Manual of Petroleum Measurement Standards Chapter 11—Physical Properties Data

Section 5—Density/Weight/Volume Intraconversion

Part 3—Conversions for Absolute Density at 15 °C

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

FIRST EDITION, MARCH 2009

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Measurement Coordination

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Contents

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 Volumes XI/XII (ASTM D1250-80, IP 200). This standard gives the following equivalents for any value of absolute density at 15 °C:

— relative density at 15 °C;

— absolute density at 60 °F;

— relative density at 60 °F (old Table 51);

— API gravity at 60 °F (old Table 51);

— density at 15 °C (similar to old Table 56);

— conversion of apparent density at 15 °C to absolute density at 15 °C;

— cubic metres per metric ton at 15 °C *in vacuo* and *in air* (similar to old Table 56);

— cubic metres per short ton at 15 °C *in vacuo* and *in air;*

— cubic metres per long ton at 15 °C *in vacuo* and *in air;*

— pounds per U.S. gallon at 60 °F *in vacuo* and *in air;*

— U.S. gallons per pound at 60 °F *in vacuo* and *in air;*

— short tons per 1000 litres (cubic metres) at 15 °C *in vacuo* and *in air* (old Table 57);

— short tons per 1000 U.S. gallons at 60 °F *in vacuo* and *in air;*

— U.S. gallons per short ton at 60 °F *in vacuo* and *in air;*

— short tons per barrel at 60 °F *in vacuo* and *in air;*

— barrels per short ton at 60 °F *in vacuo* and *in air;*

— long tons per 1000 litres (cubic metres) at 15 °C *in vacuo* and *in air* (old Table 57);

— U.S. gallons per metric ton at 60 °F *in vacuo* and *in air* (old Table 58);

— barrels per metric ton at 60 °F *in vacuo* and *in air* (old Table 58);

— long tons per 1000 U.S. gallons at 60 °F *in vacuo* and *in air;*

— U.S. gallons per long ton at 60 °F *in vacuo* and *in air;*

— long tons per barrel at 60 °F *in vacuo* and *in air;*

— barrels per long ton at 60 °F *in vacuo* and *in air.*

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

— litres at 15 °C to U.S. gallons at 60 °F;

— cubic metres at 15 °C to barrels at 60 °F (old Table 52).

This standard is intended for application to bulk liquid quantities.

This standard provides implementation procedures for conversion of absolute density at 15 °C to equivalent densities in both *in vacuo* and *in air* values. A derivation of the *in air* equation is presented in Section B.5. *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 API gravity and relative density in the oil industry, absolute density is recommended instead.

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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 reference 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 D1250-1959 [1], *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 Edition [2], *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*

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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 millimetre 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, and 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 *v* 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 *in air* (apparent density) at 15 °C
D^{60}	density at 60 °F

D_a^{60}	density *in air* (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/cm^3	grams per cubic centimetre
g/mL	grams per millilitre
L	litre
lb	pound
LT	long ton
m^3	cubic metre
MT	metric ton (1000 kilograms, 1 million grams)
ST	short ton
ρ_{15}	density of water at 15 °F
VCF$_t$	volume correction factor at temperature t (°C 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 Relative Density at 15 °C Equivalent to Absolute Density at 15 °C

The following equation (see Section B.1) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C (D^{15}) and relative density at 15 °C ($D^{15}{}_{15}$):

$$D^{15}{}_{15} = \frac{D^{15}}{999.102} \qquad (1)$$

Solve Equation (1) with values of D^{15} and round the result to five places past the decimal for further use.

4.2 Absolute Density at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.2) defines the relationship between absolute density in kilograms per cubic metre at 15 °C and absolute density in kilograms per cubic metre at 60 °F (15.5556 °C):

$$D^{60} \text{in kg/m}^3 = D^{15} \times \text{VCF}_{15.5556} \qquad (2)$$

Solve Equation (2) with values of D^{15} and round the result to two places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 absolute density at 60 °F for gasoline equivalent to a 15 °C absolute density of 743.57? Using Table 54B from API *MPMS* Ch. 11.1:

$$D^{60} \text{in kg/m}^3 = 743.57 \times 0.99932 = 743.06$$

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

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

$$D^{60}{}_{60} = \frac{D^{15} \times \mathrm{VCF}_{15.5556}}{999.016} \tag{3}$$

Solve Equation (3) with values of D^{15} and round the result to five places past the decimal. As this calculation includes a $\mathrm{VCF}_{15.5556}$, 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 a 15 °C absolute density of 743.57? Using Table 54B from API *MPMS* Ch. 11.1:

$$D^{60}{}_{60} = 743.57 \times 0.99932/999.016 = 0.74380$$

4.4 API Gravity at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.4) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and API gravity at 60/60 °F:

$$°\mathrm{API} = \frac{141.5 \times 999.016}{D^{15} \times \mathrm{VCF}_{15.5556}} - 131.5 \tag{4}$$

Solve Equation (4) with values of D^{15} and round the result to two places past the decimal. As this calculation includes a $\mathrm{VCF}_{15.5556}$, 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 API gravity at 60 °F for gasoline equivalent to a 15 °C absolute density of 743.57? Using Table 54B from API *MPMS* Ch. 11.1:

$$°\mathrm{API} = \frac{141.5 \times 999.016}{743.57 \times 0.99932} - 131.5 = 58.74$$

4.5 Apparent Density at 15 °C Equivalent to Absolute Density at 15 °C

The following equation (see Section B.5) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and apparent density (*in air*) at 15 °C in kilograms per cubic metre or kilograms per 1000 L:

$$D_a{}^{15} \text{in kg/m}^3 = 1.000149926\ D^{15} - 1.199407795 \tag{5}$$

Solve Equation (5) with values of D^{15} and round the result to two places past the decimal.

EXAMPLE

Gasoline has a 15 °C absolute density of 743.57 kg/m³. What is the scale weight of 10 L at 15 °C?

$$D_a^{15} \text{in kg/m}^3 = 1.000149926 \times 743.57 - 1.199407795 = 742.48 \text{ kg/m}^3 = 7.4248 \text{ kg/10 L}$$

NOTE If weighed in an evacuated chamber, the 10 L would weigh 7.4357 kg (10.9 grams more.)

4.6 Conversion of Apparent Density at 15 °C to Absolute Density at 15 °C

The following equation (see Section B.6) expresses the relationship between apparent density in kilograms per cubic metre at 15 °C and absolute density in kilograms per cubic metre at 15 °C:

$$D^{15} = \frac{D_a^{15} + 1.199407795}{1.000149926} \tag{6}$$

Solve Equation (6) with values of D_a^{15} and round the result to two places past the decimal.

