

Manual of Petroleum Measurement Standards Chapter 11—Physical Properties Data

Section 5—Density/Weight/Volume Intraconversion

Part 2—Conversions for Relative Density (60/60 °F)

Adjunct to: ASTM D1250-08 and IP 200/08

FIRST EDITION, MARCH 2009



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Measurement Coordination

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Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, D.C. 20005, standards@api.org.

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Introduction

API MPMS Ch. 11.5.1, API MPMS Ch. 11.5.2, and API MPMS Ch. 11.5.3 are intended to replace API MPMS Ch. 11.1-1980 Volumes XI/XII (ASTM D1250-80, IP 200/80). This standard gives the following equivalents for any value of relative density (60/60 °F):

- API gravity at 60 °F (old Table 21);
- absolute density at 60 °F;
- absolute density at 15 °F (old Table 21);
- pounds per U.S. gallon at 60 °F in and *in air* (old Table 26);
- U.S. gallons per pound at 60 °F *in vacuo* and *in air* (old Table 26);
- short tons per 1000 U.S. gallons at 60 °F *in vacuo* and *in air* (old Table 27);
- U.S. gallons per short ton at 60 °F *in vacuo* and *in air* (old Table 28);
- short tons per barrel at 60 °F *in vacuo* and *in air* (old Table 27);
- barrels per short ton at 60 °F *in vacuo* and *in air* (old Table 28);
- long tons per 1000 U.S. gallons at 60 °F *in vacuo* and *in air* (old Table 29);
- U.S. gallons per long ton at 60 °F *in vacuo* and *in air* (old Table 30);
- long tons per barrel at 60 °F *in vacuo* and *in air* (old Table 29);
- barrels per long ton at 60 °F *in vacuo* and *in air* (old Table 30);
- metric tons per 1000 U.S. gallons at 60 °F *in vacuo* and *in air*;
- metric tons per barrel at 60 °F *in vacuo* and *in air*;
- barrels per metric ton at 60 °F *in vacuo* and *in air*;
- cubic metres per short ton at 15 °C *in vacuo* and *in air* (old Table 31);
- cubic metres per long ton at 15 °C *in vacuo* and *in air* (old Table 31).

While not related to relative density, the following are included for user convenience:

- U.S. gallons at 60 °F to litres at 15 °C (old Table 22);
- barrels at 60 °F to litres at 15 °C (old Table 22, Table 52).

This standard is intended for application to bulk liquid quantities.

This standard provides implementation procedures for conversion of relative density (60/60 °F) to equivalent densities in both *in vacuo* and *in air* values. A derivation of the *in air* equation is presented in Section B.4. *in air* values reflect the buoyancy effect of air if a substance were to be weighed in the air, and thus are slightly less than *in vacuo* values by approximately 0.1 % to 0.2 %. Although *in air* implementation procedures are presented in this standard in

recognition of certain common industry practices, *in vacuo* values are recommended because they more accurately represent the amount of material present.

Furthermore, as there is no known technical reason for the continued use of relative density in the oil industry, absolute density is recommended instead (see API *MPMS* Ch. 11.5.3). This standard is presented, however, for the convenience of certain current common industry practices.

Chapter 11—Physical Properties Data

Section 5—Density/Weight/Volume Intraconversion

Part 2—Conversions for Relative Density (60/60 °F)

Implementation Guidelines

This revised standard is effective upon the date of publication and supersedes the applicable parts of API *MPMS* Ch. 11.1-1980, Volumes XI/XII. However, due to the nature of the changes in this revised standard, it is recognized that guidance concerning an implementation period may be needed in order to avoid disruptions within the industry and ensure proper application. As a result, it is recommended that this revised standard be utilized on all new applications no later than TWO YEARS after the publication date. An application, for this purpose, is defined as the point where the calculation is applied.

Once the revised standard is implemented in a particular application, the previous standard will no longer be used in that application.

However, the use of API standards remains voluntary and the decision on when to utilize a standard is an issue that is subject to the negotiations between the parties involved in the transaction.

1 Scope

These intraconversion tables are applicable to all crude oils, petroleum products, and petrochemicals.

2 References

The following referenced documents are indispensable for the application 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.

API *MPMS* Chapter 11.1-2004, *Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils*

API *MPMS* Chapter 11.4.1-2003, *Density of Water and Water VCFs for Volumetric Meter Proving*

API *MPMS* Chapter 15-2001, *Guideline for the Use of the International System of Units (SI) in the Petroleum and Allied Industries*

ASTM D1250-1959¹, *Report on the Development, Construction, and Preparation of the ASTM-IP Petroleum Measurement Tables*

12th General Conference on Weights and Measures (1964)

NIST Handbook 44-2002 Edition², *Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices*

NIST Handbook 44-2007 Edition, Appendix C

NIST Handbook 105-1 (Revised 1990), *Specifications and Tolerances for Reference Standards and Field Standard Weights and Measures*

¹ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

² National Institute of Standards and Technology, 100 Bureau Drive, Stop 3460, Gaithersburg, Maryland 20899, www.nist.gov.

3 Definitions and Abbreviations

3.1 Definitions

3.1.1

absolute density

The density of a substance is the mass of the substance occupying unit volume at a specified temperature at atmospheric pressure or equilibrium vapor pressure. Density as so defined is sometimes referred to as “true density” or as “density *in vacuo*,” or often just plain “density.” When reporting density, the units of mass and volume used and the temperature of the determination must be stated (e.g. kilograms per cubic metre or grams per millilitre at t °F or t °C). For the oil industry, if the temperature is unstated, standard temperature (60 °F or 15 °C) should be assumed.

3.1.2

API gravity

A term used by the petroleum industry to express the relative density of petroleum liquids (also see **relative density**). The relationship between API gravity and relative density (formerly called specific gravity) is shown in Equation (1). API gravity is a dimensionless number; as it is derived from absolute density, it is “*in vacuo*.”

3.1.3

apparent density

See **density *in air***.

3.1.4

apparent weight

See **weight *in air***.

3.1.5

density *in air*

Apparent weight of a substance occupying unit volume.

3.1.6

density *in vacuo*

See **absolute density**.

3.1.7

grams per cubic centimetre

An expression of density in SI (metric) units, also equal to grams per millilitre.

3.1.8

grams per millilitre

An expression of density in SI (metric) units, also equal to grams per cubic centimetre.

3.1.9

kilograms per cubic metre

An expression of density in SI (metric) units, numerically equivalent to grams per litre. This is the common unit of density currently used in the oil industry.

3.1.10

mass

An absolute measure of a particular quantity of matter. Mass is defined in terms of a standard mass, therefore, the mass of an object is simply a multiple of the mass standard. The mass of an object remains constant regardless of its location, whereas weight varies with altitude. The metric unit of mass is the kilogram (kg).

3.1.11**relative density**

The ratio of the density of a substance at a specific temperature to the density of a reference substance at a reference temperature. When reporting results, explicitly state the temperatures of each, e.g. 20 °C/4 °C. Formerly known as specific gravity.

3.1.12**specific gravity**

See **relative density**.

3.1.13**true weight**

See **weight *in vacuo***.

3.1.14**volume correction factor****VCF**

The ratio of a liquid's density at temperature t and pressure p to its density at standard temperature 60 °F and 14.696 pounds per square inch absolute (psia) [or 15 °C and standard pressure 101.325 kilopascals (kPa)] A liquid's volume at temperature t can be converted to its volume at reference temperature by multiplying volume at temperature t by the VCF at temperature t . For more information, refer to API MPMS Ch. 11.1, *Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils*.

3.1.15**weight**

A measure of gravitational force on an object. As gravitational force diminishes with distance from the center of the earth, weight is referenced to mean sea level. This is not to be confused with mass, which is independent of gravity and is directly proportional to the number of atoms or molecules present. The U.S. "customary" unit of weight is the pound (lb).

3.1.16**weight *in air***

The weight which a quantity of liquid would appear to have when weighed in the air against commercial weights which have been standardized so that each will have a weight in a vacuum equal to the nominal mass associated with it. During a weighing, the air exerts a net buoyancy force upon the liquid equal to the mass of air displaced by the liquid minus the mass of air displaced by the weights (for more information, see Section B.4).

3.1.17**weight *in vacuo***

The weight of a mass in a vacuum, with no air buoyancy effect.

3.2 Abbreviations

| | |
|------------------------------|---|
| °API | degrees API gravity |
| bbl | barrel (42 U.S. gallons) |
| cm³ | cubic centimetre |
| D^{15} | density at 15 °C |
| D_a^{15} | density <i>in air</i> (apparent density) at 15 °C |
| D^{60} | density at 60 °F |
| D_a^{60} | density <i>in air</i> (apparent density) at 60 °F |

| | |
|-------------------------|---|
| D_{60}^{60} | relative density at 60 °F |
| g | gram |
| gal | U.S. gallon |
| gal/lb | U.S. gallons per pound |
| g/cm³ | grams per cubic centimetre |
| g/mL | grams per millilitre |
| L | litre |
| lb | pound |
| LT | long ton |
| m³ | cubic metre |
| MT | metric ton (1000 kilograms, 1 million grams) |
| ST | short ton |
| ρ_{60} | density of water at 60 °F |
| VCF_t | volume correction factor at temperature t (°F in this standard) and one atmosphere pressure unless otherwise specified. |

4 Implementation Procedures

Derivations of the equations below are presented in Annex B. API MPMS Ch. 12 governs all rounding. Absent specific direction from API MPMS Ch. 12, results should be rounded as indicated below.

4.1 API Gravity at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.1) expresses the relationship between relative density (D_{60}^{60}) and API gravity at 60 °F:

$$^{\circ}\text{API} = \frac{141.5}{D_{60}^{60}} - 131.5 \quad (1)$$

Solve Equation (1) with values of D_{60}^{60} and round the result to two places past the decimal for further use.

4.2 Absolute Density at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.2) defines the relationship between relative density (60/60 °F) and density D_{60}^{60} in kilograms per cubic metre at 60 °F:

$$D_{60}^{60} \text{ in kg/m}^3 = D_{60}^{60} \times 999.016 \quad (2)$$

Solve Equation (2) with values of D_{60}^{60} and round the result to two places past the decimal for further use.

