Chapter 2 Measurement of Temperature

CONTENTS

Chapter 2　Measurement of Temperature

2.1　Definition and units

Heat balance difference of atmosphere between regions creates temperature distribution. This temperature distribution generates wind current along with cloud and rainfall phenomena. Thus, atmospheric temperature is one of the most important meteorological elements as well as wind and precipitation.

WMO recommends to measure atmospheric temperature at the height from 1.25 to 2m above ground at a representative location of region, as standard.

2.1.1　Definition of atmospheric temperature

The thermodynamic temperature is defined as one of the seven quantities (length, mass, time, electric current, thermodynamic temperature, amount of substance and luminous intensity) in the International System of Unit (SI). The definition of unit is as described below:

The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

Temperature and temperature difference can be expressed in both Kelvin and Celsius. Relation of temperature in degree Celsius (t, unit : °C) and thermodynamic temperature in Kelvin (T, unit : K) is shown as follows. Degree Celsius is commonly used in meteorological observation.

$t/°C = T/K - 273.15$

Phase diagram of water and outline of water triple point cell is shown in Figure 2.1 and Figure 2.2.

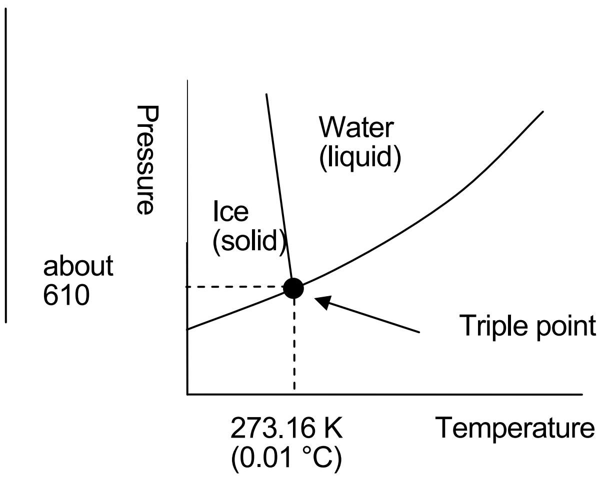


Figure 2.1　Phase diagram of water

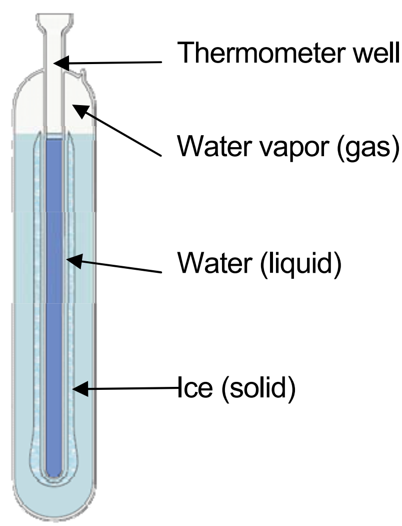


Figure 2.2　Water triple point

2.1.2 The international temperature scale

The international temperature scale is a temperature scale to accord with the results of thermodynamic temperature measurements along with the definition of thermodynamic temperature in 2.1.1 and it is defined based on several fixed points of temperature (defining fixed points) such as phase transition temperature of substance and using several types of stable thermometers. First international temperature scale was established in 1927. Since then it was revised several times to expand temperature range and improve accuracy. Currently the international temperature scale of 1990 (ITS-90) is in effect.

The ITS-90 defines the fixed points of temperature, the type of instrument along with method to interpolate in between fixed points of temperature（Table 2.1, Table 2.2）.

For the temperature range used in meteorological observation, a platinum resistance thermometer is specified as the interpolate instrument. To be a standard, an acceptable platinum resistance thermometer must be made from pure, strain-free platinum, and it must satisfy at least one of the following two relations:

$R\ (29.7646\ °C) / R\ (0.01\ °C) \geq 1.11807$

$R\ (-38.8344\ °C) / R\ (0.01\ °C) \leq 0.844235$

($R\ (t\ °C)$: resistance at t °C)

This determines the purity of platinum and its state of annealing.

By using the interpolation formula defined in the ITS-90, temperatures in between the fixed points of temperature can be determined from measurements obtained by a platinum resistance thermometer.

Table 2.1 Defining fixed points of the ITS-90

Number	Temperature		Substance(*1)	State(*2)
	T_{90}/K	t_{90}/°C		
1	3 to 5	-270.15 to -268.15	He	V
2	13.8033	-259.3467	e-H_2	T
3	～ 17	～ -276.15	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	M
10	302.9146	29.7646	Ga	F
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 ^{3}He 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 point;
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 101325 Pa, at which the solid and liquid phases are in equilibrium)

Table 2.2 Types of instrument for interpolation of the ITS-90

Types of instrument for interpolation	Applicable temperature range	Principle
Helium vapor pressure thermometer	0.65 K - 5.0 K	Relation of vapor pressure and temperature of helium-4 and helium-3
Interpolating gas thermometer	3.0 K - 24.5561 K	Relation of pressure and temperature of constant volume of gas when use helium-4 and helium-3 as working fluid
Platinum resistance thermometer	13.8033 K - 1234.93 K	Relation of electrical resistance and temperature of platinum
Radiation thermometer	1234.93 K -	Planck's law of radiation

2.2 Principles of Instruments

There are many types of thermometers. The major ones employ the characteristics of expansion and contraction of substance according to the temperature, employ the valuable of electrical characteristics (electrical resistance) of substance according to temperature, or employ characteristics between temperature and heat radiation energy emitted from surface of substance.

Air temperature continuously fluctuates within a range of 1 to 2 °C over individual periods of several seconds. WMO advises that the best representative value of air temperature is the average taken over a one-minute period, meaning that a number of readings should be made if a thermometer with a very small time constant is used. Rapid fluctuations are smoothed with a thermometer that has a large time constant. However, if the time constant is too large, lags in response to temperature variation will cause errors. The time constant of a thermometer varies inversely with the square root of wind speed, and WMO recommends that the time constant be 30 to 60 seconds for a wind speed of 5 ms^{-1}.

2.2.1 Electric thermometers

Electric thermometer includes electrical resistance thermometer, semiconductor thermometer (thermistor) and thermocouple thermometer. Platinum resistance thermometer is explained as a representative electric thermometer in this section.