EXAMPLE

10 L of gasoline weighs 7.4248 kg at 15 °C. What is its absolute density in kilograms per cubic metre at 15 °C?

Convert kilograms per 10 L to kilograms per cubic metre and use Equation (6) to calculate the *in vacuo* density:

$$D_a^{15} = 7.4248 \text{ kg/10 L} \times 100/100 = 742.48 \text{ kg/1000 L} = 742.48 \text{ kg/m}^3$$

$$D^{15} = \frac{742.48 \text{ kg/m}^3 + 1.199407795}{1.000149926} = 743.57 \text{ kg/m}^3$$

4.7 Cubic Metres per Metric Ton at 15 °C Equivalent to Absolute Density at 15 °C

The following equation (see Section B.7) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding cubic metres per metric ton *in vacuo*:

$$1/D^{15} \text{ in m}^3\text{/MT} = \frac{1}{D^{15} \times 0.001} \tag{7}$$

The following equation (see Section B.7) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding cubic metres per metric ton *in air*:

$$1/D_a^{15} \text{ in m}^3\text{/MT} = \frac{1}{(1.000149926\ D^{15} - 1.199407795) \times 0.001} \tag{8}$$

Solve Equations (7) and (8) with values of D^{15} and round the result to nine places past the decimal for further use.

EXAMPLE

A tanker of gasoline having a 15 °C density of 743.57 kg/m³ is invoiced at 42,783.4816 MT. What is the 15 °C volume in cubic metres?

Use Equation (7) to calculate the *in vacuo* intraconversion factor:

$$1/D^{15} \text{ in m}^3\text{/MT} = \frac{1}{743.57 \times 0.001} = 1.344863295 \text{ in m}^3\text{/MT}$$

The 42,783.4816 MT of gasoline is then equivalent to (rounding as indicated in Table 1):

$$15\ °\text{C m}^3 = 1.344863295\ \text{m}^3/\text{MT} \times 42{,}783.4816\ \text{MT} = 57{,}537.934\ \text{m}^3$$

4.8 Cubic Metres per Short Ton at 15 °C Equivalent to Absolute Density at 15 °C

The following equation (see Section B.8) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding cubic metres per short ton *in vacuo*:

$$1/D^{15}\ \text{in m}^3/\text{ST} = \frac{1}{D^{15} \times 0.001102311311} \tag{9}$$

The following equation (see Section B.8) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding cubic metres per short ton *in air*:

$$1/D_a^{15}\ \text{in m}^3/\text{ST} = \frac{1}{(1.000149926\ D^{15} - 1.199407795) \times 0.001102311311} \tag{10}$$

Solve Equations (9) and (10) with values of D^{15} and round the result to nine places past the decimal for further use.

EXAMPLE

An incoming shipment of gasoline having a 15 °C density of 743.57 kg/m^3 is invoiced at 47,160.7157 ST. What is the 15 °C volume in cubic metres?

Use Equation (9) to calculate the *in vacuo* intraconversion factor:

$$1/D^{15}\ \text{in m}^3/\text{ST} = \frac{1}{743.57 \times 0.001102311311} = 1.220039458\ \text{m}^3/\text{ST}$$

The 47,160.7157 ST of gasoline is then equivalent to (rounding as indicated in Table 1):

$$15\ °\text{C m}^3 = 1.220039458\ \text{m}^3/\text{ST} \times 47{,}160.7157\ \text{ST} = 57{,}537.934\ \text{m}^3$$

4.9 Cubic Metres per Long Ton at 15 °C Equivalent to Absolute Density at 15 °C

The following equation (see Section B.9) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding cubic metres per long ton *in vacuo*:

$$1/D^{15}\ \text{in m}^3/\text{LT} = \frac{1}{D^{15} \times 0.0009842065276} \tag{11}$$

The following equation (see Section B.9) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding cubic metres per long ton *in air*:

$$1/D_a^{15}\ \text{in m}^3/\text{LT} = \frac{1}{(1.000149926\ D^{15} - 1.199407795) \times 0.0009842065276} \tag{12}$$

Solve Equation (11) and Equation (12) with values of D^{15} and round the result to nine places past the decimal for further use.

EXAMPLE

An incoming shipment of gasoline having a 15 °C density of 743.57 kg/m^3 is invoiced at 42,107.7819 LT. What is the 15 °C volume in cubic metres?

Use Equation (11) to calculate the *in vacuo* intraconversion factor:

$$1/D^{15} \text{ in m}^3/\text{LT} = \frac{1}{743.57 \times 0.0009842065276} = 1.366444193 \text{ m}^3/\text{LT}$$

The 42,107.7819 LT of gasoline is then equivalent to (rounding as indicated in Table 1):

$$15\ °\text{C m}^3 = 1.366444193 \text{ m}^3/\text{LT} \times 42{,}107.7819 \text{ LT} = 57{,}537.934 \text{ m}^3$$

4.10 Pounds per U.S. Gallon at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.10) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding pounds per U.S. gallon *in vacuo*:

$$D^{60} \text{ in lb/gal} = D^{15} \times \text{VCF}_{15.5556} \times 0.008345404452 \qquad (13)$$

The following equation (see Section B.10) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding pounds per U.S. gallon *in air*:

$$D_a^{60} \text{ in lb/gal} = (1.000149926 \times D^{15} \times \text{VCF}_{15.5556} - 1.199407795) \times 0.008345404452 \qquad (14)$$

Solve Equations (13) and (14) with values of D^{15} and round the result to nine places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 tanker of gasoline having a 15 °C density of 743.57 kg/m^3 is determined to contain 361,902.72 bbl at 60 °F. What is the *in vacuo* weight in pounds of the cargo?

Use Equation (13) to calculate the *in vacuo* intraconversion factor:

$$D^{60} \text{ in lb/gal} = 743.57 \times 0.99932 \times 0.008345404452 = 6.201172722 \text{ lb/gal}$$

The 361,902.72 bbl of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight } in\ vacuo = 6.201172722 \text{ lb/gal} \times 361{,}902.72 \text{ bbl} \times 42 \text{ gal/bbl} = 94{,}257{,}294 \text{ lb}$$

4.11 U.S. Gallons per Pound at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.11) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding U.S. gallons per pound *in vacuo*:

$$1/D^{60} \text{ in gal/lb} = \frac{1}{D^{15} \times \text{VCF}_{15.5556} \times 0.008345404452} \qquad (15)$$

The following equation (see Section B.11) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding U.S. gallons per pound *in air*:

$$1/D_a^{60} \text{ in gal/lb } = \frac{1}{(1.000149926 \times D^{15} \times \text{VCF}_{15.5556} - 1.199407795) \times 0.008345404452} \quad (16)$$

Solve Equations (15) and (16) with values of D^{15} and round the result to ten places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 15 °C density of 743.57 kg/m^3 is invoiced at 94, 257,294 lb. What is the 60 °F volume in U.S. gallons and barrels?

Use Equation (15) to calculate the *in vacuo* intraconversion factor:

$$1/D^{60} \text{ in gal/lb } = \frac{1}{743.57 \times 0.99932 \times 0.008345404452} = 0.1612598205 \text{ gal/lb}$$

The 94,257,294 lb of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60 \text{ °F gal } = 0.1612598205 \text{ gal/lb} \times 94{,}257{,}294 \text{ lb} = 15{,}199{,}914 \text{ gal}$$

If barrels are the desired volume unit, do not round the intermediate U.S. gallons, just the final result. The 94,257,294 lb of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60 \text{ °F gal } = 0.1612598205 \text{ gal/lb} \times 94{,}257{,}294 \text{ lb / 42 gal/bbl} = 361{,}902.72 \text{ bbl}$$

4.12 Short Tons per 1000 Litres (Cubic Metre) at 15 °C Equivalent to Absolute Density at 15 °C

The following equation (see Section B.12) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding short tons per 1000 L *in vacuo*:

$$D^{15} \text{ in ST/1000 L } = D^{15} \times 0.001102311311 \quad (17)$$

The following equation (see Section B.12) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding short tons per 1000 L *in air*:

$$D_a^{15} \text{ in ST/1000 L } = (1.000149926\ D^{15} - 1.199407795) \times 0.001102311311 \quad (18)$$

Solve Equations (17) and (18) with values of D^{15} and round the result to ten places past the decimal for further use.

