Designation: E617 – 13

Standard Specification for Laboratory Weights and Precision Mass Standards[1]

This standard is issued under the fixed designation E617; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers weights and mass standards used in laboratories, specifically classes 000, 00, 0, 1, 2, 3, 4, 5, 6 and 7. This specification replaces National Bureau of Standards Circular 547, Section 1, which is out of print.

1.2 This specification contains the principal physical characteristics and metrological requirements for weights that are used.

1.2.1 For the verification of weighing instruments;

1.2.2 For the calibration of weights of a lower class of accuracy; and

1.2.3 With weighing instruments.

1.3 Maximum Permissible Errors (formerly tolerances) and design restrictions for each class are described in order that both individual weights or sets of weights can be chosen for appropriate applications.

1.4 The values stated in SI units are to be regarded as standard.

1.5 Weight manufacturers must be able to provide evidence that all new weights comply with specifications in this standard (e.g., material, density, magnetism, surface finish, mass values, uncertainties). Statements of compliance by calibration laboratories during subsequent calibrations must meet the requirements of ISO/IEC 17025, 5.10.4.2 and indicate on the calibration report which sections have or have not been assessed.

2. Referenced Documents

2.1 *ISO Standards:*[2]

ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories (2005)

2.2 *NIST Standards:*[3]

NIST Handbook 143 State Weights and Measures Laboratories Program Handbook (2007)

NIST SP 811 Guide for the Use of the International System of Unit (SI) 2008 Edition

NIST SP 1038 The International System of Units (SI) – Conversion Factors for General Use (May 2006)

NISTIR 5672 Advanced Mass Calibration and Measurement Assurance Program for State Calibration Laboratories (2012)

NISTIR 6969 Selected Laboratory and Measurement Practices to Support Basic Mass Calibrations (2012)

NIST Technical Note 1297 (1994) Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results

2.3 *OIML Standards:*[4]

OIML D 28 Conventional Value of the Result of Weighing in Air (2004)

OIML R111–1e04 Weights of classes E1, E2, F1, F2, M1, M1–2, M2, M2–3 and M3 Part 1: Metrological and Technical Requirements (2004)

2.4 *BIPM Standards:*

VIM: JCGM 200:2012 International Vocabulary of Metrology–Basic and General Concepts and Associated Terms

GUM: JCGM 100:2008 Evaluation of Measurement Data–Guide to the Expression of Uncertainty in Measurement

2.5 *EURAMET Standards:*

EURAMET/cg-18/V. 3.0 Guidelines on the Calibration of Non-Automatic Weighing Intruments (2011)

2.6 *Additional Reference Documents:*

CIPM-2007 Revised Formula for the Density of Moist Air, A. Picard, R. S. Davis, M. Glaser, and K. Fujii

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *accuracy class of weights*—a class of weights that meets certain metrological requirements intended to keep the errors within specified limits.

3.1.2 *balance*—instument indicating apparent mass that is sensitive to the following forces:

[1] This specification is under the jurisdiction of ASTM Committee E41 on Laboratory Apparatusand is the direct responsibility of Subcommittee E41.06 on Weighing Devices.

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[2] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.

[3] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

[4] Available from Organisation Internationale de Metrologie Legale, 11 Rue Turgot, 75009 Paris, France.

$F_g = m \cdot g$	Force due to gravity
$F_b = v \cdot \rho_a \cdot g = \frac{m}{\rho} \rho_a \cdot g$	Air buoyancy equal to the weight of the displaced air.
$F_z = \mu_o \int\int_v\int (M + \chi H) \frac{\partial H}{\partial z} dV$	Vertical component of the magnetic interaction between the weight and the balance or the environment, or both.

H and *M* are vectors; *z* is the vertical cartesian coordinate. If magnetic effects are negligible, i.e. the permanent magnetization (*M*) of the weight and the magnetic susceptibility (χ) are sufficiently small, and the balance is calibrated with reference weights of well-known mass, the balance can be used to indicate the conventional mass, m_c, of a body under conventionally chosen conditions.

3.1.3 *calibration (of weights)*—the acts of determining the mass difference between a standard of known mass value and an "unknown" test weight or set of weights, establishing the mass value and conventional mass value of the "unknown," and of determining a quantitative estimate of the uncertainty to be assigned to the stated mass or conventional mass value of the "unknown," or both, and providing metrological traceability to the "unknown."

3.1.3.1 *calibration (generally)*—set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards.

3.1.4 *calibration certificate*—certificate issued by calibration laboratories to document the results of a calibration.

3.1.5 *conventional mass*—conventional value of the result of weighing in air, in accordance to International Recommendation OIML D 28. For a weight taken at 20°C, the conventional mass is the mass of a reference weight of a density of 8000 kg/m^3 which it balances in air of density of 1.2 kg/m^3.

3.1.6 *correction*—mass values are traditionally expressed by two numbers, one being the nominal mass of the weight, and the second being a correction. The mass of the weight is the assigned nominal value plus the assigned correction. Positive corrections indicate that the weight embodies more mass than is indicated by the assigned nominal value. Negative corrections indicate that the weight embodies less mass than is indicated by the assigned nominal value. The correction is equivalent to the "error."

3.1.7 *international prototype kilogram*—the platinum-iridium cylinder maintained at the International Bureau of Weights and Measures (BIPM), at Sevres, France with an internationally accepted defined mass of 1 kg.

3.1.8 *magnetism*—effect that generates an attractive or repulsive force.

3.1.8.1 *(volume) magnetic susceptibility (χ)*—measure of the ability of a medium to modify a magnetic field. It is related to the magnetic permeability (μ) by the relation: $\mu/\mu_0 = 1 + \chi$. The quantity μ/μ_0 is sometimes referred to as the relative permeability, μ_r.

3.1.8.2 *(permanent) magnetization (M)*—parameter that specifies a magnetic state of material bodies such as weights, in the absense of an external magnetic field (most generally, magnetization is a vecotr whose magnitude and direction are not necessarily constant within the material). The magnetization of a body generates an inhomogeneous magnetic field in space and thus may produce magnetic forces on other materials.

3.1.9 *mass*—physical quantity, which can be ascribed to any material object and which gives a measure of its quantity of matter. The unit of mass is the kilogram.

3.1.10 *maximum permissible errors*—the maximum amount by which the sum of the conventional mass of the weight, its deviation from nominal value and its associated uncertainty is allowed to deviate from the assigned nominal value.

3.1.11 *metrological traceability*—property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty. Metrological traceability requires an established calibration hierarchy. Elements for confirming metrological traceability to be an unbroken chain to an international measurement standard or a national measurement standard (IPK or NPS), shall include a documented measurement uncertainty, a documented measurement procedure, accredited technical competence, metrological traceability to the SI, and established calibration intervals (see current VIM: JCGM 200).

3.1.12 *reference standard*—a standard, generally of the highest metrological quality available at a given location, from which measurements made at that location are derived.

3.1.13 *roughness parameter or R-parameter (R_a or R_z)*—parameter that describes the assessed roughness profile of a sample. The letter R is indicative of the type of assessed profile, in this case R for roughness profile. The assessed profile of a sample can be in terms of different profile types: a roughness profile or R-parameter, primary profile or P-parameter, a waviness profile or W-parameter.

3.1.14 *set of weights*—a series of weights, usually presented in a case so arranged to make possible any weighing of all loads between the mass of the weight with the smallest nominal value and the sum of the masses of all weights of the series with a progression in which the mass of the smallest nominal value weight constitutes the smallest step of the series.

3.1.15 *temperature (t)*—in degrees Celsius, is related to the absolute thermodynamic temperature scale, called the Kelvin scale, by $t = T - 273.15$ K.

3.1.16 *test weight (m_t)*—weight that is to be tested according to this standard.

3.1.17 *tolerance test*—verification that the conventional mass of the weights and their corresponding uncertainties as tested are correct within the maximum permissible errors of the respective weight class.

3.1.18 *uncertainty*—non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used.

3.1.19 *units*—the units used are: *(1)* for mass, the milligram (mg), the gram (g) and the kilogram (kg); *(2)* for density, the kilogram per cubic meter (kg m^{-3}).

3.1.20 *U.S. National prototype standard*—platinum-iridium kilogram identified as K20, maintained at the National Institute of Standards and Technology, with value assigned relative to the International Prototype Kilogram provides the United States access to the mass unit.

3.1.21 *weight*—material measure of mass, regulated in regard to its physical and metrological characteristics: shape, dimensions, material, surface quality, nominal value, density, magnetic properties and maximum permissible error.

NOTE 1—The term "weight" is also used as the physical quantity of the gravitational force of a body. From the context it is usually clear in which sense the term is used. If the sense is not clear, one may use the words "weight force" or "weight piece," depending on its meaning.