EXAMPLE

What is the relative density at 60 °F for gasoline equivalent to an absolute density at 60 °F of 0.74431?

$$D_{60}^{60} \text{ in kg/m}^3 = 0.74431 \times 999.016 = 743.58 \text{ kg/m}^3$$

4.3 Absolute Density at 15 °C Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.3) expresses the relationship between relative density (60/60 °F) and density at 15 °C in kilograms per cubic metre:

$$D^{15} \text{ in kg/m}^3 = D^{60}_{60} \times 999.016 \times VCF_{59} \quad (3)$$

Solve Equation (3) with values of D^{60}_{60} and round the result to two places past the decimal for further use. As this calculation includes a VCF_{59} , the result is product specific. Crude oils, generalized products, and lubricants will use API MPMS Ch. 11.1-2004. Other products may use different tables.

EXAMPLE

What is the relative density at 60 °F for gasoline equivalent to an absolute density at 60 °F of 0.74431? Using Table 6B from API MPMS Ch. 11.1:

$$D^{15} \text{ in kg/m}^3 = 0.74431 \times 999.016 \times 1.00068 = 744.08 \text{ kg/m}^3$$

4.4 Pounds per U.S. Gallon at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.4) expresses the relationship between relative density (60/60 °F) and the corresponding density in pounds per U.S. gallon *in vacuo*:

$$D^{60} \text{ in lb/gal} = D^{60}_{60} \times 0.999016 \times 8.345404452 \quad (4)$$

The following equation (see Section B.4) expresses the relationship between relative density (60/60 °F) and the corresponding density in pounds per U.S. gallon *in air*:

$$D_a^{60} \text{ in lb/gal} = (0.9991657784 D^{60}_{60} - 0.001199407795) \times 8.345404452 \quad (5)$$

Solve Equation (4) or Equation (5) with values of D^{60}_{60} and round the result to nine places past the decimal for further use.

EXAMPLE

A tank car of gasoline having a 60 °F relative density of 0.74431 is determined to contain 24,386 U.S. gal at 60 °F. What is the *in vacuo* weight in pounds of the cargo?

Use Equation (4) to calculate the *in vacuo* intraconversion factor:

$$D^{60} \text{ in lb/gal} = 0.74431 \times 0.999016 \times 8.345404452 = 6.205455805 \text{ lb/gal}$$

The 24,386 U.S. gal of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight in vacuo} = 6.205455805 \text{ lb/gal} \times 24,386 \text{ gal} = 151,326 \text{ lb}$$

EXAMPLE

A tanker of gasoline having a 60 °F relative density of 0.74431 is determined to contain 361,901.00 bbl at 60 °F. What is the *in vacuo* weight in pounds of the cargo?

Use Equation (4) to calculate the *in vacuo* intraconversion factor:

$$D^{60} \text{ in lb/gal} = 0.74431 \times 0.999016 \times 8.345404452 = 6.205455805 \text{ lb/gal}$$

The 361,901.00 bbl of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight in vacuo} = 6.205455805 \text{ lb/gal} \times 361,901 \text{ bbl} \times 42 \text{ gal/bbl} = 94,321,948 \text{ lb}$$

4.5 U.S. Gallons per Pound at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.5) expresses the relationship between relative density (60/60 °F) and the corresponding U.S. gallons per pound *in vacuo*:

$$1/D^{60} \text{ in gal/lb} = \frac{1}{D_{60}^{60} \times 0.999016 \times 8.345404452} \quad (6)$$

The following equation (see Section B.5) expresses the relationship between relative density (60/60 °F) and the corresponding U.S. gallons per pound *in air*:

$$1/D_a^{60} \text{ in gal/lb} = \frac{1}{(0.9991657784 D_{60}^{60} - 0.001199407795) \times 8.345404452} \quad (7)$$

Solve Equation (6) or Equation (7) with values of D_{60}^{60} and round the result to ten places past the decimal for further use.

EXAMPLE

An incoming shipment of gasoline having a 60 °F relative density of 0.74431 is invoiced at 94,321,948 lb. What is the 60 °F volume in U.S. gallons?

Use Equation (6) to calculate the *in vacuo* intraconversion factor:

$$1/D^{60} \text{ in gal/lb} = \frac{1}{0.74431 \times 0.999016 \times 8.345404452} = 0.1611485170 \text{ gal/lb}$$

The 94,321,948 lb of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60 \text{ °F gal} = 0.1611485170 \text{ gal/lb} \times 94,321,948 \text{ lb} = 15,199,842 \text{ gal}$$

4.6 Short Tons per 1000 U.S. Gallon at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.6) expresses the relationship between relative density (60/60 °F) and the corresponding short tons per 1000 U.S. gallons *in vacuo*:

$$D^{60} \text{ in ST/1000 gal} = D_{60}^{60} \times 0.999016 \times 4.172702226 \quad (8)$$

The following equation (see Section B.6) expresses the relationship between relative density (60/60 °F) and the corresponding short tons per 1000 U.S. gallons *in air*:

$$D_a^{60} \text{ in ST/1000 gal} = (0.9991657784 D_{60}^{60} - 0.001199407795) \times 4.172702226 \quad (9)$$

Solve Equation (8) or Equation (9) with values of D_{60}^{60} and round the result to nine places past the decimal for further use.

EXAMPLE

A tanker of gasoline having a 60 °F relative density of 0.74431 is determined to contain 361,901.00 bbl at 60 °F. What is the *in vacuo* weight in short tons?

Use Equation (8) to calculate the *in vacuo* intraconversion factor:

$$D^{60}_{\text{in ST/1000 gal}} = 0.74431 \times 0.999016 \times 4.172702226 = 3.102727902 \text{ ST/1000 gal}$$

The 361,901.00 bbl of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight in vacuo} = 3.102727902 \text{ ST/1000 gal} \times 361,901 \text{ bbl} \times 42 \text{ gal/bbl} = 47,160.9739 \text{ ST}$$

4.7 U.S. Gallons per Short Ton at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.7) expresses the relationship between relative density (60/60 °F) and the corresponding U.S. gallons per short ton *in vacuo*:

$$1/D^{60}_{\text{in gal/ST}} = \frac{1000}{D^{60}_{60} \times 0.999016 \times 4.172702226} \quad (10)$$

The following equation (see Section B.7) expresses the relationship between relative density (60/60 °F) and the corresponding U.S. gallons per short ton *in air*:

$$1/D_a^{60}_{\text{in gal/ST}} = \frac{1000}{(0.9991657784 D^{60}_{60} - 0.001199407795) \times 4.172702226} \quad (11)$$

Solve Equation (10) or Equation (11) with values of D^{60}_{60} and round the result to seven places past the decimal for further use.

EXAMPLE

An incoming shipment of gasoline having a 60 °F relative density of 0.74431 is invoiced at 47,160.9739 ST. What is the 60 °F volume in U.S. gallons?

Use Equation (10) to calculate the *in vacuo* intraconversion factor:

$$1/D^{60}_{\text{in gal/ST}} = \frac{1000}{0.74431 \times 0.999016 \times 4.172702226} = 322.2970339 \text{ gal/ST}$$

The 47,160.9739 ST of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60 \text{ °F gal} = 322.2970339 \text{ gal/ST} \times 47,160.9739 \text{ ST} = 15,199,842 \text{ gal}$$

4.8 Short Tons per Barrel at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.8) expresses the relationship between relative density (60/60 °F) and the corresponding short tons per barrel *in vacuo*:

$$D^{60}_{\text{in ST/bbl}} = D^{60}_{60} \times 0.999016 \times 0.1752534935 \quad (12)$$

The following equation (see Section B.8) expresses the relationship between relative density (60/60 °F) and the corresponding short tons per barrel *in air*:

$$D_a^{60} \text{ in ST/bbl} = (0.9991657784 D_{60}^{60} - 0.001199407795) \times 0.1752534935 \quad (13)$$

Solve Equation (12) or Equation (13) with values of D_{60}^{60} and round the result to ten places past the decimal for further use.

EXAMPLE

A tanker of gasoline having a 60 °F relative density of 0.74431 is determined to contain 361,901.00 bbl at 60 °F. What is the *in vacuo* weight in short tons?

Use Equation (12) to calculate the *in vacuo* intraconversion factor:

$$D^{60} \text{ in ST/bbl} = 0.74431 \times 0.999016 \times 0.1752534935 = 0.1303145719 \text{ ST/bbl}$$

The 361,901.00 bbl of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight in vacuo} = 0.1303145719 \text{ ST/bbl} \times 361,901 \text{ bbl} = 47,160.9739 \text{ ST}$$

4.9 Barrels per Short Ton at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.9) expresses the relationship between relative density (60/60 °F) and the corresponding barrels per short ton *in vacuo*:

$$1/D_a^{60} \text{ in bbl/ST} = \frac{1}{D_{60}^{60} \times 0.999016 \times 0.1752534935} \quad (14)$$

The following equation (see Section B.9) expresses the relationship between relative density (60/60 °F) and the corresponding U.S. gallons per short ton *in air*:

$$1/D_a^{60} \text{ in bbl/ST} = \frac{1}{(0.9991657784 D_{60}^{60} - 0.001199407795) \times 0.1752534935} \quad (15)$$

Solve Equation (14) or Equation (15) with values of D_{60}^{60} and round the result to nine places past the decimal for further use.

EXAMPLE

An incoming shipment of gasoline having a 60 °F relative density of 0.74431 is invoiced at 47,160.9739 ST. What is the 60 °F volume in barrels?

Use Equation (14) to calculate the *in vacuo* intraconversion factor:

$$1/D^{60} \text{ in bbl/ST} = \frac{1}{0.74431 \times 0.999016 \times 0.1752534935} = 7.673738903 \text{ bbl/ST}$$

The 47,160.9739 ST of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60 \text{ °F bbl} = 7.673738903 \text{ bbl/ST} \times 47,160.9739 \text{ ST} = 361,901.00 \text{ bbl}$$

4.10 Long Tons per 1000 U.S. Gallons at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.10) expresses the relationship between relative density (60/60 °F) and the corresponding long tons per 1000 U.S. gallons *in vacuo*:

$$D^{60} \text{ in LT/1000 gal} = D_{60}^{60} \times 0.999016 \times 3.725626988 \quad (16)$$

The following equation (see Section B.10) expresses the relationship between relative density (60/60 °F) and the corresponding long tons per 1000 U.S. gallons *in air*:

$$D_a^{60} \text{ in LT/1000 gal} = (0.9991657784 D_{60}^{60} - 0.001199407795) \times 3.725626988 \quad (17)$$

Solve Equation (16) or Equation (17) with values of D_{60}^{60} and round the result to nine places past the decimal for further use.

