Calibration of thermometer (Lecture and Training)

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Outline

1. Temperature measurement and calibration of thermometer (theory)

2. Calibration of thermometer (practice)
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<td>Calibration room(1F)</td>
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<td>Lecture room(3F)</td>
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1. Temperature measurement (theory)

1-1. Definition of temperature in the SI unit
1-2. ITS-90
1-3. Required uncertainty in meteorological observation
1-4. Types of thermometer
1-5. Traceability and calibration methods in JMA
1-1. Definition of temperature in the SI unit
Definition of the SI unit of thermodynamic temperature (kelvin)

"The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water."
1-2. ITS-90
The International Temperature Scale of 1990 (ITS-90)

\[ t/°C = T/K - 273.15 \]

- \( T \): thermodynamic temperature (unit: Kelvin)
- \( t \): temperature in degrees Celsius (unit: °C)

History
- 1927: ITS-27 (The International Temperature Scale of 1927)
- 1948: IPTS-48 (The International Practical Temperature Scale of 1948)
- 1968: IPTS-68 (The International Practical Temperature Scale of 1968)
- 1976: EPS-76 (The 1976 Provisional 0.5K to 30K Temperature Scale)
- 1990: ITS-90
The International Temperature Scale of 1990 (ITS-90)

Defined to correspond with thermodynamic temperature

- Fixed points
- Interpolation methods/instruments
- Interpolation formula
### The International Temperature Scale of 1990 (ITS-90)

#### Types of instrument for ITS-90 interpolation

<table>
<thead>
<tr>
<th>Type of instrument for interpolation</th>
<th>Applicable temperature range</th>
<th>Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium vapor pressure thermometer</td>
<td>0.65 K – 5.0 K</td>
<td>Relationship between vapor pressure and the temperature of helium-4 and helium-3</td>
</tr>
<tr>
<td>Interpolating gas thermometer</td>
<td>3.0 K – 24.5561 K</td>
<td>Relationship between pressure and the temperature of a constant volume of gas with helium-4 and helium-3 as working fluids</td>
</tr>
<tr>
<td>Platinum resistance thermometer</td>
<td>13.8033 K – 1,234.93 K</td>
<td>Relationship between electrical resistance and the temperature of platinum</td>
</tr>
<tr>
<td>Radiation thermometer</td>
<td>1,234.93 K –</td>
<td>Planck's law of radiation</td>
</tr>
</tbody>
</table>
Defining fixed points of the ITS-90

<table>
<thead>
<tr>
<th>Number</th>
<th>Temperature</th>
<th>Substance(*1)</th>
<th>State(*2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 to 5</td>
<td>-270.15 to -268.15</td>
<td>He</td>
</tr>
<tr>
<td>2</td>
<td>13.8033</td>
<td>-259.3467</td>
<td>e-H₂</td>
</tr>
<tr>
<td>3</td>
<td>~17</td>
<td>~-256.15</td>
<td>e-H₂(or He)</td>
</tr>
<tr>
<td>4</td>
<td>~20.3</td>
<td>~-252.85</td>
<td>e-H₂(or He)</td>
</tr>
<tr>
<td>5</td>
<td>24.5561</td>
<td>-248.5939</td>
<td>Ne</td>
</tr>
<tr>
<td>6</td>
<td>54.3584</td>
<td>-218.7916</td>
<td>O₂</td>
</tr>
<tr>
<td>7</td>
<td>83.8058</td>
<td>-189.3442</td>
<td>Ar</td>
</tr>
<tr>
<td>8</td>
<td>234.3156</td>
<td>-38.8344</td>
<td>Hg</td>
</tr>
<tr>
<td>9</td>
<td>273.16</td>
<td>0.01</td>
<td>H₂O</td>
</tr>
<tr>
<td>10</td>
<td>302.9146</td>
<td>29.7646</td>
<td>Ga</td>
</tr>
<tr>
<td>11</td>
<td>429.7485</td>
<td>156.5985</td>
<td>In</td>
</tr>
<tr>
<td>12</td>
<td>505.078</td>
<td>231.928</td>
<td>Sn</td>
</tr>
<tr>
<td>13</td>
<td>692.677</td>
<td>419.527</td>
<td>Zn</td>
</tr>
<tr>
<td>14</td>
<td>933.473</td>
<td>660.323</td>
<td>Al</td>
</tr>
<tr>
<td>15</td>
<td>1234.93</td>
<td>961.78</td>
<td>Ag</td>
</tr>
<tr>
<td>16</td>
<td>1337.33</td>
<td>1064.18</td>
<td>Au</td>
</tr>
<tr>
<td>17</td>
<td>1357.77</td>
<td>1084.62</td>
<td>Cu</td>
</tr>
</tbody>
</table>

(*1) All substances except 3He are of natural isotopic composition; e-H₂ is hydrogen at the equilibrium concentration of the ortho- and para-molecular forms.

