiff brush), and weigh them on the laboratory balance (m_{xw}). Dry the stones and gravel in the oven (4.2.2.8) at (105 ± 2) °C and after cooling weigh them, in grams, on the laboratory balance (m_x).

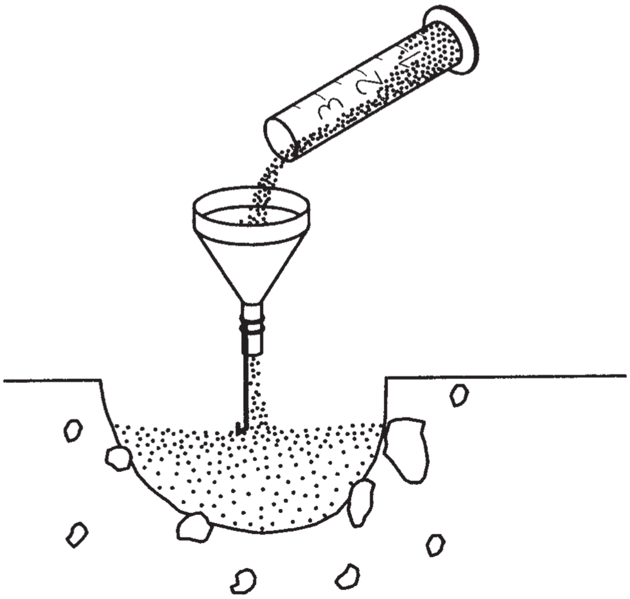
Determine the water content of the fine soil (<2,0 mm diameter) by drying a representative sample (5 g to 10 g) of known mass in the oven at (105 ± 2) °C until constant mass is reached. Remove the sample from the oven and allow to cool in the desiccator. Weigh the sample on the laboratory balance. Calculate the water content (w) as a mass ratio of the moist sample.



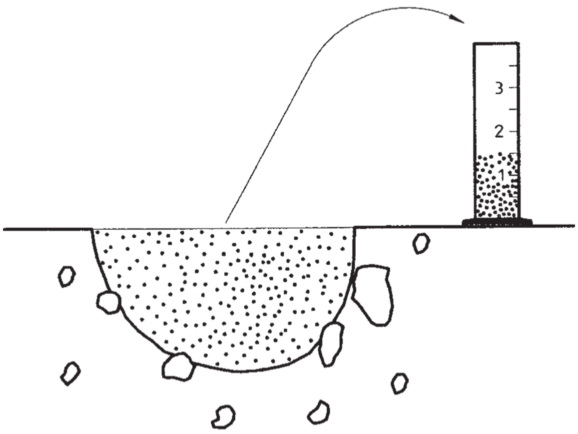
a) Level off soil surface



b) Dig a hole



c) Fill with sand



d) Remove the excess sand and measure its volume

Figure 1 — Excavation method — Field procedure

4.2.5 Calculation

The dry bulk density of the soil layer is calculated using Formula (3) to Formula (6):

$$\rho_{\mathrm{b,s}} = \frac{m_{\mathrm{x}} + m_{\mathrm{fp}}}{V} \tag{3}$$

$$m_{\mathrm{fp}} = m_{\mathrm{pw}} - m_{\mathrm{xw}} - m_{\mathrm{w}} \tag{4}$$

$$m_{\mathrm{w}} = w \cdot m_{\mathrm{fw}} \tag{5}$$

$$m_{\mathrm{fw}} = m_{\mathrm{pw}} - m_{\mathrm{xw}} \tag{6}$$

where

$\rho_{b,s}$ is the dry bulk density of the soil, in grams per cubic centimetre, g/cm^3;

m_x is the mass of dry gravels and stones, in grams, g;

m_{fp} is the mass of the dry fine soil, in grams, g;

V is the volume of the hole, in cubic centimetres, cm^3;

m_{pw} is the mass of the excavated moist soil, in grams, g;

m_w is the mass of the water from the excavated fine soil, in grams, g;

w is the water content of the excavated fine moist soil, in grams of water per gram of oven-dried soil;

m_{xw} is the mass of moist gravels and stones, in grams, g;

m_{fw} is the mass of the moist fine soil, in grams, g.