Platinum resistance thermometer employs platinum characteristics which changes resistance according to the temperature. It allows us to obtain temperature by measuring electrical resistance. High purity platinum is used since contaminants greatly affect resistance. Sensor for meteorological observation is made with thin sheet of mica or porcelain wrapped with platinum wire, and it is placed in stainless protective tube which has excellent thermal conductivity and corrosion resistant then made it to complete water proof. Diagram of sensor and connection of platinum resistant thermometer is shown in Figure 2.3.

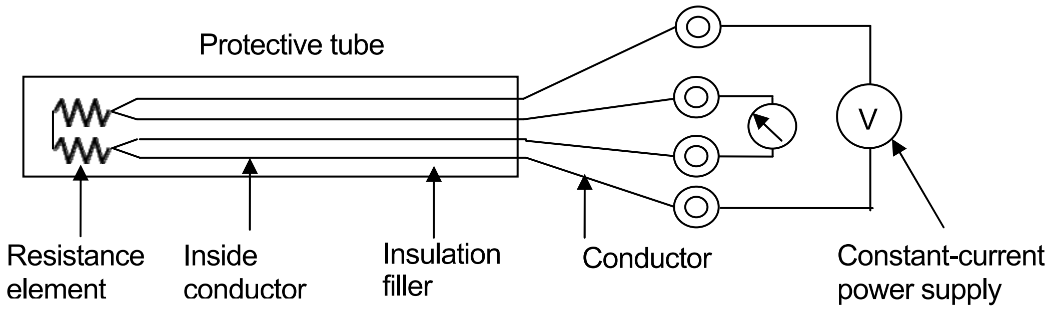


Figure 2.3 Diagram of sensor and connection of platinum resistant thermometer(4 conductor system)

Resistance change of platinum according to temperature is converted to electrical signals (current or voltage signal) by converter. Then the signal is sent to indicator or recorder and displayed or processed as atmospheric temperature. An example of the relation between temperature and resistance of platinum resistance thermometer is shown in Figure 2.4.

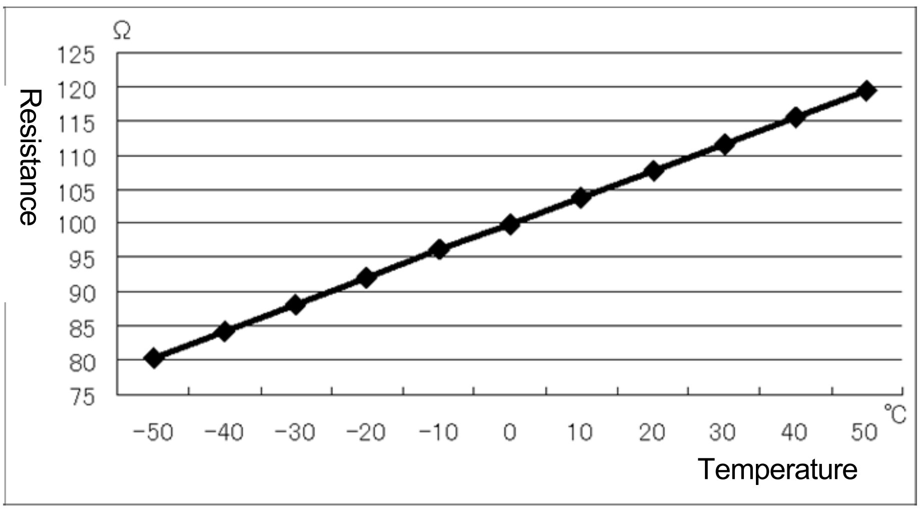


Figure 2.4 Example of the relation between resistance and temperature of platinum resistance thermometer (Source: Japanese Industrial Standard(JIS), Resistance thermometer sensors (JIS C1604))

The advantage of platinum resistance thermometer is the electric measurement which allows remote measurement and automated observation. The disadvantage is necessity of ensuring stable power supply to platinum resistance.

There are 2-conductor system, 3-conductor system and 4-conductor system in the method of inside conductor connection (Figure 2.5). 2-conductor system is impractical because it is unable to remove effect of conductor resistance. 3-conductor system consists of 2 conductors on one terminal of a resistance element and 1 conductor on the other terminal. This method enables to remove effect of conductor resistance. However, this is based on the premises, conductor has identical material, length and electrical resistance and temperature distribution must be the same. 4-conductor system consists of 2 conductors connected on each terminal of resistant element. This method can remove effect of conductor resistant. 4-conductor system has the highest accuracy as a thermometer.

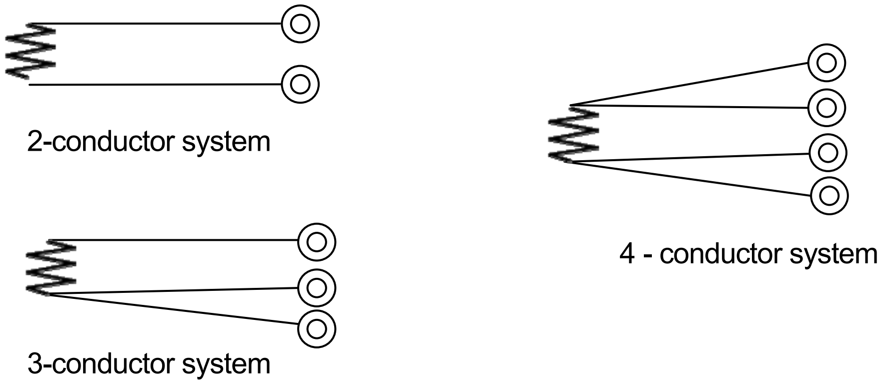


Figure 2.5 Diagram of inside conductor connection

2.2.2 Liquid-in-glass Thermometers

A liquid-in-glass thermometer measures temperature based on the thermal expansion of mercury or spirit alcohol in a glass container. The boiling point of mercury is 356.72 °C, and its melting point is -38.86 °C. The boiling point of methyl alcohol is 64.65 °C, and its melting point is -97.78 °C. Because mercury has low thermal capacity, high heat conductivity, inertness in relation to a glass capillary tube and a high boiling point, it is an ideal thermometric liquid except for its relatively high melting point. Accordingly, mercury thermometers are used for ordinary meteorological observations, and spirit thermometers are used for those involving temperatures below the melting point of mercury.

A liquid-in-glass thermometer consists of a capillary glass tube with a bulb at one end filled with a thermometric liquid, vacuumed and sealed. By reading the position of the liquid level on a scale, a temperature value can be obtained. Designs can be classified as either the sheathed type or the unsheathed type. A sheathed thermometer consists of a bulb, a slender capillary glass tube connected to it, a milky-white scale plate attached to the capillary tube, and an outer glass tube that encloses them. An unsheathed thermometer consists of a thick-walled capillary glass tube with a scale marked directly on it.

