22 Feb. 2013

Calibration of thermometer
(Lecture and Training)

Koichi NAKASHIMA

Scientific Officer

Regional Instrument Centre Tsukuba

Observations Division, Observations Department

Japan Meteorological Agency

Outline

1. Temperature measurement and calibration of thermometer (theory)
2. Calibration of thermometer (practice)

Schedule

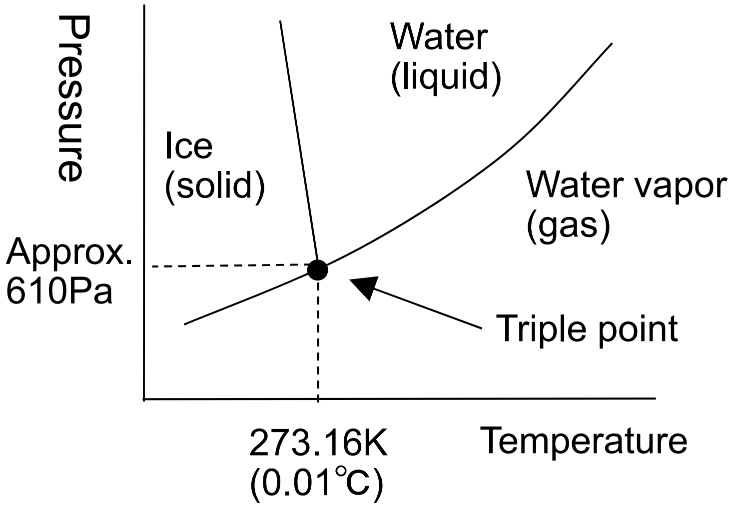
	Contents	Place
1	Theory	Lecture room(3F)
2	Coffee Break	
3	Practice (Calibration)	Calibration room(1F)
4	Coffee Break	
5	・Review of practice results ・Uncertainty evaluation	Lecture room(3F)

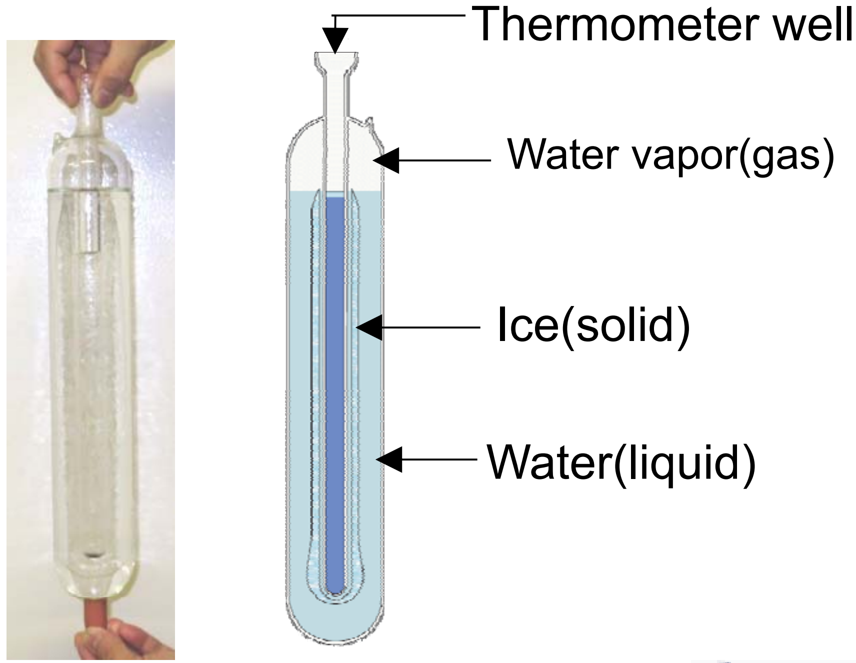
1. Temperature measurement (theory)

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."





Water triple point cell

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

Type of instrument for interpolation	Applicable temperature range	Principle
Helium vapor pressure thermometer	0.65 K – 5.0 K	Relationship between vapor pressure and the temperature of helium-4 and helium-3
Interpolating gas thermometer	3.0 K – 24.5561 K	Relationship between pressure and the temperature of a constant volume of gas with helium-4 and helium-3 as working fluids
Platinum resistance thermometer	13.8033 K – 1,234.93 K	Relationship between electrical resistance and the temperature of platinum
Radiation thermometer	1,234.93 K –	Planck's law of radiation

Defining fixed points of the ITS-90

Number	Temperature		Substance(*1)	State(*2)
	T90/K	t90/℃		
1	3 to 5	-270.15 to -268.15	He	V
2	13.8033	-259.3467	e-H_2	T
3	～17	～-256.15	e-H_2(or He)	V(or G)
4	～20.3	～-252.85	e-H_2(or He)	V(or G)
5	24.5561	-248.5939	Ne	T
6	54.3584	-218.7916	O_2	T
7	83.8058	-189.3442	Ar	T
8	**234.3156**	**-38.8344**	**Hg**	**T**
9	**273.16**	**0.01**	**H_2O**	**T**
10	**302.9146**	**29.7646**	**Ga**	**M**
11	**429.7485**	**156.5985**	**In**	**F**
12	505.078	231.928	Sn	F
13	692.677	419.527	Zn	F
14	933.473	660.323	Al	F
15	1234.93	961.78	Ag	F
16	1337.33	1064.18	Au	F
17	1357.77	1084.62	Cu	F

(*1)All substances except 3He are of natural isotopic composition;

e-H_2 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

OPERATIONAL MEASUREMENT UNCERTAINTY REQUIREMENTS AND INSTRUMENT PERFORMANCE

(See explanatory notes at the end of the table; numbers in the top row indicate column numbers.)

1		2	3	4	5	6	7	8	9
	Variable	*Range*	*Reported resolution*	*Mode of measurement/ observation*	*Required measurement uncertainty*	*Sensor time constant*	*Output averaging time*	*Achievable measurement uncertainty*	*Remarks*
1.	**Temperature**								
1.1	Air temperature	–80 – +60°C	0.1 K	I	0.3 K for ≤ –40ºC 0.1 K for > –40ºC and ≤ +40ºC 0.3 K for > +40ºC	20 s	1 min	0.2 K	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
1.2	Extremes of air temperature	–80 – +60°C	0.1 K	I	0.5 K for ≤ –40ºC 0.3 K for > –40ºC and ≤ +40ºC 0.5 K for > +40ºC	20 s	1 min	0.2 K	
1.3	Sea surface temperature	–2 – +40°C	0.1 K	I	0.1 K	20 s	1 min	0.2 K	
1.4	Soil temperature	–50 – +50°C	0.1 K	I		20 s	1 min	0.2 K	

Air temperature
Achievable measurement uncertainty; 0.2 K

<CIMO Guide>

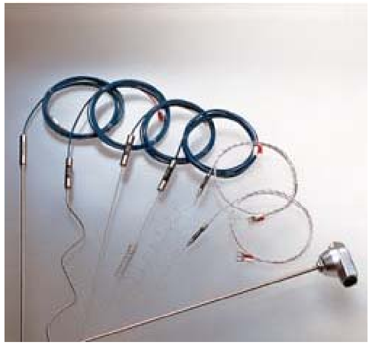
1-4. Types of thermometer

Types of thermometer

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

   etc.

