1. About CSIR

The Council of Scientific and Industrial Research (CSIR) was established in September 1942 as an autonomous body which emerged as the largest research and development organization in India. It is funded by Ministry of Science and Technology.

The research and development activities include:

Aerospace Engineering,

Structural Engineering,

Ocean Sciences,

Life Sciences,

Metallurgy,

Chemicals,

Mining,

Food and Environment.

1.1 About CSIR-NPL

National Physical Laboratory (NPL) is a laboratory under CSIR and is the National Metrology Institute (NMI) of India located in New Delhi its primary function is research in various fields such as maintaining national standards of India, calibration of weights and measures, giving Indian reference materials.

2. METROLOGY

Metrology is the Science of Measurement. It is derived from two Greek Words: Metro= Measurement :: Logy= Science.

It is the field of knowledge concerned with measurement and includes both theoretical and practical problems with reference to measurement.

It is the process of making precise measurements of the relative positions and orientations of different optical, mechanical, electrical, thermal components etc.

Elements of Metrology:

Standard : It is a physical representation of unit of measurement.

Work piece : It is the object to be measured/ measured part.

Instruments : It is a device with the help of which the measurement can be done. It should be selected based on the tolerance of the parts to be measured.

Person : Person who carry out the mechanism of the job.

2.1 PHYSICAL QUANTITY

A physical property that can be measured and described by a number.

Fundamental Quantity: Does not depend upon any other physical quantities for their measurements.

Derived Quantity: Depends on fundamental quantities for their measurements.

The standard used for the measurement of physical quantity is called Unit. CGS system of units uses centimetre, gram, second for fundamental quantities length, mass and time.

MKS system of units uses metre, kilogram, second for fundamental quantities length, mass and time.

FPS system of units uses foot, pound, second for fundamental quantities length, mass and time.

2.2 Seven Fundamental Units: (revised as per new definition)

1. **Kilogram (kg)**: The kilogram, symbol kg, is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant h to be 6.626 070 15 x 10^{-34} when expressed in the unit J s, which is equal to kg m^2 s^{-1}, where the metre and the second are defined in terms of c and $\Delta\nu_{Cs}$.

   This definition implies the exact relation h = 6.626 070 15 x 10^{-34} kg m^2 s^{-1}. Inverting this relation gives an exact expression for the kilogram in terms of the three defining constants h, $\Delta\nu_{Cs}$ and c:

   $$1\,\mathrm{kg} = \left(\frac{h}{6.626\,070\,15\times10^{-34}}\right)\mathrm{m}^{-2}\mathrm{s}$$

   which is equal to

   $$1\,\mathrm{kg} = \frac{(299\,792\,458)^2}{(6.626\,070\,15\times10^{-34})(9\,192\,631\,770)}\frac{h\,\Delta\nu_{\mathrm{Cs}}}{c^2} \approx 1.475\,5214\times10^{40}\,\frac{h\,\Delta\nu_{\mathrm{Cs}}}{c^2}$$

   The effect of this definition is to define the unit kg m^2 s^{-1} (the unit of both the physical quantities action and angular momentum). Together with the definitions of the second and the metre this leads to a definition of the unit of mass expressed in terms of the Planck constant h.

2. **Length (m):** The metre, symbol m, is the SI unit of length. It is defined by taking the fixed numerical value of the speed of light in vacuum *c* to be 299 792 458 when expressed in the unit m s^{-1}, where the second is defined in terms of the caesium frequency $\Delta\nu_{Cs}$.

   This definition implies the exact relation *c* = 299 792 458 m s^{-1}. Inverting this relation gives an exact expression for the metre in terms of the defining constants *c* and $\Delta\nu_{Cs}$:

$$1\,\text{m} = \left(\frac{c}{299\ 792\ 458}\right)\text{s} = \frac{9\ 192\ 631\ 770}{299\ 792\ 458}\frac{c}{\Delta\nu_{\text{Cs}}} \approx 30{,}663\ 319\frac{c}{\Delta\nu_{\text{Cs}}}\,.$$

   The effect of this definition is that one metre is the length of the path travelled by light in vacuum during a time interval with duration of 1/299 792 458 of a second.

3. **Second (s):** The second, symbol s, is the SI unit of time. It is defined by taking the fixed numerical value of the caesium frequency $\Delta\nu_{Cs}$, the unperturbed ground-state hyperfine transition frequency of the caesium-133 atom, to be 9 192 631 770 when expressed in the unit Hz, which is equal to s^{-1}.

   This definition implies the exact relation $\Delta\nu_{Cs}$ = 9 192 631 770 Hz. Inverting this relation gives an expression for the unit second in terms of the defining constant $\Delta\nu_{Cs}$:

$$1\,\text{Hz} = \frac{\Delta\nu_{\text{Cs}}}{9\ 192\ 631\ 770}$$

or

$$1\,\text{s} = \frac{9\ 192\ 631\ 770}{\Delta\nu_{\text{Cs}}}\,.$$

The effect of this definition is that the second is equal to the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the unperturbed ground state of the ^{133}Cs atom.

4. **Ampere (A):** The ampere, symbol A, is the SI unit of electric current. It is defined by taking the fixed numerical value of the elementary charge *e* to be 1.602 176 634 x 10^{-19} when expressed in the unit C, which is equal to A s, where the second is defined in terms of $\Delta\nu_{Cs}$.

   This definition implies the exact relation e = 1.602 176 634 x 10^{-19} A s. Inverting this relation gives an exact expression for the unit ampere in terms of the defining constants *e* and $\Delta\nu_{Cs}$:

$$1\,\mathrm{A} = \left(\frac{e}{1.602\ 176\ 634 \times 10^{-19}}\right)\mathrm{s}^{-1}$$

   which is equal to

$$1\,\mathrm{A} = \frac{1}{(9\ 192\ 631\ 770)(1.602\ 176\ 634 \times 10^{-19})}\Delta\nu_{\mathrm{Cs}}e \approx 6.789\ 687 \times 10^{8}\,\Delta\nu_{\mathrm{Cs}}e$$

   The effect of this definition is that one ampere is the electric current corresponding to the flow of 1/(1.602 176 634 x 10^{-19}) elementary charges per second.

5. **Kelvin (K)**: The kelvin, symbol K, is the SI unit of thermodynamic temperature. It is defined by taking the fixed numerical value of the Boltzmann constant *k* to be 1.380 649 x 10^{-23} when expressed in the unit J K^{-1}, which is equal to kg m^2 s^{-2} K^{-1}, where the kilogram, metre and second are defined in terms of *h*, *c* and $\Delta\nu_{Cs}$.

   This definition implies the exact relation k = 1.380 649 x 10^{-23} kg m^2 s^{-2} K^{-1}. Inverting this relation gives an exact expression for the kelvin in terms of the defining constants *k*, *h* and $\Delta\nu_{Cs}$:

$$1\,\mathrm{K} = \left(\frac{1.380\,649}{k}\right) \times 10^{-23}\ \mathrm{kg\ m^2\ s^{-2}}$$

which is equal to

$$1\,\mathrm{K} = \frac{1.380\ 649 \times 10^{-23}}{\left(6.626\ 070\ 15 \times 10^{-34}\right)\left(9\ 192\ 631\ 770\right)} \frac{\Delta\nu_{\mathrm{Cs}} h}{k} \approx 2.266\ 6653 \frac{\Delta\nu_{\mathrm{Cs}} h}{k}$$

The effect of this definition is that one kelvin is equal to the change of thermodynamic temperature that results in a change of thermal energy $k\,T$ by 1.380 649 x 10^{-23} J.

6. **Mole (mol):** The mole, symbol mol, is the SI unit of amount of substance. One mole contains exactly 6.022 140 76 x 10^{23} elementary entities. This number is the fixed numerical value of the Avogadro constant, N_A, when expressed in the unit mol^{-1} and is called the Avogadro number.

   The amount of substance, symbol *n*, of a system is a measure of the number of specified elementary entities. An elementary entity may be an atom, a molecule, an ion, an electron, any other particle or specified group of particles.

   This definition implies the exact relation N_A = 6.022 140 76 x 10^{23} mol^{-1}. Inverting this relation gives an exact expression for the mole in terms of the defining constant N_A:

$$1\,\mathrm{mol} = \left(\frac{6.022\,140\,76 \times 10^{23}}{N_{\mathrm{A}}}\right)$$

   The effect of this definition is that the mole is the amount of substance of a system that contains 6.022 140 76 x 10^{23} specified elementary entities.

7. **Candela (cd):** The candela, symbol cd, is the SI unit of luminous intensity in a given direction. It is defined by taking the fixed numerical value of the luminous efficacy of monochromatic radiation of frequency 540 x 10^{12} Hz, K_{cd}, to be 683 when expressed in the unit lm W^{-1}, which is equal to cd sr W^{-1}, or cd sr kg^{-1} m^{-2} s^3, where the kilogram, metre and second are defined in terms of *h*, *c* and $\Delta\nu_{Cs}$.

   This definition implies the exact relation K_{cd} = 683 cd sr kg^{-1} m^{-2} s^3 for monochromatic radiation of frequency ν= 540 x 10^{12} Hz. Inverting this relation gives an exact expression for the candela in terms of the defining constants K_{cd}, *h* and $\Delta\nu_{Cs}$:

$$1\ \text{cd} = \left(\frac{K_{\text{cd}}}{683}\right) \text{kg m}^2\ \text{s}^{-3}\ \text{sr}^{-1}$$

   which is equal to

$$1\ \text{cd} = \frac{1}{\left(6.626\ 070\ 15 \times 10^{-34}\right)\left(9\ 192\ 631\ 770\right)^2 683} (\Delta\nu_{\text{Cs}})^2\ h\ K_{\text{cd}}$$

$$\approx 2.614\ 830 \times 10^{10}\ (\Delta\nu_{\text{Cs}})^2\ h\ K_{\text{cd}}$$

   The effect of this definition is that one candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} Hz and has a radiant intensity in that direction of (1/683) W/sr.

Traceability:

The property of the result of a measurement whereby it can be related to stated references usually national or international standards, through an unbroken chain of comparison all having stated uncertainties.

Weight:
A body with some mass is attracted towards the centre of the earth with some force. This force of attraction is known as weight and is proportional to the mass of the body.

Conventional Mass:
The conventional value of the result of weighing of a body in air is equal to the mass of a reference weight of a density of 8000 kg/m^3 at reference temperature of 20 degrees Celsius which balances this body in air of a reference density of 1.2 kg/m^3.

3. MASS METROLOGY

It comprises experiments on the Fundamental Quantity Mass and its derived quantity Volume, Density, Viscosity.

3.1 Mass: SI unit is kg.

When the mass values are measured in vacuum is called mass.

Air Buoyancy: Si unit is kg/m^3.

Air is a fluid and exerts an upward force, called the buoyant force, on all object placed in it. This buoyant force is equal to the weight of air displaced by the object.

The density of air can vary between 1.1 kg/m^3 to 1.3 kg/m^3 which is equivalent to a change of 25 mg in the weight of a stainless steel kilogram of volume 125 cm^3.

3.2 Volume: SI unit is m^3.

It is the measure of the capacity of a container. The volume of a body may be defined as the integral taken over the 3-space representation of the outer boundary of the body (measured in cartesian coordinates x,y,z) with respect to a differential element dxdydz. An approximate value is provided by the number of non-overlapping unit cubes that may be fitted inside the boundary of that body. If the body is hollow (contains an inner unfilled space, and an inner boundary) then the net volume is the difference between the volume calculated over the outer boundary and the volume calculated over the inner boundary.

3.3 Density: SI unit is kg/m^3.

Density of the substance is the measure of the amount of matter that is present in a certain volume of it.

3.4 Viscosity: SI unit is m^2/s.

Internal property of fluid that offers resistance to flow. It is caused by the friction between the layers of fluid.

Dynamic Viscosity: SI unit is Pascal-second (Pa-s).