3.2 *Symbols:*

Symbol	Unit	Definition
A	–	represents weighing the reference weight in a weighing cycle
B	–	represents weighing the test weight in a weighing cycle
C	–	correction factor for air buoyancy
D	kg	difference of balance readings between minimum and maximum values from eccentricity test
d	kg	scale interval
d_1	m	estimated distance between centers of weights during loading
d_2	m	estimated distance from the center of the load receptor to one of the corners
F_b	N	air buoyancy equal to the weight of the displaced air
F_g	N	gravitational force
F_z	N	magnetic force between a mass comparator and a weight in the vertical or z-direction
g	m s^{-2}	gravitational acceleration
H	A m^{-1}	magnetizing field strength
hr	%	relative humidity
I	kg	indication of the weighing instruments (scale division)
ΔI	kg	indication difference of the balance, where $\Delta I = I_t - I_r$
ΔI_1	kg	indication difference using an automatic exchange mechanism with weights in first position
ΔI_2	kg	indication difference using an automatic exchange mechanism with weights in reversed position
ΔI_s	kg	change in indication of balance due to sensitivity weight
i	–	subscript used as an index in summations
j	–	subscript for number of test weights or number of series of measurements
k	–	coverage factor, typically 2 or 3
M	A m^{-1}	permanent magnetization (see also $\mu_0 M$)
m	kg	mass of a rigid body (weight)
Δm	kg	mass difference, usually between test and reference weight
δm	kg	maximum permissible error on the weights
m_0	kg	mass, nominal value of the weight (e.g. 1 kg)
m_c	kg	conventional mass of the weight
Δm_c	kg	conventional mass difference between test weight and reference weight
$\Delta \overline{m_c}$	kg	average conventional mass difference between test weight and reference weight
m_{cr}	kg	conventional mass of the reference weight
m_{ct}	kg	conventional mass of the test weight
m_s	kg	mass of the sensitivity weight
m_t	kg	mass of the test weight
n	–	subscript for number of measurement sequences
p	Pa	barometric pressure
R_a	µm	mean height of roughness profile (R-parameter)
R_z	µm	maximum height of roughness profile (R-parameter)
r	–	subscript for reference weight
s	–	subscript for sensitivity weight
s	kg	standard deviation
s^2	kg^2	variance
T	K	thermodynamic temperature using the International Temperature Scale of 1990 (ITS-90)
ΔT^*	°C	initial difference between weight temperature and laboratory temperature
t	–	subscript for test weight
t	°C	temperature in degrees Celsius, where $t = T - 273.15$ K
U	kg	uncertainty, expanded uncertainty
u	kg	uncertainty, standard uncertainty
u_b	kg	uncertainty of air buoyancy correction
u_{ba}	kg	uncertainty of the balance
u_c	kg	combined standard uncertainty
u_d	kg	uncertainty due to the display resolution of a digital balance
u_E	kg	uncertainty due to eccentricity
u_F	kg m^{-3}	uncertainty of the formula used to calculate air density
u_{hr}	%	uncertainty in relative humidity
u_{inst}	kg	uncertainty due to instability of the reference weight
u_{ma}	kg	uncertainty due to magnetism
u_p	Pa	uncertainty in barometric pressure
u_s	kg	uncertainty due to the sensitivity of the balance
u_t	°C	uncertainty in temperature
u_w	kg	uncertainty due to the weighing process
V	m^3	volume of a solid body (weight)
z	m	vertical cartesian coordinate
μ	N A^{-2}	magnetic permeability
μ_0	N A^{-2}	magnetic constant (magnetic permeability of vacuum), $\mu_0 = 4\pi \times 10^{-7}$ N A^{-2}
$\mu_0 M$	T	magnetic polarization
μ_r	–	relative magnetic permeability (μ/μ_0)
v_{eff}	–	effective degrees of freedom
ρ	kg m^{-3}	mass of a rigid body (weight)
ρ_0	kg m^{-3}	density of air as a reference value equal to 1.2 kg m^{-3}
ρ_a	kg m^{-3}	density of moist air
ρ_{al}	kg m^{-3}	density of moist air during the last (previous) calibration of the reference weight
ρ_r	kg m^{-3}	density of a reference weight with mass m_r
ρ_t	kg m^{-3}	density of the weight being tested
χ	–	magnetic susceptibility

4. Maximum Permissible Errors

4.1 For each weight, the expanded uncertainty U at approximately 95 % confidence (See Section 9) of the conventional mass shall be less than or equal to one-third of the maximum permissible error given in Table 1 as defined in Section 9.

TABLE 1 Maximum Permissible Errors

NOTE 1—Maximum Permissible Errors are reported in SI units, typically milligrams.

NOTE 2—The "grain" is the same in avoirdupois, troy and apothecaries units of mass.

NOTE 3—See NIST SP 811 and NIST SP 1038 for conversion and units of measure.

Denomination Metric	±mg except as noted									
	Class 000	Class 00	Class 0	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
5000 kg					25 g	50 g	100 g	250 g	500 g	750 g
3000 kg					15 g	30 g	60 g	150 g	300 g	450 g
2000 kg					10 g	20 g	40 g	100 g	200 g	300 g
1000 kg					5 g	10 g	20 g	50 g	100 g	150 g
500 kg					2.5 g	5 g	10 g	25 g	50 g	75 g
300 kg					1.5 g	3 g	6.0 g	15 g	30 g	45 g
200 kg					1 g	2 g	4.0 g	10 g	20 g	30 g
100 kg					500 mg	1 g	2.0 g	5 g	10 g	15 g
50 kg	13 mg	25 mg	63 mg	125 mg	250	500 mg	1.0 g	2.5 g	5 g	7.5 g
30 kg	7.5	15	38	75	150	300	600 mg	1.5 g	3 g	4.5 g
25 kg	6.25	12.5	31	62	125	250	500	1.2 g	2.5 g	4.5 g
20 kg	5.0	10	25	50	100	200	400	1.0 g	2 g	3.8 g
10 kg	2.5	5.0	13	25	50	100	200	500 mg	1 g	2.2 g
5 kg	1.3	2.5	6.0	12	25	50	100	250	500 mg	1.4 g
3 kg	0.75	1.5	3.8	7.5	15	30	60	150	300	1.0 g
2 kg	0.5	1.0	2.5	5.0	10	20	40	100	200	750 mg
1 kg	0.25	0.5	1.3	2.5	5.0	10	20	50	100	470
500 g	0.13	0.25	0.60	1.2	2.5	5.0	10	30	50	300
300 g	0.075	0.15	0.38	0.75	1.5	3.0	6.0	20	30	210
200 g	0.05	0.10	0.25	0.50	1.0	2.0	4.0	15	20	160
100 g	0.025	0.05	0.13	0.25	0.50	1.0	2.0	9	10	100
50 g	0.015	0.030	0.060	0.12	0.25	0.60	1.2	5.6	7	62
30 g	0.014	0.026	0.037	0.074	0.15	0.45	0.90	4.0	5	44
20 g	0.013	0.025	0.037	0.074	0.10	0.35	0.70	3.0	3	33
10 g	0.010	0.020	0.025	0.050	0.074	0.25	0.50	2.0	2	21
5 g	0.005	0.010	0.017	0.034	0.054	0.18	0.36	1.3	2	13
3 g	0.005	0.010	0.017	0.034	0.054	0.15	0.30	0.95	2.0	9.4
2 g	0.005	0.010	0.017	0.034	0.054	0.13	0.26	0.75	2.0	7.0
1 g	0.005	0.010	0.017	0.034	0.054	0.10	0.20	0.50	2.0	4.5
500 mg	0.002	0.003	0.005	0.010	0.025	0.080	0.16	0.38	1.0	3.0
300 mg	0.002	0.003	0.005	0.010	0.025	0.070	0.14	0.30	1.0	2.2
200 mg	0.002	0.003	0.005	0.010	0.025	0.060	0.12	0.26	1.0	1.8
100 mg	0.002	0.003	0.005	0.010	0.025	0.050	0.10	0.20	1.0	1.2
50 mg	0.002	0.003	0.005	0.010	0.014	0.042	0.085	0.16	0.50	0.88
30 mg	0.002	0.003	0.005	0.010	0.014	0.038	0.075	0.14	0.50	0.68
20 mg	0.002	0.003	0.005	0.010	0.014	0.035	0.070	0.12	0.50	0.56
10 mg	0.002	0.003	0.005	0.010	0.014	0.030	0.060	0.10	0.50	0.40
5 mg	0.002	0.003	0.005	0.010	0.014	0.028	0.055	0.080	0.20	
3 mg	0.002	0.003	0.005	0.010	0.014	0.026	0.052	0.070	0.20	
2 mg	0.002	0.003	0.005	0.010	0.014	0.025	0.050	0.060	0.20	
1 mg	0.002	0.003	0.005	0.010	0.014	0.025	0.050	0.050	0.10	
0.5 mg	0.002	0.003	0.005	0.010	0.014	0.025	0.050	0.050	0.10	
0.3 mg	0.002	0.003	0.005	0.010	0.014	0.025				
0.2 mg	0.002	0.003	0.005	0.010	0.014					
0.1 mg	0.002	0.003	0.005	0.010						
0.05 mg	0.002	0.003	0.005							
Avoirdupois Pound			Class 0 mg	Class 1 mg	Class 2 g & mg	Class 3 g & mg	Class 4 g & mg	Class 5 g & mg	Class 6 g & mg	Class 7 g & mg
10000 lb					23 g	45 g	90 g	227 g	454 g	680 g
5000 lb					11 g	22 g	44 g	113 g	227 g	340 g
3000 lb					7 g	14 g	28 g	68 g	136 g	204 g
2500 lb					6 g	12 g	24 g	57 g	113 g	170 g
2000 lb					4.5 g	9 g	18 g	45 g	91 g	136 g
1000 lb					2.3 g	4.5 g	9 g	23 g	45 g	68 g
500 lb					1.7 g	2.3 g	4.6 g	11 g	23 g	34 g
100 lb			57 mg	110 mg	230 mg	460 mg	920 mg	2.3 g	4.5 g	6.8 g
50 lb			29	57	110	220	440	1.1 g	2.3 g	4.1 g
30 lb			17	34	68	140	260	680 mg	1.4 g	3 g
25 lb			14	28	56	110	220	570	1.1 g	2.5 g
20 lb			12	23	46	92	180	450	910 mg	2 g
10 lb			5.5	11	22	44	88	230	450	1.3 g
5 lb			2.7	5.4	11	22	43	110	230	760 mg
3 lb			1.7	3.4	6.8	14	27	68	140	510
2 lb			1.2	2.3	4.6	9.2	18	45	91	430
1 lb			0.55	1.1	2.2	4.4	8.8	27	45	270
0.5 lb			0.27	0.54	1.1	2.2	4.3	15	23	160
0.3 lb			0.17	0.34	0.68	1.4	2.7	10	14	110
0.2 lb			0.12	0.23	0.46	0.92	1.8	8.1	9.7	91