These are mainly used for meteorological observation



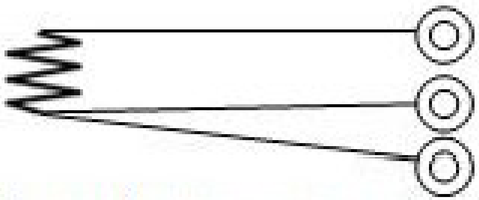
CHINO Corporation(Japan)

2. Radiation thermometer

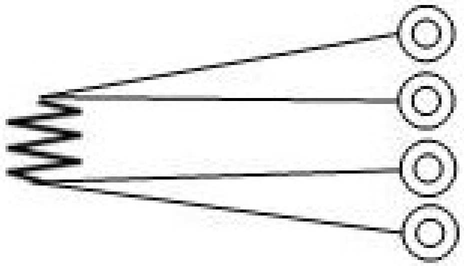
CHINO Corporation(Japan

Platinum resistance thermometer

2-conductor system



3-conductor system

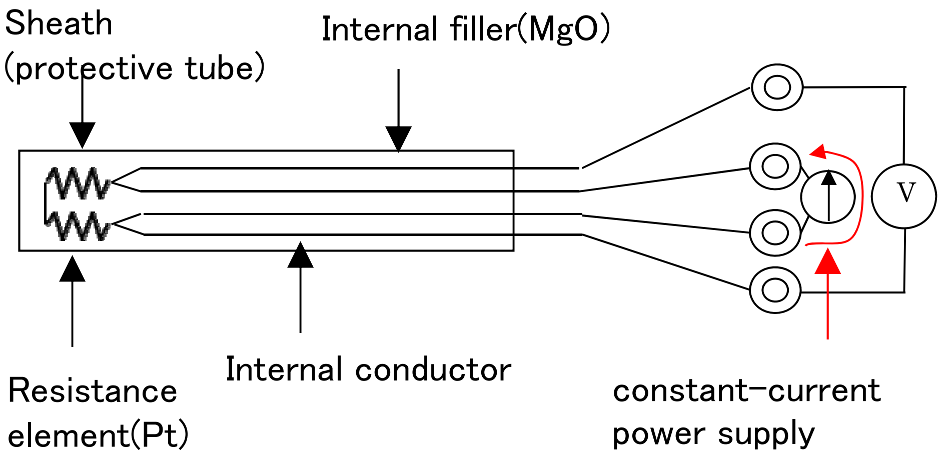


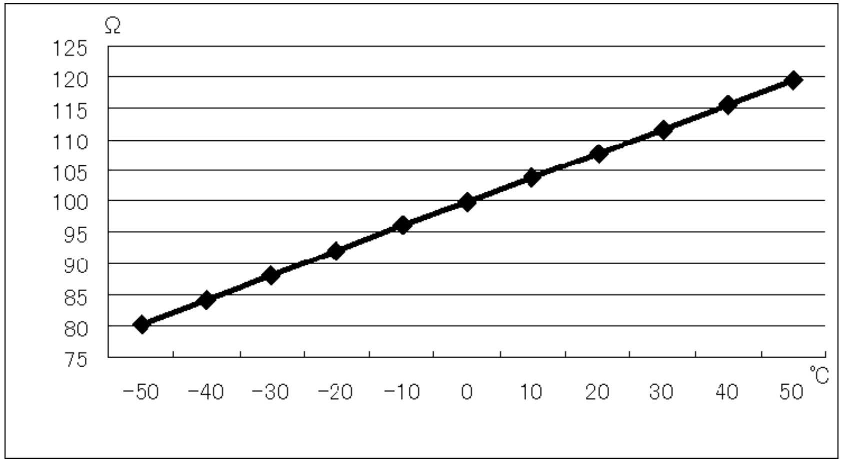
4-conductor system

Internal conductor connection

気象庁

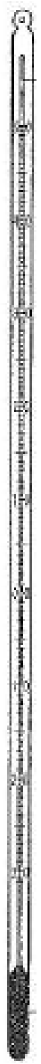
Platinum resistance thermometer





Example of the relationship between temperature and resistance

Liquid in glass thermometer



Principle;

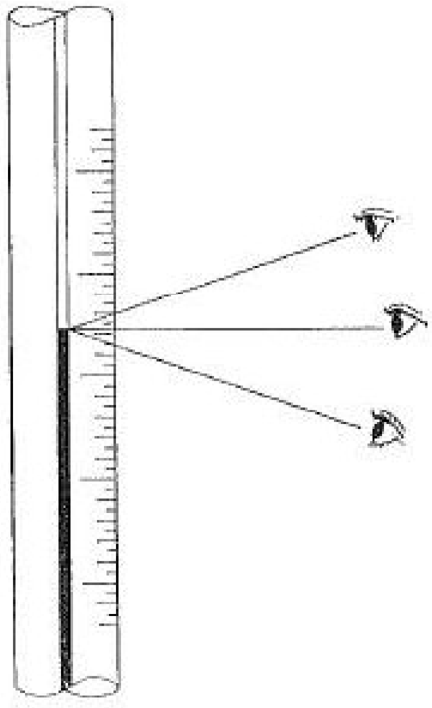
Liquid in glass thermometers make use of the differential expansion of a pure liquid with respect to its glass container to indicate the Temperature.

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)

Jan. 2013 by JMA

Measurement standards traceable to national standards

National Metrology Institute of Japan

Temperature fixed points

- Indium point (156.5985℃)
- Mercury point (-38.8344℃)
- Water triple point (0.01 ℃)

Standard resistor (100Ω)

Calibration:
- every year NSR-160
- every 2 years Water triple-point cell Standard resistor

JMA Standard

Meteorological Instruments Center (JMA)

Platinum resistance thermometer

NSR-160 (Netsushin, Japan)

Alternating current bridge F-600 (ASL, UK)

Water triple-point cell (0.01℃)

Standard resistor(100Ω)

Check: every 6 months Using water triple-point cell

Calibration : every year

Working Standard

Platinum resistance thermometer

TS-81A (Chino, Japan)

Alternating current bridge F-250 (ASL, UK)

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

Alternating current bridge F-250 (ASL, UK)

Calibration : at the time of installation

Calibration: every 5 years

Field Instruments

Observatory (JMA)

Platinum resistance thermometer

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

Tolerable range: ±0.4℃

Mercury-in-glass thermometer (psychrometer)

気象庁

Traceability of Temperature (JMA)

Jan. 2013 by JMA

Measurement standards traceable to national standards	JMA Standard	Working Standard	Field Instruments
National Metrology Institute of Japan	Meteorological Instruments Center (JMA)	Meteorological Instruments Center (JMA)	Observatory (JMA)

National Metrology Institute of Japan

Temperature fixed points

- Indium point (156.5985℃)
- Mercury point (-38.8344℃)
- Water triple point (0.01 ℃)

Standard resistor (100Ω)

Calibration:
- every year NSR-160
- every 2 years Water triple-point cell Standard resistor

JMA Standard

Platinum resistance thermometer

NSR-160 (Netsushin, Japan)

Alternating current bridge F-600 (ASL, UK)

Water triple-point cell (0.01℃)

Standard resistor(100Ω)

Check: every 6 months Using water triple-point cell

Calibration : every year

Working Standard

Platinum resistance thermometer

TS-81A (Chino, Japan)