EXAMPLE

An incoming shipment of gasoline having a 15 °C density of 743.57 kg/m^3 is invoiced at 57,537.934 m^3. What is the *in vacuo* weight in short tons?

Use Equation (17) to calculate the *in vacuo* intraconversion factor:

$$D^{15} \text{ in ST/1000 L } = 743.57 \times 0.001102311311 = 0.8196456215 \text{ ST/1000 L}$$

Since 1 m^3 = 1000 L, 57,537.934 m^3 of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight } in\ vacuo = 0.8196456215 \text{ ST/1000 L} \times 57{,}537{,}934 \text{ L} = 47{,}160.7157 \text{ ST}$$

4.13 Short Tons per 1000 U.S. Gallons at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.13) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding short tons per 1000 gal *in vacuo*:

$$D^{60} \text{ in ST/1000 gal} = D^{15} \times \text{VCF}_{15.5556} \times 0.004172702226 \tag{19}$$

The following equation (see Section B.13) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding short tons per 1000 gal *in air*:

$$D_a^{60} \text{ in ST/1000 gal} = (1.000149926 \times D^{15} \times \text{VCF}_{15.5556} - 1.199407795) \times 0.004172702226 \tag{20}$$

Solve Equation (19) and Equation (20) with values of D^{15} and round the result to nine places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 tanker of gasoline having a 15 °C density of 743.57 kg/m^3 is determined to contain 361,902.72 bbl at 60 °F. What is the *in vacuo* weight in short tons of the cargo?

Use Equation (19) to calculate the *in vacuo* intraconversion factor:

$$D^{60} \text{ in ST/1000 gal} = 743.57 \times 0.99932 \times 0.004172702226 = 3.100586361 \text{ ST/1000 gal}$$

The 361,902.72 bbl of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight } in\ vacuo = 3.100586361 \text{ ST/1000 gal} \times 361{,}902.72 \text{ bbl} \times 42 \text{ gal/bbl} = 47{,}128.6468 \text{ ST}$$

4.14 U.S. Gallons per Short Ton at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.14) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding U.S. gallons per short ton *in vacuo*:

$$1/D^{60} \text{ in gal/ST} = \frac{1000}{D^{15} \times \text{VCF}_{15.5556} \times 0.004172702226} \tag{21}$$

The following equation (see Section B.14) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding U.S. gallons per short ton *in air*:

$$1/D_a^{60} \text{ in gal/ST} = \frac{1000}{(1.000149926 \times D^{15} \times \text{VCF}_{15.5556} - 1.199407795) \times 0.004172702226} \tag{22}$$

Solve Equation (21) and Equation (22) with values of D^{15} and round the result to seven places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 15 °C density of 743.57 kg/m^3 is invoiced at 47,128.6468 ST. What is the 60 °F volume in U.S. gallons?

Use Equation (21) to calculate the *in vacuo* intraconversion factor:

$$1/D^{60} \text{ in gal/ST} = \frac{1000}{743.57 \times 0.99932 \times 0.004172702226} = 322.5196410 \text{ gal/ST}$$

The 47,128.6468 ST of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60\ °\text{F gal} = 322.5196410 \text{ gal/ST} \times 47{,}128.6468 \text{ ST} = 15{,}199{,}914 \text{ gal}$$

4.15 Short Tons per Barrel at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.15) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding short tons per barrel *in vacuo*:

$$D^{60} \text{ in ST/bbl} = D^{15} \times \text{VCF}_{15.5556} \times 0.0001752534935 \tag{23}$$

The following equation (see Section B.15) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding short tons per barrel *in air*:

$$D_a^{60} \text{ in ST/bbl} = (1.000149926 \times D^{15} \times \text{VCF}_{15.5556} - 1.199407795) \times 0.0001752534935 \tag{24}$$

Solve Equation (23) and Equation (24) with values of D^{15} and round the result to ten places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 tanker of gasoline having a 15 °C density of 743.57 kg/m^3 is determined to contain 361,902.72 bbl at 60 °F. What is the *in vacuo* weight in short tons of the cargo?

Use Equation (23) to calculate the *in vacuo* intraconversion factor:

$$D^{60} \text{ in ST/bbl} = 743.57 \times 0.99932 \times 0.0001752534935 = 0.1302246272 \text{ ST/bbl}$$

The 361,902.72 bbl of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight } in\ vacuo = 0.1302246272 \text{ ST/bbl} \times 361{,}902.72 \text{ bbl} = 47{,}128.6468 \text{ ST}$$

4.16 Barrels per Short Ton at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.16) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding barrels per short ton *in vacuo*:

$$1/D^{60} \text{ in bbl/ST} = \frac{1}{D^{15} \times \text{VCF}_{15.5556} \times 0.0001752534935} \tag{25}$$

The following equation (see Section B.16) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding barrels per short ton *in air*:

$$1/D_a^{60} \text{ in bbl/ST} = \frac{1}{(1.000149926 \times D^{15} \times \text{VCF}_{15.5556} - 1.199407795) \times 0.0001752534935} \tag{26}$$

Solve Equation (25) and Equation (26) with values of D^{15} and round the result to nine places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 15 °C density of 743.57 kg/m^3 is invoiced at 47,128.6468 ST. What is the 60 °F volume in U.S. gallons?

Use Equation (25) to calculate the *in vacuo* intraconversion factor:

$$1/D^{60} \text{ in bbl/ST} = \frac{1}{743.57 \times 0.99932 \times 0.0001752534935} = 7.679039071 \text{ bbl/ST}$$

The 47,128.6468 ST of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60 \text{ °F bbl} = 7.679039071 \text{ bbl/ST} \times 47,128.6468 \text{ ST} = 361,902.72 \text{ bbl}$$

4.17 Long Tons per 1000 Litres (Cubic Metre) at 15 °C Equivalent to Absolute Density at 15 °C

The following equation (see Section B.17) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding long tons per 1000 L *in vacuo*:

$$D^{15} \text{ in LT/1000 L} = D^{15} \times 0.0009842065276 \tag{27}$$

The following equation (see Section B.17) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding long tons per 1000 L *in air*:

$$D_a^{15} \text{ in LT/1000 L} = (1.000149926\ D^{15} - 1.199407795) \times 0.0009842065276 \tag{28}$$

Solve Equation (27) and Equation (28) with values of D^{15} and round the result to ten places past the decimal for further use.