It is the measure of fluid's resistance to shear flow when some external force is applied.

$$\tau = \frac{F}{A} = \mu \frac{dV}{dy}$$

3.5 Kinematic Viscosity: SI unit is m^2/s.

It is the ratio of dynamic viscosity to density of that fluid. It measures the resistance of fluid under the action of gravity.

$$\vartheta = \frac{\mu}{\rho}$$

3.6 Calibration of Weights: Calibration means the relationship between the displayed value and the true mass. Calibration of a weight is carried out by comparing it against a reference weight of known mass whose nominal mass is equal to that of test weight. The comparison is done on a suitable weighing instrument. The indication of the weighing instrument is used only for the difference between reference weight and test weight. The comparison of two weights is always carried out according to the substitution method using ABBA or ABA or $AB_1 \ldots B_nA$ weighing cycle to eliminate linear drift.

3.7 Uncertainty: It is a parameter which is associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the Measurand.

When specifying the uncertainty, it is necessary to indicate the principle on which the calculation has been made.

It is an estimate that characterizes the range of values with in which the true value of a Measurand lies.

4. OPTICAL/DIMENSIONAL METROLOGY

4.1 **Introduction: Optical metrology** is the science and technology concerning measurements using light. These measurements may focus on the properties of light itself or other properties such as distance. **Dimensional metrology** is the science of calibrating and using physical measurement equipment to quantify the physical size of or distance from any given object.

It is concerned with measurements of:

- Length
- Displacement/ texture
- Angle
- Surface texture
- Form

4.2 **Dimension:** Physical size of or distance from any given object.

5. TASKS ASSIGNED:

5.1 TASK 1: Calibration of Weights at different altitudes.

Fig. 1: Weights that are used for the experiment.

Case 1:

Weight= 200 g

Height= Ground floor

Materials used= A: Stainless steel B: Brass

Sl. No.	A_1 (g)	B_1 (g)	B_2 (g)	A_2 (g)	Δmi (g)	$(\Delta m - \Delta mi)^2$ (g^2)
1.	199.99999	200.00199	200.00205	199.99999	2.030×10^{-3}	5.5225×10^{-10}
2.	199.99999	200.00197	200.00194	199.99992	2.020×10^{-3}	1.8225×10^{-10}
3.	199.99994	200.00194	200.00195	199.99993	2.010×10^{-3}	12.2500×10^{-12}
4.	199.99992	200.00188	200.00188	199.99988	1.980×10^{-3}	7.0225×10^{-10}
5.	199.99985	200.00186	200.00186	199.99983	2.020×10^{-3}	1.8225×10^{-10}
6.	199.99984	200.00188	200.00187	199.99986	2.025×10^{-3}	3.4225×10^{-10}
7.	199.99985	200.00186	200.00185	199.99984	1.995×10^{-3}	1.3225×10^{-10}
8.	199.99984	200.00189	200.00190	199.99990	2.025×10^{-3}	3.4225×10^{-10}
9.	199.99992	200.00193	200.00189	199.99991	1.995×10^{-3}	1.3225×10^{-10}
10.	199.99991	200.00189	200.00188	199.99993	1.965×10^{-3}	17.2225×10^{-10}

Mean $\Delta mi = 2.0065\times10^{-3}$ g

Mean $(\Delta m - \Delta mi)^2 = 4.30249\times10^{-9}$ g^2

Mean Temp. = 24.038 ºC

Mean r.h. = 53.19 %

Mean Pressure= 993.6 mbar

Density of test weight= 8400 mg/cm^3

Density of reference weight= 7950 mg/cm^3

Volume of test weight = m/ρ_t =23.809 5 cm^3

Volume of reference weight = m/ρ_r = 25.157 2 cm^3

1. Standard Deviation, $s = \sqrt{[(4.30249\times10^{-9})/(10-1)]}$
   $= 2.186\times10^{-5}$ g

   Standard Uncertainty, $u_w = s/\sqrt{n} = (2.186\times10^{-5})/\sqrt{10}$
   $= 6.914\times10^{-6}$ g

2. Standard Uncertainty in reference, u_r (type B)
   u=7µg; k=2

u_r=3.5µg; *k*=1

3. Standard uncertainty in air buoyancy correction, u_b (type B)

   Uncertainty in density of test weight = 100 mg/cm^3; *k*=1

   Uncertainty in density of reference weight = 70 mg/cm^3; *k*=1

   Uncertainty in the volume of test weight = 0.283446 cm^3

   Uncertainty in the volume of reference weight = 0.22151 cm^3

   Now,

   Uncertainty in the formula used, $u_f = 2\times10^{-4}.\rho_a$

   Uncertainty in barometer, u_p = 0.06 mbar; k=1

   Uncertainty in temperature, u_t = 0.15 °C ; k=1

   Uncertainty in relative humidity, u_{rh} = 0.65 %; k=1

   Standard Uncertainty of the air density, u_{pa}

   $u_{pa} = \rho_a \times \sqrt{}\ [(u_r/\rho_a)^2 + (u_p/p)^2 + (u_t/t)^2 + (u_{r.h.}/10^4)^2]$

   Air density; $\rho_a = 0.34848(p) – 0.009(r.h.).e^{(0.061\times t)}/(273.15+t)$

   ρ_a = 1.156727 mg/cm^3

   $u_{pa} = 7.127198\times10^{-3}$ mg/cm^3

   Standard uncertainty due to buoyancy correction:

   $u_b = \sqrt{}\ [(v_t - v_r)^2 \times (u_{pa})^2 \times (u^2_{vt} - u^2_{vr}) \times (\rho_a - \rho_o)^2]$

   $u_b = 9.97\times10^{-3}$ mg

4. Standard Uncertainty due to display resolution (d) of a digital balance, u_d = 0.01 mg

   $u_d = d/\sqrt{6}$
   $= 0.01$ mg $/\sqrt{6}$
   $= 4.08248\times10^{-3}$ mg

5. Expanded Uncertainty, $u_c = \sqrt{}\ [u^2_w + u^2_r + u^2_b + u^2_d]$
   u_c = 0.014031248 mg

   Effective 'DoF'= $v_{eff} = (n-1)\times u^4_c/u^4_w$
   = 74.2175 >20

   So, k = 2.

   Expanded Uncertainty = u = $u_c \times k$
   = 28.062496 μg
   ≈ 28 μg

Case 2:

Weight= 200g

Height= Ground floor

Materials used= A: Stainless steel B: Brass

Sl. No.	A_1 (g)	B_1 (g)	B_2 (g)	A_2 (g)	Δmi (g)	$(\Delta m - \Delta mi)^2$ (g^2)
1.	199.99989	200.00181	200.00180	199.99989	1.915×10^{-3}	3.08025×10^{-9}
2.	199.99990	200.00185	200.00184	199.99990	1.945×10^{-3}	6.50250×10^{-10}
3.	199.99988	200.00185	200.00184	199.99986	1.975×10^{-3}	2.02500×10^{-11}
4.	199.99984	200.00182	200.00179	199.99979	1.990×10^{-3}	3.80250×10^{-10}
5.	199.99983	200.00178	200.00177	199.99978	1.955×10^{-3}	2.40250×10^{-10}
6.	199.99978	200.00178	200.00174	199.99976	1.990×10^{-3}	3.80250×10^{-10}
7.	199.99980	200.00180	200.00176	199.99979	1.985×10^{-3}	2.10250×10^{-10}
8.	199.99977	200.00176	200.00175	199.99980	1.970×10^{-3}	2.50000×10^{-13}
9.	199.99978	200.00178	200.00176	199.99981	1.975×10^{-3}	2.02500×10^{-11}
10.	199.99975	200.00178	200.00174	199.99976	2.005×10^{-3}	1.19025×10^{-9}

Mean $\Delta mi = 1.9705\times10^{-3}$ g

Mean $(\Delta m - \Delta mi)^2 = 6.1725\times10^{-9}$ g^2

Mean Temp. = 24.36 ºC

Mean r.h.= 53.1 %

Mean Pressure= 993.6 mbar

Density of test weight= 8400 mg/cm^3

Density of reference weight= 7950 mg/cm^3

Volume of test weight = m/ρ_t =23.8095 cm^3

Volume of reference weight = m/ρ_r = 25.1572 cm^3

1. Standard Deviation, $s = \sqrt{[(6.1725\times10^{-9})/(10-1)]}$
   $= 2.61884\times10^{-5}$ g

   Standard Uncertainty, $u_w = s/\sqrt{n} = (2.61884\times10^{-5})/\sqrt{10}$
   $= 8.28\times10^{-6}$ g

2. Standard Uncertainty in reference, u_r (type B)
   $u=7\mu g$; $k=2$
   $u_r=3.5\mu g$; $k=1$
3. Standard Uncertainty in air buoyancy correction, u_b (type B)
   Uncertainty in density of test weight = 100 mg/cm^3; k=1
   Uncertainty in density of reference weight = 70 mg/cm^3; k=1
   Uncertainty in the volume of test weight = 0.283446 cm^3
   Uncertainty in the volume of reference weight = 0.22151 cm^3
   Now,
   Uncertainty in the formula used, $u_f = 2\times10^{-4}.\rho_a$
   Uncertainty in barometer, u_p = 0.06 mbar; k=1
   Uncertainty in temperature, $u_t = 0.15\ °C$; k=1
   Uncertainty in relative humidity, u_{rh} = 0.65 %; k=1
   Standard Uncertainty of the air density, u_{pa}
   $u_{pa} = \rho_a \times \sqrt{} [(u_r/\rho_a)^2 + (u_p/p)^2 + (u_t/t)^2 + (u_{r.h.}/10^4)^2]$

   Air density; $\rho_a = 0.34848(P) – 0.009(r.h.).e^{(0.061\times t)}/(273.15+t)$
   $\rho_a = 1.15810651\ mg/cm^3$
   $u_{pa} = 7.23116426\times10^{-3}\ mg/cm^3$
   Standard Uncertainty due to buoyancy correction:
   $u_b = \sqrt{} [(v_t - v_r)^2 \times (u_{pa})^2 \times (u^2_{vt} - u^2_{vr}) \times (\rho_a - \rho_o)^2]$
   u_b = 0.010085 mg.

4. Standard Uncertainty due to display resolution (d) of a digital balance, u_d = 0.01 mg

   $u_d = d/\sqrt{6}$
   $= 0.01/\sqrt{6}$
   $= 4.08248\times10^{-3}$ mg

5. Expanded Uncertainty, $u_c = \sqrt{} [u^2_w + u^2_r + u^2_b + u^2_d]$
   u_c = 0.013357666 mg
   Effective ‘dof’= $v_{eff} = (n-1)\times u^4_c/u^4_w$
   = 125.3355359 >20
   So, k = 2.