TABLE 1 *Continued*

Denomination Metric	±mg except as noted									
	Class 000	Class 00	Class 0	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
0.1 lb			0.055	0.11	0.22	0.44	1.1	5.1	6.8	56
0.05 lb			0.027	0.054	0.11	0.36	0.77	3.0	4.5	33
0.03 lb			0.017	0.034	0.068	0.32	0.59	2.0	3.2	22
0.02 lb			0.017	0.034	0.046	0.23	0.45	1.8	2.3	19
0.01 lb			0.012	0.023	0.034	0.16	0.34	1.2	1.4	12
0.005 lb			0.0075	0.015	0.024	0.14	0.27	0.86	0.91	7
0.003 lb			0.0075	0.015	0.024	0.11	0.22	0.64	0.91	5
0.002 lb			0.0075	0.015	0.024	0.091	0.19	0.50	0.91	4
0.001 lb			0.0075	0.015	0.024	0.068	0.15	0.36	0.91	3
0.0005 lb			0.009	0.023	0.07	0.15	0.3	0.9	3	
0.0003 lb			0.009	0.023	0.07	0.15	0.3	0.9	3	
0.0002 lb			0.009	0.023	0.07	0.15	0.3	0.9	3	
0.0001 lb			0.009	0.023	0.07	0.15	0.3	0.9	3	
0.00005 lb			0.009	0.023	0.07	0.15	0.3	0.9	3	
0.00003 lb			0.009	0.023	0.07	0.15	0.3	0.9	3	
0.00002 lb			0.009	0.023	0.07	0.15	0.3	0.9	3	
0.00001 lb			0.009	0.023	0.07	0.15	0.3	0.9	3	
Avoirdupois Ounce			Class 0 mg	Class 1 mg	Class 2 mg	Class 3 mg	Class 4 mg	Class 5 mg	Class 6 mg	Class 7 mg
10 oz			0.4	0.7	1.4	2.8	5.4	19	45	320
8 oz			0.3	0.6	1.2	2.3	4.5	16	23	180
5 oz			0.18	0.35	0.70	1.4	2.8	12	16	160
4 oz			0.14	0.28	0.55	1.1	2.3	9.5	11	110
3 oz			0.12	0.23	0.45	0.91	1.8	8.2	8.1	73
2 oz			0.07	0.13	0.26	0.64	1.3	5.9	5.4	48
1 oz			0.04	0.07	0.14	0.42	0.86	3.9	3.2	28
1/2 oz			0.02	0.04	0.08	0.3	0.59	2.5	2.3	25
1/4 oz			0.015	0.03	0.06	0.2	0.43	1.5	1.4	9.1
1/8 oz			0.015	0.029	0.058	0.16	0.31	1.1	0.91	4.3
1/16 oz			0.013	0.025	0.050	0.12	0.24	0.73	0.91	4.3
1/32 oz			0.008	0.015	0.030	0.095	0.19	0.5	0.91	4.3
1/64 oz			0.006	0.012	0.024	0.077	0.15	0.36	0.91	4.3
0.50 oz					0.080	0.3	0.59	2.5	2.3	25
0.3 oz					0.068	0.23	0.45	1.8	1.4	9.1
0.2 oz					0.057	0.19	0.38	1.4	0.91	5.9
0.1 oz					0.050	0.14	0.29	0.91	0.91	4.3
0.05 oz					0.050	0.11	0.23	0.64	0.91	2.0
0.03 oz					0.030	0.095	0.19	0.45	0.91	2.0
0.02 oz					0.023	0.077	0.18	0.4	0.91	2.0
0.01 oz					0.023	0.064	0.14	0.3	0.91	2.0
0.005 oz					0.023	0.054	0.11	0.23	**	**
0.003 oz					0.023	0.05	0.095	0.19	**	**
0.002 oz					0.023	0.044	0.086	0.16	**	**
0.001 oz					0.023	0.038	0.077	0.13	**	**
0.0005 oz					0.023	0.031	0.064	0.11	**	**
0.0003 oz					0.023	0.029	0.059	0.095	**	**
0.0002 oz					0.023	0.027	0.054	0.086	**	**
0.0001 oz					0.023	0.026	0.05	0.073	**	**
Troy Ounce			Class 0	Class 1	Class 2 mg	Class 3 mg	Class 4 mg	Class 5 g & mg	Class 6 g & mg	Class 7
1000 oz t					160 mg	310 mg	620 mg	1.6 g	3.2 g	
500 oz t					80	160	310	770 mg	1.5 g	
300 oz t					45	90	190	470	940 mg	
200 oz t					31	62	120	310	620	
100 oz t					16	31	62	160	320	
50 oz t					8	16	31	77	150	
30 oz t					4.6	9.1	19	47	94	
20 oz t					3.1	6.2	12	35	58	
10 oz t					1.6	3.1	6.2	21	32	
5 oz t					0.8	1.6	3.1	12	16	
3 oz t					0.46	0.91	1.9	8.4	9.3	
2 oz t						0.71	1.4	6.4	8.0	
1 oz t						0.45	0.91	4.2	4.2	
0.5 oz t						0.31	0.62	2.6	2.6	
0.3 oz t						0.24	0.49	1.9	1.9	
0.2 oz t						0.20	0.40	1.5	2.3	
0.1 oz t						0.15	0.30	0.97	2.0	
0.05 oz t						0.12	0.23	0.65	2.0	
0.03 oz t						0.097	0.19	0.49	2.0	
0.02 oz t						0.084	0.17	0.41	1.1	
0.01 oz t						0.071	0.14	0.31	1.0	
0.005 oz t						0.056	0.11	0.23	1.0	
0.003 oz t						0.049	0.097	0.19	1.0	
0.002 oz t						0.044	0.091	0.17	0.50	

TABLE 1 *Continued*

Denomination Metric	±mg except as noted									
	Class 000	Class 00	Class 0	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
0.001 oz t						0.038	0.078	0.14	0.50	
0.0005 oz t						0.033	0.065	0.11	0.50	
0.0003 oz t						0.030	0.060	0.097	0.50	
0.0002 oz t						0.028	0.056	0.084	0.50	
0.0001 oz t						0.026	0.052	0.071	0.50	
Pennyweight			Class 0	Class 1	Class 2	Class 3	Class 4 g & mg	Class 5 g & mg	Class 6 g & mg	Class 7
10000 dwt							0.31 g	0.78 g	1.5 g	
5000 dwt							0.16 g	0.39 g	0.78 g	
3000 dwt							91 mg	0.23 g	0.46 g	
2000 dwt							62	0.16 g	0.32 g	
1000 dwt							31	78 mg	0.16 g	
500 dwt							16	41	82 mg	
300 dwt							9.1	28	56	
200 dwt							6.2	21	42	
100 dwt							3.1	12	24	
50 dwt							1.6	7.8	16	
30 dwt							1.2	5.3	11	
20 dwt							0.91	4.2	8.4	
10 dwt							0.62	2.6	5.2	
5 dwt							0.44	1.7	3.4	
3 dwt							0.34	1.3	2.6	
2 dwt							0.3	0.97	1.9	
1 dwt							0.23	0.65	1.3	
Grain			Class 0	Class 1	Class 2	Class 3	Class 4 mg	Class 5 mg	Class 6 mg	Class 7
10000 gr							13	36	36	
5000 gr							6.5	22	22	
3000 gr							3.9	15	15	
2000 gr							2.6	11	11	
1000 gr							1.4	6.3	6.3	
500 gr							0.91	3.2	3.2	
300 gr							0.65	2.3	2.3	
200 gr							0.57	1.4	1.4	
100 gr							0.4	0.91	0.91	
50 gr							0.3	0.91	0.91	
30 gr							0.25	0.71	0.71	
20 gr							0.21	0.58	0.58	
10 gr							0.17	0.42	0.42	
5 gr							0.14	0.31	0.31	
3 gr							0.12	0.25	0.25	
2 gr							0.11	0.22	0.22	
1 gr							0.091	0.17	0.17	
0.5 gr							0.078	0.14	0.14	
0.3 gr							0.071	0.12	0.12	
0.2 gr							0.064	0.11	0.11	
0.1 gr							0.056	0.091	0.091	
0.05 gr							0.052	0.071	0.071	
0.03 gr							0.051	0.071	0.071	
0.02 gr							0.05	0.071	0.071	
0.01 gr							0.05	0.071	0.071	
Carat			Class 0	Class 1	Class 2	Class 3 mg	Class 4 mg	Class 5 mg	Class 6 mg	Class 7 mg
5000 c						10	20	50	100	470
3000 c						6.0	12	36	60	334
2000 c						4.0	8.0	27	44	287
1000 c						2.0	4.0	15	20	160
500 c						1.0	2.0	9	10	100
300 c						0.69	1.3	6	8	70
200 c						0.52	1.0	4.4	5	44
100 c						0.35	0.7	3	3	33
50 c						0.25	0.50	2	2	21
30 c						0.19	0.40	1.4	2	13
20 c						0.16	0.33	1	2	13
10 c						0.13	0.26	0.75	2	13
5 c						0.10	0.20	0.5	2	13
3 c						0.086	0.17	0.39	1	3
2 c						0.075	0.15	0.32	1	3
1 c						0.060	0.12	0.26	1	3
0.5 c						0.050	0.10	0.2	1	3
0.3 c						0.044	0.089	0.18	0.5	0.88
0.2 c						0.040	0.080	0.15	0.5	0.88
0.1 c						0.035	0.070	0.12	0.5	0.88
0.05 c						0.030	0.060	0.1	0.5	0.88