EXAMPLE

A tanker of gasoline having a 60 °F relative density of 0.74431 is determined to contain 361,901.00 bbl at 60 °F. What is the *in vacuo* weight in long tons?

Use Equation (16) to calculate the *in vacuo* intraconversion factor:

$$D^{60} \text{ in LT/1000 gal} = 0.74431 \times 0.999016 \times 3.725626988 = 2.770292770 \text{ LT/1000 gal}$$

The 361,901.00 bbl of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight in vacuo} = 2.770292770 \text{ LT/1000 gal} \times 361,901 \text{ bbl} \times 42 \text{ gal/bbl} = 42,108.0124 \text{ LT}$$

4.11 U.S. Gallons per Long Ton at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.11) expresses the relationship between relative density (60/60 °F) and the corresponding U.S. gallons per long ton *in vacuo*:

$$1/D^{60} \text{ in gal/LT} = \frac{1000}{D_{60}^{60} \times 0.999016 \times 3.725626988} \quad (18)$$

The following equation (see Section B.11) expresses the relationship between relative density (60/60 °F) and the corresponding U.S. gallons per long ton *in air*:

$$1/D_a^{60} \text{ in gal/LT} = \frac{1000}{(0.9991657784 D_{60}^{60} - 0.001199407795) \times 3.725626988} \quad (19)$$

Solve Equation (18) or Equation (19) with values of D_{60}^{60} and round the result to seven places past the decimal for further use.

EXAMPLE

An incoming shipment of gasoline having a 60 °F relative density of 0.74431 is invoiced at 42,108.0124 LT. What is the 60 °F volume in U.S. gallons?

Use Equation (18) to calculate the *in vacuo* intraconversion factor:

$$1/D^{60} \text{ in gal/LT} = \frac{1000}{0.74431 \times 0.999016 \times 3.725626988} = 360.9726779 \text{ gal/LT}$$

The 42,108.0124 LT of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60 \text{ °F gal} = 360.9726779 \text{ gal/LT} \times 42,108.0124 \text{ LT} = 15,199,842 \text{ gal}$$

4.12 Long Tons per Barrel at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.12) expresses the relationship between relative density (60/60 °F) and the corresponding long tons per barrel *in vacuo*:

$$D^{60} \text{ in LT/bbl} = D^{60}_{60} \times 0.999016 \times 0.1564763335 \quad (20)$$

The following equation (see Section B.12) expresses the relationship between relative density (60/60 °F) and the corresponding long tons per barrel *in air*:

$$D_a^{60} \text{ in LT/bbl} = (0.9991657784 D^{60}_{60} - 0.001199407795) \times 0.1564763335 \quad (21)$$

Solve Equation (20) or Equation (21) with values of D^{60}_{60} and round the result to ten places past the decimal for further use.

EXAMPLE

A tanker of gasoline having a 60 °F relative density of 0.74431 is determined to contain 361,901.00 bbl at 60 °F. What is the *in vacuo* weight in long tons?

Use Equation (20) to calculate the *in vacuo* intraconversion factor:

$$D^{60} \text{ in LT/bbl} = 0.74431 \times 0.999016 \times 0.1564763335 = 0.1163522964 \text{ LT/bbl}$$

The 361,901.00 bbl of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight in vacuo} = 0.1163522964 \text{ LT/bbl} \times 361,901 \text{ bbl} = 42,108.0124 \text{ LT}$$

4.13 Barrels per Long Ton at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.13) expresses the relationship between relative density (60/60 °F) and the corresponding barrels per long ton *in vacuo*:

$$1/D^{60} \text{ in bbl/LT} = \frac{1}{D^{60}_{60} \times 0.999016 \times 0.1564763335} \quad (22)$$

The following equation (see Section B.13) expresses the relationship between relative density (60/60 °F) and the corresponding U.S. gallons per long ton *in air*:

$$1/D_a^{60} \text{ in bbl/LT} = \frac{1}{(0.9991657784 D_{60}^{60} - 0.001199407795) \times 0.1564763335} \quad (23)$$

Solve Equation (22) or Equation (23) with values of D_{60}^{60} and round the result to nine places past the decimal for further use.

EXAMPLE

An incoming shipment of gasoline having a 60 °F relative density of 0.74431 is invoiced at 42,108.0124 LT. What is the 60 °F volume in barrels?

Use Equation (22) to calculate the *in vacuo* intraconversion factor:

$$1/D^{60} \text{ in bbl/LT} = \frac{1}{0.74431 \times 0.999016 \times 0.1564763335} = 8.594587570 \text{ bbl/LT}$$

The 42,108.0124 LT of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60 \text{ °F bbl} = 8.594587570 \text{ bbl/LT} \times 42,108.0124 \text{ LT} = 361,901 \text{ bbl}$$

4.14 Metric Tons per 1000 U.S. Gallons at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.14) expresses the relationship between relative density (60/60 °F) and the corresponding metric tons per 1000 U.S. gallons *in vacuo*:

$$D^{60} \text{ in MT/1000 gal} = D_{60}^{60} \times 0.999016 \times 3.785411784 \quad (24)$$

The following equation (see Section B.14) expresses the relationship between relative density (60/60 °F) and the corresponding metric tons per 1000 U.S. gallons *in air*:

$$D_a^{60} \text{ in MT/1000 gal} = (0.9991657784 D_{60}^{60} - 0.001199407795) \times 3.785411784 \quad (25)$$

Solve Equation (24) or Equation (25) with values of °API at 60 °F and round the result to nine places past the decimal for further use.

EXAMPLE

A tanker of gasoline having a 60 °F relative density of 0.74431 is determined to contain 361,901.00 bbl at 60 °F. What is the *in vacuo* weight in metric tons?

Use Equation (24) to calculate the *in vacuo* intraconversion factor:

$$D^{60} \text{ in MT/1000 gal} = 0.74431 \times 0.999016 \times 3.785411784 = 2.814747405 \text{ MT/1000 gal}$$

The 361,901.00 bbl of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight in vacuo} = 2.814747405 \text{ MT/1000 gal} \times 361,901 \text{ bbl} \times 42 \text{ gal/bbl} = 42,783.7158 \text{ MT}$$

4.15 Metric Tons per Barrel at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.15) expresses the relationship between relative density (60/60 °F) and the corresponding metric tons per barrel *in vacuo*:

$$D^{60}_{\text{in MT/bbl}} = D^{60}_{60} \times 0.999016 \times 0.1589872949 \quad (26)$$

The following equation (see Section B.15) expresses the relationship between relative density (60/60 °F) and the corresponding metric tons per barrel *in air*:

$$D_a^{60}_{\text{in MT/bbl}} = (0.9991657784 D^{60}_{60} - 0.001199407795) \times 0.1589872949 \quad (27)$$

Solve Equation (26) or Equation (27) with values of °API at 60 °F and round the result to ten places past the decimal for further use.

EXAMPLE

A tanker of gasoline having a 60 °F relative density of 0.74431 is determined to contain 361,901.00 bbl at 60 °F. What is the *in vacuo* weight in metric tons?

Use Equation (26) to calculate the *in vacuo* intraconversion factor:

$$D^{60}_{\text{in MT/bbl}} = 0.74431 \times 0.999016 \times 0.1589872949 = 0.1182193910 \text{ MT/bbl}$$

The 361,901.00 barrels of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight in vacuo} = 0.1182193910 \text{ MT/bbl} \times 361,901 \text{ bbl} = 42,783.7158 \text{ MT}$$

4.16 Barrels per Metric Ton at 60 °F Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.16) expresses the relationship between relative density (60/60 °F) and the corresponding barrels per metric ton *in vacuo*:

$$1/D^{60}_{\text{in bbl/MT}} = \frac{1}{D^{60}_{60} \times 0.999016 \times 0.1589872949} \quad (28)$$

The following equation (see Section B.16) expresses the relationship between relative density (60/60 °F) and the corresponding metric tons per barrel *in air*:

$$1/D_a^{60}_{\text{in bbl/MT}} = \frac{1}{(0.9991657784 D^{60}_{60} - 0.001199407795) \times 0.1589872949} \quad (29)$$

Solve Equation (28) or Equation (29) with values of °API at 60 °F and round the result to nine places past the decimal for further use.

EXAMPLE

A tanker of gasoline having a 60 °F relative density of 0.74431 is invoiced at 42,783.7158 MT. What is the 60 °F volume in barrels?

Use Equation (28) to calculate the *in vacuo* intraconversion factor:

$$1/D^{60}_{\text{in bbl/MT}} = \frac{1}{0.74431 \times 0.999016 \times 0.1589872949} = 8.458849191 \text{ bbl/MT}$$

The 42,783.7158 MT of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60\text{ °F bbl} = 8.458849191\text{ bbl/MT} \times 42,783.7158\text{ MT} = 361,901.00\text{ bbl}$$

4.17 Cubic Metres per Short Ton at 15 °C Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.17) expresses the relationship between relative density (60/60 °F) and the corresponding cubic metres at 15 °C per short ton *in vacuo*:

$$1/D^{15}\text{ in m}^3/\text{ST} = \frac{1/\text{VCF}_{59}}{D^{60}_{60} \times 0.999016 \times 1.102311311} \quad (30)$$

The following equation (see Section B.17) expresses the relationship between relative density (60/60 °F) and the corresponding cubic metres at 15 °C per short ton *in air*:

$$1/D_a^{15}\text{ in m}^3/\text{ST} = \frac{1/\text{VCF}_{59}}{(0.9991657784 D^{60}_{60} - 0.001199407795) \times 1.102311311} \quad (31)$$

Solve Equation (30) or Equation (31) with values of D^{60}_{60} and round the result to nine places past the decimal for further use. As this calculation includes a VCF_{59} , the result is product specific. Crude oils, generalized products, and lubricants will use API *MPMS* Ch. 11.1-2004. Other products may use different tables.

EXAMPLE

An incoming shipment of gasoline having a 60 °F relative density of 0.74431 is invoiced at 47,160.9739 ST. What is the 15 °C volume in cubic metres?