   Expanded Uncertainty = $u = u_c \times k$
   $= 26.715332\ \mu g$
   $\approx 27\ \mu g$

Case 3:

Weight = 200 g

Height= Second floor

Materials used= A: Stainless steel B: Brass

S. No.	A_1 (g)	B_1 (g)	B_2 (g)	A_2 (g)	Δmi (g)	$(\Delta m - \Delta mi)^2$ (g^2)
1.	200.00269	200.00467	200.00458	200.00264	1.960×10^{-3}	1.8225×10^{-10}
2.	200.00263	200.00455	200.00462	200.00267	1.935×10^{-3}	1.48225×10^{-9}
3.	200.00268	200.00467	200.00459	200.00261	1.985×10^{-3}	1.3225×10^{-10}
4.	200.00260	200.00460	200.00458	200.00268	1.950×10^{-3}	5.5225×10^{-10}
5.	200.00269	200.00462	200.00460	200.00255	1.990×10^{-3}	2.7225×10^{-10}
6.	200.00267	200.00474	200.00453	200.00270	1.950×10^{-3}	5.5225×10^{-10}
7.	200.00275	200.00468	200.00468	200.00271	1.950×10^{-3}	5.5225×10^{-10}
8.	200.00269	200.00471	200.00470	200.00265	2.035×10^{-3}	3.78225×10^{-9}
9.	200.00266	200.00462	200.00469	200.00269	1.98×10^{-3}	4.225×10^{-11}
10.	200.00270	200.00471	200.00462	200.00263	2.0×10^{-3}	7.0225×10^{-10}

Mean $\Delta mi = 1.9735\times10^{-3}$ g
Mean $(\Delta m - \Delta mi)^2 = 8.2525\times10^{-9}\ g^2$

Mean Temp. = 23.225 ºC

Mean r.h.= 55.45 %

Mean Pressure= 993 mbar

Density of test weight= 8400 mg/cm^3

Density of reference weight= 7950 mg/cm^3

Volume of test weight = m/ρ_t =23.8095 cm^3

Volume of reference weight = m/ρ_r = 25.1572 cm^3

1. Standard Deviation, $s = \sqrt{[(8.2525\times10^{-9})/(10-1)]}$
 $= 3.028109\times10^{-5}$ g

 Standard Uncertainty, $u_w = s/\sqrt{n} = (3.028109\times10^{-5})/\sqrt{10}$
 $= 9.57572\times10^{-6}$ g

2. Standard Uncertainty in reference, u_r (type B)
   u=7µg; k=2
   u_r=3.5µg; k=1
3. Standard Uncertainty in air buoyancy correction, u_b (type B)

   Uncertainty in density of test weight = 100 mg/cm^3; k=1

   Uncertainty in density of reference weight = 70 mg/cm^3; k=1

   Uncertainty in the volume of test weight = 0.283446 cm^3

   Uncertainty in the volume of reference weight = 0.22151 cm^3

   Now,

   Uncertainty in the formula used, $u_f = 2\times10^{-4}.\rho_a$

   Uncertainty in barometer, u_p = 0.06 mbar; k=1

   Uncertainty in temperature, u_t = 0.15 $°C$; k=1

   Uncertainty in relative humidity, u_{rh} = 0.65 %; k=1

   Standard Uncertainty of the air density, u_{pa}

   $u_{pa} = \rho_a \times \sqrt{}\ [(u_r/\rho_a)^2 + (u_p/p)^2 + (u_t/t)^2 + (u_{r.h.}/10^4)^2]$

   Air density; $\rho_a = 0.34848(p) – 0.009(r.h.).e^{(0.061\times t)}/(273.15+t)$

   ρ_a = 1.16063 mg/cm^3

   $u_{pa} = 7.5002962\times10^{-3}$ mg/cm^3

   Standard Uncertainty due to buoyancy correction:

   $u_b = \sqrt{}\ [(v_t - v_r)^2 \times (u_{pa})^2 \times (u^2_{vt} - u^2_{vr}) \times (\rho_a - \rho_o)^2]$

   u_b = 0.010464605 mg

4. Standard Uncertainty due to display resolution (d) of a digital balance, u_d = 0.01 mg

   $u_d = d/\sqrt{6}$
   $= 0.01/\sqrt{6}$
   $= 4.08248\times10^{-3}$ mg

5. Expanded Uncertainty, $u_c = \sqrt{}\ [u^2_w + u^2_r + u^2_b + u^2_d]$
   u_c = 0.015169674 mg
   Effective 'dof'= $v_{eff} = (n-1)\times u^4_c/u^4_w$
   = 56.6 >20
   So, k = 2.

   Expanded Uncertainty = u = $u_c \times k$
   = 30.33948 μg
   ≈ 31 μg

Case 4:

Weight= 200 g

Height= Second floor

Materials used= A: Stainless steel B: Brass

Sl. No.	A_1 (g)	B_1 (g)	B_2 (g)	A_2 (g)	Δmi (g)	$(\Delta m - \Delta mi)^2$ (g)^2
1.	200.00261	200.00451	200.00452	200.00260	1.910×10^{-3}	4.410×10^{-10}
2.	200.00262	200.00454	200.00458	200.00265	1.925×10^{-3}	1.296×10^{-9}
3.	200.00262	200.00455	200.00452	200.00269	1.880×10^{-3}	8.100×10^{-11}
4.	200.00263	200.00448	200.00455	200.00259	1.905×10^{-3}	2.560×10^{-10}
5.	200.00256	200.00449	200.00448	200.00251	1.950×10^{-3}	3.721×10^{-9}
6.	200.00254	200.00443	200.00444	200.00258	1.875×10^{-3}	1.960×10^{-10}
7.	200.00254	200.00444	200.00440	200.00258	1.860×10^{-3}	8.410×10^{-10}
8.	200.00252	200.00443	200.00441	200.00259	1.865×10^{-3}	5.760×10^{-10}
9.	200.00257	200.00446	200.00442	200.00262	1.845×10^{-3}	1.936×10^{-9}
10.	200.00256	200.00444	200.00447	200.00260	1.875×10^{-3}	1.960×10^{-10}

Mean $\Delta mi = 1.889\times10^{-3}$ g

Mean $(\Delta m - \Delta mi)^2 = 9.54\times10^{-9}$ g^2

Mean Temp. = 22.84 ºC

Mean r.h.= 53.4 %

Mean Pressure= 992.5 mbar

Density of test weight= 8400 mg/cm^3

Density of reference weight= 7950 mg/cm^3

Volume of test weight = m/ρ_t =23.8095 cm^3

Volume of reference weight = m/ρ_r = 25.1572 cm^3

1. Standard Deviation, s = √ [(9.54×10^{-9})/ (10-1)]
   = 3.255764119×10^{-5} g

   Standard Uncertainty, $u_w = s/\sqrt{n}$ = (3.255764119×10^{-5})/√10
   = 1.029563×10^{-5} g

2. Standard Uncertainty in reference, u_r (type B)
   u=7µg; k=2

u_r=3.5µg; k=1

3. Standard Uncertainty in air buoyancy correction, u_b (type B)

   Uncertainty in density of test weight = 100 mg/cm^3; k=1

   Uncertainty in density of reference weight = 70 mg/cm^3; k=1

   Uncertainty in the volume of test weight = 0.283446 cm^3

   Uncertainty in the volume of reference weight = 0.22151 cm^3

   Now,

   Uncertainty in the formula used, $u_f = 2\times10^{-4}.\rho_a$

   Uncertainty in barometer, u_p = 0.06 mbar; k=1

   Uncertainty in temperature, u_t = 0.15 $°C$; k=1

   Uncertainty in relative humidity, u_{rh} = 0.65 %; k=1

   Standard Uncertainty of the air density, u_{pa}

   $u_{pa} = \rho_a \times \sqrt{} [(u_r/\rho_a)^2 + (u_p/p)^2 + (u_t/t)^2 + (u_{r.h.}/10^4)^2]$

   Air density; $\rho_a = 0.34848(p) - 0.009(r.h.).e^{(0.061\times t)}/(273.15+t)$

   ρ_a = 1.16196696 mg/cm^3

   $u_{pa} = 7.635365991\times10^{-3}$ mg/cm^3

   Standard Uncertainty due to buoyancy correction:

   $u_b = \sqrt{} [(v_t - v_r)^2 \times (u_{pa})^2 \times (u^2_{vt} - u^2_{vr}) \times (\rho_a - \rho_o)^2]$

   u_b = 0.010464605 mg

4. Standard Uncertainty due to display resolution (d) of a digital balance, u_d = 0.01 mg

   $u_d = d/\sqrt{6}$

   $= 0.01/\sqrt{6}$

   $= 4.08248\times10^{-3}$ mg

5. Expanded Uncertainty, $u_c = \sqrt{} [u^2_w + u^2_r + u^2_b + u^2_d]$

   u_c = 0.015634084 mg

   Effective 'dof'= $v_{eff} = (n-1)\times u^4_c/u^4_w$

   = 47.85 >20

   So, k = 2.

   Expanded Uncertainty = u = $u_c \times k$

   = 31.268168 μg

   ≈ 32 μg

Case 5:

Weight= 20g

Height= Ground floor

Materials used= A: Stainless steel B: Brass

Sl. No.	A_1 (g)	B_1 (g)	B_2 (g)	A_2 (g)	Δmi (g)	$(\Delta m - \Delta mi)^2$ (g^2)
1.	200.00019	200.00101	200.00101	200.00021	8.10×10^{-4}	1.1025×10^{-10}
2.	200.00021	200.00102	200.00102	200.00021	8.10×10^{-4}	1.1025×10^{-10}
3.	200.00016	200.00098	200.00098	200.00016	8.20×10^{-4}	2.5000×10^{-13}
4.	200.00016	200.00099	200.00099	200.00019	8.15×10^{-4}	3.0250×10^{-11}
5.	200.00017	200.00101	200.00099	200.00018	8.25×10^{-4}	2.0250×10^{-11}
6.	200.00015	200.00100	200.00100	200.00015	8.50×10^{-4}	8.7025×10^{-10}
7.	200.00016	200.00100	200.00099	200.00018	8.25×10^{-4}	2.0250×10^{-11}
8.	200.00018	200.00099	200.00099	200.00017	8.15×10^{-4}	3.0250×10^{-11}
9.	200.00018	200.00100	200.00100	200.00019	8.15×10^{-4}	3.0250×10^{-11}
10.	200.00017	200.00099	200.00099	200.00017	8.20×10^{-4}	2.5000×10^{-13}

Mean $\Delta mi = 8.205\times10^{-4}$ g

Mean $(\Delta m - \Delta mi)^2 = 1.2225\times10^{-9}\ g^2$

Mean Temp. = 24.336 ºC

Mean r.h.= 55.17 %

Mean Pressure= 993.6 mbar

Density of test weight= 8400 mg/cm^3

Density of reference weight= 7950 mg/cm^3

Volume of test weight = m/ρ_t =2.38095 cm^3

Volume of reference weight = m/ρ_r = 2.51572 cm^3

1. Standard Deviation, $s = \sqrt{[(1.2225\times10^{-9})/ (10-1)]}$
   $= 1.16547\times10^{-5}$ g

   Standard Uncertainty, $u_w = s/\sqrt{n} = (1.16547\times10^{-5})/\sqrt{10}$
   $= 3.6856\times10^{-6}$ g

2. Standard Uncertainty in reference, u_r (type B)
   u=3µg; k=2

u_r=1.5µg; k=1

3. Standard Uncertainty in air buoyancy correction, u_b (type B)

   Uncertainty in density of test weight = 100 mg/cm^3; k=1

   Uncertainty in density of reference weight = 70 mg/cm^3; k=1

   Uncertainty in the volume of test weight = 0.0283446 cm^3

   Uncertainty in the volume of reference weight = 0.022151 cm^3

   Now,

   Uncertainty in the formula used, $u_f = 2\times10^{-4}.\rho_a$

   Uncertainty in barometer, u_p = 0.06 mbar; k=1

   Uncertainty in temperature, $u_t = 0.15\ °C$; k=1

   Uncertainty in relative humidity, u_{rh} = 0.65 %; k=1

   Standard Uncertainty of the air density, u_{pa}

   $u_{pa} = \rho_a \times \sqrt{[(u_r/\rho_a)^2 + (u_p/p)^2 + (u_t/t)^2 + (u_{r.h.}/10^4)^2]}$

   Air density; $\rho_a = 0.34848(p) – 0.009(r.h.).e^{(0.061\times t)}/(273.15+t)$

   ρ_a = 1.156554 mg/cm^3

   $u_{pa} = 7.13315\times10^{-3}$ mg/cm^3

   Standard Uncertainty due to buoyancy correction:

   $u_b = \sqrt{[(v_t - v_r)^2 \times (u_{pa})^2 \times (u^2_{vt} - u^2_{vr}) \times (\rho_a - \rho_o)^2]}$

   u_b = 0.0010045056 mg

4. Standard Uncertainty due to display resolution (d) of a digital balance, u_d = 0.01 mg

   $u_d = d/\sqrt{6}$
   $= 0.01/\sqrt{6}$
   $= 4.08248\times10^{-3}$ mg

5. Expanded Uncertainty, $u_c = \sqrt{[u^2_w + u^2_r + u^2_b + u^2_d]}$

   u_c = 0.0057887236 mg

   Effective 'dof'= $v_{eff} = (n-1)\times u^4_c/u^4_w$
   = 54.76977 >20

   So, k = 2.