(*2) V: vapour pressure pont; T: triple point(temperature at which the solid, liquid, and vapour phases are in equilibrium); G: gas thermometer point; M,F: melting point, freezing point

(temperature, at a pressure of 101325Pa, at which the solid and liquid phases are in equilibrium)
1-3. Required uncertainty in meteorological observation
<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
<th>Reported resolution</th>
<th>Mode of measurement/observation</th>
<th>Required measurement uncertainty</th>
<th>Sensor time constant</th>
<th>Output averaging time</th>
<th>Achievable measurement uncertainty</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2 K</td>
<td>Achievable uncertainty and effective time-constant may be affected by the design of the thermometer solar radiation screen Time-constant depends on the air-flow over the sensor</td>
</tr>
<tr>
<td>1.1 Air temperature</td>
<td>-80 to +60°C</td>
<td>0.1 K</td>
<td>I</td>
<td>0.3 K for ≤ -40°C 0.1 K for &gt; -40°C and ≤ +40°C 0.3 K for &gt; +40°C</td>
<td>20 s</td>
<td>1 min</td>
<td>0.2 K</td>
<td></td>
</tr>
<tr>
<td>1.2 Extremes of air temperature</td>
<td>-80 to +60°C</td>
<td>0.1 K</td>
<td>I</td>
<td>0.5 K for ≤ -40°C 0.3 K for &gt; -40°C and ≤ +40°C 0.5 K for &gt; +40°C</td>
<td>20 s</td>
<td>1 min</td>
<td>0.2 K</td>
<td></td>
</tr>
<tr>
<td>1.3 Sea surface temperature</td>
<td>-2 to +40°C</td>
<td>0.1 K</td>
<td>I</td>
<td>0.1 K</td>
<td>20 s</td>
<td>1 min</td>
<td>0.2 K</td>
<td></td>
</tr>
<tr>
<td>1.4 Soil temperature</td>
<td>-50 to +50°C</td>
<td>0.1 K</td>
<td>I</td>
<td></td>
<td>20 s</td>
<td>1 min</td>
<td>0.2 K</td>
<td></td>
</tr>
</tbody>
</table>

Air temperature
Achievable measurement uncertainty; 0.2 K
1-4. Types of thermometer
Types of thermometer

1. Contact-type thermometer
   - Platinum resistance thermometer
   - Liquid in glass thermometer
   - Thermocouple etc.

2. Radiation thermometer

These are mainly used for meteorological observation

CHINO Corporation (Japan)
Platinum resistance thermometer

2-conductor system

3-conductor system

4-conductor system

Internal conductor connection
Platinum resistance thermometer

Sheath (protective tube)
Internal filler (MgO)
Resistance element (Pt)
Internal conductor
constant-current power supply

Example of the relationship between temperature and resistance

Example of the relationship between temperature and resistance
Liquid in glass thermometer

**Principle;**
Liquid in glass thermometers make use of the differential expansion of a pure liquid with respect to its glass container to indicate the temperature.

**Precaution for use;**
If bubbles or breakage in the liquid column are found, repair is necessary.

Check that the scale plate of a thermometer does not move, and that the scale mark has not disappeared.
Liquid in glass thermometer

Caution for reading;
The observer ensures that the straight line from his/her eye to the meniscus, or index.
1-5. Traceability and calibration methods in JMA
Traceability of Temperature (JMA)

JMA Standard
- Platinum resistance thermometer
  - NSR-160 (Netsushin, Japan)
  - Alternating current bridge F-600 (ASL, UK)
  - Water triple-point cell (0.01 °C)

Working Standard
- Platinum resistance thermometer
  - TS-81A (Chino, Japan)
  - Alternating current bridge F-250 (ASL, UK)

Field Instruments
- Platinum resistance thermometer

Meteorological Instruments Center (JMA)

National Metrology Institute of Japan
- Temperature fixed points
  - Indium point (156.5985 °C)
  - Mercury point (-38.8344 °C)
  - Water triple point (0.01 °C)
- Standard resistor (100 Ω)
  - Calibration: every year
  - Check: every 6 months