Alternating current bridge F-250 (ASL, UK)

Calibration: every 5 years

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

Alternating current bridge F-250 (ASL, UK)

Field Instruments

Calibration : at the time of installation

Platinum resistance thermometer

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

Tolerable range: ±0.4℃

Mercury-in-glass thermometer (psychrometer)

Traceability of Temperature (JMA)

Jan. 2013 by JMA

Measurement standards traceable to national standards	JMA Standard	Working Standard	Field Instruments
National Metrology Institute of Japan	Meteorological Instruments Center (JMA)	Meteorological Instruments Center (JMA)	Observatory (JMA)

Temperature fixed points

- Indium point (156.5985℃)
- Mercury point (-38.8344℃)
- Water triple point (0.01 ℃)

Standard resistor (100Ω)

Calibration:
- every year NSR-160
- every 2 years Water triple-point cell Standard resistor

Platinum resistance thermometer

NSR-160 (Netsushin, Japan)

Alternating current bridge F-600 (ASL, UK)

Water triple-point cell (0.01℃)

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: every 5 years

Calibration : at the time of installation

Platinum resistance thermometer

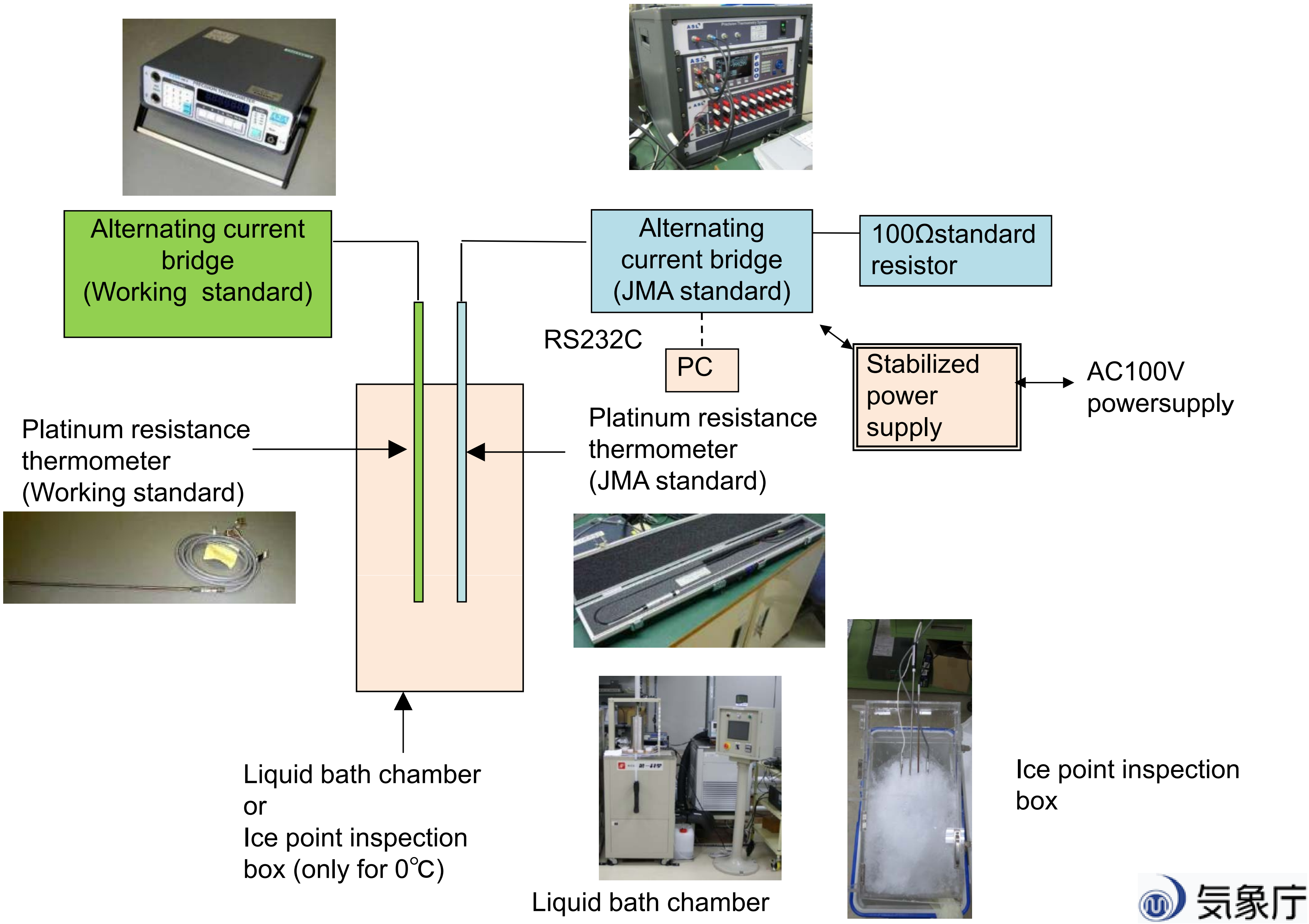
Check:
- every 3 months (manned observatory)
- every year (automatic weather station)

Tolerable range: ±0.4℃

Mercury-in-glass thermometer (psychrometer)

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

Alternating current bridge F-250 (ASL, UK)


Alternating current bridge (Working standard)
Alternating current bridge (JMA standard)
100Ωstandard resistor
RS232C
PC
Stabilized power supply
AC100V powersupply
Platinum resistance thermometer (Working standard)
Platinum resistance thermometer (JMA standard)
Liquid bath chamber or Ice point inspection box (only for 0℃)
Liquid bath chamber
Ice point inspection box
気象庁

Traceability of Temperature (JMA)

Jan. 2013 by JMA

Measurement standards traceable to national standards	JMA Standard	Working Standard	Field Instruments
National Metrology Institute of Japan	Meteorological Instruments Center (JMA)	Meteorological Instruments Center (JMA)	Observatory (JMA)

National Metrology Institute of Japan

Temperature fixed points

- Indium point (156.5985℃)
- Mercury point (-38.8344℃)
- Water triple point (0.01 ℃)

Standard resistor (100Ω)

Calibration:
- every year NSR-160
- every 2 years Water triple-point cell Standard resistor

JMA Standard

Platinum resistance thermometer

NSR-160 (Netsushin, Japan)

Alternating current bridge F-600 (ASL, UK)

Water triple-point cell (0.01℃)

Standard resistor(100Ω)

Check: every 6 months Using water triple-point cell

Working Standard

Platinum resistance thermometer

TS-81A (Chino, Japan)

Alternating current bridge F-250 (ASL, UK)

Calibration : every year

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

TS-81A (Chino, Japan)

Alternating current bridge F-250 (ASL, UK)

Field Instruments

Platinum resistance thermometer

Calibration : at the time of installation

Calibration: every 5 years

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

Tolerable range: ±0.4℃

Mercury-in-glass thermometer (psychrometer)

気象庁

Traceability of Temperature (JMA)

Jan. 2013 by JMA

Measurement standards traceable to national standards	JMA Standard	Working Standard	Field Instruments
National Metrology Institute of Japan	Meteorological Instruments Center (JMA)	Meteorological Instruments Center (JMA)	Observatory (JMA)