EXAMPLE

An incoming shipment of gasoline having a 15 °C density of 743.57 kg/m^3 is invoiced at 57,537.934 m^3. What is the *in vacuo* weight in long tons?

Use Equation (27) to calculate the *in vacuo* intraconversion factor:

$$D^{15} \text{ in LT/1000 L} = 743.57 \times 0.0009842065276 = 0.7318264477 \text{ LT/1000 L}$$

Since 1 m^3 = 1000 L, 57,537.934 m^3 of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight } \textit{in vacuo} = 0.7318264477 \text{ LT/1000 L} \times 57,537,934 \text{ L} = 42,107.7818 \text{ LT}$$

4.18 U.S. Gallons per Metric Ton at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.18) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding U.S. gallons per metric ton *in vacuo*:

$$1/D^{60} \text{ in gal/MT } = \frac{1}{D^{15} \times \text{VCF}_{15.5556} \times 0.000003785411784} \tag{29}$$

The following equation (see Section B.18) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding U.S. gallons per metric ton *in air*:

$$1/D_a{}^{60} \text{ in gal/MT } = \frac{1}{(1.000149926 \times D^{15} \times \text{VCF}_{15.5556} - 1.199407795) \times 0.000003785411784} \tag{30}$$

Solve Equation (29) and Equation (30) with values of D^{15} and round the result to seven places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 15 °C density of 743.57 kg/m^3 is invoiced at 42,754.3891 MT. What is the 60 °F volume in U.S. gallons?

Use Equation (29) to calculate the *in vacuo* intraconversion factor:

$$1/D^{60} \text{ in gal/MT } = \frac{1}{743.57 \times 0.99932 \times 0.000003785411784} = 355.5170483 \text{ gal/MT}$$

The 42,754.3890 MT of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60 \text{ °F gal } = 355.5170483 \text{ gal/MT} \times 42{,}754.3891 \text{ MT} = 15{,}199{,}914 \text{ gal}$$

4.19 Barrels per Metric Ton at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.19) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding barrels per metric ton *in vacuo*:

$$1/D^{60} \text{ in bbl/MT } = \frac{1}{D^{15} \times \text{VCF}_{15.5556} \times 0.0001589872949} \tag{31}$$

The following equation (see Section B.19) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding barrels per metric ton *in air*:

$$1/D_a{}^{60} \text{ in bbl/MT } = \frac{1}{(1.000149926 \times D^{15} \times \text{VCF}_{15.5556} - 1.199407795) \times 0.0001589872949} \tag{32}$$

Solve Equation (31) and Equation (32) with values of D^{15} and round the result to nine places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 15 °C density of 743.57 kg/m^3 is invoiced at 42,754.3891 MT. What is the 60 °F volume in barrels?

Use Equation (31) to calculate the *in vacuo* intraconversion factor:

$$1/D^{60} \text{ in bbl/MT } = \frac{1}{743.57 \times 0.99932 \times 0.0001589872949} = 8.464691627 \text{ bbl/MT}$$

The 42,754.3891 MT of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60\ °\text{F gal } = 8.464691627 \text{ bbl/MT} \times 42{,}754.3891 \text{ MT} = 361{,}902.72 \text{ bbl}$$

4.20 Long Tons per 1000 U.S. Gallons at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.20) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding long tons per 1000 gal *in vacuo*:

$$D^{60} \text{ in LT/1000 gal } = D^{15} \times \text{VCF}_{15.5556} \times 0.003725626988 \tag{33}$$

The following equation (see Section B.20) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding long tons per 1000 gal *in air*:

$$D_a^{60} \text{ in LT/1000 gal } = (1.000149926 \times D^{15} - 1.199407795) \times 0.003725626988 \tag{34}$$

Solve Equation (33) and Equation (34) with values of D^{15} and round the result to nine places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 tanker of gasoline having a 15 °C density of 743.57 kg/m^3 is determined to contain 361,902.72 bbl at 60 °F. What is the *in vacuo* weight in long tons of the cargo?

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

$$D^{60} \text{ in LT/1000 gal } = 743.57 \times 0.99932 \times 0.003725626988 = 2.768380680 \text{ LT/1000 gal}$$

The 361,902.72 bbl of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight } \textit{in vacuo} = 2.768380680 \text{ LT/1000 gal} \times 361{,}902.72 \text{ bbl} \times 42 \text{ gal/bbl} = 42{,}079.1489 \text{ LT}$$

4.21 U.S. Gallons at 60 °F per Long Ton Equivalent to Absolute Density at 15 °C

The following equation (see Section B.21) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding U.S. gallons per long ton *in vacuo*:

$$1/D^{60} \text{ in gal/LT } = \frac{1000}{D^{15} \times \text{VCF}_{15.5556} \times 0.003725626988} \tag{35}$$

The following equation (see Section B.21) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding U.S. gallons per long ton *in air*:

$$1/D_a^{60} \text{ in gal/LT} = \frac{1000}{(1.000149926 \times D^{15} \times \text{VCF}_{15.5556} - 1.199407795) \times 0.003725626988} \quad (36)$$

Solve Equation (35) and Equation (36) with values of D^{15} and round the result to seven places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 15 °C density of 743.57 kg/m^3 is invoiced at 42,079.1489 LT. What is the 60 °F volume in U.S. gallons?

Use Equation (35) to calculate the *in vacuo* intraconversion factor:

$$1/D^{60} \text{ in gal/LT} = \frac{1000}{743.57 \times 0.99932 \times 0.003725626988} = 361.2219979 \text{ gal/LT}$$

The 42,079.1489 LT of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60 \text{ °F gal} = 361.2219979 \text{ gal/LT} \times 42{,}079.1489 \text{ LT} = 15{,}199{,}914 \text{ gal}$$

4.22 Long Tons per Barrel at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.22) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding long tons per barrel *in vacuo*:

$$D^{60} \text{ in LT/bbl} = D^{15} \times \text{VCF}_{15.5556} \times 0.0001564763335 \quad (37)$$

The following equation (see Section B.22) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding long tons per barrel *in air*:

$$D_a^{60} \text{ in LT/bbl} = (1.000149926 \times D^{15} \times \text{VCF}_{15.5556} - 1.199407795) \times 0.0001564763335 \quad (38)$$

Solve Equation (37) and Equation (38) with values of D^{15} and round the result to ten places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 tanker of gasoline having a 15 °C density of 743.57 kg/m^3 is determined to contain 361,902.72 bbl at 60 °F. What is the *in vacuo* weight in long tons of the cargo?

Use Equation (37) to calculate the *in vacuo* intraconversion factor:

$$D^{60} \text{ in LT/bbl} = 743.57 \times 0.99932 \times 0.0001564763335 = 0.1162719885 \text{ LT/bbl}$$

The 361,902.72 bbl of gasoline is then equivalent to (rounding as indicated in Table 1):

$$\text{Weight } \textit{in vacuo} = 0.1162719885 \text{ LT/bbl} \times 361{,}902.72 \text{ bbl} = 42{,}079.1489 \text{ LT}$$

4.23 Barrels per Long Ton at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.23) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding barrels per long ton *in vacuo*:

$$1/D^{60} \text{ in bbl/LT} = \frac{1}{D^{15} \times \text{VCF}_{15.5556} \times 0.0001564763335} \quad (39)$$

The following equation (see Section B.23) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the corresponding barrels per long ton *in air*:

$$1/D_a^{60} \text{ in bbl/LT} = \frac{1}{(1.000149926 \times D^{15} \times \text{VCF}_{15.5556} - 1.199407795) \times 0.0001564763335} \quad (40)$$

Solve Equation (39) and Equation (40) with values of D^{15} and round the result to nine places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 15 °C density of 743.57 kg/m^3 is invoiced at 42,079.1489 LT. What is the 60 °F volume in U.S. gallons?