TABLE 1 *Continued*

Denomination Metric	±mg except as noted									
	Class 000	Class 00	Class 0	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
0.03 c						0.028	0.056	0.08	0.2	
0.02 c						0.027	0.053	0.07	0.2	
0.01 c						0.025	0.050	0.06	0.2	
Apothecary Ounce										
12 oz ap							7.5	15	45	290
10 oz ap							4.5	9	36	280
6 oz ap							3.5	7	23	184
5 oz ap							3.0	6	18	144
4 oz ap							2.5	5	16	128
3 oz ap							1.50	3	11	110
2 oz ap							1.00	2	9.1	91
1 oz ap							0.60	1.2	4.5	40
Apothecary Dram										
6 dr ap							0.40	0.8	3.6	36
5 dr ap							0.30	0.6	2.7	27
4 dr ap							0.27	0.55	2.3	23
3 dr ap							0.20	0.4	1.8	18
2 dr ap							0.20	0.4	1.8	18
1 dr ap							0.17	0.35	1.4	14
Apothecary Scruple										
2 s ap							0.17	0.35	1.4	14
1 s ap							0.15	0.30	0.91	9.1

4.1.1 For each weight, the conventional mass, m_c (determined with an expanded uncertainty), shall not differ by more than the difference: maximum permissible error δm minus expanded uncertainty, from the nominal value of the weight, m_o:

$$m_o - (\delta m - U) \leq (m_c) \leq m_o + (\delta m - U) \quad (1)$$

4.2 Maximum permissible errors for classes 000, 00, 0, 1, 2, 3, 4, 5, 6 and 7 are given in Table 1. These maximum permissible errors apply to conventional mass values.

NOTE 2—Maximum Permissible Errors for weights of denomination intermediate between those listed, the maximum permissible error shall be proportional to the values shown.

4.3 For class 000, 00 and 0 weights, which are always accompanied by certificates giving the mass values and uncertainties, the deviation from the nominal value, $m_c - m_0$, shall be taken into account by the user.

5. Physical Characteristics

5.1 *Construction:*

5.1.1 *Type*—Weights are divided into two types based upon the design:

5.1.1.1 *Type I*—These weights are of one-piece construction and contain no added adjusting material. They must be specified when weights are to be used as standards for the calibration of weights of Classes 000, 00, 0, 1, 2 and 3, and where maximum stability is required. A precise measurement of density can only be made for one-piece weights.

5.1.1.2 *Type II*—Weights of this type can be of any appropriate design such as screw knob, ring, or sealed plug. Adjusting material can be used as long as it is of a material at least as stable as the base material and is contained in such a way that it will not become separated from the weight.

5.1.2 Class 000, 00 and 0 shall be Type I, one piece construction. Weights with nominal values less than 1 g shall have unique shapes to differentiate the weights from one another. See Table 2. The shape of weights smaller than 1 mg shall be discussed and verified with the customer.

5.1.3 Class 1, 2, 3, 4, 5, 6 and 7 may be either Type I or Type II depending on the application.

5.2 *Design*—A weight may have any shape that does not introduce features that reduce the reliability. All weights shall be free of ragged or sharp edges or ends. Both sheet metal and wire weights shall be free of cracks such as may be formed from bending.

5.3 *Surface Area*—For classes 000, 00, 0, 1, 2, 3 and 4 the surface area is not to exceed twice the area of a cylinder of equal height and diameter for weights 1 g and above. Sheet metal weights or wire weights may be used below 1 g. For Classes 5, 6 and 7 the total surface areas should be minimized to the extent possible.

5.4 *Material:*

5.4.1 *Class 000, 00, 0, 1, 2, 3, 4, and 5 Weights*—The hardness of this material and its resistance to wear and corrosion shall be similar to or better than that of austenitic stainless steel.

5.4.2 *Classes 6 and 7*—Cylindrical class 6 and 7 weights below 5 kg and class 6 and 7 weights below 100 g shall be made of steel or a material whose hardness and resistance to corrosion is similar or better than that of steel. Other cylindrical class 6 and 7 weights of 5 kg or greater shall be made of grey cast iron or of another material whose brittleness and resistance to corrosion is similar or better than that of grey cast

TABLE 2 Shape of Weights 1 g or Less

Nominal Values	Polygonal Sheets	Wires
5, 50, 500 mg	Pentagon	Pentagon
3, 30, 300 mg	Circle	Circle
2, 20, 200 mg	Square	Square
1, 10, 100, 1000 mg	Triangle	Triangle

iron. The surface of the weights may be treated with a suitable coating in order to improve their corrosion resistance. This coating shall withstand shocks and outdoor weather conditions.

5.5 *Magnetism*—Weights shall not exceed maximum permissible magnetic properties as listed in Tables 3 and 4 for any portion of the weight. If the values of all local measurements of magnetization and susceptibility are less than these limits, then it may be assumed that the uncertainty components due to the magnetism of the weight are negligible. The maximum permanent magnetization and magnetic susceptibilities given in Tables 3 and 4 are such that, at magnetic fields and magnetic field gradients possibly present on balance pans, they produce a change of the conventional mass of less than 1/10 of the maximum permissible error of the test weight.

NOTE 3—Magnetic susceptibility may be tested in accordance with OIML R 111-1, Annex B. Cast iron cannot have a susceptibility specification of any real value.

5.6 *Density*—Because of the effect of the buoyant force of air on a weight, precision measurements of mass require that the volume of the weight be known, as well as the density of the air in which it is being measured, so that appropriate corrections can be made. For weights of higher precision, the range of density is limited to values at or near the density of well-established standards, such as are used by primary calibration laboratories. For Class 000 and 00 the manufacturer shall provide a measured value for the density of the weights. As lower precision of measurement is required, so the range of density is broadened. See Table 5.

5.6.1 The determination of the minimum and maximum density limits for nominal values not listed in Table 5 shall be converted to metric values and the limits of the metric value next greater than the converted value used. (Example: 1 apothecary ounce class 4 is equal to 31.1034768 g, therefore the density limits are equal to values listed in Table 5 for 50 g.)

NOTE 4—Materials used to make weights for special applications that do not fall within the density limits stated above, should have stated densities or density determinations performed.

5.7 *Finish*—The surface of the weights (including the base and corners) shall be smooth, the edges shall be rounded, and the weights shall not be porous.

5.7.1 The surface quality of a weight shall not exceed maximum values of surface roughness, R_a and R_z through visual inspection using a hand held gage. See Table 6.

5.7.2 For weights with recessed areas for easier handling, the recessed area and handle should have a finish with surface roughness no greater than R_z = 1 µm and R_A = 0.2 µm. The outer diameter, top and bottom surface roughness must meet Table 6.

5.8 *Adjustment:*

TABLE 3 Maximum Polarization, $\mu_0 M$, (µT)

Weight Class	000, 00 and 0	1	2 and 3	4 and 5	6 and 7
Maximum polarization, $\mu_0 M$, (µT)	2.5	8	25	80	Not applicable

TABLE 4 Maximum Magnetic Susceptibility, χ

Weight Class	000, 00 and 0	1	2 and 3	4 and 5	6 and 7
$m \le 1$ g	0.25	0.9	10	Not applicable	Not applicable
2 g $\le m \le$ 10 g	0.06	0.18	0.7	4	Not applicable
20 g $\le m$	0.02	0.07	0.2	0.8	Not applicable

5.8.1 *Type I Weights*—Weights shall be adjusted by abrasion, grinding or any appropriate method. The surface requirements shall be met at the end of the adjustment process.

5.8.2 *Type II Weights*—Weights with adjusting cavities shall be adjusted with the same material from which they are made, or with materials that are at least as stable and of similar density as the base material. For weights which have sealing caps, the cap may be made of aluminum. The back-up spacer should be of a similar material as the weight. Adjusting material and back-up disc must meet the magnetic requirements specified for the accuracy class of the weight.

5.9 *Marking:*

5.9.1 Class 000, 00 and 0 weights shall not bear any indication of nominal value and shall not be marked unless used to distinguish from another class 000, 00 or 0 weight, provided that the surface quality and stability of the weights are not affected by the markings or by the process used to mark it.

5.9.2 *Numerical Value for Classes 1, 2, 3, 4, 5, 6 and 7*—The nominal value of each weight shall appear on the surface of each weight. Only the numerical portion of the weight value needs to be on the surface of weights. Weights made of wire or too small to be marked shall not be marked but should be identifiable by their shape or number of bends.

5.9.3 *Units of Weight*—Weights 100 g and greater may be marked with the unit name or abbreviation. In the case of sets of non-metric weights, at least the largest weight of a particular set should be marked with the unit name or abbreviation. In any case the unit shall not be included where such marking would be illegible.

5.9.4 *Abbreviations*—The accepted abbreviation may be used in marking. Abbreviations are shown in Appendix X2. Periods shall not be used with abbreviations in marking weights.

5.9.5 *Multiple Weights*—Multiple weights of the same nominal value included in a set of weights shall have distinguishing marks.

5.9.6 *Depth of Markings*—Markings shall be clear, shallow, relatively broad, and free of burrs and sharp angles. Markings shall not perforate or crack sheet metal weights.