National Metrology Institute of Japan

Temperature fixed points

- Indium point (156.5985℃)
- Mercury point (-38.8344℃)
- Water triple point (0.01 ℃)

Standard resistor (100Ω)

Calibration:
- every year NSR-160
- every 2 years Water triple-point cell Standard resistor

JMA Standard

Platinum resistance thermometer

NSR-160 (Netsushin, Japan)

Alternating current bridge F-600 (ASL, UK)

Water triple-point cell (0.01℃)

Standard resistor(100Ω)

Check: every 6 months Using water triple-point cell

Calibration : every year

Working Standard

Platinum resistance thermometer

TS-81A (Chino, Japan)

Alternating current bridge F-250 (ASL, UK)

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

Alternating current bridge F-250 (ASL, UK)

Calibration : at the time of installation

Calibration : every 5 years

Field Instruments

Platinum resistance thermometer

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

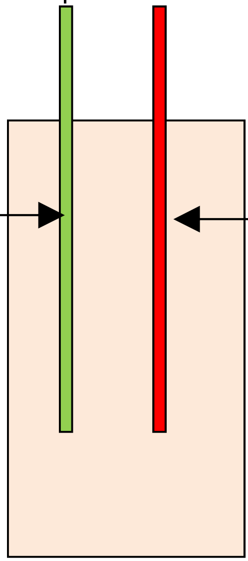
Tolerable range: ±0.4℃

Mercury-in-glass thermometer (psychrometer)

<Not 0°C>

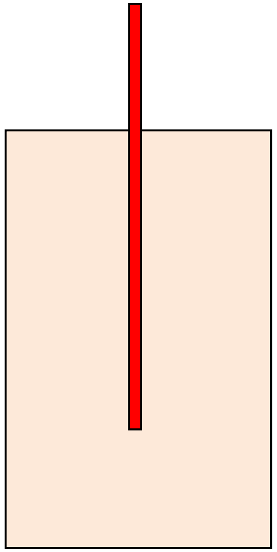
<0°C>

Alternating current bridge (Working standard)



Platinum resistance thermometer (Working standard)

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



Liquid bath chamber

Ice point inspection box

2. Calibration of thermometer (practice)

Today's practice

1. Calibration practice at 0℃（ Ice point ）
   (Mr. NOMURA)
2. Calibration practice at 30℃（ 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℃（Ice point）

⬇

2. Calibration practice at 30℃（Liquid bath chamber）

Group B; <Oman, Pakistan, Qatar, Sri Lanka, Thailand, VietNam, China>

1. Calibration practice at 30℃（Liquid bath chamber）

⬇

2. Calibration practice at 0℃（Ice point

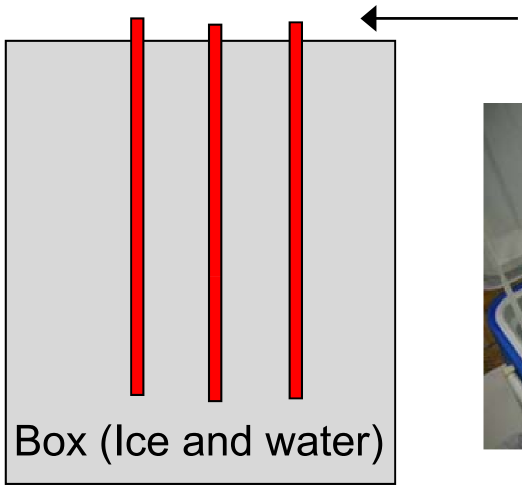
1. Calibration practice at 0℃(Ice point)

Calibrated items:

Liquid-in-glass thermometer : 3sets

Goal:

Estimate instrumental error at 0℃.



2. Calibration practice at 30℃（Liquid bath chamber）

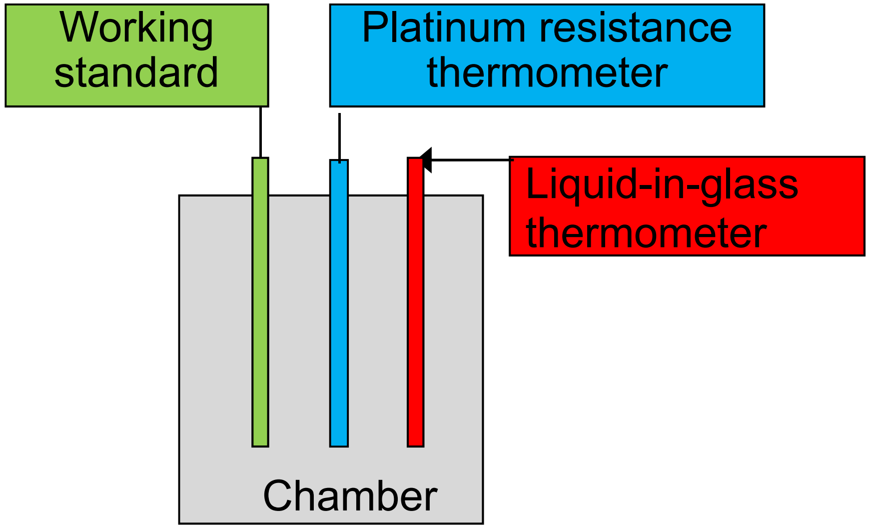
Calibrated items:

Liquid-in-glass thermometer : 1set

Platinum resistance thermometer : 1set

Goal:

Estimate instrumental error and uncertainty at 30℃.