Observatory (JMA)
- Platinum resistance thermometer
  - Check: every 3 months

Calibration:
- At the time of installation
- Every year
- Every 5 years

Check:
- Every 6 months
- Using water triple-point cell
- Every 3 months
- Using water triple-point cell

Tolerable range:
- ±0.4 °C
Measurement standard traceable to national standards

National Metrology Institute of Japan

Temperature fixed points
- Indium point (156.5985°C)
- Mercury point (-38.8344°C)
- Water triple point (0.01°C)

Standard resistor (100Ω)

Temperature fixed points
- Indium point (156.5985°C)
- Mercury point (-38.8344°C)
- Water triple point (0.01°C)

Platinum resistance thermometer
- NSR-160 (Netsushin, Japan)
- Alternating current bridge F-600 (ASL, UK)
- Water triple-point cell (0.01°C)
- Standard resistor (100Ω)

Check: every 6 months Using water triple-point cell
Calibration: every year

Platinum resistance thermometer
- TS-81A (Chino, Japan)
- Alternating current bridge F-250 (ASL, UK)

Calibration: at the time of installation
Calibration: every year

Standard resistor (100Ω)
Calibration: every year
- NSR-160
- every 2 years
- Water triple-point cell Standard resistor

Check: every 3 months (manned observatory)
- every year (automatic weather station)

Platinum resistance thermometer
- TS-81A (Chino, Japan)

Alternating current bridge F-250 (ASL, UK)

Mercury-in-glass thermometer

Tolerable range: ±0.4°C

Meteorological Instruments Center (JMA)

Field Instruments

Observatory (JMA)
Traceability of Temperature (JMA)

JMA Standard

Working Standard

Field Instruments

Meteorological Instruments Center (JMA)

Observatory (JMA)

Measurement standards traceable to national standards

National Metrology Institute of Japan

Temperature fixed points
- Indium point (156.5985°C)
- Mercury point (-38.8344°C)
- Water triple point (0.01°C)

Standard resistor (100Ω)

Platinum resistance thermometer
- NSR-160 (Netsushin, Japan)
- Alternating current bridge F-600 (ASL, UK)
- Water triple-point cell (0.01°C)

Platinum resistance thermometer
- TS-81A (Chino, Japan)
- Alternating current bridge F-250 (ASL, UK)

Calibration:
- Every year
- Every 2 years

Water triple-point cell

Standard resistor

Check:
- Every 6 months
Using water triple-point cell

Platinum resistance thermometer
- TS-81A (Chino, Japan)

Alternating current bridge
- F-250 (ASL, UK)

Calibration:
- Every 5 years

Check:
- Every 3 months
(manned observatory)
- Every year (automatic weather station)

Tolerable range:
±0.4°C

Platinum resistance thermometer

Alternating current bridge
- F-250 (ASL, UK)

Mercury-in-glass thermometer

Meteorological Instrument Center

Japan Meteorological Agency

Meteorological Agency

Jan. 2013 by JMA
Alternating current bridge (Working standard)

100Ω standard resistor

RS232C

Stabilized power supply

AC100V power supply

PC

Liquid bath chamber

Ice point inspection box (only for 0℃)

Liquid bath chamber

Platinum resistance thermometer (Working standard)

Platinum resistance thermometer (JMA standard)

Meteorological Instrument Center Japan Meteorological Agency
Traceability of Temperature (JMA)

- JMA Standard
- Working Standard
- Field Instruments

**National Metrology Institute of Japan**

**Meteorological Instruments Center (JMA)**

**Observatory (JMA)**

- Temperature fixed points
  - Indium point (156.5985°C)
  - Mercury point (-38.8344°C)
  - Water triple point (0.01 °C)

- Standard resistor (100Ω)
  - Calibration: every year
  - every 2 years
  - Water triple-point cell
  - Standard resistor

- Calibration: every year
  - NSR-160 (Netsushin, Japan)
  - Alternating current bridge F-600 (ASL, UK)
  - Water triple-point cell (0.01°C)

- Check: every 6 months
  - Using water triple-point cell

- Uncertainty (95% level)
  - 0 < T < 50°C: ±0.036K
  - T = 0°C: ±0.013K
  - -40 < T < 0°C: ±0.045K

- Mercury-in-glass thermometer
  - Tolerable range: ±0.4°C

- Alternating current bridge
  - F-250 (ASL, UK)