   Expanded Uncertainty = $u = u_c \times k$
   = 11.577447 μg
   ≈ 12 μg

Case 6:

Weight= 20 g

Height= Ground floor

Materials used= A: Stainless steel B: Brass

Sl. No.	A_1 (g)	B_1 (g)	B_2 (g)	A_2 (g)	Δmi (g)	$(\Delta m - \Delta mi)^2$ (g^2)
1.	200.00020	200.00099	200.00099	200.00018	8.00×10^{-4}	4.00×10^{-12}
2.	200.00019	200.00098	200.00099	200.00021	7.85×10^{-4}	1.69×10^{-10}
3.	200.00015	200.00094	200.00095	200.00015	7.95×10^{-4}	9.00×10^{-12}
4.	200.00013	200.00092	200.00093	200.00012	8.00×10^{-4}	4.00×10^{-12}
5.	200.00015	200.00097	200.00093	200.00016	7.95×10^{-4}	9.00×10^{-12}
6.	200.00016	200.00094	200.00095	200.00015	7.90×10^{-4}	6.40×10^{-11}
7.	200.00015	200.00095	200.00094	200.00013	8.05×10^{-4}	4.90×10^{-11}
8.	200.00014	200.00096	200.00096	200.00016	8.10×10^{-4}	1.44×10^{-10}
9.	200.00013	200.00094	200.00094	200.00015	8.00×10^{-4}	4.00×10^{-12}
10.	200.00014	200.00094	200.00095	200.00015	8.00×10^{-4}	4.00×10^{-12}

Mean $\Delta mi = 7.98\times10^{-4}$ g

Mean $(\Delta m - \Delta mi)^2 = 4.56\times10^{-10}$ g^2

Mean Temp. = 24.426 ºC

Mean r.h.= 55.13 %

Mean Pressure= 993.6 mbar

Density of test weight= 8400 mg/cm^3

Density of reference weight= 7950 mg/cm^3

Volume of test weight = m/ρ_t =2.38095 cm^3

Volume of reference weight = m/ρ_r = 2.51572 cm^3

1. Standard Deviation, $s = \sqrt{[(4.56\times10^{-10})/(10-1)]}$
   $= 7.118052\times10^{-6}$ g

   Standard Uncertainty, $u_w = s/\sqrt{n} = (7.118052\times10^{-6})/\sqrt{10}$
   $= 2.2509\times10^{-6}$ g

2. Standard Uncertainty in reference, u_r (type B)
   u=3µg; k=2

u_r=1.5µg; k=1

3. Standard Uncertainty in air buoyancy correction, u_b (type B)

 Uncertainty in density of test weight = 100 mg/cm^3; k=1

 Uncertainty in density of reference weight = 70 mg/cm^3; k=1

 Uncertainty in the volume of test weight = 0.0283446 cm^3

 Uncertainty in the volume of reference weight = 0.022151 cm^3

 Now,

 Uncertainty in the formula used, $u_f = 2\times10^{-4}.\rho_a$

 Uncertainty in barometer, u_p = 0.06 mbar; k=1

 Uncertainty in temperature, $u_t = 0.15\ °C$; k=1

 Uncertainty in relative humidity, u_{rh} = 0.65 %; k=1

 Standard Uncertainty of the air density, u_{pa}

 $u_{pa} = \rho_a \times \sqrt{[(u_r/\rho_a)^2 + (u_p/p)^2 + (u_t/t)^2 + (u_{r.h.}/10^4)^2]}$

 Air density; $\rho_a = 0.34848(p) – 0.009(r.h.).e^{(0.061\times t)}/(273.15+t)$

 ρ_a = 1.156169198 mg/cm^3

 $u_{pa} = 7.104536892\times10^{-3}$ mg/cm^3

 Standard Uncertainty due to buoyancy correction:

 $u_b = \sqrt{[(v_t - v_r)^2 \times (u_{pa})^2 \times (u^2_{vt} - u^2_{vr}) \times (\rho_a - \rho_o)^2]}$

 u_b = 0.002434 mg

4. Standard Uncertainty due to display resolution (d) of a digital balance, u_d = 0.01 mg

 $u_d = d/\sqrt{6}$

 $= 0.01/\sqrt{6}$

 $= 4.08248\times10^{-3}$ mg

5. Expanded Uncertainty, $u_c = \sqrt{[u^2_w + u^2_r + u^2_b + u^2_d]}$

 u_c = 0.0054687795 mg

 Effective 'dof'= $v_{eff} = (n-1)\times u^4_c/u^4_w$

 = 313.6023964 >20

 So, k = 2.

 Expanded Uncertainty = u = $u_c \times k$

 = 10.937559 μg

 ≈ 11 μg

Case 7:

Weight= 20 g

Height= Second floor

Materials used= A: Stainless steel B: Brass

Sl. No.	A_1 (g)	B_1 (g)	B_2 (g)	A_2 (g)	Δmi (g)	$(\Delta m - \Delta mi)^2$ (g^2)
1.	200.00049	200.00127	200.00131	200.00049	8.00×10^{-4}	7.56900×10^{-9}
2.	200.00050	200.00130	200.00129	200.00049	8.00×10^{-4}	7.56900×10^{-9}
3.	200.00052	200.00129	200.00129	200.00045	8.05×10^{-4}	6.72400×10^{-9}
4.	200.00047	200.00124	200.00124	200.00046	7.75×10^{-4}	1.25440×10^{-8}
5.	200.00045	200.00125	200.00123	200.00042	8.05×10^{-4}	6.72400×10^{-9}
6.	200.00045	200.00124	200.00126	200.00044	8.05×10^{-4}	6.72400×10^{-9}
7.	200.00043	200.00121	200.00124	200.00044	7.90×10^{-4}	9.40900×10^{-9}
8.	200.00046	200.00129	200.00129	200.00044	16.80×10^{-4}	6.28849×10^{-7}
9.	200.00049	200.00127	200.00126	200.00043	8.05×10^{-4}	6.72400×10^{-9}
10.	200.00047	200.00127	200.00124	200.00042	8.10×10^{-4}	5.92900×10^{-9}

Mean $\Delta mi = 8.87\times10^{-4}$ g

Mean $(\Delta m - \Delta mi)^2 = 6.98765\times10^{-7}$ g^2

Mean Temp. = 23.185 ºC

Mean r.h.= 54.9 %

Mean Pressure= 993 mbar

Density of test weight= 8400 mg/cm^3

Density of reference weight= 7950 mg/cm^3

Volume of test weight = m/ρ_t =2.38095 cm^3

Volume of reference weight = m/ρ_r = 2.51572 cm^3

1. Standard Deviation, s = $\sqrt{[(6.98765\times10^{-7})/(10-1)]}$
   = 2.7864×10^{-4} g
   Standard Uncertainty, $u_w = s/\sqrt{n} = (2.7864\times10^{-4})/\sqrt{10}$
   = 8.8113878×10^{-5} g

2. Standard Uncertainty in reference, u_r (type B)
   u=3µg; k=2
   u_r=1.5µg; k=1

3. Standard Uncertainty in air buoyancy correction, u_b (type B)

   Uncertainty in density of test weight = 100 mg/cm^3; k=1

   Uncertainty in density of reference weight = 70 mg/cm^3; k=1

   Uncertainty in the volume of test weight = 0.0283446 cm^3

   Uncertainty in the volume of reference weight = 0.022151 cm^3

   Now,

   Uncertainty in the formula used, $u_f = 2\times10^{-4}.\rho_a$

   Uncertainty in barometer, u_p = 0.06 mbar; k=1

   Uncertainty in temperature, $u_t = 0.15\ °C$; k=1

   Uncertainty in relative humidity, u_{rh} = 0.65 %; k=1

   Standard Uncertainty of the air density, u_{pa}

   $u_{pa} = \rho_a \times \sqrt{} [(u_r/\rho_a)^2 + (u_p/p)^2 + (u_t/t)^2 + (u_{r.h.}/10^4)^2]$

   Air density; $\rho_a = 0.34848(p) – 0.009(r.h.).e^{(0.061\times t)}/(273.15+t)$

   $\rho_a = 1.160875826$ mg/cm^3

   $u_{pa} = 7.514812634\times10^{-3}$ mg/cm^3

   Standard Uncertainty due to buoyancy correction:

   $u_b = \sqrt{} [(v_t - v_r)^2 \times (u_{pa})^2 \times (u^2_{vt} - u^2_{vr}) \times (\rho_a - \rho_o)^2]$

   u_b = 0.00408248 mg

4. Standard Uncertainty due to display resolution (d) of a digital balance, u_d = 0.01 mg

   $u_d = d/\sqrt{6}$

   $= 0.01/\sqrt{6}$

   $= 4.08248\times10^{-3}$ mg

5. Expanded Uncertainty, $u_c = \sqrt{} [u^2_w + u^2_r + u^2_b + u^2_d]$

   u_c = 0.0098820819 mg

   Effective 'dof'= $v_{eff} = (n-1)\times u^4_c/u^4_w$

   = 14.23 <20

   So, k = 1.

   Expanded Uncertainty = $u = u_c \times k$

   = 9.882081 μg

   $\approx$ 10 μg

Case 8:

Weight= 20g

Height= Second floor

Materials used= A: Stainless steel B: Brass

Sl. No.	A_1 (g)	B_1 (g)	B_2 (g)	A_2 (g)	Δmi (g)	$(\Delta m - \Delta mi)^2$ (g^2)
1.	200.00040	200.00127	200.00129	200.00046	8.50×10^{-4}	5.6250×10^{-11}
2.	200.00041	200.00129	200.00127	200.00044	8.55×10^{-4}	6.2500×10^{-12}
3.	200.00040	200.00127	200.00126	200.00044	8.45×10^{-4}	1.5625×10^{-10}
4.	200.00045	200.00130	200.00129	200.00043	8.55×10^{-4}	6.2500×10^{-12}
5.	200.00041	200.00129	200.00132	200.00046	8.70×10^{-4}	1.5625×10^{-10}
6.	200.00043	200.00127	200.00132	200.00045	8.55×10^{-4}	6.2500×10^{-12}
7.	200.00041	200.00127	200.00129	200.00044	8.55×10^{-4}	6.2500×10^{-12}
8.	200.00047	200.00129	200.00130	200.00042	8.50×10^{-4}	5.6250×10^{-11}
9.	200.00045	200.00131	200.00131	200.00042	8.75×10^{-4}	3.0625×10^{-10}
10.	200.00043	200.00131	200.00129	200.00044	8.65×10^{-4}	5.6250×10^{-11}

Mean $\Delta mi = 8.575\times10^{-4}$ g

Mean $(\Delta m - \Delta mi)^2 = 8.125\times10^{-10}$ g^2

Mean Temp. = 22.955 ºC

Mean r.h.= 53.3 %

Mean Pressure= 993 mbar

Density of test weight= 8400 mg/cm^3

Density of reference weight= 7950 mg/cm^3

Volume of test weight = m/ρ_t =2.38095 cm^3

Volume of reference weight = m/ρ_r = 2.51572 cm^3

1. Standard Deviation, $s = \sqrt{[(8.125\times10^{-10})/(10-1)]}$
   $= 2.7864\times10^{-4}$ g

   Standard Uncertainty, $u_w = s/\sqrt{n} = (2.7864\times10^{-4})/\sqrt{10}$
   $= 9.50146\times10^{-6}$ g

2. Standard Uncertainty in reference, u_r (type B)
   u=3µg; k=2

u_r=1.5µg; k=1

3. Standard Uncertainty in air buoyancy correction, u_b (type B)

   Uncertainty in density of test weight = 100 mg/cm^3; k=1

   Uncertainty in density of reference weight = 70 mg/cm^3; k=1

   Uncertainty in the volume of test weight = 0.0283446 cm^3

   Uncertainty in the volume of reference weight = 0.022151 cm^3

   Now,

   Uncertainty in the formula used, $u_f = 2\times10^{-4}.\rho_a$

   Uncertainty in barometer, u_p = 0.06 mbar; k=1

   Uncertainty in temperature, u_t = 0.15 $°C$; k=1

   Uncertainty in relative humidity, u_{rh} = 0.65 %; k=1

   Standard Uncertainty of the air density, u_{pa}

   $u_{pa} = \rho_a \times \sqrt{[(u_r/\rho_a)^2 + (u_p/p)^2 + (u_t/t)^2 + (u_{r.h.}/10^4)^2]}$

   Air density; $\rho_a = 0.34848(p) – 0.009(r.h.).e^{(0.061\times t)}/(273.15+t)$

   ρ_a = 1.162070 mg/cm^3

   $u_{pa} = 7.597830211\times10^{-3}$ mg/cm^3

   Standard Uncertainty due to buoyancy correction:

   $u_b = \sqrt{[(v_t - v_r)^2 \times (u_{pa})^2 \times (u^2_{vt} - u^2_{vr}) \times (\rho_a - \rho_o)^2]}$

   u_b = 0.001057323321 mg

4. Standard Uncertainty due to display resolution (d) of a digital balance, u_d = 0.01 mg

   $u_d = d/\sqrt{6}$

   $= 0.01/\sqrt{6}$

   $= 4.08248\times10^{-3}$ mg

5. Expanded Uncertainty, $u_c = \sqrt{[u^2_w + u^2_r + u^2_b + u^2_d]}$

   u_c = 0.005390951025 mg

   Effective ‘dof’= $v_{eff} = (n-1)\times u^4_c/u^4_w$

   = 93.27 > 20

   So, k = 2.