The advantages of liquid-in-glass thermometers are their simple design, simple observation method and the possibility of temperature measurement anywhere as they require no electric power for operation. The disadvantage is that careful handling is required because the glass material is fragile.

Several types of liquid-in-glass thermometers are used to measure maximum temperature, minimum temperature and soil temperature in addition to ordinary air temperature.

(1) Maximum thermometers

A maximum thermometer is a mercury thermometer used to measure the maximum temperature within a certain period. It has a narrow part in the capillary tube where mercury passage is constricted between the bulb and the starting point of the scale (Figure 2.6). As the air temperature rises, the mercury exits the bulb and passes through the constriction. When the air temperature falls, the mercury column breaks at this point.

Thus, the mercury in the capillary tube cannot return to the bulb, and remains in the column indicating the maximum temperature.

Observation of maximum temperature is carried out once or twice a day. After measurement, the thermometer is held at the head and the mercury in the capillary tube is shaken back into the bulb to reset its indication to the current air temperature.

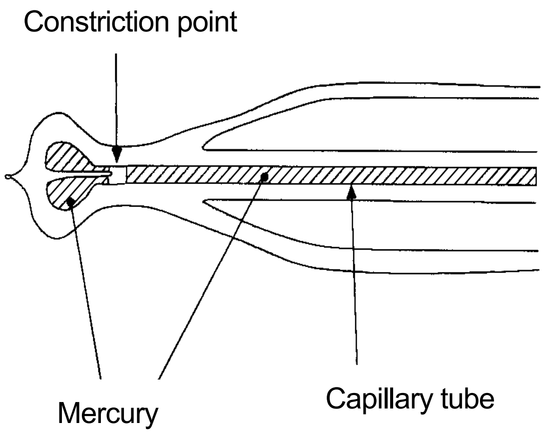


Figure 2.6 Constriction point of a maximum thermometer

(2)Minimum thermometers

A minimum thermometer is a spirit thermometer used to measure the minimum temperature within a certain period. It has a dumbbell-shaped index of colored glass in the spirit column (Figure 2.7). As the air temperature falls, the index is dragged by the surface tension of the spirit and moves toward the bulb with the top of the column. When the temperature rises, the index is left in position because the spirit flows through it. As a result, it remains in the column indicating the minimum temperature.

Observation of minimum temperature is carried out once or twice a day. After measurement, the column is inclined while keeping the bulb higher than the head, and the index is gradually slid back to the top of the column.

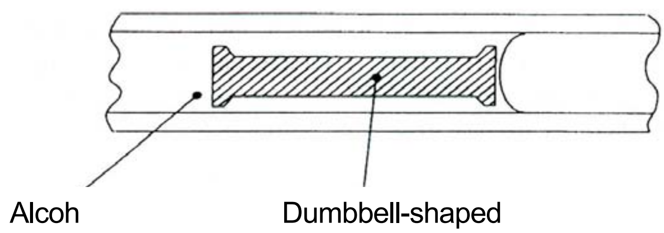


Figure 2. 7 Dumbbell-shaped index of minimum

(3)Soil thermometers

A bent-stem soil thermometer is generally used to measure soil temperature between the ground surface and a depth of 20 cm underground, and has a bend between the bulb and the scale (Figure 2.8). To install this type of thermometer, the bulb should be buried at the prescribed depth with the scale above the ground. The ground surface above the bulb should not be shaded. The scale above the ground should be supported on a post and shielded from solar radiation with a small sunshade made of white painted wood or aluminum. When setting up the thermometer to measure the ground surface temperature, it should be ensured that the bulb is buried close to the ground surface in such a way that exposure is avoided.

When soil is frozen or covered with snow, soil thermometers should be removed to prevent damage.

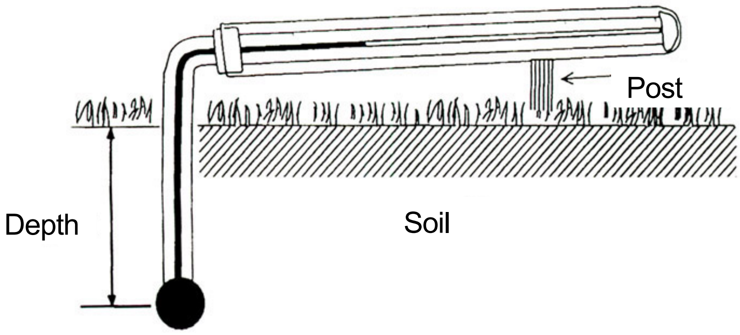


Figure 2. 8　Bent-stem soil thermometer

To measure soil temperatures at greater depths of 50 to 100 cm, a steel pipe of the desired length is driven into the soil and a mercury-in-glass thermometer is suspended in the pipe with a chain. A thermometer with a large time constant should be used to minimize any change in indication between removal from the pipe and reading. With this setup, it takes time for the indication to stabilize once the thermometer is placed underground. In order to minimize changes in indication during measurement and to protect the thermometer, it is advisable to cover the bulb with a rubber cap or install the unit in a wooden, glass or plastic pipe coated with wax or metallic paint.