Use Equation (39) to calculate the *in vacuo* intraconversion factor:

$$1/D^{60} \text{ in bbl/LT} = \frac{1}{743.57 \times 0.99932 \times 0.0001564763335} = 8.600523759 \text{ bbl/LT}$$

The 42,079.1489 LT of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60\ °\text{F bbl} = 8.600523759 \text{ bbl/LT} \times 42{,}079.1489 \text{ LT} = 361{,}902.72 \text{ bbl}$$

4.24 Litres at 15 °C to Gallons at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.24) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the conversion of litres at 15 °C to U.S. gallons at 60 °F:

$$\text{gal}_{60\ °\text{F}} = \text{L}_{15\ °\text{C}} / (3.785411784 \times \text{VCF}_{15.5556}) \quad (41)$$

Using the liquid's density (15 °C) to obtain its VCF at 15.5556 °C, solve the parenthetical part of Equation (41) and round the result to ten places past the decimal for further use. As this calculation includes a $\text{VCF}_{15.5556}$, 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 15 °C density of 743.57 kg/m^3 is invoiced at 57,498.808 cubic metres. What is the 60 °F volume in U.S. gallons?

Use Equation (41) to calculate the intraconversion factor:

$$60\ °\text{F gal}/15\ °\text{C L} = 1/(3.785411784 \times 0.99932) = 0.2643518116 \text{ gal/L}$$

Since 1 m^3 = 1000 L, 57,498.808 m^3 of gasoline is then equivalent to (rounding as indicated in Table 1):

$$60\ °\text{F gal} = 0.2643518116\ \text{gal/L} \times 57{,}498{,}808\ \text{L} = 15{,}199{,}914\ \text{gal}$$

4.25 Cubic Metres at 15 °C to Barrels at 60 °F Equivalent to Absolute Density at 15 °C

The following equation (see Section B.25) expresses the relationship between absolute density in kilograms per cubic metre at 15 °C and the conversion of cubic metres at 15 °C to barrels at 60 °F:

$$\text{bbl}_{60\ °\text{F}} = \text{m}^3_{15\ °\text{C}}/(0.1589872949 \times \text{VCF}_{15.5556}) \tag{42}$$

Using the liquid's Density (15 °C) to obtain its VCF at 15.5556 °C, solve the parenthetical part of Equation (42) and round the result to nine places past the decimal for further use. As this calculation includes a $VCF_{15.5556}$, 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 15 °C density of 743.57 kg/m^3 is invoiced at 57,498.808 cubic metres. What is the 60 °F volume in barrels?

Calculate the intraconversion factor from Equation (42):

$$\text{bbl}_{60\ °\text{F}} = 1/(0.1589872949 \times 0.99932) = 6.294090753\ \text{bbl/m}^3$$

The 57,498.808 cubic metres of gasoline at 15 °C is then equivalent to (rounding as indicated in Table 1):

$$60\ °\text{F bbl} = 6.294090753\ \text{bbl/m}^3 \times 57{,}498.80\ \text{m}^3 = 361{,}902.72\ \text{bbl}$$

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 above 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 gallon 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 lb 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
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 g/cm^3	**x**.xxxxx
Density lb/gal	**x**.xxxxx
Density kg/m^3	**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/cm^3** 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/cm^3** (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 of **999.102 kg/m^3** (0.999102 g/mL) at 15 °C and **999.016 kg/m^3** (0.999016 g/mL) at 60 °F (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 Relative Density at 15 °C Equivalent to Absolute Density at 15 °C

A liquid's relative density D^t_t is defined as its absolute density D^t divided by the absolute density of water at that temperature ρ^t. Relative density at reference temperature 15 °C (D^{15}_{15}) is therefore:

$$D^{15}_{15} = \frac{D^{15}}{\rho^{15}} \tag{B.1}$$

The density of water can be obtained from Annex A. The units of both densities must be identical (g/mL, kg/m^3, lb/gal, etc.). Relative density is dimensionless.

B.2 Absolute Density at 60 °F Equivalent to Absolute Density at 15 °C

A liquid's volume correction factor (VCF) is defined as its absolute density at temperature t divided by its absolute density at reference temperature. For a liquid temperature of 15.5556 °C (60 °F) and a reference temperature 15 °C (59 °F), the VCF is:

$$\mathrm{VCF}_{15.5556} = \frac{D^{15.5556}}{D^{15}} \tag{B.2}$$

Absolute density at 15 °C can thus be converted to absolute density at 60 °F by multiplying by the liquid's VCF for 15.5556 °C (crude oils, generalized products, and lubricants will use API *MPMS* Ch. 11.1-2004; other products may use different tables).

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

As explained in Section B.1, relative density at reference temperature 15.5556 °C (60 °F) is thus:

$$D^{60}_{60} = \frac{D^{15.5556}}{\rho^{15.5556}} \tag{B.3}$$

Absolute density in kilograms per cubic metre at 15 °C can be converted to relative density at 60 °F by substituting Equation (B.2) into Equation (B.3) and 999.016 kg/m^3 for $\rho^{15.5556}$.

$$D^{60}_{60} = \frac{D^{15} \times \mathrm{VCF}_{15.5556}}{999.016} \tag{B.4}$$

The liquid's VCF at 60 °F ($\mathrm{VCF}_{15.5556}$) is obtained from the appropriate table (crude oils, generalized products, and lubricants will use API *MPMS* Ch. 11.1-2004; other products may use different tables).

B.4 API Gravity at 60 °F Equivalent to Absolute Density at 15 °C

The relationship between relative density at 60 °F and API gravity at 60 °F is defined as:

$$°\mathrm{API} = \frac{141.5}{D^{60}_{60}} - 131.5 \tag{B.5}$$

Absolute density in kilograms per cubic metre at 15 °C can be converted to API gravity at 60 °F by substituting Equation (B.4) into Equation (B.5):

$$°\text{API} = \frac{141.5 \times 0.999016}{D^{15} \times \text{VCF}_{15.5556}} - 131.5$$

The liquid's VCF at 15.5556 °C is obtained from the appropriate table (crude oils, generalized products, and lubricants will use API *MPMS* Ch. 11.1-2004; other products may use different tables).

B.5 Apparent Density at 15 °C Equivalent to Absolute Density at 15 °C

Conversion of absolute density in kilograms per cubic metre at temperature t (D^t) to various units of density *in vacuo* is a straight unit conversion since absolute density is by definition *in vacuo*:

$$D^t \text{ in other density units} = D^t \times f \tag{B.6}$$

where f is a constant for converting kilograms per cubic metre to any other density units.