- Platinum resistance thermometer
  - TS-81A (Chino, Japan)
  - Calibration: every 5 years
  - at the time of installation

- Standard resistor (100Ω)
  - Calibration: every year (automatic weather station)
  - every year (manned observatory)

- Meteorological Instrument Center
Measurement standards traceable to national standards

National Metrology Institute of Japan

Temperature fixed points
- Indium point (156.5985°C)
- Mercury point (-38.8344°C)
- Water triple point (0.01°C)

Standard resistor (100Ω)

Calibration:
- every year
- every 2 years
- Water triple-point cell
- Standard resistor

Check:
- every 6 months
- Using water triple-point cell

Platinum resistance thermometer
- NSR-160 (Netsushin, Japan)
- Alternating current bridge F-600 (ASL, UK)
- Water triple-point cell (0.01°C)
- Standard resistor (100Ω)

Calibration:
- every year

Platinum resistance thermometer
- TS-81A (Chino, Japan)
- Alternating current bridge F-250 (ASL, UK)

Calibration:
- at the time of installation
- every 5 years
- every 3 months
- (manned observatory)
- every year (automatic weather station)

Check:
- every 3 months
- every year

Platinum resistance thermometer
- NSR-160
- every 2 years
- Water triple-point cell
- Standard resistor

Calibration:
- every year

Platinum resistance thermometer
- TS-81A (Chino, Japan)

Mercury-in-glass thermometer
- TS-81A (Chino, Japan)

Alternating current bridge
- F-250 (ASL, UK)

Tolerable range:
- ±0.4°C

Meteorological Instrument Center (JMA)

Observatory (JMA)

Traceability of Temperature (JMA)

Jan. 2013 by JMA
<Not 0°C>

Alternating current bridge (Working standard)

Platinum resistance thermometer (Working standard)

Platinum resistance thermometer or Mercury-in-glass thermometer (Field instruments)

Liquid bath chamber

<0°C>

Ice point inspection box

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2. Calibration of thermometer (practice)
Today’s practice

1. Calibration practice at 0°C (Ice point) (Mr. NOMURA)
2. Calibration practice at 30°C (Liquid bath chamber) (Mr. NAKASHIMA)

Participants are separated into 2 groups. Each group do two practice in turn.
Today’s practice

Group A;
<Bangladesh, Cambodia, Laos, Maldives, Mongolia, Myanmar, Nepal>
1. Calibration practice at 0°C (Ice point)
2. Calibration practice at 30°C (Liquid bath chamber)

Group B; <Oman, Pakistan, Qatar, Sri Lanka, Thailand, VietNam, China>
1. Calibration practice at 30°C (Liquid bath chamber)
2. Calibration practice at 0°C (Ice point)
1. Calibration practice at 0°C (Ice point)

Calibrated items:
Liquid-in-glass thermometer : 3sets

Goal:
Estimate instrumental error at 0°C.
2. Calibration practice at 30°C (Liquid bath chamber)

Calibrated items:
- Liquid-in-glass thermometer: 1 set
- Platinum resistance thermometer: 1 set

Goal:
Estimate instrumental error and uncertainty at 30°C.
<Practice time>
Conditions (hypothesis)

1. Calibration method
   To compare working standard and instruments to be calibrated in chamber. Observer makes 5 times comparative reading.

2. Working standard
   (1) Standard uncertainty of the working standard is 0.03°C due to calibration certificate.
   (2) Minimum unit (resolution): 0.01°C

3. Instruments to be calibrated
   Minimum unit (resolution):
   - 0.01°C (Platinum resistance thermometer)
   - 0.1°C (Liquid-in-glass thermometer)

4. Chamber
   Distribution of temperature: ±0.03°C (manufacturer’s specification)
List up of input quantities and possible sources which effect measurement results

Reference standard

(a-3) Uncertainty of reference standard

(a-1) Variations in repeated observations

(a-2) Resolution

Instrument to be calibrated

(b-1) Variations in repeated observations

(b-2) Resolution

Chamber

(c-1) Distribution

Fishbone diagram
Uncertainty estimate example:

Liquid-in-glass thermometer;
Minimum unit (resolution): 0.1°C (Liquid-in-glass thermometer)
## Budget Sheet