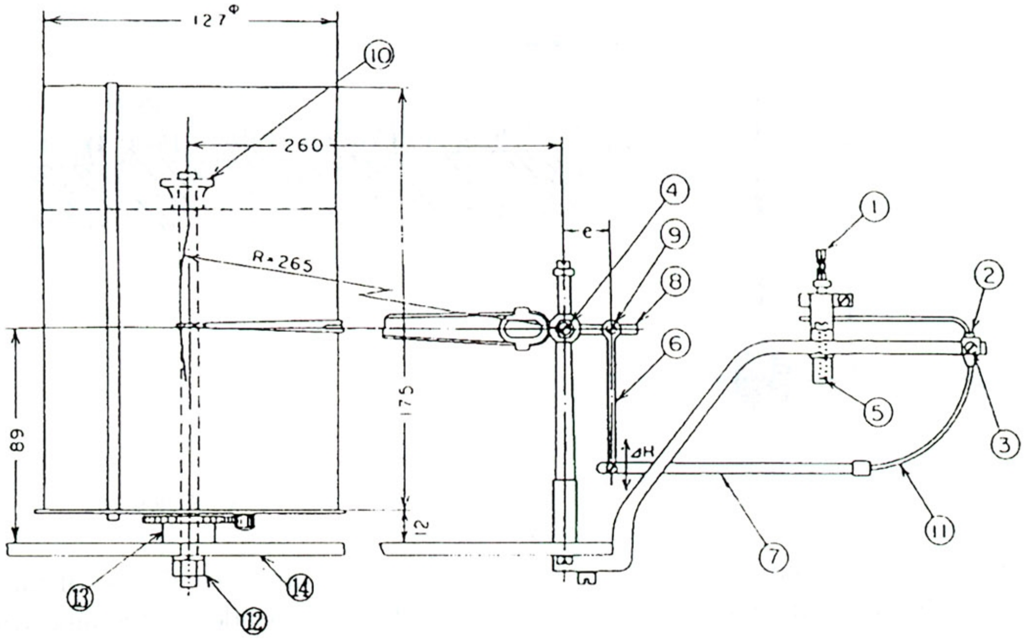
Other types used as soil thermometers are thermographs consisting of a mercury temperature sensor with a recorder connected by a fine metallic tube filled with mercury, platinum resistance thermometers and thermocouple thermometers.

2.2.3　Bimetallic Thermographs

A bimetallic thermograph is a unit consisting of a bimetal and a clock-driven drum on which a recording chart is wound. The curvature of the bimetal changes in response to temperature variations, and this curvature change is recorded on a chart. The bimetal consists of two metal plates with different expansion coefficients welded or brazed and then rolled to an appropriate thickness. As the temperature changes, the bimetal curves due to the difference in the expansion coefficients of the two metals. This change is mechanically magnified and then recorded.

The structure of a bimetallic thermograph is shown in Figure 2.9. When the bimetal ⑪ curves in response to temperature change, the bimetal lever ⑦ attached to the end of the bimetal moves with it. This motion is transmitted to the magnification adjustment lever ⑧ via the steel strip ⑥, and moves the pen arm attached to the magnification adjustment lever. In this way, the temperature change causing the bimetal to curve is recorded on the chart on the clock-driven drum with the pen tip at the end of the pen arm.

The advantage of bimetallic thermographs is that air temperature can be charted over a certain period even where no electric power supply is available. The disadvantages are that its accuracy is lower than those of liquid-in-glass and electrical thermometers, its mechanism does not allow continuous recording over long periods, and remote sensing is not possible.



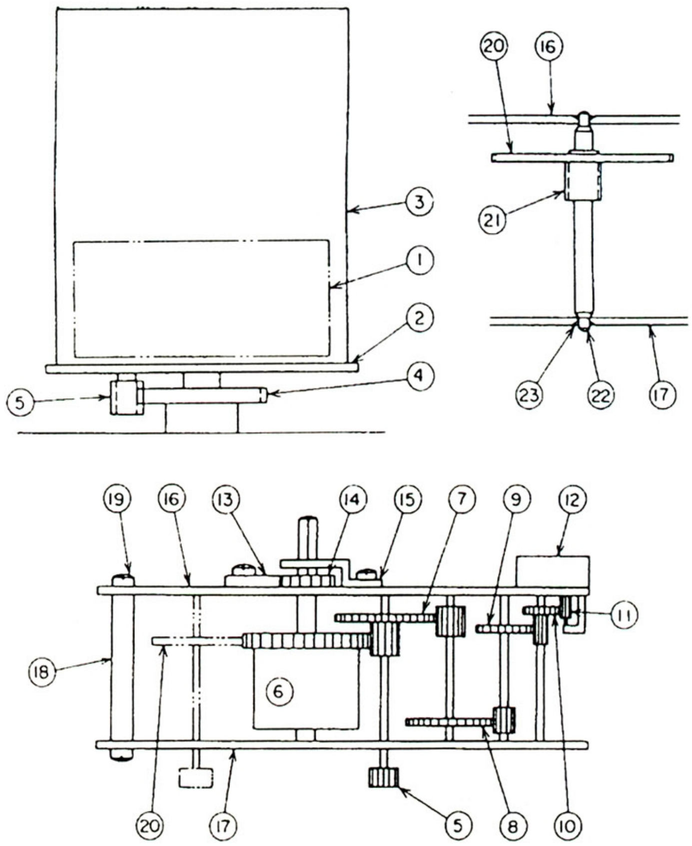
① Indicator adjustment screw ② Sensor attachment screw ③Stopping screw
④ Nut to stop pen arm ⑤ Spring ⑥ Steel strip
⑦ Bimetal lever ⑧ Magnification adjustment ⑨ Screw to stop
⑩ Screw pushing clock-driven drum ⑪ Bimetal ⑫ Attachment nut for clock-driven drum axis
⑬ Washer ⑭ Stand table Unit: mm

Figure 2. 9 Bimetal thermograph structure

2.2.4 Clock-driven Drums

A clock-driven drum is a self-registering instrument that rotates at a constant rate and creates a record on a chart around it. It runs on a spring-driven or battery-powered clock, and the typical recording period is one or seven days.

The structure of a one-day spring-driven drum is shown in Figure 2.10. The clockwork is held in the clock-driven drum *A*. The force of the spring wound up in the spring box ⑥ is transmitted through the gears to the rotation-driving unit ⑫, which causes the clock drum to turn at a constant rate. The drum can be turned by hand as needed to synchronize the time lines on the recording chart. A seven-day drum has an additional gear ⑳ meshed with the gear in the spring box, and a rotation adjustment gear ⑤ is attached to the shaft of the additional gear to reduce the speed of the drum.



① Clock device
② Bottom plate
③ Cylinder of clock-driven drum
④ Central gear
⑤ Rotation adjustment gear
⑥ Spring box
⑦ Second gear
⑧ Third gear
⑨ Fourth gear
⑩ Fifth gear
⑪ Interaction pinion
⑫ Rotation-driving unit
⑬ Unit pushing gear connecting to spring box
⑮ Attachment to gear connecting to spring box
⑯ Upper panel
⑰ Lower panel
⑱ Stay
⑲ Screw attaching to stay
⑳ Gear
㉑ Pinion
㉒ Pivot
㉓ Oil reservoir

Figure 2. 10 Names of clock-driven parts

2.2.5 Louvered Screens

Louvered screens (Figure 2.11) protect thermometers and psychrometers from rain and wind as well as solar and other types of radiation. Ideally there should be a double louver at the sides and a double drain board at the bottom, and the roof should consist of two layered boards that allow airflow between them. There is usually a single door, but some screens in low-latitude areas have two doors to the north and south. Screens must be placed so that the thermometers inside are not exposed to direct sunlight when the door is opened, and should be designed with a small heat capacity while allowing adequate space between the walls and the instruments. Both the inner and outer sides of screens should be painted white and be water repellent. Most are made of wood, but some are made of plastic.