5.9.7 *User Marking*—It is recommended for a user to clearly identify individual weights as it helps to link a weight to its calibration certificate or verification document. The acceptable maximum values for user markings are given in Table 7.

6. Ordering Information

6.1 Selection of type and class depends upon the application of the weights. For reference standards, stability and information about the values of the weights is more important than the closeness of the values to nominal. Weights to be used with

TABLE 5 Minimum and Maximum Limits for Density

Nominal Value	ρ_{min}, ρ_{max} (10^3 kg m^{-3}) Class of Weight					
	000	00 and 0	1	2 and 3	4 and 5	6 and 7
≥ 100 g	7.967 – 8.033	7.934 – 8.067	7.81 – 8.21	7.39 – 8.73	6.4 – 10.7	≥ 4.4
50 g	7.960 – 8.04	7.92 – 8.08	7.74 – 8.28	7.27 – 8.89	6.0 – 12.0	≥ 4.0
20 g	7.900 – 8.09	7.84 – 8.17	7.50 – 8.57	6.6 – 10.1	4.8 – 24.0	≥ 2.6
10 g	7.87 – 8.14	7.74 – 8.28	7.27 – 8.89	6.0 – 12.0	≥ 4.0	≥ 2.0
5 g	7.87 – 8.13	7.62 – 8.42	6.9 – 9.6	5.3 – 16.0	≥ 3.0	
2 g	7.62 – 8.42	7.27 – 8.89	6.0 – 12.0	≥ 4.0	≥ 2.0	
1 g	7.28 – 8.90	6.9 – 9.6	5.3 – 16.0	≥ 3.0		
500 mg	7.50 – 8.60	6.3 – 10.9	≥ 4.4	≥ 2.2		
200 mg	6.7 – 9.6	5.3 – 16.0	≥ 3.0			
100 mg	6.0 – 12	≥ 4.4				
50 mg	≥ 4.8	≥ 3.4				
20 mg	≥ 2.5	≥ 2.3				

TABLE 6 Maximum Values of Surface Roughness

	Classes 000, 00, 0	Classes 1, 2	Classes 3, 4	Class 5	Classes 6, 7
R_A (µm)	0.1	0.2	0.4	1	25
R_Z (µm)	0.5	1	2	5	100

TABLE 7 Maximum Number of User Markings

Class	Nominal Value	Height of Lettering	Maximum Number of Signs, Numerals, or Letters
000 – 7	< 1 g	1 mm	2
000, 00, 0	≥ 1 g	2 mm	3
1	≥ 1 g	3 mm	5
2 – 7	1 g to 100 g	3 mm	5
2 – 7	200 g to 10 kg	5 mm	5
2 - 3	≥ 20 kg	7 mm	5
4 – 7	≥ 20 kg	12 mm	5

balances of low precision do not require small maximum permissible errors, nor need the choice of materials be limited to those of high stability. Appendix X1 should serve as a guide in selecting weights for specific applications.

6.2 *Class*—Maximum permissible errors for Classes 000 through 7 are shown in Table 1. Lower numbers indicate smaller maximum permissible errors.

6.3 *Lifters:*

6.3.1 Classes 000, 00, 0, 1, 2, 3, and 4 shall be supplied with lifters when sets of weights are ordered. Individual weights shall be supplied with lifters when specified by the purchaser. Lifters or forceps shall securely hold the weights for which they are designed. Additional pressure shall not cause the dropping of small weights or the forceful ejection of large weights.

6.3.2 For weights 500 g or larger, the parts of the lifter that come in contact with the weights shall be covered with a non-magnetic material softer than the surface of the weight, such as plastic or chamois skin from which the grease has been removed.

6.3.3 For smaller weights, the lifters may be of the same design where practical or may be of a non-magnetic material softer than the weights, such as close-grained wood or plastics not affected by alcohol. When the parts of the lifters or forceps which come in contact with the weights are not covered by a soft material, they shall be smooth and polished and the edges on which the weight may be lifted shall be well rounded.

6.3.4 If forceps are used for lifting small weights, stainless steel forceps with nonmetallic tips may be used, where the tips that come in contact with the weights are covered with a material softer than the surface of the weight, such as plastic or chamois skin from which the grease has been removed. The forceps may also be made of a material softer than the weights, such as close-grained wood or plastics not affected by alcohol. When the parts of the forceps which come in contact with the weights are not covered by a soft material, they shall be smooth and polished and the edges on which the weight may be lifted shall be well rounded.

6.4 *Cases:*

6.4.1 Classes 000, 00, 0, 1, 2, 3, and 4 weights, when supplied in sets, may be supplied with one or more cases or shall meet customer specifications for cases. The case shall be designed so that as long as the lid remains closed, the weights shall be held secure, and when possible the pocket depth shall be such that the shoulder of the weight does not extend above the edge of the pocket. The hinges and locks shall be adequate to hold the lid closed with any reasonable handling. There shall be no discoloration of weights due to the lining of the case, such as might result from long storage in a warm or damp location. This condition does not apply to weights not designed to be handled manually.

6.4.2 *Pockets*—A separate pocket shall be supplied for each weight and for each forceps and lifter, except that extremely large lifters may not require pockets. All pockets shall be large enough so that no appreciable friction shall be encountered in inserting or removing weights. If the cover is not lined, the individual holes in the cover shall be smooth or lined. Pockets for weights 1 g or equivalent or larger shall be constructed of a smooth nonabrasive material, or lined with a smooth, nonabrasive material.

6.5 *Denominations*—The customer's purchase order or contract shall define the contents of the weight set.

6.6 *Density Identification*—Weights that are to be calibrated shall carry identification of the density of the various materials of which the weights are manufactured. Identification of density shall be displayed on the certificate, or on the cover or interior of the box.

6.7 *Special Requirements*—If a customer has specific requirements that deviate from this standard (that is, material, shape, maximum permissible errors, etc.) the manufacturer may use this specification as a reference, not a requirement, to provide the customer with the weights that they need.

7. Certificates

7.1 *Calibration*—Laboratories issuing calibration reports for weights and weight sets shall have evidence of metrological traceability to the International System of Units (SI). Calibration certificates shall be issued only by laboratories having a quality system complying with the requirements of ISO/IEC 17025, which has preferably been verified by third party assessment (accreditation).

7.1.1 *Calibration Certificates*—A calibration certificate shall state, as a minimum: the conventional mass of each weight, m_c, an indication of whether a weight has been adjusted prior to calibration, its expanded uncertainty, U, and the value of the coverage factor, k.

7.1.2 Class 000, 00, and 0 weights shall be accompanied by a calibration certificate.

7.1.3 The certificate for Class 000, 00, and 0 weights shall state, as a minimum, the values of conventional mass, m_c, the expanded uncertainty, U, and the coverage factor, k, and the density or volume for each weight. In addition, the certificate shall state if the density or volume was measured or estimated.

7.2 *Calibration, initial verification from the manufacturer and subsequent calibration:*

7.2.1 Table 8 gives the required tests for initial calibration from the manufacturer and subsequent calibration. The categories of weights that are subject to calibration or initial calibration from the manufacturer should also be subject to re-calibration, making it possible to verify that they have maintained their metrological properties. Any weights found defective at the time of re-calibration shall be reviewed with the customer.

7.2.2 For subsequent calibration, as a minimum, the weights shall be visually inspected for design and surface conditions and the mass checked.

8. Test Procedures

8.1 Weight manufacturers must be able to provide evidence that all new weights comply with specifications in this standard (e.g., material, density, magnetism, surface finish, mass values, uncertainties). Statements of compliance by calibration laboratories during subsequent calibrations must meet the requirements of ISO/IEC 17025, 5.10.4.2 and indicate on the calibration report which sections have or have not been assessed.

8.2 *Cleaning Weights:*

8.2.1 It is important to clean weights before any measurements are made because the cleaning process may change the mass of the weight. Cleaning should not remove any significant amounts of weight material. Weights should be handled and stored in such a way that they stay contamination-free. Before calibration, dust and any foreign particles shall be removed. Care must be taken not to change the surface properties of the weight (i.e. by scratching the weight).

8.2.2 If a weight contains significant amounts of contamination that cannot be removed by the methods cited above, the weight or some part of it can be washed with clean alcohol, distilled water or other solvents. Weights with internal cavities should normally not be immersed in the solvent to avoid the possibility that the fluid will penetrate the opening. If there is a need to monitor the stability of a weight in use, the mass of the weight should, if possible, be determined before cleaning.

8.2.3 After weights are cleaned with solvents they shall be stabilized for the times given in Table 9.

8.3 *Thermal Stabilization*—Prior to performing any calibration tests, the weights need to be acclimated to the ambient conditions of the laboratory. In particular, weights of classes 000, 00, 0, 1 and 2 should be close to the temperature in the weighing area. The mandatory minimum times required for temperature stabilization (depending on weight size, weight class and on the difference between the initial temperature of the weights and the room temperature in the laboratory) are shown in Table 10. As a practical guideline, a minimum waiting time of 24 hours is required for temperature stabilization of the weight with the laboratory environment for weight classes 000, 00, 0, 1, and 2.

8.4 *Environmental Conditions*—The calibration of weights shall be performed at stable ambient conditions at temperatures close to room temperature. Required conditions are given in Table 11.

8.4.1 For 000, 00, 0 and 1 class weights, the temperature shall be within 17 °C to 23.5 °C. The environmental conditions shall be within the specifications of the weighing instrument.