Use Equation (30) to calculate the *in vacuo* intraconversion factor:

$$1/D^{15}\text{ in m}^3/\text{ST} = \frac{1/1.00068}{0.74431 \times 0.999016 \times 1.102311311} = 1.219197935\text{ m}^3/\text{ST}$$

The 47,160.9739 ST of gasoline is then equivalent to (rounding as indicated in Table 1):

$$15\text{ °C m}^3 = 1.219197935\text{ m}^3/\text{ST} \times 47,160.9739\text{ ST} = 57,498.562\text{ m}^3$$

4.18 Cubic Metres per Long Ton at 15 °C Equivalent to Relative Density (60/60 °F)

The following equation (see Section B.18) expresses the relationship between relative density (60/60 °F) and the corresponding cubic metres at 15 °C per short ton *in vacuo*:

$$1/D^{60}\text{ in m}^3/\text{LT} = \frac{1/\text{VCF}_{59}}{D^{60}_{60} \times 0.999016 \times 0.9842065276} \quad (32)$$

The following equation (see Section B.18) expresses the relationship between relative density (60/60 °F) and the corresponding cubic metres per long ton *in air*:

$$1/D_a^{60}\text{ in m}^3/\text{LT} = \frac{1/\text{VCF}_{59}}{(0.9991657784 D^{60}_{60} - 0.001199407795) \times 0.9842065276} \quad (33)$$

Solve Equation (32) or Equation (33) with values of D_{60}^{60} and round the result to nine places past the decimal for further use. As this calculation includes a VCF_{59} , the result is product specific. Crude oils, generalized products, and lubricants will use API MPMS Ch. 11.1-2004. Other products may use different tables.

EXAMPLE

An incoming shipment of gasoline having a 60 °F relative density of 0.74431 is invoiced at 42,108.0124 LT. What is the 15 °C volume in cubic metres?

Use Equation (32) to calculate the *in vacuo* intraconversion factor:

$$1/D^{15} \text{ in m}^3/\text{LT} = \frac{1/1.00068}{0.74431 \times 0.999016 \times 0.9842065276} = 1.365501688 \text{ m}^3/\text{LT}$$

The 42,108.0124 LT of gasoline is then equivalent to (rounding as indicated in Table 1):

$$15 \text{ } ^\circ\text{C m}^3 = 1.365501688 \text{ m}^3/\text{LT} \times 42,108.0124 \text{ LT} = 57,498.562 \text{ m}^3$$

4.19 U.S. Gallons at 60 °F to Litres at 15 °C for Relative Density (60/60 °F)

The following equation (see Section B.19) expresses the relationship between U.S. gallons at 60 °F and litres at 15 °C:

$$L_{15 \text{ } ^\circ\text{C}} = \text{gal}_{60 \text{ } ^\circ\text{F}} \times (3.785411784/VCF_{59}) \quad (34)$$

Using the liquid's relative density (60/60 °F) to obtain its VCF at 59 °F, solve the parenthetical part of Equation (34) and round the result to nine places past the decimal for further use. As this calculation includes a VCF_{59} , the result is product specific. Crude oils, generalized products, and lubricants will use API MPMS Ch. 11.1-2004. Other products may use different tables.

EXAMPLE

A quantity of gasoline having a 60 °F relative density of 0.74431 is determined to be 15,199,842 U.S. gal at 60 °F. What is the volume in litres at 15 °C?

Use Equation (34) to calculate the intraconversion factor:

$$L_{15 \text{ } ^\circ\text{C}}/\text{gal} = 3.785411784/1.00068 = 3.782839453 \text{ L}_{15 \text{ } ^\circ\text{C}}$$

The 15,199,842 U.S. gal of gasoline at 60 °F is then equivalent to (rounding as indicated in Table 1):

$$15 \text{ } ^\circ\text{C L} = 3.782839453 \text{ L}_{15 \text{ } ^\circ\text{C}}/\text{gal} \times 15,199,842 \text{ gal} = 57,498,562 \text{ L}_{15 \text{ } ^\circ\text{C}}$$

4.20 Barrels at 60 °F to Cubic Metres at 15 °C for Relative Density (60/60 °F)

The following equation (see Section B.20) expresses the relationship between barrels at 60 °F and the cubic metres at 15 °C:

$$\text{m}^3_{15 \text{ } ^\circ\text{C}} = \text{bbl}_{60 \text{ } ^\circ\text{F}} \times (0.1589872949/VCF_{59}) \quad (35)$$

Using the liquid's relative density (60/60 °F) to obtain its VCF at 59 °F, solve the parenthetical part of Equation (35) and round the result to ten places past the decimal for further use. As this calculation includes a VCF_{59} , the result is

product specific. Crude oils, generalized products, and lubricants will use API *MPMS* Ch. 11.1-2004. Other products may use different tables.

EXAMPLE

A quantity of gasoline having a 60 °F relative density of 0.74431 is determined to be 361,901 bbl at 60 °F. What is the volume in litres at 15 °C?

Use Equation (35) to calculate the intraconversion factor:

$$\text{m}^3_{15\text{ }^{\circ}\text{C}}/\text{bbl} = 0.1589872949/1.00068 = 0.1588792570 \text{ m}^3_{15\text{ }^{\circ}\text{C}}/\text{bbl}$$

The 361,901 bbl of crude at 60 °F is then equivalent to (rounding as indicated in Table 1):

$$15\text{ }^{\circ}\text{C m}^3 = 0.1588792570 \text{ m}^3_{15\text{ }^{\circ}\text{C}}/\text{bbl} \times 361,901 \text{ bbl} = 57,498.562 \text{ m}^3$$

5 Rounding

5.1 Data Level

The exact unit relationships displayed in Annex A and used in Annex B contain varying significant figures. For the purposes of this standard the intermediate constants derived in Annex B from these exact relationships are rounded to 10 significant figures.

API *MPMS* Ch. 12 governs all rounding. Absent specific direction from API *MPMS* Ch. 12, the implementation procedures detailed in Section 4 specify the rounding for each intraconversion.

As the current version of API *MPMS* Ch. 12 states, rounding during the use of the intraconversion factors is influenced by the source of the data. For example, if a container's capacity tables are in whole gallons then all subsequent gallons values should be recorded accordingly. In those cases where there are no other limiting factors (i.e. direction by API *MPMS* Ch. 12), the operator should be guided by Table 1, which is intended for application to bulk liquid quantities. Other considerations may apply for smaller quantities; e.g. while Table 1 recommends the calculated weight of a bulk cargo (say a barge of asphalt) be rounded to whole pounds or kilograms, a user may wish to calculate the weight of a barrel of product to two or three decimal places. The significant digits in Table 1 provide consistency within this standard and may differ slightly from the current API *MPMS* Ch. 12.

5.2 Rounding of Numbers

Chain calculations should be performed without rounding or truncation. When a calculation result is to be rounded to a specific number of decimals, it shall always be rounded off in one step to the number of figures to be recorded and not rounded in two or more successive steps. When the figure to the right of the last place to be retained is less than 5, the figure in the last place retained should be unchanged. When figure to the right of the last place to be retained is 5 to 9, the figure in the last place should be increased by 1.

Table 1—Significant Digits for Bulk Quantities ^a

| Units | No. of Decimals |
|--------------------------------------|-----------------|
| Litres | x,xxx,xxx.0 |
| U.S. Gallons | x,xxx,xxx.0 |
| Barrels | xxx,xxx.xx |
| Cubic metres | xxx,xxx.xxx |
| Pounds | xxx.0 |
| Short tons | xxx,xxx.xxxx |
| Long tons | xxx,xxx.xxxx |
| Metric tons | xxx,xxx.xxxx |
| API gravity @ 60 °F | xxx.xx |
| Density grams per cubic centimetre | x.xxxxx |
| Density in pounds per U.S. gallon | x.xxxxx |
| Density in kilograms per cubic metre | xxxx.xx |
| Relative density | x.xxxxx |
| Temperature °F | xxx.x |
| Temperature °C | xxx.x5 |
| VCF | x.xxxxx |

^a Densities and relative density are presented with six significant figures to reflect values obtainable with modern high precision instrumentation.

Annex A

Physical Constants

This annex is included for documentation purposes only and is not necessary for implementation of this standard.

Exact Constants and Factors Used in Calculations (NIST Handbook 44, Appendix C) *

| | | |
|--------------------|---|---------------|
| 1 lb | = 0.45359237 kg | = 453.59237 g |
| 1 ST | = 2000 lb | |
| 1 LT | = 2240 lb | |
| 1 MT | = 1000 kg | |
| 1 bbl | = 42 (U.S.) gal | |
| 1 in. ³ | = 0.016387064 L | |
| 1 (U.S.) gal | = 231 in. ³ | |
| 1 L | = 1.000000 dm ³ [12th General Conference on Weights and Measures (1964)] | |
| 1 mL | = 1 cm ³ | |
| 1 m ³ | = 1000 L | |

* The volume factors are solely for conversion at the same temperature.

A.1 Density of Weights

NIST Handbook 44, Appendix B and Handbook 105-1 state that brass is no longer used for balance weights due to its softness. A generic reference weight of **8.0 g/cm³** density at 20 °C is used by international agreement. Since a specific material is no longer specified, no calculation of density at reference temperature can be made.

A.2 Density of Standard Air

NIST Handbook 44, Appendix B and Handbook 105-1 specify a temperature of 20 °C for air buoyancy calculations. The latest International Committee of Weights and Measures (CIPM) 81/91 Air Density Executable File yields a density of **0.001199228 g/cm³** (760 mm, 50 % humidity, 20 °C). The program is available at <http://ts.nist.gov/ts/htdocs/230/235/labmetrologypage.htm> (as of this printing).

A.3 Density of Water

The equation of Patterson and Morris [Metrologia, 31, 277 – 288 (1994)] yields a density of water at 60 °F of **999.016 kg/m³**, or 0.999016 g/mL (see API MPMS Ch. 11.4.1).

Annex B

Derivation of Equations

This annex is included for documentation purposes only and is not necessary for implementation of this standard. All calculated conversion factors are derived from exact relationships as found in Appendix C of Handbook 44.

B.1 API Gravity at 60 °F Equivalent to Relative Density (60/60 °F)

The relationship between relative density at 60 °F (D_{60}^{60}) and API gravity is defined as:

$$^{\circ}\text{API} = \frac{141.5}{D_{60}^{60}} - 131.5 \quad (\text{B.1})$$

API gravity and relative density are dimensionless terms.