4.3 Substitute methods

With growing maximum particle size, it is necessary to enlarge the hole to be excavated according to ASTM D4914 and DIN 18125-2 to get representative samples. The larger the hole, the more fill material needs to be provided and transported. Therefore, it can be useful to replace dry, graded sand (4.2.2.6) by other fill material like

— free water (see ASTM D5030),

— water or another liquid in a rubber balloon (see ASTM D2167), and

— plastic balls (see Annex A).

Table 1 characterizes common methods by mean sample weight and sample volume, as well as by their applicability for different soil materials.

NOTE Minimum sample size S_s in kg can be estimated from maximum particle size P_{smax} in millimetres by $S_s = P_{smax} \cdot \frac{P_{smax}}{256}$, see EN 932-1.

Table 1 — Characterization of some common substitute methods

<table>
<tr><th>Substitute method</th><th>Maximum particle size
mm</th><th>Sample weight
kg</th><th>Sample volume
l</th><th colspan="5">Applicable on</th></tr>
<tr><td>Core method (4.1)</td><td>less than 13</td><td>0,15 to 2,25</td><td>0,1 to 1,5</td><td rowspan="5">cohesive soil without coarse grain</td><td>—</td><td rowspan="5">fine and medium sand</td><td>—</td><td>—</td></tr>
<tr><td>Balloon method (ASTM D2167)</td><td>less than 38</td><td>3 to 15</td><td>2 to 10</td><td>no sharp grains</td><td rowspan="4">gravelly sand and sandy gravel</td><td rowspan="4">gravel with less than 10 % sand or finer</td></tr>
<tr><td>Sand method (4.2, ASTM D1556)</td><td>less than 38</td><td>7,5 to 45</td><td>5 to 30</td><td rowspan="3">cohesive soil with coarse grain</td></tr>
<tr><td>Sand method (4.2, ASTM D4914)</td><td>38 to 200 (max. 400)</td><td>15 to 300</td><td>10 to 200</td></tr>
<tr><td>Water method (ASTM D5030)</td><td>38 to 200 (max. 400)</td><td>15 to 750</td><td>10 to 500</td></tr>
<tr><td>Plastic balls (Annex A)</td><td>more than 200</td><td>750 to 2 250</td><td>500 to 1 500</td><td colspan="5">gravel, cobbles, boulders with less than 20 % sand or finer</td></tr>
</table>

Make sure that the selected method achieves standard deviations less than or equal to 0,015 (0,02) g/cm^3 for inner laboratory repeated (inter-laboratory compared) analyses concerning core and balloon method and 0,020 (0,030) g/cm^3 concerning all other methods (DIN 18125-2).

4.4 Clod method

4.4.1 Principle

The dry bulk density of clods, or coarse peds, can be calculated from their mass and volume. The volume can be determined by coating a clod of known mass with a water-repellent substance and weighing it, first in air and then again while immersed in water, making use of Archimedes' principle. The clod or ped should be stable in order to cohere during coating, weighing and handling. The clod method usually gives higher bulk density values than other methods, because the interclod spaces are not taken into account.