TABLE 8 Requirements for Determining Which Tests Shall Be Performed for Initial Verification from the Manufacturer and Subsequent Calibration

Test	Density ρ			Surface Roughness			Magnetic Susceptibility χ			Permanent Magnetism *M*			Conventional Mass		
Class	000 - 1	2 - 4	5 - 7	000 - 1	2 - 4	5 - 7	000 - 1	2 - 4	5 - 7	000 - 1	2 - 4	5 - 7	000 - 1	2 - 4	5 - 7
IV	√			V	V	V	√	√		√	√	√	√	√	√
SC				V	V	V				*	*	*	√	√	√

Legend:

IV = Initial verification from the manufacturer that is performed when the weight is first put into service.
SC = Subsequent or periodic calibration.
V = Visual inspection only.
√ = Testing required.
* = In case of doubt, permanent magnetization of a weight can be tested during subsequent calibration.
+ = Applies only for class 000 and 00.

TABLE 9 Stabilization Time after Cleaning

Weight Class	000, 00 and 0	1	2	3 - 7
After cleaning with alcohol	7 – 10 days	3 – 6 days	1 – 2 days	1 hour
After cleaning with distilled water	4 – 6 days	2 – 3 days	1 day	1 hour

TABLE 10 Thermal Stabilization in Hours

ΔT*	Nominal Value	Class 000, 00 and 0	Class 1	Class 2	Class 3 – 7
± 20 °C	1000, 2000, 5000 kg	-	-	79	5
	100, 200, 500 kg	-	70	33	4
	10, 20, 50 kg	45	27	12	3
	1, 2, 5 kg	18	12	6	2
	100, 200, 500 g	8	5	3	1
	10, 20, 50 g	2	2	1	1
	< 10 g	1	1	1	0.5
± 5 °C	1000, 2000, 5000 kg	-	-	1	1
	100, 200, 500 kg	-	40	2	1
	10, 20, 50 kg	36	18	4	1
	1, 2, 5 kg	15	8	3	1
	100, 200, 500 g	6	4	2	0.5
	10, 20, 50 g	2	1	1	0.5
	< 10 g	0.5	0.5	0.5	0.5
± 2 °C	1000, 2000, 5000 kg	-	-	1	0.5
	100, 200, 500 kg	-	16	1	0.5
	10, 20, 50 kg	27	10	1	0.5
	1, 2, 5 kg	12	5	1	0.5
	100, 200, 500 g	5	3	1	0.5
	< 100 g	2	1	1	0.5
±0.5 °C	1000, 2000, 5000 kg	-	-	-	-
	100, 200, 500 kg	-	1	0.5	0.5
	10, 20, 50 kg	11	1	0.5	0.5
	1, 2, 5 kg	7	1	0.5	0.5
	100, 200, 500 g	3	1	0.5	0.5
	< 100 g	1	0.5	0.5	0.5

ΔT*= Initial difference between weight temperature and laboratory temperature.

TABLE 11 Required Ambient Conditions during Calibration

Weight class	Temperature change during calibration
000, 00 and 0	± 0.3 ºC per hour with a maximum of ± 0.5 ºC per 12 hours
1	± 0.7 ºC per hour with a maximum of ± 1 ºC per 12 hours
2	± 1.5 ºC per hour with a maximum of ± 2 ºC per 12 hours
3	± 2 ºC per hour with a maximum of ± 3.5 ºC per 12 hours
4-7	± 3 ºC per hour with a maximum of ± 5 ºC per 12 hours
Weight class	Range of relative humidity (hr) of the air
000, 00 and 0	40 % to 60 % with a maximum of ± 5 % per 4 hours
1	40 % to 60 % with a maximum of ± 10 % per 4 hours
4 - 7	40 % to 60 % with a maximum of ± 15 % per 4 hours

8.4.2 If the air density deviates from 1.2 kg m^{-3} by more than 10 %, mass values shall be used in calculations and the conventional mass shall be calculated from the mass.

8.4.3 *Weighing Instrument*—The metrological characteristics of the weighing instrument used shall be known from earlier measurements and its resolution, linearity, repeatability and eccentricity shall be such that the required uncertainty can be reached.

8.4.4 *Reference Weights*—The reference weight shall generally be of a higher class of accuracy than the weight to be calibrated. In the calibration of weights of class 000, 00 and 0, the reference weight shall have similar or better metrological characteristics (magnetic properties, surface roughness) than the weight to be calibrated.

8.5 *Weighing Design:*

8.5.1 *Scope*—This section describes two methods for the determination of the conventional mass of weights in a weight set:

(1) The direct comparison method; and

(2) The subdivision/multiplication method, which applies only for a set of weights.

8.5.1.1 Three different weighing cycles are described, all of which are forms of substitution weighing intended for, but not limited to, single-pan balances.

8.5.1.2 Prior to mass determination, the density of the weights shall be known with sufficient accuracy. In addition, the environmental conditions and the metrological characteristics of the weighing instruments used in the mass determination shall be known with sufficient accuracy. Formulae for the determination of the conventional mass and its uncertainty are to be followed.

8.5.2 *Direct Comparison*—Usually the test weight should be calibrated by comparison against one or more reference weights. In each comparison, the nominal mass of the test weight and the reference weight should be equal. A check standard can be used to monitor the measurement process.

NOTE 5—Special problems may arise when calibrating class 000, 00 and 0 weights of less than one gram. This is partially due to a relatively large uncertainty of the reference weights in this range. Further, the instability of the weighing instruments and a large surface area are factors that negatively influence the uncertainty of measurement. Therefore, the subdivision method is strongly recommended for such weights.

8.5.3 *Subdivision*—An entire set of weights can be calibrated against one or more reference weights. This method requires several weighings within each decade in the set. In these weighings, different combinations of weights of equal total nominal mass are compared. This method is mainly used to calibrate sets of class 000, 00 and 0 weights when the highest accuracy is required. If with this method, only one reference weight is used, the number of weighing equations shall be larger than the number of unknown weights and an appropriate adjustment calculation shall be performed in order to avoid propagating errors. If more than one reference weight is used, the number of equations may be equal to the number of unknown weights. In this case, no adjustment calculation is necessary. The advantage of such methods lies in the fact that they include a certain redundancy that offers greater confidence in the results. However, these methods, particularly the adjustment calculation, require more advanced mathematics.

8.5.4 *Weighing Cycles*—Accepted procedures for three different weighing cycles for a single comparison weighing are described below.

NOTE 6—Other procedures and weighing cycles may be used. If in particular, weighing cycles are used that are not independent from each other, such as $A_1 B_2 A_2$, $A_2 B_2 A_3$, ..., the uncertainty has to be evaluated by considering covariance terms and the formula given in Section 9 must be modified correspondingly.

8.5.4.1 In the weighing cycles, "A" represents weighing the reference weight and "B" represents weighing the test weight. The cycles ABBA and ABA are normally used when calibrating class 000, 00, 0, 1, 2 and 3 weights.

8.5.4.2 The cycle $AB_1...B_nA$ is often used when calibrating class 4, 5, 6 and 7 weights, but is generally not recommended for class 000, 00, 0, 1, 2, and 3 weights. If, however, a mass comparator with an automatic weight exchange mechanism is used and if the system is installed in a protecting housing, this cycle can also be accepted for class 000, 00, 0, 1, 2, 3, and 4 weights calibrations.

8.5.4.3 Only cycles ABBA and ABA are useful in subdivision weighing. More than one reference weight can be used. In this case the weighing cycle can be applied for each reference weight separately. The reference weights may then be compared against one another.

8.5.5 *Comparison of the test weight with one reference weight (recommended for class 000, 00, 0, 1, 2, 3, and 4 weights)*—A variety of weighing cycles can be utilized. For two weights the following cycles, which are best known as ABBA and ABA, are possible. These cycles eliminate linear drift.

Cycle ABBA ($r_1t_1t_2r_2$): Ir_{11}, It_{11}, It_{21}, Ir_{21}, ..., Ir_{1n}, It_{1n}, It_{2n}, Ir_{2n}

$$\Delta I_i = (I_{t1\,i} - I_{r1\,i} - I_{r2\,i} + I_{r2\,i})/2 \tag{2}$$

where $i = 1, \ldots, n$

Cycle ABA ($r_1t_1r_2$): Ir_{11}, It_{11}, Ir_{21}, ..., Ir_{1n}, It_{1n}, Ir_{2n}

$$\Delta I_i = I_{t1\,i} - (I_{r1\,i} + I_{r2\,i})/2 \tag{3}$$

where $i = 1, \ldots, n$

8.5.5.1 In cycles ABBA and ABA, n is the number of sequences. The i values are given in the order in which the weights should be placed on the weighing pan. Here the subscripts "r" and "t" denote the reference weight and test weight respectively. ΔI_i is the indication difference from measurement sequence i.

8.5.5.2 The time interval between weighings should be kept constant.

8.5.5.3 If there is a need to determine the sensitivity of the weighing instrument during the weighing process, the sequence ABBA can be modified to the form I_r, I_t, I_{t+ms}, I_{r+ms}, where "*ms*" is the sensitivity weight.

8.5.6 Comparison of several test weights of the same nominal mass with one reference weight (cycle $AB_1\ldots B_nA$). If several test weights t(j) (j = 1, ..., J) with the same nominal mass are to be calibrated simultaneously the weighing cycle ABA can be modified into $AB_1\ldots B_nA$ as follows:

Cycle $AB_1\ldots B_nA$: Ir_{11}, $It_{(1)1}$, $It_{(2)1}$, ...,$It_{(J)1}$, Ir_{21}, Ir_{12}, $It_{(J)2}$, $It_{(J-1)2}$, ...,$It_{(1)2}$, Ir_{22}, … {Ir_{1i-1}, $It_{(1)i-1}$, $It_{(2)i-1}$, ..., $It_{(J)i-1}$, Ir_{2i-1}, Ir_{1i}, $It_{(J)i}$, $It_{(J-1)i}$,..., $It_{(1)i}$, Ir_{2i}}

$$\Delta I_{i(j)} = I_{t(j)\,i} - (I_{r1\,i} + I_{r2\,i})/2 \tag{4}$$

where $i = 1, \ldots, n$

8.5.6.1 If the drift in the weighing indication is negligible, i.e., less than or equal to one third of the required uncertainty, it is not necessary to invert the order of the test weights in $AB_1\ldots B_nA$ when repeating the sequence. The number of weights shall normally not be more than 5 ($J \leq 5$).