   Expanded Uncertainty = u = $u_c \times k$

   = 10.781902 μg

   ≈ 11 μg

Case 9:

Weight= 20g

Height= Ground floor

Materials used= A: Stainless steel B: Brass

Sl. No.	A_1 (g)	B_1 (g)	B_2 (g)	A_2 (g)	Δmi (g)	$(\Delta m - \Delta mi)^2$ (g^2)
1.	200.000144	200.000952	200.000944	200.000148	8.02×10^{-4}	7.840×10^{-12}
2.	200.000142	200.000940	200.000936	200.000132	8.01×10^{-4}	1.444×10^{-11}
3.	200.000126	200.000940	200.000932	200.000136	8.05×10^{-4}	4.000×10^{-14}
4.	200.000134	200.000932	200.000936	200.000142	7.96×10^{-4}	7.744×10^{-11}
5.	200.000140	200.000938	200.000936	200.000124	8.05×10^{-4}	4.000×10^{-14}
6.	200.000120	200.000936	200.000940	200.000136	8.10×10^{-4}	2.704×10^{-11}
7.	200.000132	200.000938	200.000944	200.000144	8.03×10^{-4}	3.240×10^{-12}
8.	200.000134	200.000938	200.000952	200.000128	8.14×10^{-4}	8.464×10^{-11}
9.	200.000142	200.000958	200.000944	200.000138	8.11×10^{-4}	3.844×10^{-11}
10.	200.000134	200.000938	200.000950	200.000152	8.01×10^{-4}	1.444×10^{-11}

Mean $\Delta mi = 8.048\times10^{-4}$ g

Mean $(\Delta m - \Delta mi)^2 = 2.676\times10^{-10}\ g^2$

Mean Temp. = 24.336 ºC

Mean r.h.= 55.17 %

Mean Pressure= 993.6 mbar

Density of test weight= 8400 mg/cm^3

Density of reference weight= 7950 mg/cm^3

Volume of test weight = m/ρ_t =2.38095 cm^3

Volume of reference weight = m/ρ_r = 2.51572 cm^3

1. Standard Deviation, $s = \sqrt{[(2.676\times10^{-10})/(10-1)]}$
   $= 5.4528\times10^{-6}$ g

   Standard Uncertainty, $u_w = s/\sqrt{n} = (5.4528\times10^{-6})/\sqrt{10}$
   $= 1.72433\times10^{-6}$ g

2. Standard Uncertainty in reference, u_r (type B)
   u=3µg; k=2

u_r=1.5µg; k=1

3. Standard Uncertainty in air buoyancy correction, u_b (type B)

   Uncertainty in density of test weight = 100 mg/cm^3; k=1

   Uncertainty in density of reference weight = 70 mg/cm^3; k=1

   Uncertainty in the volume of test weight = 0.0283446 cm^3

   Uncertainty in the volume of reference weight = 0.022151 cm^3

   Now,

   Uncertainty in the formula used, $u_f = 2\times10^{-4}.\rho_a$

   Uncertainty in barometer, u_p = 0.06 mbar; k=1

   Uncertainty in temperature, u_t = 0.15 $°C$; k=1

   Uncertainty in relative humidity, u_{rh} = 0.65 %; k=1

   Standard Uncertainty of the air density, u_{pa}

   $u_{pa} = \rho_a \times \sqrt{[(u_r/\rho_a)^2 + (u_p/p)^2 + (u_t/t)^2 + (u_{r.h.}/10^4)^2]}$

   Air density; $\rho_a = 0.34848(p) - 0.009(r.h.).e^{(0.061\times t)}/(273.15+t)$

   ρ_a = 1.156554 mg/cm^3

   $u_{pa} = 7.13315 \times10^{-3}$ mg/cm^3

   Standard Uncertainty due to buoyancy correction:

   $u_b = \sqrt{[(v_t - v_r)^2 \times (u_{pa})^2 \times (u^2_{vt} - u^2_{vr}) \times (\rho_a - \rho_o)^2]}$

   u_b = 0.0010045056 mg

4. Standard Uncertainty due to display resolution (d) of a digital balance, u_d = 0.002 mg

   $u_d = d/\sqrt{6}$
   $= 0.002/\sqrt{6}$
   $= 8.1649658\times10^{-4}$ mg

5. Expanded Uncertainty, $u_c = \sqrt{[u^2_w + u^2_r + u^2_b + u^2_d]}$

   u_c = 0.00262659706 mg

   Effective 'dof'= $v_{eff} = (n-1)\times u^4_c/u^4_w$
   = 48.454574 > 20

   So, k = 2.

   Expanded Uncertainty = u = $u_c \times k$
   = 5.25319412 μg
   ≈ 6 μg

Case 10:

Weight= 20g

Height= Ground floor

Materials used= A: Stainless steel B: Brass

Sl. No.	A_1 (g)	B_1 (g)	B_2 (g)	A_2 (g)	Δmi (g)	$(\Delta m - \Delta mi)^2$ (g^2)
1.	200.000136	200.000934	200.000940	200.000146	7.96×10^{-4}	1.8769×10^{-10}
2.	200.000152	200.000960	200.000962	200.000150	8.10×10^{-4}	9.0000×10^{-14}
3.	200.000136	200.000950	200.000942	200.000130	8.13×10^{-4}	1.0890×10^{-11}
4.	200.000138	200.000948	200.000942	200.000134	8.09×10^{-4}	4.9000×10^{-13}
5.	200.000132	200.000948	200.000946	200.000144	8.09×10^{-4}	4.9000×10^{-13}
6.	200.000142	200.000960	200.000964	200.000146	8.18×10^{-4}	6.8890×10^{-11}
7.	200.000150	200.000954	200.000946	200.000150	8.00×10^{-4}	9.4090×10^{-11}
8.	200.000142	200.000958	200.000954	200.000154	8.08×10^{-4}	2.8900×10^{-12}
9.	200.000142	200.000962	200.000956	200.000148	8.14×10^{-4}	1.8490×10^{-11}
10.	200.000130	200.000950	200.000950	200.000130	8.20×10^{-4}	1.0609×10^{-10}

Mean $\Delta mi = 8.097\times10^{-4}$ g

Mean $(\Delta m - \Delta mi)^2 = 4.901\times10^{-10}$ g^2

Mean Temp. = 24.336 ºC

Mean r.h.= 55.17 %

Mean Pressure= 993.6 mbar

Density of test weight= 8400 mg/cm^3

Density of reference weight= 7950 mg/cm^3

Volume of test weight = m/ρ_t =2.38095 cm^3

Volume of reference weight = m/ρ_r = 2.51572 cm^3

1. Standard Deviation, $s = \sqrt{[(4.901\times10^{-10})/(10-1)]}$
   $= 7.3794\times10^{-6}$ g

   Standard Uncertainty, $u_w = s/\sqrt{n} = (7.3794\times10^{-6})/\sqrt{10}$
   $= 2.33357\times10^{-6}$ g

2. Standard Uncertainty in reference, u_r (type B)
   u=3µg; k=2

u_r=1.5µg; k=1

3. Standard Uncertainty in air buoyancy correction, u_b (type B)

   Uncertainty in density of test weight = 100 mg/cm^3; k=1

   Uncertainty in density of reference weight = 70 mg/cm^3; k=1

   Uncertainty in the volume of test weight = 0.0283446 cm^3

   Uncertainty in the volume of reference weight = 0.022151 cm^3

   Now,

   Uncertainty in the formula used, $u_f = 2\times10^{-4}.\rho_a$

   Uncertainty in barometer, u_p = 0.06 mbar; k=1

   Uncertainty in temperature, u_t = 0.15 $°C$; k=1

   Uncertainty in relative humidity, u_{rh} = 0.65 %; k=1

   Standard Uncertainty of the air density, u_{pa}

   $u_{pa} = \rho_a \times \sqrt{[(u_r/\rho_a)^2 + (u_p/p)^2 + (u_t/t)^2 + (u_{r.h.}/10^4)^2]}$

   Air density; $\rho_a = 0.34848(p) - 0.009(r.h.).e^{(0.061\times t)}/(273.15+t)$

   ρ_a = 1.156554 mg/cm^3

   $u_{pa} = 7.13315 \times10^{-3}$ mg/cm^3

   Standard Uncertainty due to buoyancy correction:

   $u_b = \sqrt{[(v_t - v_r)^2 \times (u_{pa})^2 \times (u^2_{vt} - u^2_{vr}) \times (\rho_a - \rho_o)^2]}$

   u_b = 0.0010045056 mg

4. Standard Uncertainty due to display resolution (d) of a digital balance, u_d = 0.002 mg

   $u_d = d/\sqrt{6}$
   $= 0.002/\sqrt{6}$

   $= 8.1649658\times10^{-4}$ mg

5. Expanded Uncertainty, $u_c = \sqrt{[u^2_w + u^2_r + u^2_b + u^2_d]}$
   u_c = 0.003061249273 mg

   Effective 'dof'= $v_{eff} = (n-1)\times u^4_c/u^4_w$
   = 26.6534822 > 20

   So, k = 2.