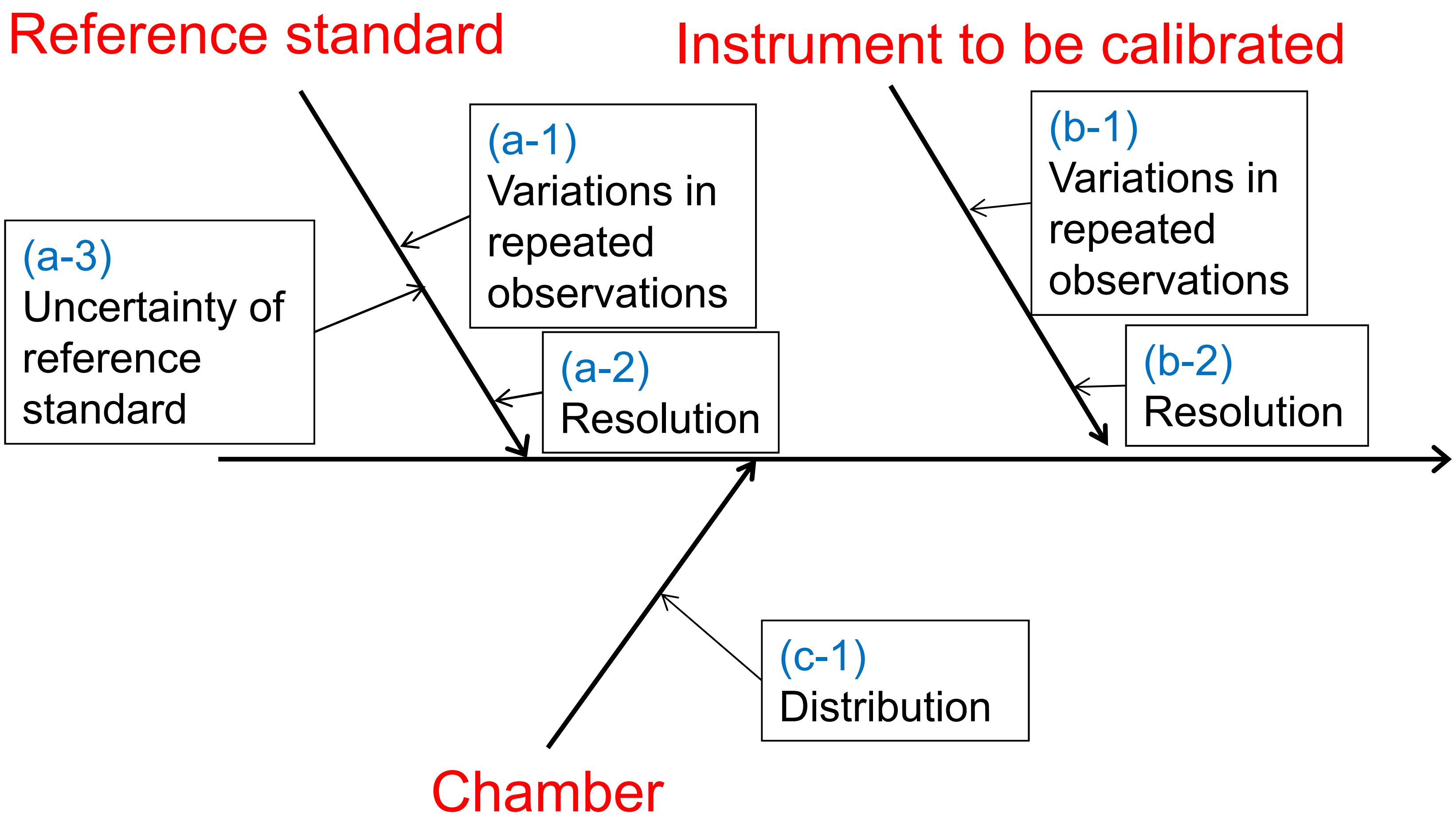


<Practice time>

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℃ due to calibration certificate.
   (2) Minimum unit (resolution): 0.01℃
3. Instruments to be calibrated
   Minimum unit (resolution):
   0.01℃ (Platinum resistance thermometer)
   0.1℃(Liquid-in-glass thermometer)
4. Chamber
   Distribution of temperature: ±0.03℃ (manufacture's specification)

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



Fishbone diagram

Uncertainty estimate example:

Liquid-in-glass thermometer;

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

Budget Sheet

Input quantities [℃]		Standard uncertainty [℃]	Evaluation method	Sensitivity coefficients	Contribution to u(y) [℃]
Standard	(a-1) Variation	?	?		
	(a-2) Resolution				
	(a-3) Standard				
To be calibrated	(b-1) Variation				
	(b-2) Resolution				
Chamber	(c-1) Distribution				

1. Calibration method

To compare working standard and instruments to be calibrated in chamber.

Observer makes 5 times comparative reading.

Budget Sheet

(a-1),(b-1)
Variations in repeated observations

Calibration Point	No.	Time of Reading	Standard thermometer			Calibrated thermometer	
			The value of reading [A]	Correction [B]	The value after correction [C]=[A]+[B]	The value of reading [D]	Error [D]-[C]
[℃]		hh:mm	[℃]	[℃]	[℃]	[℃]	[℃]
30	1	10:00	29.98	0.02	30.00	30.1	
30	2	10:02	30.02	0.02	30.04	30.2	
30	3	10:04	30.03	0.02	30.05	30.2	
30	4	10:06	29.97	0.02	29.99	30.1	
30	5	10:08	30.02	0.02	30.04	30.2	
Average					30.024	30.16	0.1
standard uncertainty					0.0121	0.0245	

"$T_{(a-1)}$" is measured values obtained from repeated observations →Type A evaluation

Average;

$$\overline{T_{(a-1)}} = \frac{(30.00 + 30.04 + 30.05 + 29.99 + 30.04)}{5} = 30.024\,[℃]$$

Experimental standard deviation of the mean;
→Standard uncertainty

$$u\left(\overline{T_{(a-1)}}\right) = 0.0121\,[℃]$$

Budget Sheet

Input quantities [℃]		**Standard uncertainty [℃]**	**Evaluation method**	**Sensitivity coefficients**	**Contribution to u(y) [℃]**
Standard	(a-1) Variation	0.0121	Type-A	?	?
	(a-2) Resolution				
	(a-3) Standard				
To be calibrated	(b-1) Variation				
	(b-2) Resolution				
Chamber	(c-1) Distribution				

Budget Sheet

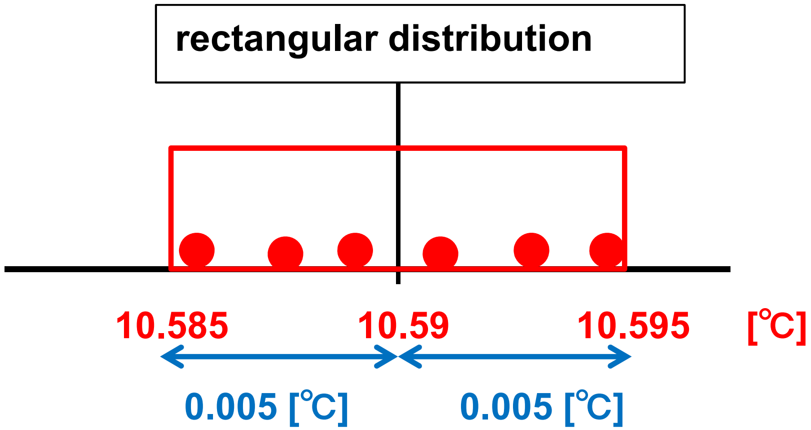
Input quantities [℃]		Standard uncertainty [℃]	Evaluation method	Sensitivity coefficients	Contribution to u(y) [℃]
Standard	(a-1) Variation	0.0121	Type-A	1	0.0121
	(a-2) Resolution				
	(a-3) Standard				
To be calibrated	(b-1) Variation				
	(b-2) Resolution				
Chamber	(c-1) Distribution				

Budget Sheet

Input quantities [℃]		Standard uncertainty [℃]	Evaluation method	Sensitivity coefficients	Contribution to u(y) [℃]
Standard	(a-1) Variation	0.0121	Type-A	1	0.0121
	(a-2) Resolution	?	?	?	?
	(a-3) Standard				
To be calibrated	(b-1) Variation				
	(b-2) Resolution				
Chamber	(c-1) Distribution				

2. Working standard
(2) Minimum unit (resolution): 0.01℃

→ Type B evaluation



Standard uncertainty of $T_{(a\text{-}2)}$;

$$u(T_{a-2}) = \frac{0.005}{\sqrt{3}} = 2.89\times10^{-3}[℃]$$

Budget Sheet

Input quantities [℃]		Standard uncertainty [℃]	Evaluation method	Sensitivity coefficients	Contribution to u(y) [℃]
Standard	(a-1) Variation	0.0121	Type-A	1	0.0121
	(a-2) Resolution	0.00289	Type-B	1	0.00289
	(a-3) Standard				
To be calibrated	(b-1) Variation				
	(b-2) Resolution				
Chamber	(c-1) Distribution				