8.5.7 *Number of weighing cycles*—The number of weighing cycles, n, shall be based on the required uncertainty and on the repeatability and reproducibility of the measurements, see Table 12.

TABLE 12 Required Minimum Number of Weighing Cycles

Class	000, 00, 0	1	2 and 3	4 and 5	6 and 7
Minimum number of ABBA	3	2	1	1	1
Minimum number of ABA	5	3	2	1	1
Minimum number of $AB_1\ldots B_nA$	5	3	2	1	1

8.6 *Data Analysis:*

8.6.1 *Average difference of conventional mass–one test weight*—For cycles ABBA and ABA, the conventional mass difference, Δm_c, between the test weight and the reference weight of a cycle, *i*, is:

$$\Delta m_c = m_{ct} - m_{cr} \tag{5}$$

$$\Delta m_{ci} = \Delta I_i + m_{cr} C_i \tag{6}$$

where:

$$C_i = (\rho_{ai} - \rho_o) \times \left(\frac{1}{\rho_t} - \frac{1}{\rho_r} \right) \tag{7}$$

The average difference of conventional mass for *n* cycles is:

$$\overline{\Delta m_c} = \frac{1}{n} \sum_{i=1}^{n} \Delta m_{ci} \tag{8}$$

8.6.1.1 If the density, ρ_t or ρ_r, of a weight is not known, but the material is known, the appropriate assumed density from Table 13 shall be used. If it is only known that the density of a weight is within the allowed limits, then the value 8 000 kg m^{-3} shall be used.

8.6.1.2 In cases where air buoyancy correction is estimated to be negligible, i.e. if:

$$|c_i| \leq \frac{1}{3} \frac{U}{m_o} \tag{9}$$

the term $m_0 C_i$ can be omitted. However, the uncertainty contribution of *C* may not be negligible (see below in 9.3.1). If only an averaged or single value of the air density is available, the buoyancy correction, $m_{cr}C$, can be applied after averaging.

8.6.2 *Average difference of conventional mass – Several test weights*—If several test weights are calibrated according to weighing cycle $AB_1 \ldots B_n A$, the average mass difference for weight *j* is obtained from Eq 8 by replacing ΔI_i with $\Delta I_{i(j)}$ in Eq 6.

8.6.3 *Average difference of conventional mass – Several series of measurements*—If there are several (*J*) identical series of measurements with average values $\overline{\Delta m_{cj}}$ and with approximately equal standard deviations the average value of all measurements is:

$$\overline{\Delta m_c} = \frac{1}{J} \sum_{j=1}^{J} \overline{\Delta m_{cj}} \tag{10}$$

8.6.3.1 Several series of measurements are usually performed only in calibration of class 000, 00, and 0 weights, when the reproducibility of weighings has to be investigated. Minimum requirements for the number of weighing cycles are in Table 12.

TABLE 13 List of Alloys Most Commonly Used for Weights

Alloy/Material	Assumed Density	Uncertainty (*k* = 2)
Platinum	21,400 kg m^{-3}	± 150 kg m^{-3}
Nickel silver	8,600 kg m^{-3}	± 170 kg m^{-3}
Brass	8,400 kg m^{-3}	± 170 kg m^{-3}
Stainless steel	7,950 kg m^{-3}	± 140 kg m^{-3}
Carbon steel	7,700 kg m^{-3}	± 200 kg m^{-3}
Iron	7,800 kg m^{-3}	± 200 kg m^{-3}
Cast iron (white)	7,700 kg m^{-3}	± 400 kg m^{-3}
Cast iron (grey)	7,100 kg m^{-3}	± 600 kg m^{-3}
Aluminum	2,700 kg m^{-3}	± 130 kg m^{-3}

8.6.4 *Conventional mass of the test weight*—The conventional mass of the test weight can be calculated from the formula:

$$m_{ct} = m_{cr} + \overline{\Delta m_c} \tag{11}$$

9. Uncertainty Calculations

NOTE 7—The uncertainty calculations are based on the current GUM: JCGM 100 and supplements. Additional guidance may be found in NIST Technical Note 1297. Uncertainty calculations are applied for mass comparisons. The uncertainty is evaluated either by the Type A or by the Type B method of evaluation. Type A evaluation is based on a statistical analysis of a series of measurements whereas Type B evaluation is based on other knowledge.

9.1 *Standard uncertainty of the weighing process, u_w (Type A)*—The standard uncertainty of the weighing process, u_w (Δm_c), is the standard deviation of the mass difference. For *n* cycles of measurements:

$$u_w\left(\overline{\Delta m_c}\right) = \frac{s(\Delta m_{ci})}{\sqrt{n}} \tag{12}$$

where $s(\Delta m_{ci})$ is defined below for the various classes of weights.

9.1.1 Classes 3, 4, 5, 6, and 7, cycles ABBA, ABA or $AB_1 \ldots B_n A$ are often applied. For these classes of weights, if the standard deviation of mass difference measurements is not known from historical data, it can be estimated as:

$$s(\Delta m_c) = \frac{\max(\Delta m_{ci}) - \min(\Delta m_{ci})}{2 \cdot \sqrt{3}} \tag{13}$$

from $n \geq 3$ cycles of measurements.

The standard deviation can also be calculated as described in 9.1.2.

9.1.2 For weight classes 000, 00, 0, 1, and 2, the variance of the mass difference, Δm_c, of the weighing process, $s^2(\Delta m_c)$, is estimated from *n* cycles of measurements by:

$$s^2(\Delta m_c) = \frac{1}{n-1} \sum_{i=1}^{n} \left(\Delta m_{ci} - \overline{\Delta m_c} \right)^2 \tag{14}$$

with *n*–1 degrees of freedom.

9.1.3 If only a few measurements are made, the estimate of $s(\Delta m_c)$ can be unreliable. A pooled estimate, obtained from earlier measurements made under similar conditions, should be used. If this is not possible, *n* should not be less than 5.

9.1.4 In the case where there are *J* series of measurements (where $J > 1$), the variance of Δm_c is calculated by pooling over the *J* series so that:

$$s^2(\Delta m_c) = \frac{1}{J} \sum_{j=1}^{J} s_j^2(\Delta m_c) \tag{15}$$

with $J(n-1)$ degrees of freedom.

NOTE 8—The subscript "*j*" is appended to $s_j^2(\Delta m_c)$ to differentiate between the standard deviations for each series.

9.2 *Uncertainty of the reference weight, $u(m_{cr})$ (Type B)*—The standard uncertainty, $u(m_{cr})$, of the mass of the reference weight should be calculated from the calibration certificate by dividing the quoted expanded uncertainty, *U*, by the coverage factor, *k* (usually *k* = 2), and should be combined with the uncertainty due to the instability of the mass of the reference weight, $u_{inst}(m_{cr})$.

$$u(m_{cr}) = \sqrt{\left(\frac{U}{k}\right)^2 + u_{inst}^2(m_{cr})} \quad (16)$$

The uncertainty due to instability of the reference weight, $u_{inst}(m_{cr})$, can be estimated from observed mass changes after the reference weight has been calibrated several times. If previous calibration values are not available, the estimation of uncertainty has to be based on experience.

9.2.1 If a combination of reference weights is used for a mass comparison and their covariances are not known, a correlation coefficient of 1 can be assumed, refer to the current GUM: JCGM 100 and supplements. This will lead to linear summation of uncertainties:

$$u(m_{cr}) = \sum_i u(m_{cri}) \quad (17)$$

where $u(m_{cri})$ is the standard uncertainty of reference weight i. This is an upper limit for the uncertainty.

9.3 *Uncertainty of the air buoyancy correction, u_b (Type B)*—The uncertainty of the air buoyancy correction can be calculated from Eq 18.

$$u_b^2 = \left[m_{cr}\frac{(\rho_r - \rho_t)}{\rho_r\rho_t}u(\rho_a)\right]^2 + [m_{cr}(\rho_a - \rho_o)]^2\frac{u^2(\rho_t)}{\rho_t^4} + m_{cr}^2(\rho_a - \rho_o)[(\rho_a - \rho_o) - 2(\rho_{al} - \rho_o)]\frac{u^2(\rho_r)}{\rho_r^4} \quad (18)$$

where ρ_{al} is the air density during the (previous) calibration of the reference weight by use of a higher order reference weight. When using Eq 18 be sure to use the same value for the uncertainty of the density of the reference weight, $u(\rho_r)$, that was used in the uncertainty calculation of the previous calibration. A larger uncertainty cannot be arbitrarily chosen.

9.3.1 Even if the air buoyancy correction is negligible, the uncertainty contribution of the buoyancy effect may not be negligible, and shall be taken into account (see Eq 18).

9.3.2 For classes 5, 6, and 7, the uncertainty due to air buoyancy correction is typically negligible and can usually be omitted.

9.3.3 For classes 2, 3 and 4, the densities of the weights have to be known with sufficient accuracy (see Table 5).

9.3.4 If the air density is not measured and the average air density for the site is used, then the uncertainty for the air density is to be estimated as:

$$u(\rho_a) = \frac{0.12}{\sqrt{3}}[\mathrm{kg\ m^{-3}}] \quad (19)$$

A lower value of uncertainty may be used if supporting data can be provided.