Because of solar and other types of radiation, the temperature of a screen may be higher than the air temperature if the level of radiation is intense, and conversely may be lower than the air temperature on a clear night. As a screen has high heat capacity, its temperature change lags behind variations in air temperature – a tendency that is remarkable when the wind is weak. To measure air temperature accurately, it is necessary to ventilate the thermometer in order to keep it and the outer air as close to thermal equilibrium as possible. Since temperatures measured with thermographs and maximum or minimum thermometers without ventilation are subject to the influence of screen temperature, their values tend to be higher by day and lower by night than values measured with a ventilated thermometer.

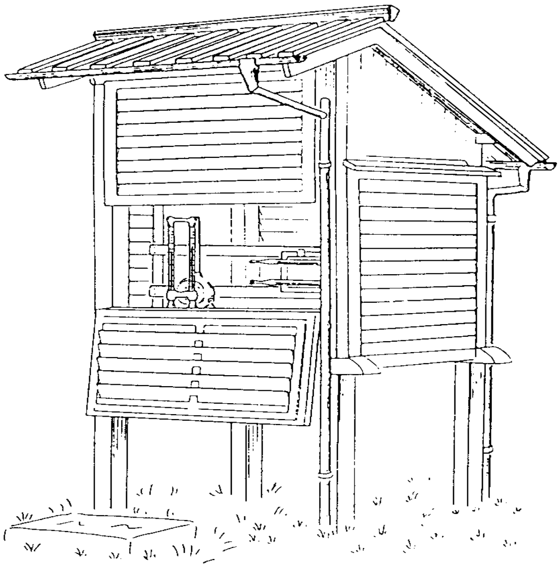


Figure 2.11 Louvered screens

2.2.6 Ventilated Shields

Ventilated shields are used to protect the sensors of instruments such as platinum resistance thermometers from solar and heat radiation. Forced ventilated shields (Figure 2.12) consist of a double cylinder made from corrosion-resistant material. A heat insulator between the inner and outer cylinders isolates heat, and the lustrous surface precludes the influence of solar and other types of radiation. An electric fan at the top provides ventilation to keep the sensor and the outer air in thermal equilibrium.

WMO recommends a ventilation speed of 2.5 to 10 m/s. JMA sets ventilators to provide an air speed of 5 to 7 m/s.

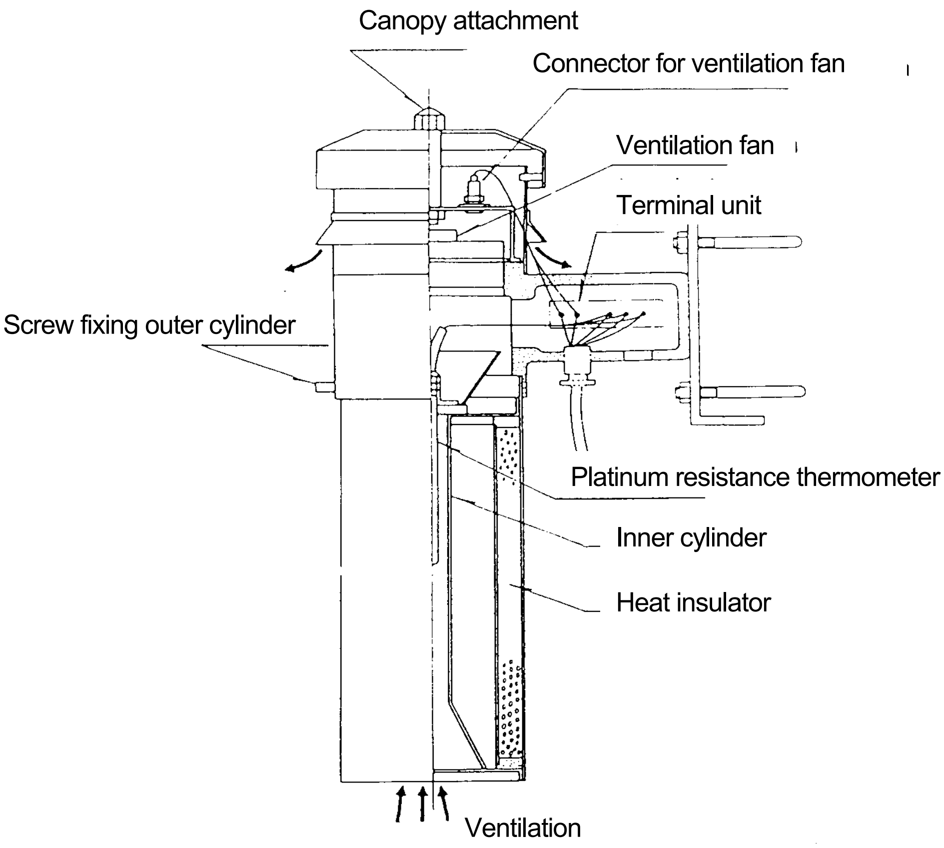


Figure 2. 12 Ventilation type thermometer shelter

2.3 Exposure and Siting

Thermometer installation should be standardized to ensure measurements that represent the ambient atmosphere and are comparable with those obtained at different places and at different times.

2.3.1 Observation Fields

An observation field is an area in which instruments are arranged in an efficient and appropriately concentrated manner. It should be level, open, flat and unshaded by trees or buildings. The ground surface should be covered with grass or maintain its natural surface on barren land, and the field should be enclosed with a fence that does not disturb wind passage. The ground should be kept clear all year round by mowing and weeding the surface occasionally. Locations on steep slopes or in hollows should be avoided because of the poor representation that results from such terrain. Any influence from changes in the surrounding conditions of the field must be taken into account. A power source and water supply for management and maintenance of the observation field and instruments are beneficial.

2.3.2 Louvered Screens and Ventilated Shields

Louvered screens or ventilated shields should be placed in observation fields as described in the previous section.

The foundations of louvered screens should be made of a sturdy material and installed firmly to reduce errors in the readings of maximum and minimum thermometers resulting from wind vibration.