   Expanded Uncertainty = u = $u_c \times k$
   = 6.122498546 μg
   ≈ 7 μg

Case 11:

Weight= 20g

Height= Second floor

Materials used= A: Stainless steel B: Brass

Sl. No.	A_1 (g)	B_1 (g)	B_2 (g)	A_2 (g)	Δmi (g)	$(\Delta m - \Delta mi)^2$ (g^2)
1.	200.000122	200.000904	200.000916	200.000134	7.82×10^{-4}	1.000×10^{-14}
2.	200.000128	200.000908	200.000908	200.000120	7.84×10^{-4}	3.610×10^{-12}
3.	200.000124	200.000906	200.000890	200.000124	7.74×10^{-4}	6.561×10^{-11}
4.	200.000124	200.000904	200.000900	200.000118	7.81×10^{-4}	1.210×10^{-12}
5.	200.000122	200.000898	200.000904	200.000114	7.83×10^{-4}	8.100×10^{-13}
6.	200.000114	200.000904	200.000904	200.000118	7.88×10^{-4}	3.481×10^{-11}
7.	200.000112	200.000896	200.000898	200.000110	7.86×10^{-4}	1.521×10^{-11}
8.	200.000108	200.000884	200.000876	200.000106	7.73×10^{-4}	8.281×10^{-11}
9.	200.000098	200.000884	200.000884	200.000102	7.84×10^{-4}	3.610×10^{-12}
10.	200.000090	200.000880	200.000878	200.000096	7.86×10^{-4}	1.521×10^{-11}

Mean $\Delta mi = 7.821\times10^{-4}$ g

Mean $(\Delta m - \Delta mi)^2 = 2.2288\times10^{-10}$ g^2

Mean Temp. = 23.08 ºC

Mean r.h.= 49 %

Mean Pressure= 992 mbar

Density of test weight= 8400 mg/cm^3

Density of reference weight= 7950 mg/cm^3

Volume of test weight = m/ρ_t =2.38095 cm^3

Volume of reference weight = m/ρ_r = 2.51572 cm^3

1. Standard Deviation, $s = \sqrt{[(2.2288\times10^{-10})/(10-1)]}$
   $= 4.976388695\times10^{-6}$ g

   Standard Uncertainty, $u_w = s/\sqrt{n} = (4.976388695\times10^{-6})/\sqrt{10}$
   $= 1.573672\times10^{-6}$ g

2. Standard Uncertainty in reference, u_r (type B)
   u=3µg; k=2

u_r=1.5µg; k=1

3. Standard Uncertainty in air buoyancy correction, u_b (type B)

   Uncertainty in density of test weight = 100 mg/cm^3; k=1

   Uncertainty in density of reference weight = 70 mg/cm^3; k=1

   Uncertainty in the volume of test weight = 0.0283446 cm^3

   Uncertainty in the volume of reference weight = 0.022151 cm^3

   Now,

   Uncertainty in the formula used, $u_f = 2\times10^{-4}.\rho_a$

   Uncertainty in barometer, u_p = 0.06 mbar; k=1

   Uncertainty in temperature, u_t = 0.15 °C; k=1

   Uncertainty in relative humidity, u_{rh} = 0.65 %; k=1

   Standard Uncertainty of the air density, u_{pa}

   $u_{pa} = \rho_a \times \sqrt{[(u_r/\rho_a)^2 + (u_p/p)^2 + (u_t/t)^2 + (u_{r.h.}/10^4)^2]}$

   Air density; $\rho_a = 0.34848(p) - 0.009(r.h.).e^{(0.061\times t)}/(273.15+t)$

   ρ_a = 1.106124464 mg/cm^3

   u_{pa} = 7.192924114 $\times10^{-3}$ mg/cm^3

   Standard Uncertainty due to buoyancy correction:

   $u_b = \sqrt{[(v_t - v_r)^2 \times (u_{pa})^2 \times (u^2_{vt} - u^2_{vr}) \times (\rho_a - \rho_o)^2]}$

   u_b = 0.001130387394 mg

4. Standard Uncertainty due to display resolution (d) of a digital balance, u_d = 0.002 mg

   $u_d = d/\sqrt{6}$
   $= 0.002/\sqrt{6}$
   $= 8.1649658\times10^{-4}$ mg

5. Expanded Uncertainty, $u_c = \sqrt{[u^2_w + u^2_r + u^2_b + u^2_d]}$

   u_c = 0.0025828058 mg

   Effective 'dof'= $v_{eff} = (n-1)\times u^4_c/u^4_w$
   = 65.3059 > 20

   So, k = 2.

   Expanded Uncertainty = u = $u_c \times k$
   = 5.1656116 μg
   ≈ 6 μg

Case 12:

Weight= 20 g

Height= Second floor

Materials used= A: Stainless steel B: Brass

Sl. No.	A_1 (g)	B_1 (g)	B_2 (g)	A_2 (g)	Δmi (g)	$(\Delta m - \Delta mi)^2$ (g^2)
1.	200.000101	200.000888	200.000886	200.000102	7.855×10^{-4}	4.000×10^{-12}
2.	200.000102	200.000892	200.000886	200.000106	7.850×10^{-4}	6.250×10^{-12}
3.	200.000100	200.000890	200.000888	200.000102	7.880×10^{-4}	2.500×10^{-13}
4.	200.000096	200.000890	200.000882	200.000100	7.880×10^{-4}	2.500×10^{-13}
5.	200.000096	200.000884	200.000884	200.000092	7.900×10^{-4}	6.250×10^{-12}
6.	200.000088	200.000874	200.000878	200.000082	7.910×10^{-4}	1.225×10^{-11}
7.	200.000082	200.000872	200.000868	200.000074	7.920×10^{-4}	2.025×10^{-11}
8.	200.000068	200.000856	200.000856	200.000068	7.880×10^{-4}	2.500×10^{-13}
9.	200.000070	200.000846	200.000846	200.000064	7.790×10^{-4}	7.225×10^{-11}
10.	200.000059	200.000848	200.000846	200.000058	7.885×10^{-4}	1.000×10^{-12}

Mean $\Delta mi = 7.875\times10^{-4}$ g

Mean $(\Delta m - \Delta mi)^2 = 1.23\times10^{-10}$ g^2

Mean Temp. = 23.395 ºC

Mean r.h.= 49.65 %

Mean Pressure= 992.5 mbar

Density of test weight= 8400 mg/cm^3

Density of reference weight= 7950 mg/cm^3

Volume of test weight = m/ρ_t =2.38095 cm^3

Volume of reference weight = m/ρ_r = 2.51572 cm^3

1. Standard Deviation, s = $\sqrt{}$ (1.23×10^{-10})/ ($\sqrt{}$10-1)
   = 3.696845×10^{-6} g

   Standard Uncertainty, $u_w = s/\sqrt{n} = (3.696845\times10^{-6})/\sqrt{10}$
   = 1.169045×10^{-6} g

2. Standard Uncertainty in reference, u_r (type B)
   u=3µg; k=2

u_r=1.5μg; k=1

3. Standard Uncertainty in air buoyancy correction, u_b (type B)

Uncertainty in density of test weight = 100 mg/cm^3; k=1

Uncertainty in density of reference weight = 70 mg/cm^3; k=1

Uncertainty in the volume of test weight = 0.0283446 cm^3

Uncertainty in the volume of reference weight = 0.022151 cm^3

Now,

Uncertainty in the formula used, $u_f = 2\times10^{-4}.\rho_a$

Uncertainty in barometer, u_p = 0.06 mbar; k=1

Uncertainty in temperature, u_t = 0.15 °C ; k=1

Uncertainty in relative humidity, $_{rh}$ = 0.65 %; k=1

Standard Uncertainty of the air density, u_{pa}

$u_{pa} = \rho_a \times \sqrt{} \, [(u_r/\rho_a)^2 + (u_p/p)^2 + (u_t/t)^2 + (u_{r.h.}/10^4)^2]$

Air density; $\rho_a = 0.34848(p) – 0.009(r.h.).e^{(0.061\times t)}/(273.15+t)$

ρ_a = 1.10353588 mg/cm^3

u_{pa} = 7.079578995 $\times10^{-3}$ mg/cm^3

Standard Uncertainty due to buoyancy correction:

$u_b = \sqrt{} \, [(v_t - v_r)^2 \times (u_{pa})^2 \times (u^2_{vt} - u^2_{vr}) \times (\rho_a - \rho_o)^2]$

u_b = 0.0011257414 mg

4. Standard Uncertainty due to display resolution (d) of a digital balance, u_d = 0.002 mg

$u_d = d/\sqrt{6}$
$= 0.002/\sqrt{6}$
$= 8.1649658\times10^{-4}$ mg

5. Expanded Uncertainty, $u_c = \sqrt{} \, [u^2_w + u^2_r + u^2_b + u^2_d]$

u_c = 0.002355979259 mg

Effective 'dof'= $v_{eff} = (n-1)\times u^4_c/u^4_w$
= 148.46 > 20

So, k = 2.

Expanded Uncertainty = u = $u_c \times k$
= 4.711958518 μg
≈ 5 μg

Tabular Form of the experimental values:

Sl. No.	Weight (g)	Floor	Display Resolution, d (mg)	Mean (g)	Expanded Uncertainty (μg)
1	200.00	Ground	0.010	2.006×10^{-3}	28
2	200.00	Ground	0.010	1.970×10^{-3}	27
3	200.00	Second	0.010	1.973×10^{-3}	31
4	200.00	Second	0.010	1.889×10^{-3}	32
5	20.00	Ground	0.010	8.205×10^{-4}	12
6	20.00	Ground	0.010	7.980×10^{-4}	11
7	20.00	Second	0.010	8.870×10^{-4}	10
8	20.00	Second	0.010	8.575×10^{-4}	11
9	20.00	Ground	0.002	8.048×10^{-4}	6
10	20.00	Ground	0.002	8.097×10^{-4}	7
11	20.00	Second	0.002	7.821×10^{-4}	6
12	20.00	Second	0.002	7.875×10^{-4}	5

5.2 TASK 2: Density measurement of different samples of water around the campus.

Descriptions of samples

In general, distilled water is used for volume determination of volumetric instruments. But in case of large volumetric vessels, use of distilled water is not practicable; hence, tap water is commonly used. Density of tap water is determined separately for applying corrections in volume. In this exercise, we have collected tap water samples in different locations in CSIR-NPL.

Fig. 2: Water samples

CASE: Determination of volume of volumetric measure (V.M.)

Name of item: Distilled water

Date: 08/07/2019

Environmental Conditions

Sl. No.	Weight of distilled water (g)	Water Temp. (ºC)	Ambient Temp., t (ºC)	Relative Humidity, r.h. (%)	Pressure, p (mbar)
1	17.7621	24.5	24.91	61.1	971.952
2	17.7640	24.6	24.95	61.1	971.958
3	17.7628	24.7	24.99	61.1	971.946
4	17.7675	24.7	25.01	61.0	972.937
5	17.7622	24.7	25.05	61.0	971.969
Mean:	**17.7637**	**24.66**	**24.982**	**61.06**	**973.306**

Calculation of air density using approximation formula:

ρ_a = [0.34848(P) – 0.009(R.H.). $e^{(0.061\times t)}$]/(273.15+t)

ρ_a = [0.34848(973.30575)-0.009(61.06). $e^{(0.061\times 24.982)}$]/ (273.15+24.982)

ρ_a = 1.129215058 mg/cm^3

Calculation of water density using Tanaka formula:
ρ_w = 0.99997495×[1-{(t-3.983035)^2×(t+301.797)/522528.9×(t+69.34881)}]

= 0.99997495× [1- {(24.66-3.983035)^2× (24.66+301.797)/522528.9× (24.66+69.34881)}]

= 0.997133784 g/ml

Volume of the VM @ 27 °C
v = (Weight of water) × {1/(ρ_w-ρ_a)} × {1-(ρ_a/ ρ_b)} × [1-Ɣ(t-27)]

v= (Weight of V.M.) ×{1/ (997.133784-1.129215058)} × {1-(1.129215058 /8000)} × [1-(33×10^{-6})

(24.66-27)]

v= 17.76372 ×1.003947259 ×10^{-3}

v= 17.833838 ml

CASE 1:

Name of item: Fluid Flow

Serial No. B1

Date: 26/06/2019

Density of tap water

Sl. No.	Temp (°C)	R.H. (%)	Pressure (mbar)	Air Density, ρ_a (mg/cm^3)	Weight of tap water (g)	Corrected weight of Water $\{1-(\rho_a/\rho_b)\}$	Volume of VM @ 27 °C (ml)	Water Temp, t (°C)	Corrected Volume of VM @ t ºC [1-Ɣ(t-27)] (ml)	Density of water, ρ_w (g/cm^3) (weight/volume of the VM) (g/ml)
1	24.17	59.0	975.0	1.134 967	17.770 7	17.768 2	17.833 8	25.2	17.832 7	0.996 380
2	24.22	58.9	975.0	1.134 766	17.771 6	17.769 1	17.833 8	24.9	17.832 6	0.996 440
3	24.25	58.8	975.0	1.134 650	17.776 3	17.773 8	17.833 8	24.8	17.832 5	0.996 707
4	24.29	58.7	974.9	1.134 375	17.771 0	17.768 5	17.833 8	24.6	17.832 4	0.996 416
5	24.28	58.7	975.0	1.134 535	17.764 1	17.761 6	17.833 8	24.8	17.832 5	0.996 023
Mean	**24.24**	**58.82**	**974.98**	**1.134 659**				**24.86**		**0.996 393**