4.4.2 Apparatus

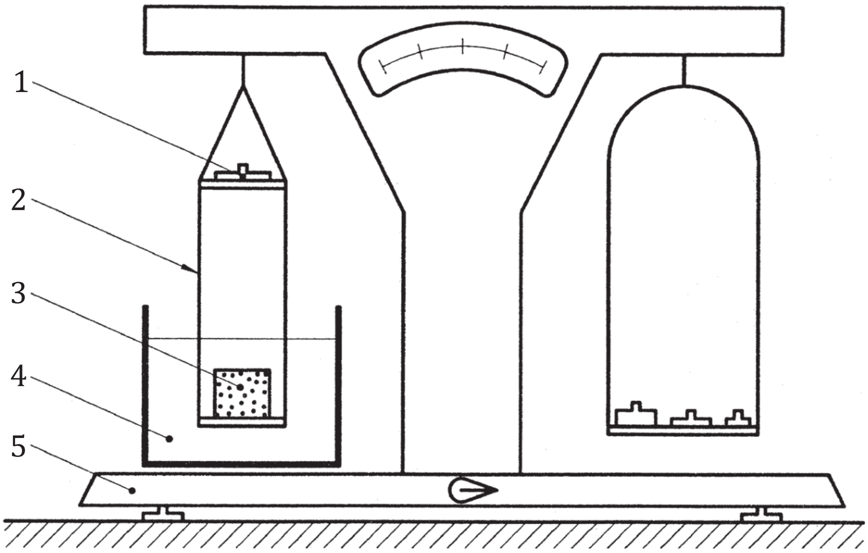
4.4.2.1 Earth digging equipment, flat shovel, spade, pick.

4.4.2.2 Sampling equipment, small flat-bladed spade, knife, chisel, hammer.

4.4.2.3 Container, of molybdenum sulfide (MoS_2) in heavy oil.

4.4.2.4 Laboratory balance with a thin wire attached to the weighing beam, from which a light frame can be suspended. The frame serves as a platform for a weighing dish, so that both frame and dish can be immersed in a container of water during weighing (Figure 2).

4.4.2.5 Thermometer.



Key

1 compensating weights
2 thin wire
3 small container
4 large container filled with water
5 laboratory balance

Figure 2 — Laboratory balance to determine the volume of clods by weighing in air and water

4.4.3 Procedure

Separate and weigh soil clods or peds with a laboratory balance (4.4.2.4) and coat them in oil (4.4.2.3). Weigh the coated clod again, once in air and once immersed in water. Measure the temperature of the water and determine its density from Table B.1. To obtain a correction for the water content of the soil, break open the clod, remove an aliquot of soil, and weigh the aliquot before and after drying in an oven at (105 ± 2) °C.

4.4.4 Calculation

The oven-dry mass of the soil clods is calculated using Formula (7):

$$m_{\mathrm{d}} = \frac{m}{1+w} \tag{7}$$

where

w is the water content of the subsample, in grams of water per gram of oven-dried soil;

m is the net mass of the moist clod in air in grams, g;

m_{d} is the net mass of the oven-dry clod in grams, g.

Calculate the bulk density of the dry clod using Formula (8):

$$\rho_{b,s} = \frac{\text{mass}}{\text{volume}} = \frac{\rho_w \times m_d}{m - m_w + m_o\left(\rho_o - \rho_w\right)} \tag{8}$$

where

$\rho_{b,s}$	is the bulk density of oven-dry sample, in grams per cubic centimetre, g/cm^3;
ρ_o	is the density of the coating oil, in grams per cubic centimetre, g/cm^3;
ρ_w	is the density of water at temperature of determination, in grams per cubic centimetre, g/cm^3;
m_d	is the oven-dry mass of soil sample (clod or ped) in grams, g;
m	is the mass of soil sample in air in grams, g;
m_w	is the mass of soil sample plus coating in water in grams, g;
m_o	is the mass of coating in air in grams, g.

4.4.5 Unified reference temperature

To get comparable dry bulk densities measured at different temperatures, the unification of a reference temperature at 20 °C according to Formula (9) is required.

$$\rho_{20\,°C} = \rho_{x\,°C} \times KF_{x\,°C} \tag{9}$$

where

$\rho_{20\,°C}$	is the dry bulk density at 20 °C in grams per cubic centimetre, g/cm^3;
$\rho_{x\,°C}$	is the dry bulk density at measured temperature in grams per cubic centimetre, g/cm^3;
$KF_{x\,°C}$	is the coefficient at measured temperature according to Table B.1.