B.2 Absolute Density at 60 °F Equivalent to Relative Density (60/60 °F)

A liquid's relative density D_{t1}^t is defined as its absolute density D^t at temperature t divided by the absolute density of water ρ^{t1} at temperature $t1$. Relative density at reference temperature 60 °F (D_{60}^{60}) is therefore:

$$D_{60}^{60} = \frac{D^{60}}{\rho^{60}} \quad (\text{B.2})$$

The density of water can be obtained from Annex A. The units of both densities must be identical (grams per millilitre, kilograms per cubic metre, pounds per U.S. gallon, etc.). Relative density is dimensionless. Substitute 999.016 kg/m³ for ρ^{60} into Equation (B.2) to obtain:

$$D^{60} \text{ in kg/m}^3 = D_{60}^{60} \times 999.016 \text{ kg/m}^3 \quad (\text{B.3})$$

B.3 Absolute Density at 15 °C Equivalent to Relative Density (60/60 °F)

A volume correction factor (VCF) is defined as the density of a liquid at temperature t (D^t) divided by the density of that liquid at reference temperature. In the U.S., reference temperature is 60 °F.

$$\text{VCF}_{60} = \frac{D^t}{D^{60}} \quad (\text{B.4})$$

Density of a liquid at 60 °F can be converted to its corresponding density at 15 °C by multiplying with the volume correction factor for that liquid at 59 °F (crude oils, generalized products, and lubricants will use API *MPMS* Ch. 11.1-2004; other products may use different tables). Substituting Equation (B.3) into Equation (B.4), with $t = 59$ °F (15 °C) gives:

$$D^{15} \text{ in kg/m}^3 = D_{60}^{60} \times 999.016 \text{ kg/m}^3 \times \text{VCF}_{59}$$

B.4 Pounds per U.S. Gallon at 60 °F Equivalent to Relative Density (60/60 °F)

Conversion of relative density (60/60 °F) to various units of density *in vacuo* is a straight unit conversion of Equation (B.3) using 0.999016 g/mL as the density of water:

$$D^{60} = D_{60}^{60} \times 0.999016 \text{ kg/m}^3 \times f \quad (\text{B.5})$$

where f is a constant for converting grams per millilitre to any other density units.

To convert grams per millilitre to pounds per gallon, Equation (B.5) is used with f being:

$$f = \frac{1 \text{ g}}{1 \text{ mL}} = \frac{1 \text{ g}/453.59237 \text{ g/lb}}{1 \text{ mL}/(231 \text{ in.}^3/\text{gal} \times 16.387064 \text{ mL/in.}^3)} = 8.345404452 \text{ lb/gal}$$

Conversion of relative density (60/60 °F) to pounds per U.S. gallon *in air* is more complicated, as the effect of the buoyancy of air must be accounted for. Consider mass d to be measured balanced on a scale *in vacuo* (no air) by an equal reference mass b . When balanced, all forces acting on the system cancel each other. Thus, force $F_d = m_d \times a$ (a = acceleration of gravity) acting on the mass m_d is balanced by an equal force $F_b = m_b \times a$ on the reference mass m_b .

$$F_d = F_b$$

$$m_d \times a = m_b \times a$$

When balanced *in air*, each mass is counteracted by a force equal to the weight of the air it displaces (Archimedes's principle). Therefore, $F_{ad} = m_{ad} \times a$ and $F_{ab} = m_{ab} \times a$, where m_{ad} is the mass of air displaced by m_d and m_{ab} is the mass of air displaced by m_b .

$$F_d - F_{ad} = F_b - F_{ab}$$

$$(m_d \times a) - (m_{ad} \times a) = (m_b \times a) - (m_{ab} \times a)$$

$$m_d - m_{ad} = m_b - m_{ab}$$

Multiplying the right side of the equation by one in the form of m_b/m_b gives:

$$m_d - m_{ad} = \frac{m_b - m_{ab}}{m_b} \times m_b$$

Similarly, multiplying each side of the equation by the volumes involved (V_d for mass m_d , V_b for mass m_b) gives:

$$(m_d - m_{ad}) \frac{V_d}{V_d} = \frac{1/V_b(m_b - m_{ab})}{(1/V_b)m_b} \times m_b$$

$$\left(\frac{m_d}{V_d} - \frac{m_{ad}}{V_d} \right) = \frac{m_b/V_b - m_{ab}/V_b}{m_b/V_b} \times (m_b/V_d)$$

For volumes at 60 °F, these ratios are densities at 60 °F. However, the air and reference weight densities to be used for air buoyancy corrections are at 20 °C (68 °F) by international agreement (see Annex A); the difference between the ratio of the densities at 20 °C (68 °F) and that at 60 °F is considered negligible. Thus:

$$D^{60} - A^{68} = \frac{B^{68} - A^{68}}{B^{68}} \times (m_b/V_d)^{60}$$

$$(m_b/V_d)^{60} = \frac{D^{60} - A^{68}}{\frac{B^{68} - A^{68}}{B^{68}}} = \frac{D^{60} - A^{68}}{1 - (A^{68}/B^{68})}$$

where

D^{60} is the density of liquid at 60 °F *in vacuo*, m_d/V_d ;

A^{68} is the density of standard air at 68 °F *in vacuo*, m_{ad}/V_d or m_{ab}/V_b ;

B^{68} is the density of the weights at 68 °F *in vacuo*, m_b/V_b ;

$(m_b/V_d)^{60}$ is the density of liquid at 60 °F *in air*.

Selection of the proper conversion factor f is used to change units from one unit system to another, say, grams per millilitre to pounds per U.S. gallon (or any other expression of density).

$$(m_b/V_d)^{60} = \frac{D^{60} - A^{68}}{1 - (A^{68}/B^{68})} \times f$$

D^{60} can be converted to relative density D^{60}_{60} with Equation (B.2):

$$(m_b/V_d)^{60} = \frac{\rho^{60} D^{60}_{60} - A^{68}}{1 - (A^{68}/B^{68})} \times f$$

Substituting D^{60}_a for $(m_b/V_d)^{60}$ and values from Annex A, we obtain:

$$D^{60}_a = (0.9991657784 D^{60}_{60} - 0.001199407795) \times f \quad (\text{B.6})$$

Conversion of grams per millilitre to pounds per U.S. gallon is again determined using f as calculated above.

B.5 U.S. Gallons per Pound at 60 °F Equivalent to Relative Density (60/60 °F)

The relationship between relative density (60/60 °F) and the volume of U.S. gallons occupied by 1 lb *in vacuo* is given by the reciprocal of Equation (B.5) with f determined as in Section B.4.

The relationship between relative density (60/60 °F) and the volume of U.S. gallons occupied by 1 lb *in air* is given by the reciprocal of Equation (B.6) with f determined as in Section B.4.

B.6 Short Tons per 1000 U.S. Gallons at 60 °F Equivalent to Relative Density (60/60 °F)

Conversion of relative density (60/60 °F) to the weight in short tons *in vacuo* of 1000 U.S. gallons is accomplished with Equation (B.5), changing from grams per millilitre to short tons per U.S. gallon by calculating f as follows:

$$f = \frac{1 \text{ g}}{1 \text{ mL}} = \frac{(1 \text{ g}/453.59237 \text{ g/lb}) \times (1000 \text{ gal}/1000 \text{ gal})}{[1 \text{ mL}/(231 \text{ in.}^3/\text{gal} \times 16.387064 \text{ mL/in.}^3)] \times 2000 \text{ lb/ST}} = 4.172702226 \text{ ST/1000 gal}$$

Conversion of relative density (60/60 °F) to the weight in short tons *in air* of 1000 U.S. gallons is accomplished with Equation (B.6), using f as calculated above.

B.7 U.S. Gallons per Short Ton at 60 °F Equivalent to Relative Density (60/60 °F)

The relationship between relative density (60/60 °F) and the volume in U.S. gallons occupied by 1 ST *in vacuo* is accomplished by the reciprocal of Equation (B.5) with f determined as in Section B.6, and multiplying by 1000.

The relationship between relative density (60/60 °F) and the volume in U.S. gallons occupied by 1 ST *in air* is accomplished by the reciprocal of Equation (B.6) with f determined as in Section B.6, and multiplying by 1000.

B.8 Short Tons per Barrel at 60 °F Equivalent to Relative Density (60/60 °F)

Conversion of relative density (60/60 °F) to the weight in short tons *in vacuo* of 1 bbl is accomplished with Equation (B.5), changing from grams per millilitre to short tons per barrel by calculating f as follows:

$$f = \frac{1 \text{ g}}{1 \text{ mL}} = \frac{(1 \text{ g}/453.59237 \text{ g/lb}) \times (42 \text{ gal/bbl})}{[1 \text{ mL}/(231 \text{ in.}^3/\text{gal} \times 16.387064 \text{ mL/in.}^3)] \times 2000 \text{ lb/ST}} = 0.1752534935 \text{ ST/bbl}$$

Conversion of relative density (60/60 °F) to the weight in short tons *in air* of 1 barrel is accomplished with Equation (B.6), using f as calculated above.

B.9 Barrels per Short Ton at 60 °F Equivalent to Relative Density (60/60 °F)

The relationship between relative density (60/60 °F) and the volume in barrels occupied by 1 ST *in vacuo* is given by the reciprocal of Equation (B.5) with f determined as in Section B.8.

The relationship between relative density (60/60 °F) and the volume in barrels occupied by 1 ST *in air* is given by the reciprocal of Equation (B.6) with f determined as in Section B.8.

B.10 Long Tons per 1000 U.S. Gallons at 60 °F Equivalent to Relative Density (60/60 °F)

Conversion of relative density (60/60 °F) to the weight in long tons *in vacuo* of 1000 U.S. gallons is accomplished with Equation (B.5), changing from grams per millilitre to long tons per U.S. gallon by calculating f as follows:

$$f = \frac{1 \text{ g}}{1 \text{ mL}} = \frac{(1 \text{ g}/453.59237 \text{ g/lb}) \times (1000 \text{ gal}/1000 \text{ gal})}{[1 \text{ mL}/(231 \text{ in.}^3/\text{gal} \times 16.387064 \text{ mL/in.}^3)] \times 2240 \text{ lb/LT}} = 3.725626988 \text{ LT/1000 gal}$$

Conversion of relative density (60/60 °F) to the weight in long tons *in air* of 1000 U.S. gallons is accomplished with Equation (B.6), using f as calculated above.