Ventilated shields should be installed vertically. If an electric fan is used for ventilation, heat from the motor or the fan should not affect the thermometer.

2.3.3 Thermometers

Due to the influence of radiation, the temperature gradient near the ground is larger at lower elevations. Accordingly, a thermometer placed close to the ground will tend to indicate higher temperatures during the daytime and lower values at night, and it is therefore recommended that general observations of air temperature be made at a height of 1.25 to 2 m above the ground (JMA sets thermometers at a height of 1.5 m). Temperature observation on the tops of buildings is not recommended because of the variable vertical temperature gradient present and the effect of radiation from the building itself.

Liquid-in-glass thermometers, including ordinary thermometers, maximum and minimum thermometers and bimetallic thermographs, are installed in louvered screens. Maximum thermometers should be installed in a position inclined about 2 degrees from the level with the bulb lower so that gravity acting on the column does not exert a force on the constriction. On the other hand, minimum thermometers should be installed level. Electrical thermometers may be installed in ventilated shields or in louvered screens.

2.4 Maintenance

2.4.1 Routine Maintenance

2.4.1.1 Electrical Thermometers

Defective contacts may cause jumps in the air temperature record. Check for such jumps and perform repair if necessary.

2.4.1.2 Liquid-in-glass Thermometers

(1) As dust or salt accumulation on the glass prevents clear readings, wipe occasionally with a cloth.

(2) If bubbles or breakage in the liquid column are found, repair is necessary.

(3) If mercury adheres to the inner wall of the capillary tube and reading the scale becomes difficult, replace the thermometer as such defects cannot be repaired.

(4) If the indication of a maximum thermometer in the vertical is different from that in a horizontal position by 0.2 °C or more, the unit should be replaced. This phenomenon is often seen when breakage in the mercury column occurs.

(5) A minimum thermometer whose index does not move with the top of the column and is left outside it cannot be repaired; replacement is necessary.

(6) If dew forms on the inner wall of the outer tube of a sheathed thermometer and reading the scale becomes difficult, replacement is necessary as the outer tube may be cracked.

2.4.1.3 Bimetallic Thermographs

(1) The reading of a bimetallic thermograph should be compared with the temperature of an aspirated psychrometer for each observation. If the difference between them exceeds 1 °C, adjust the bimetallic thermograph indicator.

(2) Dust, salt and exhaust gases are likely to accumulate on a thermograph when it is used in a louvered screen. Wipe exposed parts, pivots, bearings and the bimetallic element with a brush from time to time.

(3) If the pen moves irregularly, repair is necessary.

2.4.1.4 Clock-driven Drums

Regularly check the accuracy of the clock. If it is found to be inaccurate, detach the clock-driven drum and use the pace adjustment lever.

2.4.1.5 Louvered Screens

Always keep the inside of louvered screens clean. After a snowstorm, for example, remove any buildup of snow from them.

2.4.1.6 Ventilated Shields

Check that the fan is operating. If any unusual noise or vibration is found, detach and inspect.

2.4.2 Periodic Maintenance

2.4.2.1 Electrical Thermometers

(1) Electrical thermometers should be checked at least every three months using a portable aspirated psychrometer. Comparisons should be avoided in bad weather conditions such as those with strong wind, heavy rain/snow or dense fog, and a time when the air temperature is relatively stable should be chosen. When installing a portable aspirated psychrometer, ensure that its intake is at the same level as that of the electrical thermometer.

(2) Electrical thermometer observation errors can result from even small changes in contact resistance or slight deteriorations of insulation caused by dust or salt deposits. Ensure that wire connection terminals are tightened, and clean them with alcohol once a year.

2.4.2.2 Liquid-in-glass Thermometers

The spirit in spirit thermometers sometimes evaporates, adheres or condenses in the upper part of the capillary tube, producing errors in reading. To prevent such problems, immerse the bulb in cold water or ice and blow steam over the upper part of the tube at regular intervals to move adhered spirit back to the bulb.

2.4.2.3 Bimetallic Thermographs

Periodic maintenance of thermographs should be carried out every three months.

(1) Perform routine maintenance meticulously.

(2) If ink has solidified and soiled the pen tip, pull the tip from the pen arm and immerse it in alcohol to rinse it. If the ink passage is clogged and the pen has poor ink flow, clean its tip by inserting a firm but thin piece of paper into the split.

(3) If the traced line has become bold, replace the pen.

(4) Clean the bimetal using a brush soaked with benzine. After it has dried, wipe it with a lightly greased cloth to prevent corrosion. Do not apply too much grease, as a thick layer may affect sensitivity.

(5) Turn the indicator adjustment screw ① shown in Figure 2.9 to check whether the movement of the pen tip aligns with the time lines over the entire range. If misalignment occurs, adjust the curvature.

2.4.2.4 Clock-driven Drums

Clock-driven drums may stop due to oil shortage or deterioration. It is necessary to clean and oil the drum every two or three years. If installed in a louvered screen, a clock may stop within two years from the influences of briny air, volcanic gases, automobile exhaust gases and agricultural pesticides. When such conditions are present, more frequent inspection is required.

2.4.2.5 Louvered Screens

Wash louvered screens once or twice a year to remove soiling. If paint has peeled or soiling is difficult to remove, repaint the screen. Repainting is necessary at least once a year in areas with significant air pollution.

2.4.2.6 Ventilated Shields

Ventilated shields should be dismantled and cleaned at regular intervals to ensure efficient ventilation around the thermometer.

2.5 Calibration

All liquid-in-glass thermometers undergo a gradual shift of their zero point. It is important to inspect them at regular intervals - usually every five years. Electrical thermometers should also be inspected in a similar manner in order to monitor drift.

JMA calibrates thermometers at its calibration center using the methods described below for use at observatories.

2.5.1 Freezing-point Calibration

The temperature of 0°C is defined as that at which ice is in equilibrium with air-saturated water under standard pressure conditions. Accordingly, ice is generally used for freezing-point calibration. Care must be taken, as a temperature of 0 °C is not attained if the ice contains impurities, especially salt. Freezing-point testers (Figure 2.12), which have a hole at the bottom to allow water to drain and a thermometer, should be cleaned prior to inspection. Crush the ice to an appropriate size and place it in the freezing-point tester. Then, insert the thermometer into the tester (insert vertically for liquid-in-glass thermometers) and pack it with the crushed ice so that the entire unit is buried. When packing with crushed ice, be sure to fill the tester so that the ice comes into close contact with the bulb.