5 Test report

The test report shall contain the following information:

a) a reference to this document, i.e. ISO 11272;

b) complete identification of the sample;

c) a reference to the method used;

d) the moisture conditions of the soil during sampling;

e) the results of the determination;

f) any details not specified in this document or which are optional, as well as any factor which may have affected the results.

Annex A
(informative)

Volume measurement using plastic balls

The volume of soil removed is measured by pouring plastic balls of 2 cm diameter and having a packing density of 7,315 cm^3 per ball into the cavity until level with the soil surface, and counting the number of balls. The soil volume, V, in cubic centimetres, is calculated using Formula (A.1):

$$V = 7{,}315 \times \text{number of balls} \quad \text{(A.1)}$$

For further details on this method, see Reference [2].

Annex B
(normative)

Density of water at different temperatures

Table B.1 shows the density of water at different temperatures according to Reference [3].

Table B.1 — Density of water at different temperatures

Temperature °C	Density of water g/cm³	Coefficient KF	Temperature °C	Density of water g/cm³	Coefficient KF
15,0	0,999 10	1,000 90	23,0	0,997 54	0,999 33
15,1	0,999 09	1,000 88	23,1	0,997 52	0,999 31
15,2	0,999 07	1,000 87	23,2	0,997 49	0,999 29
15,3	0,999 06	1,000 85	23,3	0,997 47	0,999 26
15,4	0,999 04	1,000 84	23,4	0,997 45	0,999 24
15,5	0,999 02	1,000 82	23,5	0,997 42	0,999 21
15,6	0,999 01	1,000 80	23,6	0,997 40	0,999 19
15,7	0,998 99	1,000 79	23,7	0,997 37	0,999 17
15,8	0,998 98	1,000 77	23,8	0,997 35	0,999 14
15,9	0,998 96	1,000 76	23,9	0,997 32	0,999 12
16,0	0,998 95	1,000 74	24,0	0,997 30	0,999 09
16,1	0,998 93	1,000 72	24,1	0,997 27	0,999 07
16,2	0,998 91	1,000 71	24,2	0,997 25	0,999 04
16,3	0,998 90	1,000 69	24,3	0,997 23	0,999 02
16,4	0,998 88	1,000 67	24,4	0,997 20	0,998 99
16,5	0,998 86	1,000 66	24,5	0,997 17	0,998 97
16,6	0,998 85	1,000 64	24,6	0,997 15	0,998 94
16,7	0,998 83	1,000 62	24,7	0,997 12	0,998 92
16,8	0,998 81	1,000 61	24,8	0,997 10	0,998 89
16,9	0,998 79	1,000 59	24,9	0,997 07	0,998 87
17,0	0,998 78	1,000 57	25,0	0,997 05	0,998 84
17,1	0,998 76	1,000 55	25,1	0,997 02	0,998 81
17,2	0,998 74	1,000 54	25,2	0,997 00	0,998 79
17,3	0,998 72	1,000 52	25,3	0,996 97	0,998 76
17,4	0,998 71	1,000 50	25,4	0,996 94	0,998 74
17,5	0,998 69	1,000 48	25,5	0,996 92	0,998 71
17,6	0,998 67	1,000 47	25,6	0,996 89	0,998 68
17,7	0,998 65	1,000 45	25,7	0,996 87	0,998 66
17,8	0,998 63	1,000 43	25,8	0,996 84	0,998 63
17,9	0,998 62	1,000 41	25,9	0,996 81	0,998 60
18,0	0,998 60	1,000 39	26,0	0,996 79	0,998 58
18,1	0,998 58	1,000 37	26,1	0,996 76	0,998 55
18,2	0,998 56	1,000 35	26,2	0,996 73	0,998 52
18,3	0,998 54	1,000 34	26,3	0,996 71	0,998 50