Volume of the volumetric instrument =17.833838 ml

$\rho_b = 8$ g/cm^3

Calculation of air density using approximation formula:

ρ_a = [0.34848(P) – 0.009(R.H.). $e^{(0.061\times t)}$]/(273.15+t

CASE 2:

Name of item: Force Standard

Serial No. B2

Date: 03/07/2019

Density of tap water

S.NO	Temp (°C)	R.H. (%)	Pressure (mbar)	Air Density, ρ_a (mg/cm^3)	Weight of tap water (g)	Corrected weight of Water $\{1-(\rho_a/\rho_b)\}$	Volume of VM @ 27 °C (ml)	Water Temp, t (°C)	Corrected Volume of VM @ t ºC [1-Ɣ(t-27)] (ml)	Density of water, ρ_w (g/cm^3) (weight/volume of the VM) (g/ml)
1	25.52	61.2	974.1	1.127 869	17.768 6	17.766 095	17.833 8	25.1	17.769 714	0.996 341
2	25.61	61.7	973.8	1.127 097	17.772 2	17.769 696	17.833 8	24.1	17.773 901	0.996 543
3	25.68	61.7	973.8	1.126 795	17.776 7	17.774 196	17.833 8	24.1	17.778 401	0.996 796
4	25.69	61.5	973.5	1.126 437	17.761 3	17.758 799	17.833 8	24.2	17.762 941	0.995 932
5	25.72	61.5	972.2	1.124 711	17.761 0	17.758 503	17.833 8	24.2	17.762 641	0.995 915
Mean	**25.64**	**61.5**	**973.9**	**1.126 582**				**24.14**		**0.996 306**

Volume of the volumetric instrument =17.833838 ml

$\rho_b = 8$ g/cm^3

Calculation of air density using approximation formula:

$\rho_a = [0.34848(P) – 0.009(R.H.).\ e^{(0.061\times t)}]/(273.15+t)$

CASE 3:

Name of item: Cafeteria

Serial No. B3

Date: 03/07/2019

Density of tap water

S.NO	Temp (°C)	R.H. (%)	Pressure (mbar)	Air Density, ρ_a (mg/cm^3)	Weight of tap water (g)	Corrected weight of Water $\{1-(\rho_a/\rho_b)\}$	Volume of VM @ 27 °C (ml)	Water Temp, t (°C)	Corrected Volume of VM @ t ºC [1-Ɣ(t-27)] (ml)	Density of water, ρ_w (g/cm^3) (weight/volume of the VM) (g/ml)
1	25.76	61.0	974.227	1.126 948	17.761 5	17.758 998	17.833 8	25.3	17.762 496	0.995 943
2	25.78	60.9	974.193	1.126 837	17.769 3	17.766 797	17.833 8	25.3	17.770 297	0.996 381
3	25.81	60.9	974.158	1.126 667	17.767 7	17.765 198	17.833 8	25.3	17.768 697	0.996 291
4	25.82	60.8	974.111	1.126 583	17.769 6	17.767 098	17.833 8	25.3	17.770 597	0.996 397
5	25.83	60.8	974.084	1.126 509	17.763 0	17.760 499	17.833 8	25.3	17.763 996	0.996 027
Mean	**25.8**	**60.88**	**974.155**	**1.126 709**				**25.3**		**0.996 208**

Volume of the volumetric instrument =17.833838 ml

ρ_b = 8 g/cm^3

Calculation of air density using approximation formula:

$\rho_a = [0.34848(P) – 0.009(R.H.). e^{(0.061\times t)}]/(273.15+t)$

CASE 4:

Name of item: Metrology

Serial No. B4

Date: 03/07/2019

Density of tap water

S.NO	Temp (°C)	R.H. (%)	Pressure (mbar)	Air Density, ρ_a (mg/cm^3)	Weight of tap water (g)	Corrected weight of Water $\{1-(\rho_a/\rho_b)\}$	Volume of VM @ 27 °C (ml)	Water Temp, t (°C)	Corrected Volume of VM @ t ºC [1-Ɣ(t-27)] (ml)	Density of water, ρ_w (g/cm^3) (weight/volume of the VM) (g/ml)
1	25.89	60.7	974.978	1.127 307	17.783 6	17.783 349	17.833 8	25.3	17.784 598	0.997182995
2	25.92	60.5	973.781	1.125 812	17.804 8	17.802 306	17.833 8	25.3	17.805 799	0.998371747
3	25.90	60.5	973.926	1.126 067	17.788 4	17.785 961	17.833 8	25.3	17.789 398	0.997452146
4	25.87	60.5	973.865	1.126 125	17.792 8	17.790 295	17.833 8	25.3	17.802 782	0.997698868
5	25.87	60.6	973.883	1.126 131	17.787 2	17.784 696	17.833 8	25.2	17.788 256	0.997384859
Mean	**25.89**	**60.56**	**973.887**	**1.126 288**				**25.28**		**0.997618123**

Volume of the volumetric instrument =17.833838 ml

$\rho_b = 8\ g/cm^3$

Calculation of air density using approximation formula:

$\rho_a = [0.34848(P) - 0.009(R.H.).\ e^{(0.061\times t)}]/(273.15+t)$

CASE 5:

Name of item: Civil

Serial No. B5

Date: 03/07/2019

Density of tap water

S.NO	Temp (°C)	R.H. (%)	Pressure (mbar)	Air Density, ρ_a (mg/cm^3)	Weight of tap water (g)	Corrected weight of Water $\{1-(\rho_a/\rho_b)\}$	Volume of VM @ 27 °C (ml)	Water Temp, t (°C)	Corrected Volume of VM @ t ºC [1-Ɣ(t-27)] (ml)	Density of water, ρ_w (g/cm^3) (weight/volume of the VM) (g/ml)
1	25.97	60.3	974.812	1.126 827	17.764 7	17.762 198	17.833 8	25.3	17.765 597	0.996 123
2	25.98	60.2	973.737	1.125 546	17.766 8	17.764 300	17.833 8	25.3	17.767 797	0.996 240
3	26.00	60.3	973.690	1.125 391	17.792 9	17.790 397	17.833 8	25.3	17.793 898	0.997 704
4	26.01	60.2	973.688	1.125 360	17.774 8	17.771 499	17.833 8	25.3	17.775 797	0.996 689
5	26.02	60.1	973.652	1.125 290	17.760 8	17.758 302	17.833 8	25.3	17.761 797	0.995 904
Mean	**25.994**	**60.22**	**973.592**	**1.125 683**				**25.3**		**0.996 532**

Volume of the volumetric instrument =17.833838 ml

$\rho_b = 8\ g/cm^3$

Calculation of air density using approximation formula:

$\rho_a = [0.34848(P) – 0.009(R.H.).\ e^{(0.061\times t)}]/(273.15+t)$

CASE 6:

Name of item: Complex

Serial No. B6

Date: 03/07/2019

Density of tap water

S.NO	Temp (°C)	R.H. (%)	Pressure (mbar)	Air Density, ρ_a (mg/cm^3)	Weight of tap water (g)	Corrected weight of Water $\{1-(\rho_a/\rho_b)\}$	Volume of VM @ 27 °C (ml)	Water Temp, t (°C)	Corrected Volume of VM @ t ºC [1-Ɣ(t-27)] (ml)	Density of water, ρ_w (g/cm^3) (weight/volume of the VM) (g/ml)
1	25.09	59.3	972.286	1.127 804	17.777 7	17.775 193	17.833 8	25.8	17.778 404	0.996 852
2	26.12	59.2	972.276	1.123 391	17.772 2	17.769 704	17.833 8	25.8	17.772 903	0.996 543
3	26.18	59.0	972.280	1.123 369	17.777 9	17.775 403	17.833 8	25.8	17.778 604	0.996 863
4	26.20	58.9	972.278	1.123 095	17.770 4	17.767 905	17.833 8	25.8	17.771 104	0.996 443
5	26.24	58.8	972.244	1.122 899	17.773 2	17.770 705	17.833 8	25.7	17.773 962	0.996 599
Mean	**25.97**	**59.04**	**972.222**	**1.124 112**				**25.78**		**0.996 660**

Volume of the volumetric instrument =17.833838 ml

$\rho_b = 8$ g/cm^3

Calculation of air density using approximation formula:

$\rho_a = [0.34848(P) – 0.009(R.H.).\ e^{(0.061\times t)}]/(273.15+t)$

CASE 7:

Name of item: Main Gate

Serial No. B7

Date: 04/07/2019

Density of tap water

S.NO	Temp (°C)	R.H. (%)	Pressure (mbar)	Air Density, ρ_a (mg/cm^3)	Weight of tap water (g)	Corrected weight of Water $\{1-(\rho_a/\rho_b)\}$	Volume of VM @ 27 °C (ml)	Water Temp, t (°C)	Corrected Volume of VM @ t ºC [1-Ɣ(t-27)] (ml)	Density of water, ρ_w (g/cm^3) (weight/volume of the VM) (g/ml)
1	25.99	60.1	972.342	1.123 893	17.770 6	17.768 103	17.833 8	25.8	17.771 303	0.996 454
2	26.02	60.0	971.298	1.122 563	17.773 3	17.774 805	17.833 8	25.8	17.774 004	0.996 605
3	26.06	59.7	971.168	1.122 284	17.768 7	17.766 207	17.833 8	25.8	17.769 036	0.996 347
4	26.08	59.7	972.073	1.123 252	17.769 6	17.767 105	17.833 8	25.8	17.770 304	0.996 398
5	26.09	59.6	972.023	1.123 166	17.765 7	17.763 206	17.833 8	25.7	17.766 462	0.996 179
Mean	**25.05**	**59.82**	**971.781**	**1.123 032**				**25.78**		**0.996 397**

Volume of the volumetric instrument =17.833838 ml

$\rho_b = 8$ g/cm^3

Calculation of air density using approximation formula:

$\rho_a = [0.34848(P) - 0.009(R.H.). e^{(0.061\times t)}]/(273.15+t)$

CASE 8:

Name of item: NPL colony

Serial No. B8

Date: 04/07/2019

Density of tap water

S.NO	Temp (°C)	R.H. (%)	Pressure (mbar)	Air Density, ρ_a (mg/cm^3)	Weight of tap water (g)	Corrected weight of Water $\{1-(\rho_a/\rho_b)\}$	Volume of VM @ 27 °C (ml)	Water Temp, t (°C)	Corrected Volume of VM @ t °C [1-Ɣ(t-27)] (ml)	Density of water, ρ_w (g/cm^3) (weight/volume of the VM) (g/ml)
1	26.12	59.5	971.952	1.122 967	17.772 8	17.711 971	17.833 8	25.7	17.773 562	0.999 859
2	26.14	59.6	971.958	1.122 876	17.776 7	17.719 745	17.833 8	25.8	17.777 404	0.999 859
3	26.17	59.5	971.946	1.122 748	17.766 4	17.699 217	17.833 8	25.8	17.767 103	0.999 859
4	26.16	59.5	972.937	1.123 939	17.766 0	17.698 420	17.833 8	25.8	17.766 703	0.999 859
5	26.16	59.5	971.969	1.122 817	17.764 1	17.694 634	17.833 8	25.8	17.764 803	0.999 859
Mean	**26.15**	**59.52**	**971.952**	**1.123 069**				**25.78**		**0.999 859**

Volume of the volumetric instrument =17.833838 ml

$\rho_b = 8$ g/cm^3

Calculation of air density using approximation formula:

$\rho_a = [0.34848(P) - 0.009(R.H.).\ e^{(0.061\times t)}]/(273.15+t)$

Tabular Form of the experimental values

S.no.	Name of the sample	Density of water, ρ_w (g/cm^3) (weight/volume of the VM) (g/ml)	Air Density, ρ_a (mg/cm^3)
B1	Fluid Flow	0.996 461	1.134 658
B2	Force Standard	0.996 306	1.126 582
B3	Cafeteria	0.996 208	1.126 709
B4	Metrology	0.997 618	1.126 288
B5	Civil	0.996 532	1.125 683
B6	Complex	0.996 660	1.124 111
B7	Main Gate	0.996 396	1.123 032
B8	NPL colony	0.996 396	1.123 069

5.3 HYDROMETERS

A **hydrometer** is an instrument used to measure the specific gravity or relative density of liquids, i.e. the ratio of the density of the liquid to the density of water.