Budget Sheet

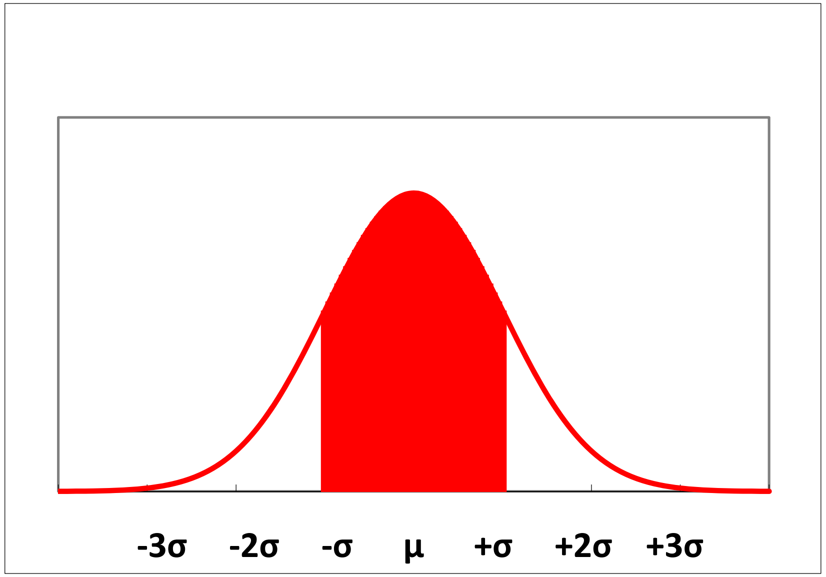
Input quantities [℃]		Standard uncertainty [℃]	Evaluation method	Sensitivity coefficients	Contribution to u(y) [℃]
Standard	(a-1) Variation	0.0121	Type-A	1	0.0121
	(a-2) Resolution	0.00289	Type-B	1	0.00289
	(a-3) Standard	?	?	?	?
To be calibrated	(b-1) Variation				
	(b-2) Resolution				
Chamber	(c-1) Distribution				

2. Working standard

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

Normal distribution

→ Type B evaluation



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

$$u(T_{a-3}) = 0.03[℃]$$

Budget Sheet

Input quantities [℃]		Standard uncertainty [℃]	Evaluation method	Sensitivity coefficients	Contribution to u(y) [℃]
Standard	(a-1) Variation	0.0121	Type-A	1	0.0121
	(a-2) Resolution	0.00289	Type-B	1	0.00289
	(a-3) Standard	0.03	Type-B	1	0.03
To be calibrated	(b-1) Variation				
	(b-2) Resolution				
Chamber	(c-1) Distribution				

Budget Sheet

Input quantities [℃]		Standard uncertainty [℃]	Evaluation method	Sensitivity coefficients	Contribution to u(y) [℃]
Standard	(a-1) Variation	0.0121	Type-A	1	0.0121
	(a-2) Resolution	0.00289	Type-B	1	0.00289
	(a-3) Standard	0.03	Type-B	1	0.03
To be calibrated	(b-1) Variation	?	?	?	?
	(b-2) Resolution				
Chamber	(c-1) Distribution				

1. Calibration method

To compare working standard and instruments to be calibrated in chamber.

Observer makes 5 times comparative reading.

Budget Sheet

(a-1),(b-1)
Variations in repeated observations

Calibration Point	No.	Time of Reading	Standard thermometer			Calibrated thermometer	
			The value of reading [A]	Correction [B]	The value after correction [C]=[A]+[B]	The value of reading [D]	Error [D]-[C]
[℃]		hh:mm	[℃]	[℃]	[℃]	[℃]	[℃]
30	1	10:00	29.98	0.02	30.00	30.1	
30	2	10:02	30.02	0.02	30.04	30.2	
30	3	10:04	30.03	0.02	30.05	30.2	
30	4	10:06	29.97	0.02	29.99	30.1	
30	5	10:08	30.02	0.02	30.04	30.2	
Average					30.024	30.16	0.1
standard uncertainty					0.0121	0.0245	

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

Average;

$$\overline{T_{(b-1)}} = \frac{(30.1 + 30.2 + 30.2 + 30.1 + 30.2)}{5} = 30.16[℃]$$

Experimental standard deviation of the mean;
→Standard uncertainty

$$u\left(\overline{T_{(b-1)}}\right) = 0.0245[℃]$$

Budget Sheet

Input quantities [℃]		Standard uncertainty [℃]	Evaluation method	Sensitivity coefficients	Contribution to u(y) [℃]
Standard	(a-1) Variation	0.0121	Type-A	1	0.0121
	(a-2) Resolution	0.00289	Type-B	1	0.00289
	(a-3) Standard	0.03	Type-B	1	0.03
To be calibrated	(b-1) Variation	0.0245	Type-A	1	0.0245
	(b-2) Resolution				
Chamber	(c-1) Distribution				

Budget Sheet

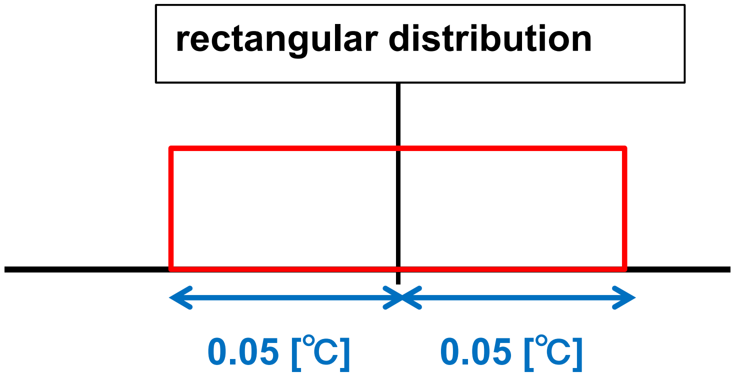
Input quantities [℃]		Standard uncertainty [℃]	Evaluation method	Sensitivity coefficients	Contribution to u(y) [℃]
Standard	(a-1) Variation	0.0121	Type-A	1	0.0121
	(a-2) Resolution	0.00289	Type-B	1	0.00289
	(a-3) Standard	0.03	Type-B	1	0.03
To be calibrated	(b-1) Variation	0.0245	Type-A	1	0.0245
	(b-2) Resolution	?	?	?	?
Chamber	(c-1) Distribution				

3. Instruments to be calibrated

Minimum unit (resolution):

0.1℃(Liquid-in-glass thermometer)

→ Type B evaluation



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

$$u(T_{b-2}) = \frac{0.05}{\sqrt{3}} = 2.89 \times 10^{-2} [℃]$$

Budget Sheet

Input quantities [℃]		Standard uncertainty [℃]	Evaluation method	Sensitivity coefficients	Contribution to u(y) [℃]
Standard	(a-1) Variation	0.0121	Type-A	1	0.0121
	(a-2) Resolution	0.00289	Type-B	1	0.00289
	(a-3) Standard	0.03	Type-B	1	0.03
To be calibrated	(b-1) Variation	0.0245	Type-A	1	0.0245
	(b-2) Resolution	0.0289	Type-B	1	0.0289
Chamber	(c-1) Distribution				