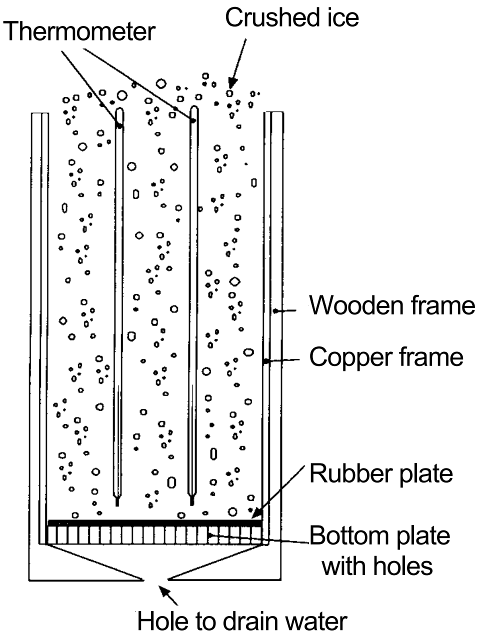


Figure 2.12 Freezing-point tester

2.5.1.1 Electrical Thermometers

Freezing-point calibration of platinum resistance thermometers (the four-wire type) is described in this section. A diagram of the circuit used for calibration is shown in Figure 2.13

(1) Wash the freezing-point tester and the platinum resistance thermometer well before calibration. Turn on the digital voltmeter and voltage current generator and wait for at least 30 minutes to allow them to stabilize.

(2) Crush ice finely in the same manner as for liquid-in-glass thermometer calibration. Insert the platinum resistance thermometer into the freezing-point tester, connect the wires as shown in Figure 2.13 and ensure close contact with the ice.

(3) Adjust the zero point of the digital voltmeter by turning S2 in Figure 2.13 to the short-circuit side and by turning the zero shift knob of the digital voltmeter.

(4) Turn the knife switches S1 and S2 to the standard resistance measurement side. A current close to the prescribed value will flow through the circuit.

(5) Keep the current at the prescribed value by turning the adjustment knob of the reference voltage current generator while watching the terminal voltage *ES* across the standard resistor *RS* with the digital voltmeter.

(6) At about 30 minutes after starting to keep the prescribed current, check the contact between the platinum resistance thermometer and the ice and begin the reading. Check the null point of the digital voltmeter first. Read the *ES* value and the voltage between the terminals of the platinum resistance thermometer *ER* alternatively two or more times. If the resulting readings indicate the same value, use that value. If two or more resistors are wired as shown in Figure 2.9, change the connections of terminals A and B successively.

(7) Calculate the resistance of the thermometer using the value derived in Step (6).

Assuming that RT is the resistance to be obtained, that RS is the resistance of the standard resistor, and that I is the measuring current, Ohm's Law provides the following equations:

$ER = RT \cdot I$ and $ES = RS \cdot I$

and the resistance value of the sensor RT at 0°C is derived from the following equation:

$RT = RS \cdot ER/ES$

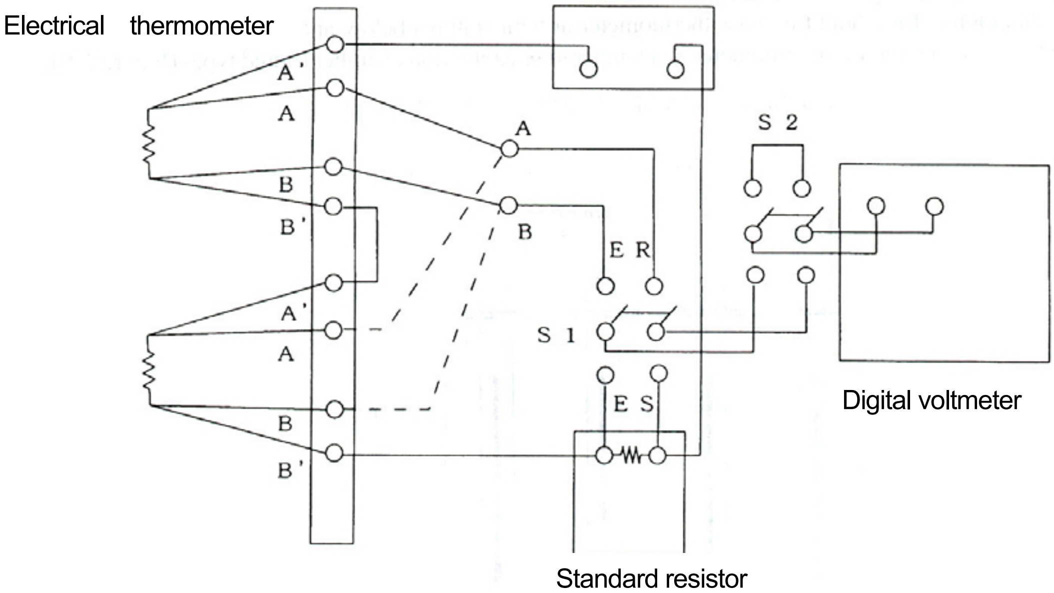


Figure 2.13 Diagram of an electrical thermometer calibration

2.5.1.2 Liquid-in-glass Thermometers

If the thermometer is too long to be covered completely, bury it at least up to the 20 °C mark. However, do not insert it so deeply that the bulb reaches the bottom of the tester.

When using ice with a temperature of lower than 0 °C, pour some pure water on it to bring its temperature up to 0 °C.

Unsheathed mercury thermometers can be inserted directly into the ice. However, because sheathed units have some amount of heat capacity, they should be cooled prior to insertion. Do not insert spirit thermometers into ice quickly; if a unit indicating a temperature of above 0 °C is inserted quickly, the spirit column may adhere to the wall of the capillary tube and the reading at freezing point may become lower by 0.1 to 0.2 °C.

Leave the thermometer in the ice for more than 10 minutes before reading the indication, and push aside ice so that the 0°C mark is visible without moving the thermometer. Leave the thermometer in the ice and add a small amount of crushed ice after the first reading. After several minutes, take another reading. If the first and second indications are the same, that value is determined as the instrument error at 0 °C. If the two indications are different, the thermometer may not be in equilibrium with the ice at freezing point, and the freezing point should be calibrated again.