Hydrometers are usually made of glass and consists of a cylindrical stem and a bulb weighted with a heavy material to make it float upright.

5.3.1 Calibration of Hydrometer:

Range: 1.000 – 1.050

Temperature: 24.83 ºC

Relative Humidity: 43.2%

Date: 12-6-2019

Description: Sr. no. IL-1009

Density hydrometer 15 ºC L56 SP (specifically for petroleum)

In case of low density, liquid used is xylene GR.

In case of high density, liquid used is tetrachloroethylene.

Std. no. ID	Observation Reading	Corrections	Corrected Value (cv)	Scale Point (sp)	(sp-cv)
9125	0.99975	+0.00010	0.99985	1.000	0.00015
8634	0.99980	+0.00005	0.99985	1.000	0.00015
9125	1.01950	+0.00015	1.01965	1.020	0.00035
8634	1.01960	+0.00010	1.01970	1.020	0.00035

5.4 TASK 3: Study of Optical Measurement instruments:

5.4.1 **Optical Flat:** An **optical flat** is an **optical-**grade piece of glass lapped and polished to be extremely **flat** on one or both sides, usually within a few tens of nanometres (billionths of a meter).

An optical flat utilizes the property of interference to exhibit the flatness on a desired surface. When an optical flat, also known as a test plate, and a work surface are placed in contact, an air wedge is formed. Areas between the flat and the work surface that are not in contact form this air wedge. The change in thickness of the air wedge will dictate the shape and orientation of the interference bands. The amount of curvature that is shown by the interference bands can be used to determine the flatness of the surface. If the air wedge is too large, then many closely spaced lines can appear, making it difficult to analyze the pattern formed. Simply applying pressure to the top of the optical flat alleviates the problem.

The determination of the flatness of any particular region of a surface is done by making two parallel imaginary lines; one between the ends of any one fringe, and the other at the top of that same fringe. The number of fringes located between the lines can be used to determine the flatness. Monochromatic light is used to create sharp contrast for viewing and in order to specify the flatness as a function of a single wavelength.

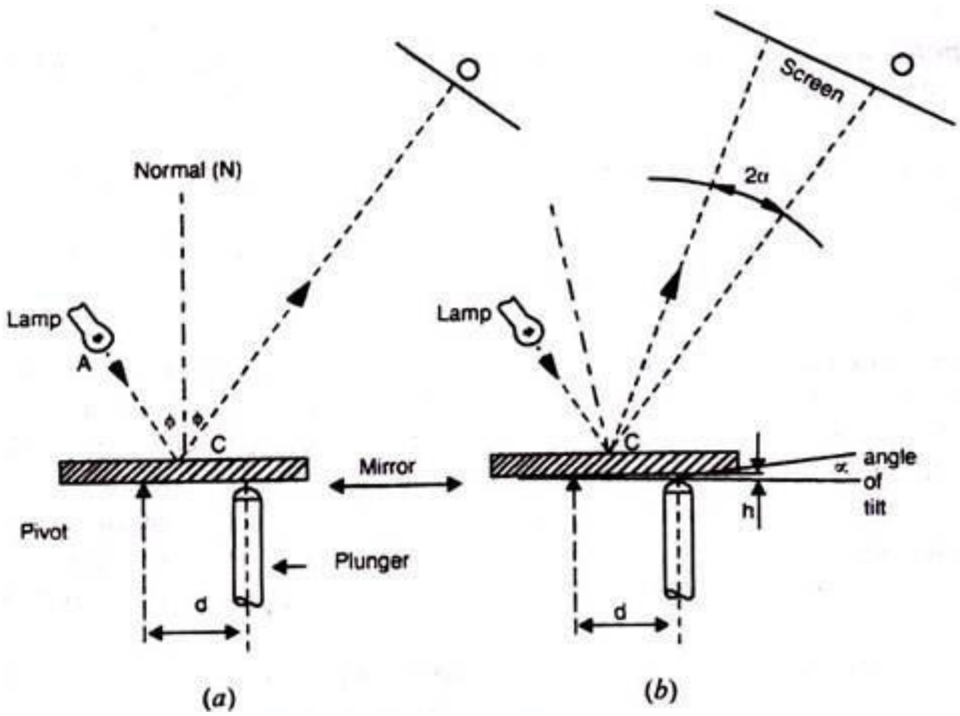
5.4.2 **Optical Comparator:** An **optical comparator** or **profile projector** is a device that applies the principles of optics to the inspection of manufactured parts. In a comparator, the magnified silhouette of a part is projected upon the screen, and the dimensions and geometry of the part are measured against prescribed limits.

Magnification in case of optical comparators is obtained with the help of light beams which has an advantage of being straight and weightless. Optical comparators have their own built in light source.

Principle of Working:

The optical principle adopted in the optical comparators is 'optical lever' and is shown in Fig.

If a ray of light AC strikes a mirror, it is reflected as ray CO such that:

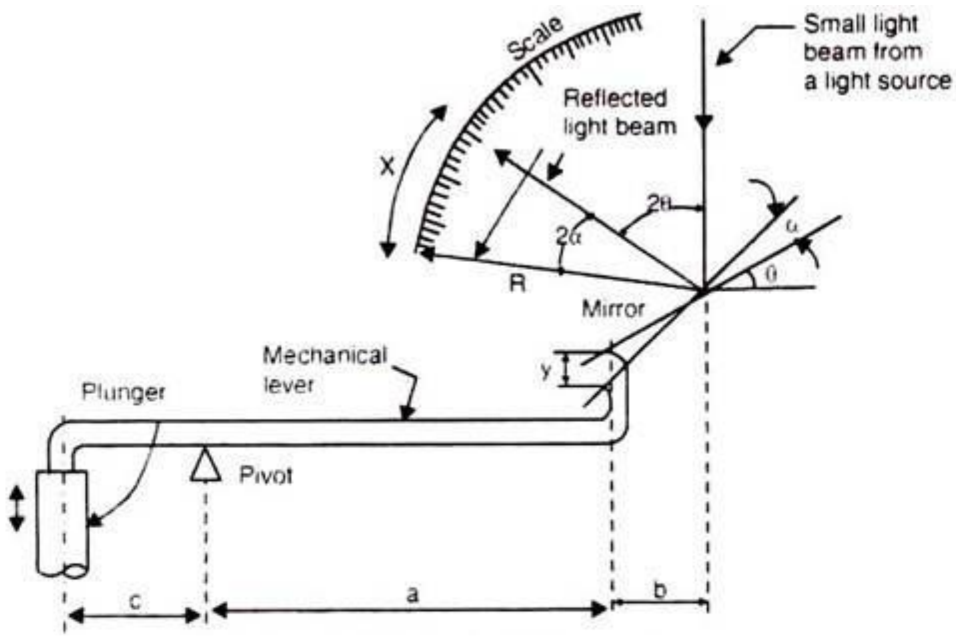


∠ACN =∠NCO

Now, if the mirror is tilted through an angle a, the reflected ray of light has moved through an angle of 2a.

In optical comparators, the minor is tilted by the measuring plunger movement and the movement of reflected light is recorded as an image on a screen.

Fig. below shows the working principle of an optical comparator in which both mechanical and optical levers are used.



Magnification:

The magnification of optical comparator is defined as "the ratio between distance moved by the indicating pointer (beam) and the displacement of plunger".

$$\text{Total Magnification} = \text{Mechanical Magnification} \times \text{Optical Magnification}$$

$$= \frac{a}{c} \times \frac{2R}{b}$$

$$= \frac{a}{c} \times \frac{X}{Y} \qquad \left(\therefore \frac{X}{Y} \simeq \frac{2R}{b}\right)$$

The Magnification of optical comparators is usually 1000:1, with measuring range of plus and minus 0.075 mm.

5.4.3 Interferometer: Interferometers are investigative tools used in many fields of science and engineering. They are called interferometers because they work by merging two or more sources of light to create an interference pattern, which can be measured and analyzed hence 'Interfere-o-meter' or interferometer.

The basic idea of interferometry involves taking a beam of light (or another type of electromagnetic radiation) and splitting it into two equal halves using what's called a **beam-splitter** (also called a half-transparent mirror or half-mirror). This is simply a piece of glass whose surface is very thinly coated with silver.

Interferometry: This technique allows a length to be measured in terms of the known wavelength of light. The light is split in two portions, by a partially reflecting mirror, which interfere after reflected back from two mirrors and a fringe pattern is imaged by a detector. When one mirror moves a distance equal to half of the wavelength, one fringe is observed to cross the detector. By electronic counting of the fringes, length can be determined to accuracies of about few nanometers.

5.5 TASK 4: STUDY OF KIBBLE BALANCE:

Dr. Bryan Kibble invented the watt balance in 1975 to improve the realization of the unit for electrical current, the ampere. With the discovery of the Quantum Hall effect in 1980 by Dr. Klaus von Klitzing and in conjunction with the previously predicted Josephson effect, this mechanical apparatus could be used to measure the Planck constant *h*. Following a proposal by Quinn, Mills, Williams, Taylor, and Mohr, the Kibble balance can be used to realize the unit of mass, the kilogram, by fixing the numerical value of Planck's constant. In 2017, the watt balance was renamed to the Kibble balance to honor the inventor, who passed in 2016.

The surrounding field is provided by a large permanent magnet system or an electromagnet. The moveable coil, once electrified, becomes an electromagnet with a field strength proportional to the amount of current it conducts. When the coil's field interacts with the surrounding magnetic field, an upward force is exerted on the coil. The magnitude of that force is controlled by adjusting the current.

The instrument was originally called a "watt" balance because it makes measurements of both current and voltage in the coil, the product of which is expressed in watts, the SI unit of power. That product equals the mechanical power of the test mass in motion.

- A test mass is placed on a pan that is attached to the coil. It exerts a downward force — its weight — which is equal to its mass (m) times the local gravitational field (g). The current applied to the coil is then adjusted until the upward force on the coil precisely balances the downward force of the weight. When the system reaches equilibrium, the current is recorded.
- At this point, it might seem that the job is finished. After all, the force (F) on the coil — which equals the weight of the mass — can be calculated with a simple equation that dates from the 19th century: $F = IBL$, where I is the current, B is the magnetic field strength, and L is the length of the wire in the coil. However, as a practical matter, the product BL is extremely hard to measure directly to the necessary accuracy.
- Michael Faraday discovered that a voltage is induced in a conductor when it travels through a magnetic field, and that the voltage is exactly proportional to the field strength and the velocity. So if the velocity is constant, the induced voltage is a sensitive measure of the field strength.

6. CONCLUSION:

In this training period, I got to learn about different procedures of measuring densities, volumes and how to calibrate weights.

I was assigned two fundamental tasks which were weight calibration at different altitudes and density measurements of various samples of water from different locations.

In case of weight calibration, I used two balances of different display resolutions at different heights. Deflection of weights was more accurate in balance of higher display resolution. The expanded uncertainty changes with respect to balances used and the height at which the calibration was done. The minute errors were due to instability, vibrational losses and problem with handling of weights and equipment.

In case of density measurement, I used eight samples of water from different locations around the NPL campus. More the density of that liquid the heavier is the liquid. The error could have been caused by the vibrational losses and atmospheric disturbances, instability etc.

In case of Optical measuring instruments, I studied about different type of optical instruments and learned the way it works. There are lot of precautions that are supposed to be taken care of before entering the black light room. I measured the deviation in the dimension of surfaces.

There is a secondary prototype of kibble balance at the mass metrology section of NPL where I learned about the principle of working of kibble balance used to measure the weight using Lorentz Law.

7. REFERENCES

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