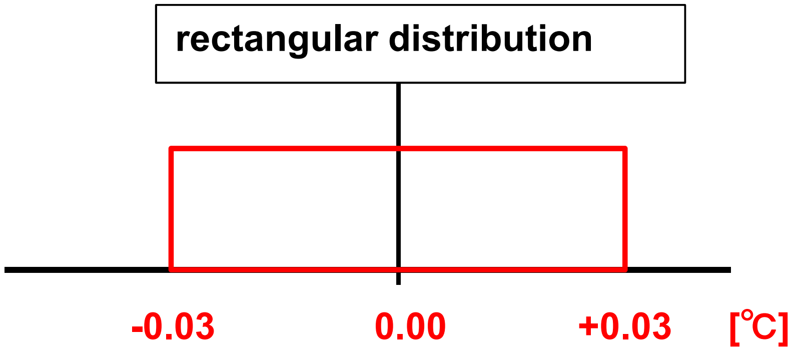
Budget Sheet

Input quantities [℃]		Standard uncertainty [℃]	Evaluation method	Sensitivity coefficients	Contribution to u(y) [℃]
Standard	(a-1) Variation	0.0121	Type-A	1	0.0121
	(a-2) Resolution	0.00289	Type-B	1	0.00289
	(a-3) Standard	0.03	Type-B	1	0.03
To be calibrated	(b-1) Variation	0.0245	Type-A	1	0.0245
	(b-2) Resolution	0.0289	Type-B	1	0.0289
Chamber	(c-1) Distribution	?	?	?	?

4. Chamber

Distribution of temperature: ±0.03℃
(manufacture's specification)

→ Type B evaluation



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

$$u(T_{c-1}) = \frac{0.03}{\sqrt{3}} = 0.0173[℃]$$

Budget Sheet

Input quantities [℃]		Standard uncertainty [℃]	Evaluation method	Sensitivity coefficients	Contribution to u(y) [℃]
Standard	(a-1) Variation	0.0121	Type-A	1	0.0121
	(a-2) Resolution	0.00289	Type-B	1	0.00289
	(a-3) Standard	0.03	Type-B	1	0.03
To be calibrated	(b-1) Variation	0.0245	Type-A	1	0.0245
	(b-2) Resolution	0.0289	Type-B	1	0.0289
Chamber	(c-1) Distribution	0.0173	Type-B	1	0.0173

Budget Sheet

Input quantities [℃]		Standard uncertainty [℃]	Evaluation method	Sensitivity coefficients	Contribution to u(y) [℃]
Standard	(a-1) Variation	0.0121	Type-A	1	0.0121
	(a-2) Resolution	0.00289	Type-B	1	0.00289
	(a-3) Standard	0.03	Type-B	1	0.03
To be calibrated	(b-1) Variation	0.0245	Type-A	1	0.0245
	(b-2) Resolution	0.0289	Type-B	1	0.0289
Chamber	(c-1) Distribution	0.0173	Type-B	1	0.0173

Combined standard uncertainty;

$$u_c(y) = \sqrt{[c_i u(x_i)]^2}$$
$$= \sqrt{0.0120^2 + 0.00289^2 + 0.03^2 + 0.0245^2 + 0.0289^2 + 0.0173^2}$$
$$\cong 0.053[℃]$$

Calibration result

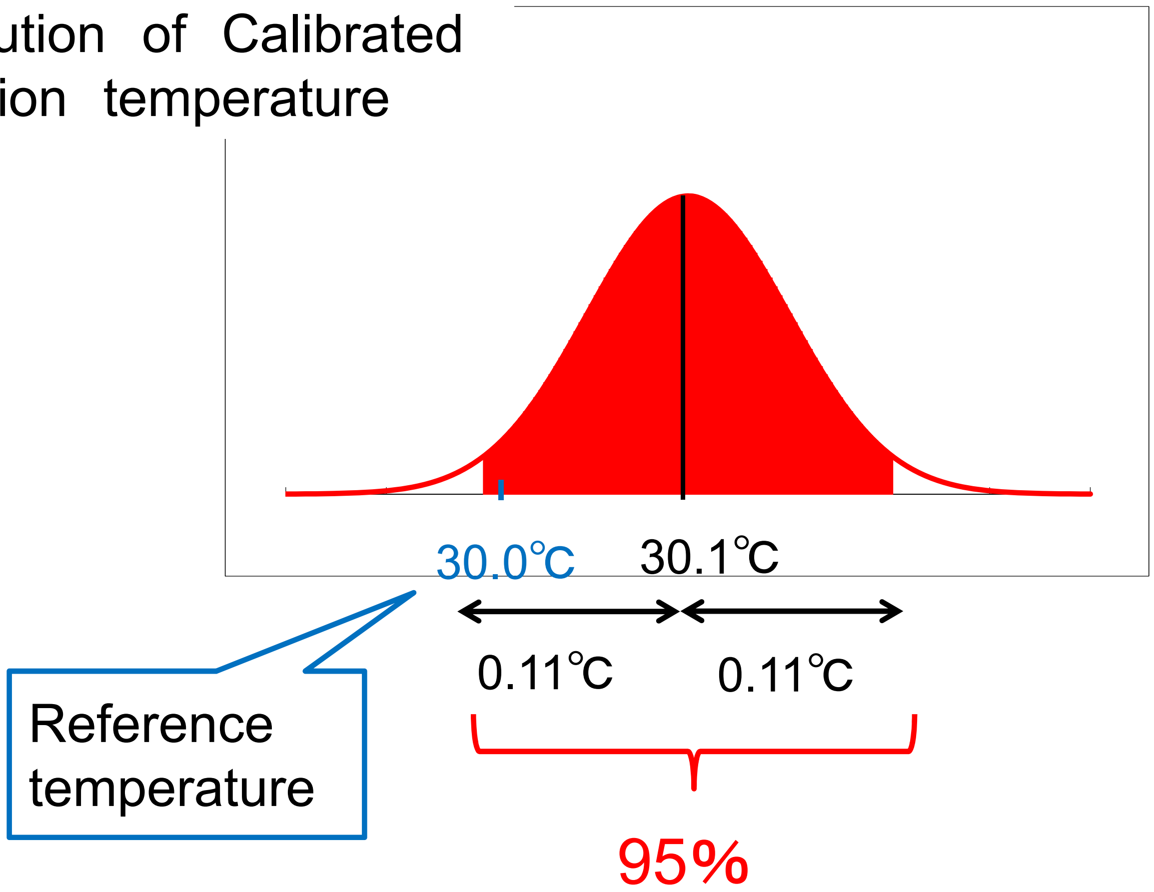
Reference temperature (A) (° C)	Calibrated indication temperature (B) (° C)	Deviation (B) - (A) (° C)	Expanded uncertainty (° C)
30.0	30.1	0.1	0.11

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 %.