Table B.1 *(continued)*

Temperature °C	Density of water g/cm³	Coefficient KF	Temperature °C	Density of water g/cm³	Coefficient KF
18,4	0,998 52	1,000 32	26,4	0,996 68	0,998 47
18,5	0,998 50	1,000 30	26,5	0,996 65	0,998 44
18,6	0,998 48	1,000 28	26,6	0,996 63	0,998 42
18,7	0,998 47	1,000 26	26,7	0,996 60	0,998 39
18,8	0,998 45	1,000 24	26,8	0,996 57	0,998 36
18,9	0,998 43	1,000 22	26,9	0,996 54	0,998 33
19,0	0,998 41	1,000 20	27,0	0,996 52	0,998 31
19,1	0,998 39	1,000 18	27,1	0,996 49	0,998 28
19,2	0,998 37	1,000 16	27,2	0,996 46	0,998 25
19,3	0,998 35	1,000 14	27,3	0,996 43	0,998 22
19,4	0,998 33	1,000 12	27,4	0,996 41	0,998 20
19,5	0,998 31	1,000 10	27,5	0,996 38	0,998 17
19,6	0,998 29	1,000 08	27,6	0,996 35	0,998 14
19,7	0,998 27	1,000 06	27,7	0,996 32	0,998 11
19,8	0,998 25	1,000 04	27,8	0,996 29	0,998 08
19,9	0,998 23	1,000 02	27,9	0,996 27	0,998 06
20,0	0,998 21	1,000 00	28,0	0,996 24	0,998 03
20,1	0,998 19	0,999 98	28,1	0,996 21	0,998 00
20,2	0,998 16	0,999 96	28,2	0,996 18	0,997 97
20,3	0,998 14	0,999 94	28,3	0,996 15	0,997 94
20,4	0,998 12	0,999 92	28,4	0,996 12	0,997 91
20,5	0,998 10	0,999 90	28,5	0,996 09	0,997 88
20,6	0,998 08	0,999 87	28,6	0,996 07	0,997 85
20,7	0,998 06	0,999 85	28,7	0,996 04	0,997 83
20,8	0,998 04	0,999 83	28,8	0,996 01	0,997 80
20,9	0,998 02	0,999 81	28,9	0,995 98	0,997 77
21,0	0,997 99	0,999 79	29,0	0,995 95	0,997 74
21,1	0,997 97	0,999 77	29,1	0,995 92	0,997 71
21,2	0,997 95	0,999 74	29,2	0,995 89	0,997 68
21,3	0,997 93	0,999 72	29,3	0,995 86	0,997 65
21,4	0,997 91	0,999 70	29,4	0,995 83	0,997 62
21,5	0,997 89	0,999 68	29,5	0,995 80	0,997 59
21,6	0,997 86	0,999 66	29,6	0,995 77	0,997 56
21,7	0,997 84	0,999 63	29,7	0,995 74	0,997 53
21,8	0,997 82	0,999 61	29,8	0,995 71	0,997 50
21,9	0,997 80	0,999 59	29,9	0,995 68	0,997 47
22,0	0,997 77	0,999 57	30,0	0,995 65	0,997 44
22,1	0,997 75	0,999 54	30,1	0,995 62	0,997 41
22,2	0,997 73	0,999 52	30,2	0,995 59	0,997 38
22,3	0,997 70	0,999 50	30,3	0,995 56	0,997 35
22,4	0,997 68	0,999 47	30,4	0,995 53	0,997 32
22,5	0,997 66	0,999 45	30,5	0,995 50	0,997 29
22,6	0,997 64	0,999 43	30,6	0,995 47	0,997 26

Table B.1 *(continued)*

Temperature °C	**Density of water** g/cm^3	**Coefficient** KF	**Temperature** °C	**Density of water** g/cm^3	**Coefficient** KF
22,7	0,997 61	0,999 40	30,7	0,995 44	0,997 23
22,8	0,997 59	0,999 38	30,8	0,995 41	0,997 20
22,9	0,997 56	0,999 36	30,9	0,995 38	0,997 16

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