Conversion of absolute density to kilograms per cubic metre *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 15 °C, these ratios are densities at 15 °C. However, the air and reference weight densities to be used for air buoyancy corrections are at 20 °C by international agreement (see Annex A); the difference between the ratio of the densities at 20 °C and that at 15 °C is considered negligible. Thus:

$$D^{15} - A^{20} = \frac{B^{20} - A^{20}}{B^{20}} \times (m_b / V_d)^{15}$$

$$(m_b / V_d)^{15} = \frac{D^{15} - A^{20}}{\frac{B^{20} - A^{20}}{B^{20}}} = \frac{D^{15} - A^{20}}{1 - (A^{20}/B^{20})}$$

where

D^{15}	is the density of liquid at 15 °C *in vacuo*, m_d / V_d;
A^{20}	is the density of standard air at 20 °C *in vacuo*, m_{ad} / V_d or m_{ab} / V_b;
B^{20}	is the density of reference mass at 20 °C *in vacuo*, m_b / V_b;
$(m_b / V_d)^{15}$	is the density of liquid at 15 °C *in air.*

As with Equation (B.6), a 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).

$$(m_b / V_d)^{15} = \frac{D^{15} - A^{20}}{1 - (A^{20}/B^{20})} \times f$$

Substituting D_a^{15} for $(m_b / V_d)^{15}$ and values from Annex A, we obtain:

$$D_a^{15} = (1.000149926\ D^{15} - 1.199407795) \times f \qquad \text{(B.7)}$$

To convert kilograms per cubic metre *in vacuo* to kilograms per cubic metre *in air*, f is unity.

B.6 Conversion of Apparent Density at 15 °C to Absolute Density at 15 °C

Like all equations, Equation (B.7) can be used in reverse to convert apparent density at 15 °C to absolute density by simply solving for absolute density:

$$D^{15} = \frac{D_a^{15} + 1.199407795 \times f}{1.000149926 \times f}$$

When D_a^{15} and D^{15} are both kilograms per cubic metre, f is unity. To convert D_a^{15} from other units to kilograms per cubic metre, use the values of f calculated in the appropriate section of Annex B.

B.7 Cubic Metres per Metric Ton at 15 °C Equivalent to Absolute Density at 15 °C

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume in cubic metres at 15 °C occupied by 1 MT *in vacuo* is accomplished by the reciprocal of Equation (B.6), changing from kilograms per cubic metre to metric tons per cubic metre by calculating f as follows:

$$f = \frac{1\text{ kg}}{1\text{ m}^3} = \frac{0.001\text{ MT}}{1\text{ m}^3} = 10^{-3}\text{ MT/m}^3$$

The relationship between absolute density in kilograms per cubic metre and the volume in cubic metres at 15 °C occupied by 1 MT *in air* is accomplished by the reciprocal of Equation (B.7) with f determined as above.

B.8 Cubic Metres per Short Ton at 15 °C Equivalent to Absolute Density at 15 °C

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume in cubic metres at 15 °C occupied by 1 ST *in vacuo* is accomplished by the reciprocal of Equation (B.6), changing from kilograms per cubic metre to short tons per cubic metre by calculating f as follows:

$$f = \frac{1 \text{ kg}}{1 \text{ m}^3} = \frac{1000 \text{ g}/453.59237 \text{ g/lb}}{1 \text{ m}^3 \times 2000 \text{ lb/ST}} = 0.001102311311 \text{ ST/m}^3$$

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume in cubic metres at 15 °C occupied by 1 ST *in air* is accomplished by the reciprocal of Equation (B.7), using f as calculated above.

B.9 Cubic Metres per Long Ton at 15 °C Equivalent to Absolute Density at 15 °C

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume in cubic metres at 15 °C occupied by 1 LT *in vacuo* is accomplished by the reciprocal of Equation (B.6), changing from kilograms per cubic metre to long tons per cubic metre by calculating f as follows:

$$f = \frac{1 \text{ kg}}{1 \text{ m}^3} = \frac{1000 \text{ g}/453.59237 \text{ g/lb}}{1 \text{ m}^3 \times 2240 \text{ lb/LT}} = 0.0009842065276 \text{ LT/m}^3$$

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume in cubic metres at 15 °C occupied by 1 LT *in air* is accomplished by the reciprocal of Equation (B.7), using f as calculated above.

B.10 Pounds per U.S. Gallon at 60 °F Equivalent to Absolute Density at 15 °C

Conversion of absolute density at 15 °C to absolute density at 60 °F is accomplished by substituting Equation (B.2) into Equation (B.6):

$$D^{60} = D^{15} \times \text{VCF}_{15.5556} \times f \qquad \text{(B.8)}$$

The liquid's VCF at 60 °F ($\text{VCF}_{15.5556}$) is obtained from the appropriate API table (crude oils, generalized products, and lubricants will use API *MPMS* Ch. 11.1-2004; other products may use different tables), and kilograms per cubic metre is changed to pounds per U.S. gallon by calculating f as follows:

$$f = \frac{1 \text{ kg}}{1 \text{ m}^3} = \frac{1000 \text{ g}/453.59237 \text{ g/lb}}{1000 \text{ L/m}^3/(231 \text{ in.}^3/\text{gal} \times 0.016387064 \text{ L/in.}^3)} = 0.008345404452 \text{ lb/gal}$$

Conversion of absolute density in kilograms per cubic metre at 15 °C to the weight in lb *in air* of 1 gal is accomplished by substituting Equation (B.2) into Equation (B.7) to produce Equation (B.9), using f as calculated above.

$$D_a^{60} = (1.00014993 D^{15} \text{VCF}_{15.5556} - 1.19940780) \times f \qquad \text{(B.9)}$$

B.11 U.S. Gallons per Pound at 60 °F Equivalent to Absolute Density at 15 °C

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of U.S. gallons occupied by 1 lb *in vacuo* is given by the reciprocal of Equation (B.8) with f determined as in Section B.10.

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of U.S. gallons occupied by 1 lb *in air* is given by the reciprocal of Equation (B.9) with f determined as in Section B.10.

B.12 Short Tons per 1000 Litres (Cubic Metre) at 15 °C Equivalent to Absolute Density at 15 °C

Conversion of absolute density in kilograms per cubic metre at 15 °C to weight in short tons *in vacuo* of 1000 L is accomplished with Equation (B.6), changing from kilograms per cubic metre to short tons per 1000 L by calculating f as follows:

$$f = \frac{1\ \text{kg}}{1\ \text{m}^3} = \frac{1000\ \text{g}/453.59237\ \text{g/lb}}{1000\ \text{L} \times 2000\ \text{lb/ST}} = 0.001102311311\ \text{ST/1000 L}$$

Conversion of absolute density in kilograms per cubic metre at 15 °C to weight in short tons *in air* of 1000 L is accomplished with Equation (B.7), using f as calculated above.