B.11 U.S. Gallons per Long Ton at 60 °F Equivalent to Relative Density (60/60 °F)

The relationship between relative density (60/60 °F) and the volume in U.S. gallons occupied by 1 LT *in vacuo* is accomplished by the reciprocal of Equation (B.5) with f determined as in Section B.10, and multiplying by 1000.

The relationship between relative density (60/60 °F) and the volume in U.S. gallons occupied by 1 LT *in air* is accomplished by the reciprocal of Equation (B.6) with f determined as in Section B.10, and multiplying by 1000.

B.12 Long Tons per Barrel at 60 °F Equivalent to Relative Density (60/60 °F)

Conversion of relative density (60/60 °F) to the weight in long tons *in vacuo* of 1 bbl is accomplished with Equation (B.5), changing from grams per millilitre to long tons per barrel by calculating f as follows:

$$f = \frac{1 \text{ g}}{1 \text{ mL}} = \frac{(1 \text{ g}/453.59237 \text{ g/lb}) \times (42 \text{ gal/bbl})}{[1 \text{ mL}/(231 \text{ in.}^3/\text{gal} \times 16.387064 \text{ mL/in.}^3)] \times 2240 \text{ lb/LT}} = 0.1564763335 \text{ LT/bbl}$$

Conversion of relative density (60/60 °F) to the weight in long tons *in air* of 1 bbl is accomplished with Equation (B.6), using f as calculated above.

B.13 Barrels per Long Ton at 60 °F Equivalent to Relative Density (60/60 °F)

The relationship between relative density (60/60 °F) and the volume in barrels occupied by 1 LT *in vacuo* is accomplished by taking the reciprocal of Equation (B.5) with f determined as in Section B.12.

The relationship between relative density (60/60 °F) and the volume in barrels occupied by 1 LT *in air* is accomplished by taking the reciprocal of Equation (B.6) with f determined as in Section B.12.

B.14 Metric Tons per 1000 U.S. Gallons at 60 °F Equivalent to Relative Density (60/60 °F)

Conversion of relative density (60/60 °F) to the weight in metric tons *in vacuo* of 1000 U.S. gallons is accomplished with Equation (B.5), changing from grams per millilitre to metric tons per 1000 U.S. gallons by calculating f as follows:

$$f = \frac{1 \text{ g}}{1 \text{ mL}} = \frac{0.000001 \text{ MT} \times 1000}{[1 \text{ mL}/(231 \text{ in.}^3/\text{gal} \times 16.387064 \text{ mL}/\text{in.}^3)] \times 1000} = 3.785411784 \text{ MT}/1000 \text{ gal}$$

Conversion of relative density (60/60 °F) to the weight in MT *in air* of 1000 U.S. gallons is accomplished with Equation (B.6), using f as calculated above.

B.15 Metric Tons per Barrel at 60 °F Equivalent to Relative Density (60/60 °F)

Conversion of relative density (60/60 °F) to the weight in metric tons *in vacuo* of 1 bbl is accomplished with Equation (B.5), changing from grams per millilitre to metric tons per barrel by calculating f as follows:

$$f = \frac{1 \text{ g}}{1 \text{ mL}} = \frac{0.000001 \text{ MT} \times 42 \text{ gal}/\text{bbl}}{1 \text{ mL}/(231 \text{ in.}^3/\text{gal} \times 16.387064 \text{ mL}/\text{in.}^3)} = 0.1589872949 \text{ MT}/\text{bbl}$$

Conversion of relative density (60/60 °F) to the weight in metric tons *in air* of 1 bbl is accomplished with Equation (B.6), using f as calculated above.

B.16 Barrels per Metric Tons at 60 °F Equivalent to Relative Density (60/60 °F)

The relationship between relative density (60/60 °F) and the volume in barrels at 60 °F occupied by 1 MT *in vacuo* is accomplished by the reciprocal of Equation (B.5) with f determined as in Section B.15.

The relationship between relative density (60/60 °F) and the volume in barrels at 60 °F occupied by 1 MT *in air* is accomplished by the reciprocal of Equation (B.6) with f determined as in Section B.15.

B.17 Cubic Metres per Short Ton at 15 °C Equivalent to Relative Density (60/60 °F)

The relationship between relative density (60/60 °F) and the volume in cubic metres at 15 °C occupied by 1 ST *in vacuo* is accomplished by the reciprocal of Equation (B.5), changing from grams per millilitre to short tons per cubic metre by calculating f as follows:

$$f = \frac{1 \text{ g}}{1 \text{ mL}} = \frac{1 \text{ g}/453.59237 \text{ g}/\text{lb}}{0.000001 \text{ m}^3 \times 2000 \text{ lb}/\text{ST}} = 1.102311311 \text{ ST}/\text{m}^3$$

The result is then divided by the liquid's VCF at 59 °F (crude oils, generalized products, and lubricants will use API MPMS Ch. 11.1-2004; other products may use different tables) to obtain cubic metres at 15 °C.

The relationship between relative density (60/60 °F) and the volume in cubic metres at 15 °C occupied by 1 ST *in air* is accomplished by the reciprocal of Equation (B.6), using f as calculated above. The result is then divided by the liquid's VCF at 59 °F (crude oils, generalized products, and lubricants will use API MPMS Ch. 11.1-2004; other products may use different tables) to obtain cubic metres at 15 °C.

B.18 Cubic Metres per Long Ton at 15 °C Equivalent to Relative Density (60/60 °F)

The relationship between relative density (60/60 °F) and the volume in cubic metres at 15 °C occupied by 1 LT *in vacuo* is accomplished by the reciprocal of Equation (B.5) using f to convert grams per millilitre to long tons per cubic metre as shown:

$$f = \frac{1 \text{ g}}{1 \text{ mL}} = \frac{1 \text{ g}/453.59237 \text{ g/lb}}{0.000001 \text{ m}^3 \times 2240 \text{ lb/LT}} = 0.9842065276 \text{ LT/m}^3$$

The result is then divided by the liquid's VCF at 59 °F (crude oils, generalized products, and lubricants will use API MPMS Ch. 11.1-2004; other products may use different tables) to obtain cubic metres at 15 °C.

The relationship between relative density (60/60 °F) and the volume in cubic metres at 15 °C occupied by 1 LT *in air* is accomplished by the reciprocal of Equation (B.6), using f as calculated above. The result is then divided by the liquid's VCF at 59 °F (crude oils, generalized products, and lubricants will use API MPMS Ch. 11.1-2004; other products may use different tables) to obtain cubic metres at 15 °C.

B.19 U.S. Gallons at 60 °F to Litres at 15 °C for Relative Density (60/60 °F)

Conversion of volume in U.S. gallons at 60 °F to litres at 15 °C is accomplished by dividing by the liquid's VCF at 59 °F (crude oils, generalized products, and lubricants will use API MPMS Ch. 11.1-2004; other products may use different tables) to obtain U.S. gallons at 15 °C and then converting U.S. gallons to litres.

$$L_{15\text{ }^{\circ}\text{C}} = \frac{\text{gal}_{60\text{ }^{\circ}\text{F}} \times (231 \text{ in.}^3/\text{gal} \times 0.016387064 \text{ L/in.}^3)}{\text{VCF}_{59}} = \frac{\text{gal}_{60\text{ }^{\circ}\text{F}} \times 3.785411784 \text{ L/gal}}{\text{VCF}_{59}}$$

B.20 Barrels at 60 °F to Cubic Metres at 15 °C for Relative Density (60/60 °F)

Conversion of volume in barrels at 60 °F to cubic metres at 15 °C is accomplished by multiplying by 42 to obtain U.S. gallons, dividing by the liquid's VCF at 59 °F (crude oils, generalized products, and lubricants will use API MPMS Ch. 11.1-2004; other products may use different tables) to obtain U.S. gallons at 15 °C, multiplying by 3.785412 to convert U.S. gallons to litres, and then dividing by 1000 to convert to cubic metres.

$$\text{m}^3_{15\text{ }^{\circ}\text{C}} = \frac{\text{bbl}_{60\text{ }^{\circ}\text{F}} \times 42 \text{ gal/bbl} \times 3.785412 \text{ L/gal}}{\text{VCF}_{59} \times 1000 \text{ L/m}^3} = \frac{0.158987304 \times \text{bbl}_{60\text{ }^{\circ}\text{F}}}{\text{VCF}_{59}}$$

$$\text{m}^3_{15\text{ }^{\circ}\text{C}} = \frac{\text{bbl}_{60\text{ }^{\circ}\text{F}} \times 42 \text{ gal/bbl} \times (231 \text{ in.}^3/\text{gal} \times 0.016387064 \text{ L/in.}^3)}{1000 \text{ L/m}^3 \times \text{VCF}_{59}} = \frac{0.1589872949 \times \text{bbl}_{60\text{ }^{\circ}\text{F}}}{\text{VCF}_{59}}$$

Annex C

Partial Tables

The partial tables are provided to assist users in checking their implementation of this standard. Remember, the implementation procedures in Section 4 are the standard, NOT these tables.

(See spreadsheet on CD.)