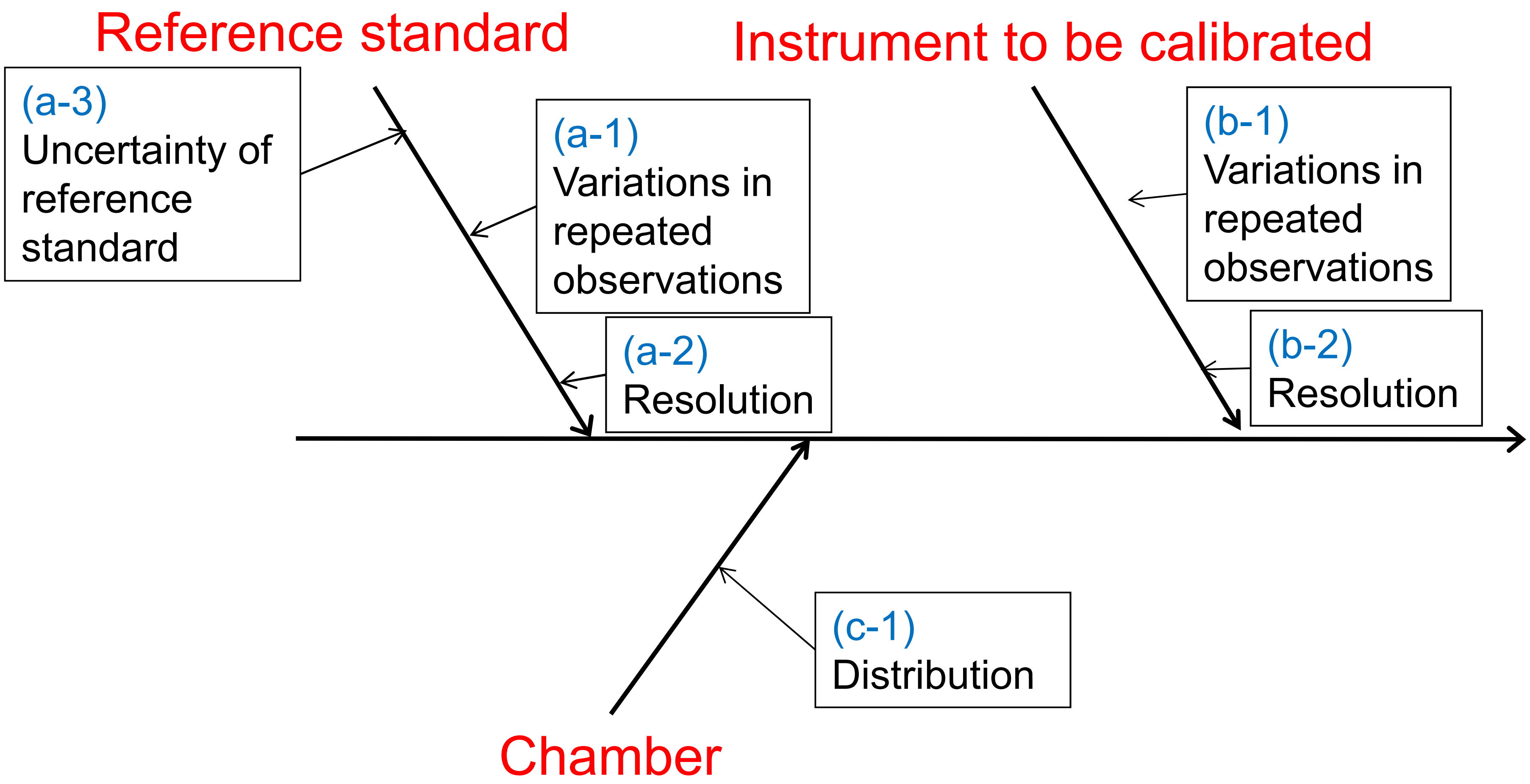
Calibration result

Image

Distribution of Calibrated Indication temperature



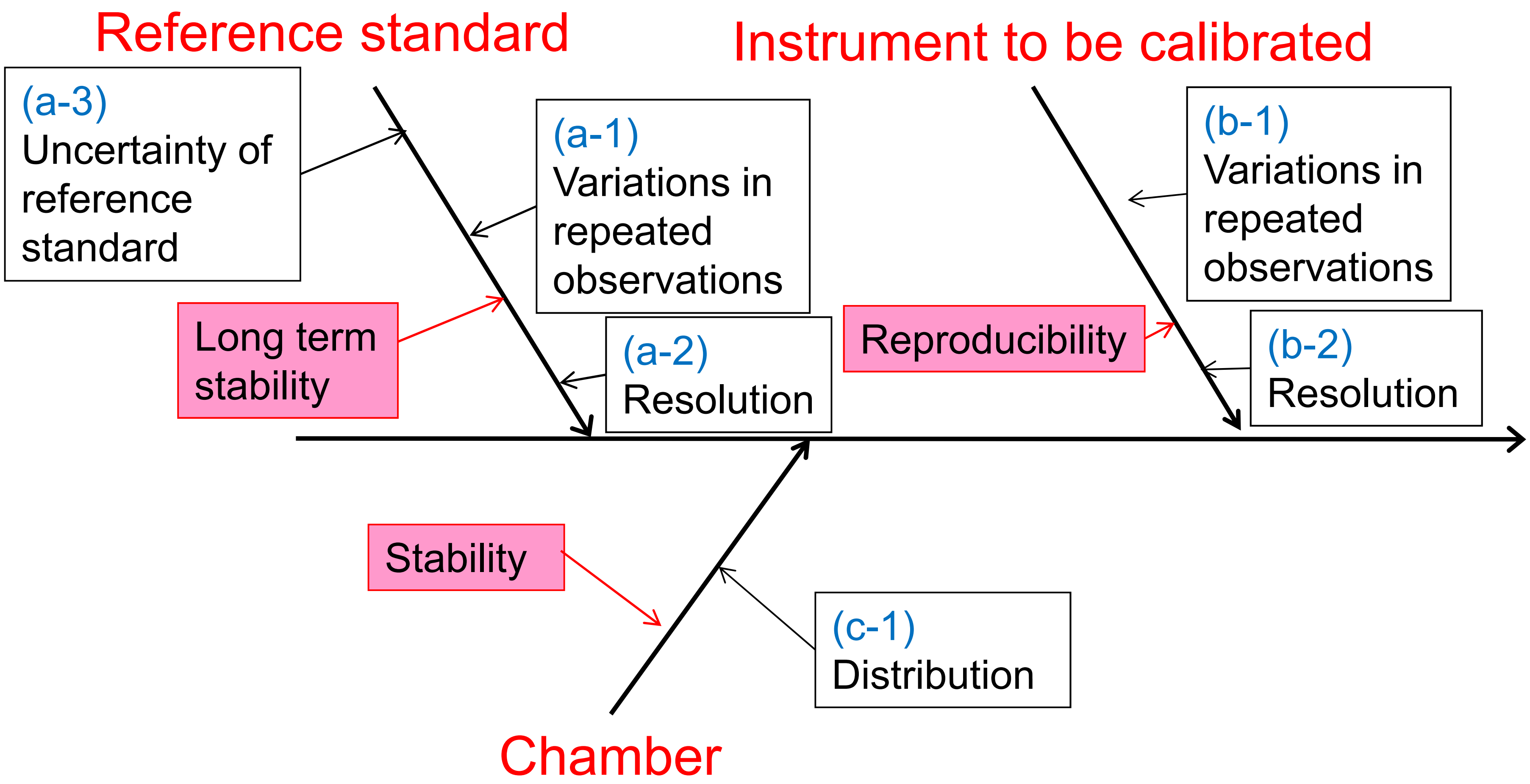
List up of input quantities and possible sources which effect measurement results



Fishbone diagram

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

for more real estimation



Fishbone diagram

Mascot of JMA ”Harerun”