<table>
<thead>
<tr>
<th>Input quantities</th>
<th>Standard uncertainty [°C]</th>
<th>Evaluation method</th>
<th>Sensitivity coefficients</th>
<th>Contribution to u(y) [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard [°C]</td>
<td>(a-1) Variation</td>
<td>?</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(a-2) Resolution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(a-3) Standard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To be calibrated</td>
<td>(b-1) Variation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(b-2) Resolution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chamber</td>
<td>(c-1) Distribution</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1. Calibration method
   To compare working standard and instruments to be calibrated in chamber.
   Observer makes 5 times comparative reading.
(a-1),(b-1)
Variations in repeated observations

<table>
<thead>
<tr>
<th>Calibration Point</th>
<th>No.</th>
<th>Time of Reading</th>
<th>Standard thermometer</th>
<th>Calibrated thermometer</th>
<th>Error [D]-[C]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>hh:mm</td>
<td>[°C]</td>
<td>[°C]</td>
<td>[°C]</td>
</tr>
<tr>
<td>30</td>
<td>1</td>
<td>10:00</td>
<td>29.98</td>
<td>0.02</td>
<td>30.00</td>
</tr>
<tr>
<td>30</td>
<td>2</td>
<td>10:02</td>
<td>30.02</td>
<td>0.02</td>
<td>30.04</td>
</tr>
<tr>
<td>30</td>
<td>3</td>
<td>10:04</td>
<td>30.03</td>
<td>0.02</td>
<td>30.05</td>
</tr>
<tr>
<td>30</td>
<td>4</td>
<td>10:06</td>
<td>29.97</td>
<td>0.02</td>
<td>29.99</td>
</tr>
<tr>
<td>30</td>
<td>5</td>
<td>10:08</td>
<td>30.02</td>
<td>0.02</td>
<td>30.04</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30.024</td>
</tr>
<tr>
<td>standard uncertainty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0121</td>
</tr>
</tbody>
</table>

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Japan Meteorological Agency
“$T_{(a-1)}$” is measured values obtained from repeated observations → Type A evaluation

Average;

$$
\overline{T_{(a-1)}} = \frac{(30.00 + 30.04 + 30.05 + 29.99 + 30.04)}{5} = 30.024 [{}^\circ C \text{ ]}
$$

Experimental standard deviation of the mean;
→ Standard uncertainty

$$
u(T_{(a-1)}) = 0.0121 [{}^\circ C \text{ ]}
$$
## Budget Sheet

<table>
<thead>
<tr>
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<th>Contribution to u(y) [°C]</th>
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<tbody>
<tr>
<td>Standard [°C]</td>
<td>(a-1) Variation</td>
<td>0.0121</td>
<td>Type-A</td>
<td>?</td>
</tr>
<tr>
<td></td>
<td>(a-2) Resolution</td>
<td></td>
<td></td>
<td>?</td>
</tr>
<tr>
<td></td>
<td>(a-3) Standard</td>
<td></td>
<td></td>
<td>?</td>
</tr>
<tr>
<td>To be calibrated</td>
<td>(b-1) Variation</td>
<td></td>
<td></td>
<td>?</td>
</tr>
<tr>
<td></td>
<td>(b-2) Resolution</td>
<td></td>
<td></td>
<td>?</td>
</tr>
<tr>
<td>Chamber</td>
<td>(c-1) Distribution</td>
<td></td>
<td></td>
<td>?</td>
</tr>
</tbody>
</table>
## Budget Sheet

<table>
<thead>
<tr>
<th>Input quantities</th>
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<th>Contribution to u(y) [°C]</th>
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</thead>
<tbody>
<tr>
<td>[°C]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a-1) Variations</td>
<td>0.0121</td>
<td>Type-A</td>
<td>1</td>
<td>0.0121</td>
</tr>
<tr>
<td>(a-2) Resolution</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a-3) Standard</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To be calibrated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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Meteorological Instrument Center
Japan Meteorological Agency
## Budget Sheet

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<td>1</td>
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<tr>
<td></td>
<td>(a-3) Standard</td>
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<td></td>
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Meteorological Instrument Center Japan Meteorological Agency
2. Working standard
(2) Minimum unit (resolution): 0.01°C

→ Type B evaluation

Standard uncertainty of $T_{(a-2)}$:

$$u(T_{a-2}) = \frac{0.005}{\sqrt{3}} = 2.89 \times 10^{-3} [{^\circ}C]$$
## Budget Sheet

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2. Working standard
(1) Standard uncertainty of the Working standard is 0.03°C due to calibration certificate.