Annex C

Annex D

Interrelation of Units of Measurement

The following table has been extracted from Appendix C of NIST Handbook 44. A more complete table is presented in API MPMS Ch. 15, *Guideline for the Use of the International System of Units (SI) in the Petroleum and Allied Industries*.

| LENGTH | |
|---------------------|---------------------------|
| To Convert | Multiply by |
| Metres: | |
| To Yards | 1.093613 |
| To Feet | 3.280840 |
| To Inches | 39.37008 |
| Yards: | |
| To Metres | 0.9144 ^Ψ |
| Feet: | |
| To Metres | 0.3048 ^Ψ |
| Inches | |
| To Centimetres | 2.54 ^Ψ |
| WEIGHT | |
| To Convert | Multiply by |
| Long Tons: | |
| To Pounds (Avdp) ** | 2240 ^Ψ |
| To Short Tons | 1.12 ^Ψ |
| To Metric Tons | 1.0160469088 ^Ψ |
| Short Tons: | |
| To Pounds (Avdp) | 2000 ^Ψ |
| To Long Tons | 0.8928571 |
| To Metric Tons | 0.90718474 ^Ψ |
| Metric Tons: | |
| To Long Tons | 0.9842065 |
| To Short Tons | 1.102311 |
| Pounds (Avdp): | |
| To Kilograms | 0.45359237 ^Ψ |
| Kilograms | |
| To Pounds (Avdp) | 2.204623 |

| VOLUME AND CAPACITY * | |
|-----------------------|-------------------|
| To Convert | Multiply by |
| U.S. Gallons: | |
| To Cubic Inches | 231 ^Ψ |
| To Cubic Feet | 0.1336806 |
| To U.S. Barrels | 0.02380952 |
| To Litres | 3.785412 |
| U.S. Barrels: | |
| To U.S. Gallons | 42 ^Ψ |
| To Cubic Inches | 9702 ^Ψ |
| To Cubic Feet | 5.6145852 |
| To Litres | 158.987304 |
| Cubic Feet: | |
| To U.S. Gallons | 7.480519 |
| To U.S. Barrels | 0.1781076 |
| To Litres | 28.31685 |
| To Cubic Metres | 0.02831685 |
| Cubic Inches: | |
| To U.S. Gallons | 0.004329004 |
| To Litres | 0.016387064 |
| Litres: | |
| To Cubic Inches | 61.02374 |
| To Cubic Feet | 0.03531467 |
| To U.S. Gallons | 0.2641721 |
| To U.S. Barrels | 0.006289812 |
| Cubic Metres: | |
| To U.S. Gallons | 264.1721 |
| To U.S. Barrels | 6.289812 |
| To Cubic Feet | 35.31467 |

* These factors are solely for conversion at the same temperature.

** Pounds (Avdp) = Avoirdupois pound

^Ψ This relationship is exact by definition. All other values are derived and rounded to the displayed precision.

Annex E

Temperature Conversions

The following table has been retained as a convenience to the user. It is based on the relationship between the Fahrenheit (°F) and Celsius (°C) temperature scales:

$$^{\circ}\text{F} = 1.8\ ^{\circ}\text{C} + 32 \quad (\text{E.1})$$

and

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32)/1.8 \quad (\text{E.2})$$

The result is rounded to 0.1. It must be remembered that the printed table enclosed does not define the conversion, the equations do. While this table gives the conversion of temperatures from °F to °C and *vice versa* for each whole degree of temperature over the range –50 (°F or °C) to +400 (°F or °C), the equations may be used for any temperature and any fraction of a degree.

The temperature to be converted is found in the center column, and the converted temperature is then read to the left for °C or to the right for °F.

EXAMPLE

What is the temperature in °F corresponding to 18 °C?

SOLUTION

Entering the table in the center column at 18, as shown below, it is seen that the answer is 64.4 °F.

| | | |
|---------------------------------|----|---------------------------------|
| $\frac{^{\circ}\text{F}}{64.4}$ | 18 | $\frac{^{\circ}\text{C}}{-7.8}$ |
|---------------------------------|----|---------------------------------|

Conversely, if the °C equivalent of 18 °F is desired, the answer is –7.8 °C.

EXAMPLE

What is the temperature in °F corresponding to 18.6 °C?

SOLUTION

Using Equation (E.1):

$$^{\circ}\text{F} = (1.8 \times 18.6) + 32 = 65.5$$

Conversely, the temperature in °C corresponding to 18.6 °F is:

$$^{\circ}\text{C} = (18.6 - 32)/1.8 = -7.4$$

| °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C |
|-------|----|-------|-----|-------|-------|-------|----|------|-------|-----|------|-------|-----|------|-------|-----|-------|---------|-----|-------|-------|-----|-------|-------|-----|-------|-------|-----|-------|
| 32.0 | 0 | -17.8 | -50 | -45.6 | -58.0 | 122.0 | 50 | 10.0 | 212.0 | 100 | 37.8 | 302.0 | 150 | 65.6 | 392.0 | 200 | 93.3 | 482.0 | 250 | 121.1 | 572.0 | 300 | 148.9 | 662.0 | 350 | 176.7 | 662.0 | 350 | 176.7 |
| 33.8 | 1 | -17.2 | -49 | -45.0 | -56.2 | 123.8 | 51 | 10.6 | 213.8 | 101 | 38.3 | 303.8 | 151 | 66.1 | 393.8 | 201 | 93.9 | 483.8 | 251 | 121.7 | 573.8 | 301 | 149.4 | 663.8 | 351 | 177.2 | 663.8 | 351 | 177.2 |
| 35.6 | 2 | -16.7 | -48 | -44.4 | -54.4 | 125.6 | 52 | 11.1 | 215.6 | 102 | 38.9 | 305.6 | 152 | 66.7 | 395.6 | 202 | 94.4 | 485.6 | 252 | 122.2 | 575.6 | 302 | 150.0 | 665.6 | 352 | 177.8 | 665.6 | 352 | 177.8 |
| 37.4 | 3 | -16.1 | -47 | -43.9 | -52.6 | 127.4 | 53 | 11.7 | 217.4 | 103 | 39.4 | 307.4 | 153 | 67.2 | 397.4 | 203 | 95.0 | 487.4 | 253 | 122.8 | 577.4 | 303 | 150.6 | 667.4 | 353 | 178.3 | 667.4 | 353 | 178.3 |
| 39.2 | 4 | -15.6 | -46 | -43.3 | -50.8 | 129.2 | 54 | 12.2 | 219.2 | 104 | 40.0 | 309.2 | 154 | 67.8 | 399.2 | 204 | 95.6 | 489.2 | 254 | 123.3 | 579.2 | 304 | 151.1 | 669.2 | 354 | 178.9 | 669.2 | 354 | 178.9 |
| 41.0 | 5 | -15.0 | -45 | -42.8 | -49.0 | 131.0 | 55 | 12.8 | 221.0 | 105 | 40.6 | 311.0 | 155 | 68.3 | 401.0 | 205 | 96.1 | 491.0 | 255 | 123.9 | 581.0 | 305 | 151.7 | 671.0 | 355 | 179.4 | 671.0 | 355 | 179.4 |
| 42.8 | 6 | -14.4 | -44 | -42.2 | -47.2 | 132.8 | 56 | 13.3 | 222.8 | 106 | 41.1 | 312.8 | 156 | 68.9 | 402.8 | 206 | 96.7 | 492.8 | 256 | 124.4 | 582.8 | 306 | 152.2 | 672.8 | 356 | 180.0 | 672.8 | 356 | 180.0 |
| 44.6 | 7 | -13.9 | -43 | -41.7 | -45.4 | 134.6 | 57 | 13.9 | 224.6 | 107 | 41.7 | 314.6 | 157 | 69.4 | 404.6 | 207 | 97.2 | 494.6 | 257 | 125.0 | 584.6 | 307 | 152.8 | 674.6 | 357 | 180.6 | 674.6 | 357 | 180.6 |
| 46.4 | 8 | -13.3 | -42 | -41.1 | -43.6 | 136.4 | 58 | 14.4 | 226.4 | 108 | 42.2 | 316.4 | 158 | 70.0 | 406.4 | 208 | 97.8 | 496.4 | 258 | 125.6 | 586.4 | 308 | 153.3 | 676.4 | 358 | 181.1 | 676.4 | 358 | 181.1 |
| 48.2 | 9 | -12.8 | -41 | -40.6 | -41.8 | 138.2 | 59 | 15.0 | 228.2 | 109 | 42.8 | 318.2 | 159 | 70.6 | 408.2 | 209 | 98.3 | 498.2 | 259 | 126.1 | 588.2 | 309 | 153.9 | 678.2 | 359 | 181.7 | 678.2 | 359 | 181.7 |
| 50.0 | 10 | -12.2 | -40 | -40.0 | -40.0 | 140.0 | 60 | 15.6 | 230.0 | 110 | 43.3 | 320.0 | 160 | 71.1 | 410.0 | 210 | 98.9 | 500.0 | 260 | 126.7 | 590.0 | 310 | 154.4 | 680.0 | 360 | 182.2 | 680.0 | 360 | 182.2 |
| 51.8 | 11 | -11.7 | -39 | -39.4 | -38.2 | 141.8 | 61 | 16.1 | 231.8 | 111 | 43.9 | 321.8 | 161 | 71.7 | 411.8 | 211 | 99.4 | 501.8 | 261 | 127.2 | 591.8 | 311 | 155.0 | 681.8 | 361 | 182.8 | 681.8 | 361 | 182.8 |
| 53.6 | 12 | -11.1 | -38 | -38.9 | -36.4 | 143.6 | 62 | 16.7 | 233.6 | 112 | 44.4 | 323.6 | 162 | 72.2 | 413.6 | 212 | 100.0 | 503.6 | 262 | 127.8 | 593.6 | 312 | 155.6 | 683.6 | 362 | 183.3 | 683.6 | 362 | 183.3 |
| 55.4 | 13 | -10.6 | -37 | -38.3 | -34.6 | 145.4 | 63 | 17.2 | 235.4 | 113 | 45.0 | 325.4 | 163 | 72.8 | 415.4 | 213 | 100.6 | 505.4 | 263 | 128.3 | 595.4 | 313 | 156.1 | 685.4 | 363 | 183.9 | 685.4 | 363 | 183.9 |
| 57.2 | 14 | -10.0 | -36 | -37.8 | -32.8 | 147.2 | 64 | 17.8 | 237.2 | 114 | 45.6 | 327.2 | 164 | 73.3 | 417.2 | 214 | 101.1 | 507.2 | 264 | 128.9 | 597.2 | 314 | 156.7 | 687.2 | 364 | 184.4 | 687.2 | 364 | 184.4 |
| 59.0 | 15 | -9.4 | -35 | -37.2 | -30.8 | 149.0 | 65 | 18.3 | 239.0 | 115 | 46.1 | 329.0 | 165 | 73.9 | 419.0 | 215 | 101.7 | 509.0 | 265 | 129.4 | 599.0 | 315 | 157.2 | 689.0 | 365 | 185.0 | 689.0 | 365 | 185.0 |
| 60.8 | 16 | -8.9 | -34 | -36.7 | -29.2 | 150.8 | 66 | 18.9 | 240.8 | 116 | 46.7 | 330.8 | 166 | 74.4 | 420.8 | 216 | 102.2 | 510.8 | 266 | 130.0 | 600.8 | 316 | 157.8 | 690.8 | 366 | 185.6 | 690.8 | 366 | 185.6 |
| 62.6 | 17 | -8.3 | -33 | -36.1 | -27.4 | 152.6 | 67 | 19.4 | 242.6 | 117 | 47.2 | 332.6 | 167 | 75.0 | 422.6 | 217 | 102.8 | 512.6 | 267 | 130.6 | 602.6 | 317 | 158.3 | 692.6 | 367 | 186.1 | 692.6 | 367 | 186.1 |
| 64.4 | 18 | -7.8 | -32 | -35.6 | -25.6 | 154.4 | 68 | 20.0 | 244.4 | 118 | 47.8 | 334.4 | 168 | 75.6 | 424.4 | 218 | 103.3 | 514.4 | 268 | 131.1 | 604.4 | 318 | 158.9 | 694.4 | 368 | 186.7 | 694.4 | 368 | 186.7 |
| 66.2 | 19 | -7.2 | -31 | -35.0 | -23.8 | 156.2 | 69 | 20.6 | 246.2 | 119 | 48.3 | 336.2 | 169 | 76.1 | 426.2 | 219 | 103.9 | 516.2 | 269 | 131.7 | 606.2 | 319 | 159.4 | 696.2 | 369 | 187.2 | 696.2 | 369 | 187.2 |
| 68.0 | 20 | -6.7 | -30 | -34.4 | -22.0 | 158.0 | 70 | 21.1 | 248.0 | 120 | 48.9 | 338.0 | 170 | 76.7 | 428.0 | 220 | 104.4 | 518.0 | 270 | 132.2 | 608.0 | 320 | 160.0 | 698.0 | 370 | 187.8 | 698.0 | 370 | 187.8 |
| 69.8 | 21 | -6.1 | -29 | -33.9 | -20.2 | 159.8 | 71 | 21.7 | 249.8 | 121 | 49.4 | 339.8 | 171 | 77.2 | 429.8 | 221 | 105.0 | 519.8 | 271 | 132.8 | 609.8 | 321 | 160.6 | 699.8 | 371 | 188.3 | 699.8 | 371 | 188.3 |
| 71.6 | 22 | -5.6 | -28 | -33.3 | -18.4 | 161.6 | 72 | 22.2 | 251.6 | 122 | 50.0 | 341.6 | 172 | 77.8 | 431.6 | 222 | 105.6 | 521.6 | 272 | 133.3 | 611.6 | 322 | 161.1 | 701.6 | 372 | 188.9 | 701.6 | 372 | 188.9 |
| 73.4 | 23 | -5.0 | -28 | -32.8 | -16.6 | 163.4 | 73 | 22.8 | 253.4 | 123 | 50.6 | 343.4 | 173 | 78.3 | 433.4 | 223 | 106.1 | 523.4 | 273 | 133.9 | 613.4 | 323 | 161.7 | 703.4 | 373 | 189.4 | 703.4 | 373 | 189.4 |
| 75.2 | 24 | -4.4 | -28 | -32.2 | -14.8 | 165.2 | 74 | 23.3 | 255.2 | 124 | 51.1 | 345.2 | 174 | 78.9 | 435.2 | 224 | 106.7 | 525.2 | 274 | 134.4 | 615.2 | 324 | 162.2 | 705.2 | 374 | 190.0 | 705.2 | 374 | 190.0 |
| 77.0 | 25 | -3.9 | -27 | -31.7 | -13.0 | 167.0 | 75 | 23.9 | 257.0 | 125 | 51.7 | 347.0 | 175 | 79.4 | 437.0 | 225 | 107.2 | 527.0 | 275 | 135.0 | 617.0 | 325 | 162.8 | 707.0 | 375 | 190.6 | 707.0 | 375 | 190.6 |
| 78.8 | 26 | -3.3 | -27 | -31.2 | -11.2 | 168.8 | 76 | 24.4 | 258.8 | 126 | 52.2 | 348.8 | 176 | 80.0 | 438.8 | 226 | 107.8 | 528.8 | 276 | 135.6 | 618.8 | 326 | 163.3 | 708.8 | 376 | 191.1 | 708.8 | 376 | 191.1 |
| 80.6 | 27 | -2.8 | -26 | -30.6 | -9.4 | 170.6 | 77 | 25.0 | 260.6 | 127 | 52.8 | 350.6 | 177 | 80.6 | 440.6 | 227 | 108.3 | 530.6 | 277 | 136.1 | 620.6 | 327 | 163.9 | 710.6 | 377 | 191.7 | 710.6 | 377 | 191.7 |
| 82.4 | 28 | -2.2 | -26 | -30.0 | -7.6 | 172.4 | 78 | 25.6 | 262.4 | 128 | 53.3 | 352.4 | 178 | 81.1 | 442.4 | 228 | 108.9 | 532.4 | 278 | 136.7 | 622.4 | 328 | 164.4 | 712.4 | 378 | 192.2 | 712.4 | 378 | 192.2 |
| 84.2 | 29 | -1.7 | -24 | -29.4 | -5.8 | 174.2 | 79 | 26.1 | 264.2 | 129 | 53.9 | 354.2 | 179 | 81.7 | 444.2 | 229 | 109.4 | 534.2 | 279 | 137.2 | 624.2 | 329 | 165.0 | 714.2 | 379 | 192.8 | 714.2 | 379 | 192.8 |
| 86.0 | 30 | -1.1 | -24 | -28.9 | -4.0 | 176.0 | 80 | 26.7 | 266.0 | 130 | 54.4 | 356.0 | 180 | 82.2 | 446.0 | 230 | 110.0 | 536.0 | 280 | 137.8 | 626.0 | 330 | 165.6 | 716.0 | 380 | 193.3 | 716.0 | 380 | 193.3 |
| 87.8 | 31 | -0.6 | -24 | -28.3 | -2.2 | 177.8 | 81 | 27.2 | 267.8 | 131 | 55.0 | 357.8 | 181 | 82.8 | 447.8 | 231 | 110.6 | 537.8 | 281 | 138.3 | 627.8 | 331 | 166.1 | 717.8 | 381 | 193.9 | 717.8 | 381 | 193.9 |
| 89.6 | 32 | 0.0 | -24 | -27.8 | -0.4 | 179.6 | 82 | 27.8 | 269.6 | 132 | 55.6 | 359.6 | 182 | 83.3 | 449.6 | 232 | 111.1 | 539.6 | 282 | 138.9 | 629.6 | 332 | 166.7 | 719.6 | 382 | 194.4 | 719.6 | 382 | 194.4 |
| 91.4 | 33 | 0.6 | -24 | -27.2 | 1.4 | 181.4 | 83 | 28.3 | 271.4 | 133 | 56.1 | 361.4 | 183 | 83.9 | 451.4 | 233 | 111.7 | 541.4 | 283 | 139.4 | 631.4 | 333 | 167.2 | 721.4 | 383 | 195.0 | 721.4 | 383 | 195.0 |
| 93.2 | 34 | 1.1 | -24 | -26.7 | 3.2 | 183.2 | 84 | 28.9 | 273.2 | 134 | 56.7 | 363.2 | 184 | 84.4 | 453.2 | 234 | 112.2 | 543.2 | 284 | 140.0 | 633.2 | 334 | 167.8 | 723.2 | 384 | 195.6 | 723.2 | 384 | 195.6 |
| 95.0 | 35 | 1.7 | -23 | -26.1 | 5.0 | 185.0 | 85 | 29.4 | 275.0 | 135 | 57.2 | 365.0 | 185 | 85.0 | 455.0 | 235 | 112.8 | 545.0 | 285 | 140.6 | 635.0 | 335 | 168.3 | 725.0 | 385 | 196.1 | 725.0 | 385 | 196.1 |
| 96.8 | 36 | 2.2 | -23 | -25.6 | 6.8 | 186.8 | 86 | 30.0 | 276.8 | 136 | 57.8 | 366.8 | 186 | 85.6 | 456.8 | 236 | 113.3 | 546.8 | 286 | 141.1 | 636.8 | 336 | 168.9 | 726.8 | 386 | 196.7 | 726.8 | 386 | 196.7 |
| 98.6 | 37 | 2.8 | -23 | -25.0 | 8.6 | 188.6 | 87 | 30.6 | 278.6 | 137 | 58.3 | 368.6 | 187 | 86.1 | 458.6 | 237 | 113.9 | 548.6 | 287 | 141.7 | 638.6 | 337 | 169.4 | 728.6 | 387 | 197.2 | 728.6 | 387 | 197.2 |
| 100.4 | 38 | 3.3 | -23 | -24.4 | 10.4 | 190.4 | 88 | 31.1 | 280.4 | 138 | 58.9 | 370.4 | 188 | 86.7 | 460.4 | 238 | 114.4 | 550.4 | 288 | 142.2 | 640.4 | 338 | 170.0 | 730.4 | 388 | 197.8 | 730.4 | 388 | 197.8 |
| 102.2 | 39 | 3.9 | -23 | -23.9 | 12.2 | 192.2 | 89 | 31.7 | 282.2 | 139 | 59.4 | 372.4 | 189 | 87.2 | 462.2 | 239 | 115.0 | 552.2 | 289 | 142.8 | 642.4 | 339 | 170.6 | 732.2 | 389 | 198.3 | 732.2 | 389 | 198.3 |
| 104.0 | 40 | 4.4 | -23 | -23.3 | 14.0 | 194.0 | 90 | 32.2 | 284.0 | 140 | 60.0 | 374.0 | 190 | 87.8 | 464.0 | 240 | 115.6 | 554.0 | 290 | 143.3 | 644.0 | 340 | 171.1 | 734.0 | 390 | 198.9 | 734.0 | 390 | 198.9 |
| 105.8 | 41 | 5.0 | -23 | -22.8 | 15.8 | 195.8 | 91 | 32.8 | 285.8 | 141 | 60.6 | 375.8 | 191 | 88.3 | 465.8 | 241 | 116.1 | 555.8 | 291 | 143.9 | 645.8 | 341 | 171.7 | 735.8 | 391 | 199.4 | 735.8 | 391 | 199.4 |
| 107.6 | 42 | 5.6 | -23 | -22.2 | 17.6 | 197.6 | 92 | 33.3 | 287.6 | 142 | 61.1 | 377.6 | 192 | 88.9 | 467.6 | 242 | 116.7 | 557.6 | 292 | 144.4 | 647.6 | 342 | 172.2 | 737.6 | 392 | 200.0 | 737.6 | 392 | 200.0 |
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