At sea level the density of air may be assumed to be 1.2 kg m^{-3}.

9.3.5 For class 000, 00, 0 and 1 weights, the density of air shall be determined. Its uncertainty is estimated from the uncertainties for temperature, pressure and air humidity. For class 000, 00, 0 and 1 the CIPM formula (2007) or an approximation can be used for the calculation of air density.

9.3.6 The variance of the air density is:

$$u^2(\rho_a) = u_F^2 + \left(\frac{\partial\rho_a}{\partial p}u_p\right)^2 + \left(\frac{\partial\rho_a}{\partial t}u_t\right)^2 + \left(\frac{\partial\rho_a}{\partial hr}u_{hr}\right)^2 \quad (20)$$

9.3.6.1 At relative humidity of $hr = 0.5$ (50 %), a temperature of 20 °C and a pressure of 101,325 Pa, the following numerical values apply approximately:

u_F = [uncertainty of the formula used] (for CIPM formula: $u_F = 10^{-4}\rho_a$)

$$\frac{\partial\rho_a}{\partial\rho} = 10^{-5}\rho_a Pa^{-1}$$

$$\frac{\partial\rho_a}{\partial t} = -3.4\cdot10^{-3}\rho_a K^{-1}$$

$$\frac{\partial\rho_a}{\partial hr} = -10^{-2}\rho_a$$

where hr = relative humidity, as a fraction.

9.3.7 The density of the reference weight, ρ_r, and its uncertainty should be known from its calibration certificate.

9.3.8 For classes 0 – 4 weights, the density, ρ_t, is not always known, so it must be either measured, or taken from the manufacturer's specifications/recommendations, or taken from Table 13.

9.4 *Uncertainty of the balance u_{ba} (Type B):*

9.4.1 *Uncertainty due to the test of balances and mass comparators*—The recommended approach to determine this component is to test the balances and mass comparators at reasonable time intervals and use the results from the test in the uncertainty calculations. When calibrating class 000, 00 and 0 weights, it is recommended to perform several test measurements at different times to ensure that there is enough information about the uncertainty at the time of the measurement.

9.4.2 *Uncertainty due to the sensitivity of the balance*—If the balance is calibrated with a sensitivity weight (or weights) of mass m_s, and of standard uncertainty $u_{(ms)}$, the uncertainty contribution due to sensitivity is:

$$u_s^2 = \left(\overline{\Delta m_c}\right)^2\left(\frac{u^2(m_s)}{m_s^2} + \frac{u^2(\Delta I_s)}{\Delta I_s^2}\right) \quad (21)$$

where:

ΔI_s = the change in the indication of the balance due to the sensitivity weight,

$u(\Delta I_s)$ = the uncertainty of ΔI_s, and

$\overline{\Delta m_c}$ = the average mass difference between the test weight and the reference weight.

If the sensitivity is not constant with time, temperature and load, its variation must be included in the uncertainty.

9.4.3 *Uncertainty due to the display resolution of a digital balance*—For a digital balance with the scale interval, d, the uncertainty due to resolution is:

TABLE 14 Coverage factor, *k*, for different effective degrees of freedom, ν_{eff}

	ν_{eff}	1	2	3	4	5	6	8	10	20	∞
95.45 %	*k*	13.97	4.53	3.31	2.87	2.65	2.52	2.37	2.28	2.13	2.000
99 %	*k*	63.66	9.92	5.84	4.60	4.03	3.71	3.36	3.17	2.85	2.576
99.73 %	*k*	235.8	19.21	9.22	6.62	5.51	4.90	4.28	3.96	3.42	3.000

$$u_d = \frac{d/2}{\sqrt{3}} \cdot \sqrt{2} \quad (22)$$

The factor √2 comes from the two readings, one with the reference weight and one with the test weight.

9.4.4 *Uncertainty due to eccentric loading*—If this contribution is known to be significant, the magnitude must be estimated and if necessary the contribution must be included in the uncertainty budget.

9.4.4.1 *Acceptable solution for the uncertainty due to eccentricity:*

$$u_E = \frac{\frac{d_1}{d_2} \cdot D}{2 \cdot \sqrt{3}} \quad (23)$$

where:

D = the difference between maximum and minimum values from the eccentricity test performed,
d_1 = the estimated distance between the centers of the weights, and
d_2 = the distance from the center of the load receptor to one of the corners.

In most cases, the uncertainty contribution u_E is already covered by the uncertainty u_w of the weighing process and may be neglected.

9.4.4.2 When using balances with an automatic weight exchange mechanism, the indication difference, ΔI, between two weights may be different when the positions are interchanged: $\Delta I_1 \neq \Delta I_2$. This may be interpreted as an eccentric loading error and the corresponding uncertainty should be estimated using Eq 24. This uncertainty contribution is applicable, if it is known from previous interchanging measurements with weights of the same nominal value. In cases when the interchange is performed during a calibration procedure, the average of the two indication differences shall be taken as the weighing result and uE can be neglected.

$$u_E = \frac{|\Delta I_1 - \Delta I_2|}{2} \quad (24)$$

NOTE 9—Eq 24 is based on the same mathematical background as Note 6 in OIML D 28.

9.4.5 *Uncertainty due to magnetism, u_{ma}*—If a weight has a high magnetic susceptibility and/or is magnetized, the magnetic interaction can often be reduced by placing a nonmagnetic spacer between the weight and the load receptor. If the weights satisfy the requirements of this standard, the uncertainty due to magnetism, u_{ma}, may be assumed to be zero.

9.4.6 *Combined standard uncertainty of the balance, u_{ba}*—The uncertainty components are added quadratically as follows:

$$u_{ba} = \sqrt{u_s^2 + u_E^2 + u_{ma}^2 + u_d^2} \quad (25)$$

9.5 *Expanded uncertainty, $U(m_{ct})$*—The combined standard uncertainty of the conventional mass of the test weight is given by:

$$u_c(m_{ct}) = \sqrt{u_w^2\left(\overline{\Delta m_c}\right) + u^2(m_{cr}) + u_b^2 + u_{ba}^2} \quad (26)$$

If the buoyancy correction, $m_{cr}C$, is not applied, a corresponding contribution for buoyancy has to be added to the combined uncertainty in addition to u_b:

$$u_c(m_{ct}) = \sqrt{u_w^2\left(\overline{\Delta m_c}\right) + u^2(m_{cr}) + u_b^2 + (m_{cr}\ C)^2 + u_{ba}^2} \quad (27)$$

The expanded uncertainty, U, of the conventional mass of the test weight is as follows:

$$U(m_{ct}) = k\ u_c(m_{ct}) \quad (28)$$

9.5.1 Usually the coverage factor, $k = 2$, should be used. However, if a pooled standard deviation of the weighing process is not known and the number of measurements cannot reasonably be increased up to 10 (as for very large weights and long weighing procedures), and the uncertainty, u_w ($\overline{\Delta m_c}$), is the dominant component in the uncertainty analysis, i.e. u_w ($\overline{\Delta m_c}$) > $u_c(m_t)$ / 2, then the coverage factor, k, should be calculated from the t-distribution assuming a 95.45 % confidence level and the effective degrees of freedom, ν_{eff} (as calculated from the Welch-Satterthwaite formula). The coverage factor, k, for different effective degrees of freedom, ν_{eff}, is given in Table 14. If it can be assumed that the type B uncertainty estimates are conservative with infinite degrees of freedom, the formula has the form:

$$\nu_{eff} = (n - 1) \cdot \frac{u_c^4(m_{ct})}{u_w^4\left(\overline{\Delta m_c}\right)} \quad (29)$$

APPENDIXES

(Nonmandatory Information)

X1. APPLICATIONS

TABLE X1.1 Applications

NOTE 1—Balance classification information can be found in NIST Handbook 44 or OIML R 76.

Class	Type	Application
0, 00, 000	I	Laboratory Reference Standards
0	I	Reference standards used for calibrating Class 1 weights
0	I	Reference standards used for calibrating Class 2 weights
1	I	Reference standards used for calibrating Class 3 weights
1	II	Calibration weights used with calibration Class I balances
1	I or II	Built in weights for high quality analytical balances

TABLE X1.1 *Continued*

Class	Type	Application
1, 2	I or II	Calibration weights used with calibration Class II balances, laboratory weights for routine analytical work
2	I or II	Standards used for calibrating Class 4 weights
3	I or II	Standards used for calibrating Class 5 weights
4	I or II	Standards used for calibrating Class 6 weights
4, 5, 6	I or II	Calibration weights used with Class III, IIIL and IIII balances. Dial scales, trip balances and platform scales
5, 6	I or II	Student laboratory use
7	I or II	Rough weighing operations in physical and chemical laboratories such as force measuring apparatus

X2. ABBREVIATIONS OF TERMS

TABLE X2.1 Abbreviations of Terms

Name of Unit	Accepted Abbreviation	Conversion Factor (g/unit of measure)
Carat	c	0.2 g
Dram, apothecary	dr ap	3.887 934 6 g
Grain, Troy	gr	0.064 798 91 g
Gram	g	1 g
Kilogram	kg	1 000 g
Milligram	mg	0.001 g
Ounce, apothecary (480 grains)	oz ap	31.103 476 8 g
Ounce, avoirdupois (437.5 grains)	oz	28.349 523 125 g
Ounce, troy (480 grains)	oz t	31.103 476 8 g
Pennyweight	dwt	1.555 173 84 g
Pound avoirdupois	lb	453.592 37 g
Scruple, apothecary	s ap	1.295 978 2 g