→ Type B evaluation

Standard uncertainty of $T_{(a-3)}$;

$$u(T_{a-3}) = 0.03[^\circ C]$$
### Budget Sheet

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Meteorological Instrument Center
Japan Meteorological Agency
1. Calibration method
To compare working standard and instruments to be calibrated in chamber.
Observer makes 5 times comparative reading.
(a-1),(b-1)  
Variations in repeated observations

<table>
<thead>
<tr>
<th>Calibration Point</th>
<th>No.</th>
<th>Time of Reading</th>
<th>Standard thermometer</th>
<th>Calibrated thermometer</th>
<th>Error [D]-[C]</th>
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</thead>
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<tr>
<td></td>
<td></td>
<td></td>
<td>The value of reading [A]</td>
<td>Correction [B]</td>
<td>The value after correction [C]=[A]+[B]</td>
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<tr>
<td></td>
<td></td>
<td>hh:mm</td>
<td>[℃]</td>
<td>[℃]</td>
<td>[℃]</td>
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<td>1</td>
<td>10:00</td>
<td>29.98</td>
<td>0.02</td>
<td>30.00</td>
</tr>
<tr>
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<td>2</td>
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<td>0.02</td>
<td>30.04</td>
</tr>
<tr>
<td>30</td>
<td>3</td>
<td>10:04</td>
<td>30.03</td>
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<td>30.05</td>
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<td>10:08</td>
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<td>30.04</td>
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<tr>
<td>Average</td>
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<td></td>
<td></td>
<td></td>
<td>30.024</td>
</tr>
<tr>
<td>standard uncertainty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0121</td>
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</tbody>
</table>
“T\(_{(a-1)}\)” is measured values obtained from repeated observations → Type A evaluation

Average;

\[
\frac{T_{(b-1)}}{5} = \frac{(30.1 + 30.2 + 30.2 + 30.1 + 30.2)}{5} = 30.16[^\circ C]
\]

Experimental standard deviation of the mean;
→ Standard uncertainty

\[
u\left(\overline{T_{(b-1)}}\right) = 0.0245[^\circ C]
\]
## Budget Sheet

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</tbody>
</table>
3. Instruments to be calibrated

Minimum unit (resolution):
0.1°C (Liquid-in-glass thermometer)

$\rightarrow$ Type B evaluation

Standard uncertainty of $T_{(b-2)}$:

$$u(T_{b-2}) = \frac{0.05}{\sqrt{3}} = 2.89 \times 10^{-2}[^\circ C]$$
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4. Chamber

Distribution of temperature: ±0.03°C
(manufacture’s specification)

→ Type B evaluation

rectangular distribution

Standard uncertainty of $T_{(c-1)}$;

$$u(T_{c-1}) = \frac{0.03}{\sqrt{3}} = 0.0173[^\circ C]$$
<table>
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Meteorological Instrument Center
Japan Meteorological Agency
Combined standard uncertainty;

\[ u_c(y) = \sqrt{\sum [c_i u(x_i)]^2} \]
\[ = \sqrt{0.0120^2 + 0.00289^2 + 0.03^2 + 0.0245^2 + 0.0289^2 + 0.0173^2} \]
\[ \approx 0.053[^{\circ}\text{C}] \]
## Calibration result

<table>
<thead>
<tr>
<th>Reference temperature (A) (°C)</th>
<th>Calibrated indication temperature (B) (°C)</th>
<th>Deviation (B) - (A) (°C)</th>
<th>Expanded uncertainty (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.0</td>
<td>30.1</td>
<td>0.1</td>
<td>0.11</td>
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</table>

**Note:**
The reported expanded uncertainty is stated as the combined standard uncertainty multiplied by the coverage factor $k = 2$, which for a normal distribution corresponds to a coverage probability of approximately 95%.
Calibration result

Image

Distribution of Calibrated Indication temperature

Reference temperature

95%
List up of input quantities and possible sources which effect measurement results

- **Reference standard**
  - (a-3) Uncertainty of reference standard
  - (a-1) Variations in repeated observations
  - (a-2) Resolution

- **Instrument to be calibrated**
  - (b-1) Variations in repeated observations
  - (b-2) Resolution

- **Chamber**
  - (c-1) Distribution
List up of input quantities and possible sources which affect measurement results for more real estimation.

Reference standard:
- (a-3) Uncertainty of reference standard
- Long term stability

Instrument to be calibrated:
- (a-1) Variations in repeated observations
- (a-2) Resolution
- Reproducibility
- (b-1) Variations in repeated observations
- (b-2) Resolution

Chamber:
- (c-1) Distribution

Fishbone diagram
Thank You!

Mascot of JMA "Harerun"