B.13 Short Tons per 1000 U.S. Gallons at 60 °F Equivalent to Absolute Density at 15 °C

Conversion of absolute density at 15 °C to the weight in short tons *in vacuo* of 1000 gal at 60 °F is accomplished with Equation (B.8), changing from kilograms per cubic metre to short tons per 1000 gal by calculating f as follows:

$$f = \frac{1\ \text{kg}}{1\ \text{m}^3} = \frac{1000\ \text{g}/453.59237\ \text{g/lb}}{[1000\ \text{L}/(231\ \text{in.}^3/\text{gal} \times 0.016387064\ \text{L/in.}^3)] \times 2000\ \text{lb/ST}} = 0.004172702226\ \text{ST/1000 gal}$$

Conversion of absolute density in kilograms per cubic metre at 15 °C to the weight in short tons *in air* of 1000 gal at 60 °F is accomplished using Equation (B.9) with f as calculated above.

B.14 U.S. Gallons per Short Ton at 60 °F Equivalent to Absolute Density at 15 °C

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of U.S. gallons at 60 °F occupied by 1 ST *in vacuo* is given by the reciprocal of Equation (B.8) with f determined as in Section B.13 and multiplied by 1000.

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of U.S. gallons at 60 °F occupied by 1 ST *in air* is given by the reciprocal of Equation (B.9) with f determined as in Section B.13 and multiplied by 1000.

B.15 Short Tons per Barrel at 60 °F Equivalent to Absolute Density at 15 °C

Conversion of absolute density at 15 °C to the weight in short tons *in vacuo* of 1 barrel at 60 °F is accomplished with Equation (B.8), changing from kilograms per cubic metre to short tons per barrel by calculating f as follows:

$$f = \frac{1\ \text{kg}}{1\ \text{m}^3} = \frac{(1000\ \text{g}/453.59237\ \text{g/lb}) \times 42\ \text{gal/bbl}}{[1000\ \text{L}/(231\ \text{in.}^3/\text{gal} \times 0.016387064\ \text{L/in.}^3)] \times 2000\ \text{lb/ST}} = 0.0001752534935\ \text{ST/bbl}$$

Conversion of absolute density in kilograms per cubic metre at 15 °C to the weight in short tons *in air* of 1 bbl is accomplished using Equation (B.9) with f as calculated above.

B.16 Barrels per Short Ton at 60 °F Equivalent to Absolute Density at 15 °C

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of barrels at 60 °F occupied by 1 ST *in vacuo* is given by the reciprocal of Equation (B.8) with f determined as in Section B.15.

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of barrels at 60 °F occupied by 1 ST *in air* is given by the reciprocal of Equation (B.9) with f determined as in Section B.15.

B.17 Long Tons per 1000 Litres (Cubic Metre) at 15 °C Equivalent to Absolute Density at 15 °C

Conversion of absolute density at 15 °C to weight in long tons *in vacuo* of 1000 L at 15 °C is accomplished with Equation (B.6), changing kilograms per cubic metre to long tons per 1000 L by calculating f as follows:

$$f = \frac{1\ \text{kg}}{1\ \text{m}^3} = \frac{(1000\ \text{g}/453.59237\ \text{g/lb}) \times 42\ \text{gal/bbl}}{1000\ \text{L} \times 2240\ \text{lb/ST}} = 0.0009842065276\ \text{LT/1000 L}$$

Conversion of absolute density in kilograms per cubic metre at 15 °C to the weight in long tons *in air* of 1000 L at 15 °C is accomplished using Equation (B.7) with f as calculated above.

B.18 U.S. Gallons at 60 °F per Metric Ton Equivalent to Absolute Density at 15 °C

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of U.S. gallons at 60 °F occupied by 1 MT *in vacuo* is given by the reciprocal of Equation (B.8), changing kilograms per cubic metre to metric tons per gallon by calculating f as follows:

$$f = \frac{1\ \text{kg}}{1\ \text{m}^3} = \frac{0.001\ \text{MT}}{1000\ \text{L}/(231\ \text{in.}^3/\text{gal} \times 0.016387064\ \text{L/in.}^3)} = 0.000003785411784\ \text{MT/gal}$$

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of U.S. gallons at 60 °F occupied by 1 MT *in air* is given by the reciprocal of Equation (B.9) with f determined as above.

B.19 Barrels at 60 °F per Metric Ton Equivalent to Absolute Density at 15 °C

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of barrels at 60 °F occupied by 1 MT *in vacuo* is given by the reciprocal of Equation (B.8), changing kilograms per cubic metre to metric tons per barrel by calculating f as follows:

$$f = \frac{1\ \text{kg}}{1\ \text{m}^3} = \frac{0.001\ \text{MT} \times 42\ \text{gal/bbl}}{1000\ \text{L}/(231\ \text{in.}^3/\text{gal} \times 0.016387064\ \text{L/in.}^3)} = 0.0001589872949\ \text{MT/gal}$$

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of barrels at 60 °F occupied by 1 MT *in air* is given by the reciprocal of Equation (B.9) with f determined as above.

B.20 Long Tons per 1000 U.S. Gallons at 60 °F Equivalent to Absolute Density at 15 °C

Conversion of absolute density at 15 °C to the weight in long tons *in vacuo* of 1000 U.S. gallons at 60 °F is accomplished with Equation (B.8), changing from kilograms per cubic metre to long tons per 1000 gal by calculating f as follows:

$$f = \frac{1\ \text{kg}}{1\ \text{m}^3} = \frac{1000\ \text{g}/453.59237\ \text{g/lb}}{[1000\ \text{L}/(231\ \text{in.}^3/\text{gal} \times 0.016387064\ \text{L/in.}^3)] \times 2240\ \text{lb/LT}} = 0.003725626988\ \text{LT/1000 gal}$$

Conversion of absolute density in kilograms per cubic metre at 15 °C to the weight in long tons *in air* of 1000 gal at 60 °F is accomplished using Equation (B.9) with f as calculated above.

B.21 U.S. Gallons at 60 °F per Long Ton Equivalent to Absolute Density at 15 °C

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of U.S. gallons at 60 °F occupied by 1 LT *in vacuo* is given by the reciprocal of Equation (B.8), with f determined as in Section B.20 and multiplied by 1000.

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of U.S. gallons at 60 °F occupied by 1 LT *in air* is given by the reciprocal of Equation (B.9) with f determined as in Section B.20 and multiplied by 1000.

B.22 Long Tons per Barrel at 60 °F Equivalent to Absolute Density at 15 °C

Conversion of absolute density at 15 °C to the weight in long tons *in vacuo* of 1 bbl at 60 °F is accomplished with Equation (B.8), changing from kilograms per cubic metre to long tons per barrel by calculating f as follows:

$$f = \frac{1\ \text{kg}}{1\ \text{m}^3} = \frac{(1000\ \text{g}/453.59237\ \text{g/lb}) \times 42\ \text{gal/bbl}}{[1000\ \text{L}/(231\ \text{in.}^3/\text{gal} \times 0.016387064\ \text{L/in.}^3)] \times 2240\ \text{lb/LT}} = 0.0001564763335\ \text{LT/bbl}$$

Conversion of absolute density in kilograms per cubic metre at 15 °C to the weight in long tons *in air* of 1 bbl at 60 °F is accomplished using Equation (B.9) with f as calculated above.

B.23 Barrels per Long Ton at 60 °F Equivalent to Absolute Density at 15 °C

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of barrels at 60 °F occupied by 1 LT *in vacuo* is given by the reciprocal of Equation (B.8), with f determined as in Section B.22.

The relationship between absolute density in kilograms per cubic metre at 15 °C and the volume of barrels at 60 °F occupied by 1 LT *in air* is given by the reciprocal of Equation (B.9) with f determined as in Section B.22.

B.24 Litres at 15 °C to Gallons at 60 °F Equivalent to Absolute Density at 15 °C

Conversion of litres at 15 °C to U.S. gallons at 60 °F is accomplished by dividing by the liquid's VCF at 15.5556 °C [obtained from the product's VCF table (crude oils, generalized products, and lubricants will use API *MPMS* Ch. 11.1-2004; other products may use different tables) to obtain litres at 60 °F, which may then be converted to U.S. gallons.

$$\text{gal}_{60\ °\text{F}} = \frac{\text{L}_{15\ °\text{C}}}{231\ \text{in.}^3/\text{gal} \times 0.016387064\ \text{L/in.}^3 \times \text{VCF}_{15.5556}} = \frac{\text{L}_{15\ °\text{C}}}{3.785411784 \times \text{VCF}_{15.5556}}$$

B.25 Cubic Metres at 15 °C to Barrels at 60 °F Equivalent to Absolute Density at 15 °C

Conversion of cubic metres at 15 °C to barrels at 60 °F is accomplished by dividing by the liquid's VCF at 15.5556 °C obtained from the product's VCF table (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 60 °F, multiplying by 1000 to obtain litres, converting litres to U.S. gallons, and finally dividing by 42 to convert to barrels.

$$\text{bbl}_{60\ °\text{F}} = \frac{\text{m}^3{}_{15\ °\text{C}} \times 1000\ \text{L/m}^3}{\text{VCF}_{15.5556} \times 231\ \text{in.}^3/\text{gal} \times 0.016387064\ \text{L/in.}^3 \times 42\ \text{gal/bbl}} = \frac{\text{m}^3{}_{15\ °\text{C}}}{0.1589872949 \times \text{VCF}_{15.5556}}$$

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 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 and Celsius temperature scales:

$$°F = 1.8\ °C + 32 \quad \text{(a)}$$

and

$$°C = (°F - 32)/1.8 \quad \text{(b)}$$

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.

°F		°C
64.4	18	–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):

$$°F = (1.8 \times 18.6) + 32 = 65.5$$

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

$$°C = (18.6 - 32)/1.8 = -7.4:$$

°F		°C	°F		°C	°F		°C	°F		°C	°F		°C	°F		°C	°F		°C	°F		°C	°F		°C
-58.0	-50	-45.6	32.0	0	-17.8	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
-56.2	-49	-45.0	33.8	1	-17.2	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
-54.4	-48	-44.4	35.6	2	-16.7	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
-52.6	-47	-43.9	37.4	3	-16.1	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
-50.8	-46	-43.3	39.2	4	-15.6	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
-49.0	-45	-42.8	41.0	5	-15.0	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
-47.2	-44	-42.2	42.8	6	-14.4	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
-45.4	-43	-41.7	44.6	7	-13.9	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
-43.6	-42	-41.1	46.4	8	-13.3	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
-41.8	-41	-40.6	48.2	9	-12.8	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
-40.0	-40	-40.0	50.0	10	-12.2	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
-38.2	-39	-39.4	51.8	11	-11.7	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
-36.4	-38	-38.9	53.6	12	-11.1	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
-34.6	-37	-38.3	55.4	13	-10.6	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
-32.8	-36	-37.8	57.2	14	-10.0	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
-31.0	-35	-37.2	59.0	15	-9.4	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
-29.2	-34	-36.7	60.8	16	-8.9	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
-27.4	-33	-36.1	62.6	17	-8.3	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
-25.6	-32	-35.6	64.4	18	-7.8	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
-23.8	-31	-35.0	66.2	19	-7.2	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
-22.0	-30	-34.4	68.0	20	-6.7	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
-20.2	-29	-33.9	69.8	21	-6.1	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
-18.4	-28	-33.3	71.6	22	-5.6	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
-16.6	-27	-32.8	73.4	23	-5.0	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
-14.8	-26	-32.2	75.2	24	-4.4	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
-13.0	-25	-31.7	77.0	25	-3.9	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
-11.2	-24	-31.1	78.8	26	-3.3	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
-9.4	-23	-30.6	80.6	27	-2.8	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
-7.6	-22	-30.0	82.4	28	-2.2	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
-5.8	-21	-29.4	84.2	29	-1.7	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
-4.0	-20	-28.9	86.0	30	-1.1	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
-2.2	-19	-28.3	87.8	31	-0.6	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
-0.4	-18	-27.8	89.6	32	0.0	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
1.4	-17	-27.2	91.4	33	0.6	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
3.2	-16	-26.7	93.2	34	1.1	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
5.0	-15	-26.1	95.0	35	1.7	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
6.8	-14	-25.6	96.8	36	2.2	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
8.6	-13	-25.0	98.6	37	2.8	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
10.4	-12	-24.4	100.4	38	3.3	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
12.2	-11	-23.9	102.2	39	3.9	192.2	89	31.7	282.2	139	59.4	372.2	189	87.2	462.2	239	115.0	552.2	289	142.8	642.2	339	170.6	732.2	389	198.3
14.0	-10	-23.3	104.0	40	4.4	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
15.8	-9	-22.8	105.8	41	5.0	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
17.6	-8	-22.2	107.6	42	5.6	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
19.4	-7	-21.7	109.4	43	6.1	199.4	93	33.9	289.4	143	61.7	379.4	193	89.4	469.4	243	117.2	559.4	293	145.0	649.4	343	172.8	739.4	393	200.6
21.2	-6	-21.1	111.2	44	6.7	201.2	94	34.4	291.2	144	62.2	381.2	194	90.0	471.2	244	117.8	561.2	294	145.6	651.2	344	173.3	741.2	394	201.1
23.0	-5	-20.6	113.0	45	7.2	203.0	95	35.0	293.0	145	62.8	383.0	195	90.6	473.0	245	118.3	563.0	295	146.1	653.0	345	173.9	743.0	395	201.7
24.8	-4	-20.0	114.8	46	7.8	204.8	96	35.6	294.8	146	63.3	384.8	196	91.1	474.8	246	118.9	564.8	296	146.7	654.8	346	174.4	744.8	396	202.2
26.6	-3	-19.4	116.6	47	8.3	206.6	97	36.1	296.6	147	63.9	386.6	197	91.7	476.6	247	119.4	566.6	297	147.2	656.6	347	175.0	746.6	397	202.8
28.4	-2	-18.9	118.4	48	8.9	208.4	98	36.7	298.4	148	64.4	388.4	198	92.2	478.4	248	120.0	568.4	298	147.8	658.4	348	175.6	748.4	398	203.3
30.2	-1	-18.3	120.2	49	9.4	210.2	99	37.2	300.2	149	65.0	390.2	199	92.8	480.2	249	120.6	570.2	299	148.3	660.2	349	176.1	750.2	399	203.9
32.0	0	-17.8	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	752.0	400	204.4

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