Voids develop as ice melts and its amount decreases, especially near the bulb. It is therefore important to squeeze the ice before reading to ensure that the thermometer and ice are in close contact. Freezing-point calibration of a maximum thermometer is carried out by leaving it in a freezing-point tester for more than 10 minutes. After this period of time, pull the thermometer out a little, tap it lightly on the rubber plate under the ice a few times and take a reading. Repeat these operations until the indication has settled, and derive the instrument error from the indication. Even when the thermometer is tapped on the rubber plate, ensure that the bulb is kept in the ice.

2.5.2 Calibration other than Freezing Point

2.5.2.1 Electrical Thermometers

Calibration of thermometers is carried out using a reference thermometer in a temperature calibration chamber by comparing both measurement values of a reference thermometer and tested thermometers (Figure 2.14).

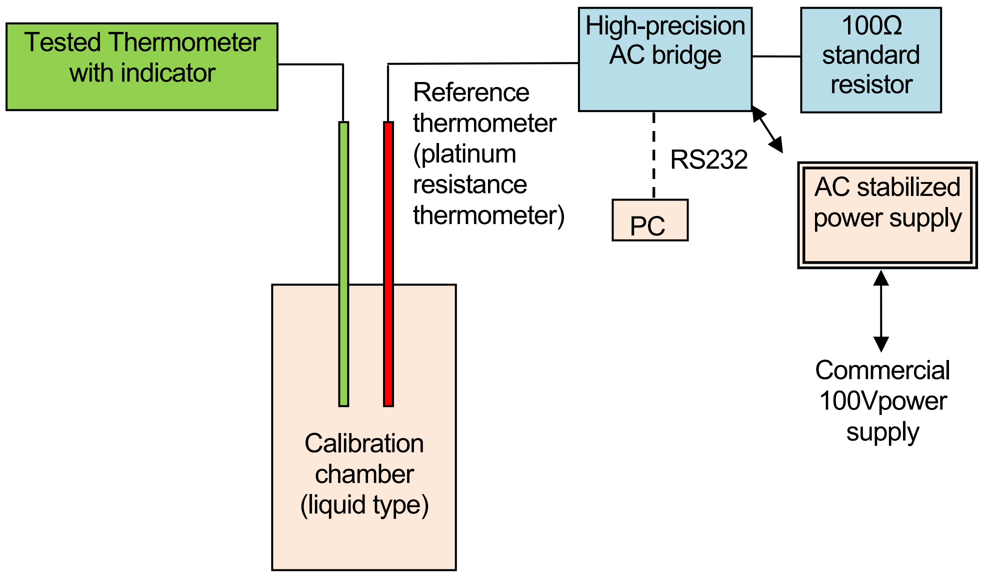


Figure 2.14 Comparative calibration of an electrical thermometer (An example in JMA)

2.5.2.2 Liquid-in-glass Thermometers

Calibration of liquid-in-glass thermometers at temperatures other than freezing point is carried out using a reference thermometer in a temperature calibration chamber (liquid type) (Figure 2.15).

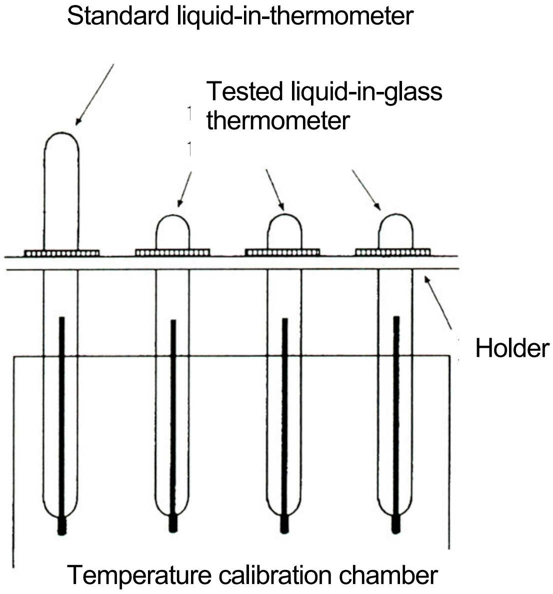


Figure 2.15 Comparative calibration of a liquid-in-thermometer (An example in JMA)

2.5.2.3 Bimetallic Thermographs

Bimetallic thermographs are calibrated in a temperature calibration chamber (air type) with its protective frame removed. Calibration is performed at three or four temperatures across the unit's entire measurement range using a reference thermometer.

2.6 Adjustment and Repair

2.6.1 Electrical Thermometers

If there is a large difference between the actual temperature and the reading of an electrical thermometer, detach the cables of the sensor (i.e., the platinum resistance thermometer) from the terminals and connect a standard resistor (of equivalent temperature) to the terminals in its place to determine whether the fault is in the sensor or in the electrical circuit. If the sensor is at fault, replace it. If the electrical circuit is at fault, it is impossible to repair it on the spot. Consult a technical expert or the manufacturer for repair. As improper tightening or defective insulation of terminals can cause faults, inspect the cables extending from the sensor to the electrical circuit and try retightening the terminals.

2.6.2 Liquid-in-glass Thermometers

2.6.2.1 Basic Instructions

(1) Because glass is fragile, repeated repairs are often required. Choose an appropriate method and repeat repair carefully as many times as needed.

(2) When a thermometer is repaired, refrain from using it for a few days until its indication stabilizes. Set spirit-in-glass thermometers vertically during the stabilization period.

2.6.2.2 Visible Issues

(1) If graduation lines on an unsheathed thermometer become blurred, they can be clarified by applying black enamel or lacquer and wiping off with a piece of hard paper.

(2) If the cap of a sheathed thermometer comes off, attach it again with an adhesive.

(3) If there is any looseness between a thermometer and the board to which it is attached, insert a piece of rubber between the unfastened clasps and the thermometer and fasten the clasps again.

(4) The scale plate of a sheathed thermometer is installed in the outer glass tube. If it comes loose, the thermometer cannot be repaired; the same applies for cracking and other damage in the glass portion.

2.6.2.3 Breakage in the Mercury Column

Breakage in the mercury column occurs when a bubble remains in it. This is often seen when mercury thermometers are transported or stored carelessly. Thermometers that are always oriented vertically can be used without problems if the bubble is small enough to be invisible without a magnifying glass. However, a bubble left as it is may become larger and make repair difficult. Repair should be performed while the bubble is small.

If the problem cannot be remedied using one method, try others as necessary.

(1) Repair by tapping

Try tapping the bulb of the thermometer on a rubber plate. If the bubble moves toward the top of the mercury column, continue tapping. Tap in the direction of the thermometer’s axis; do not tap in a transverse or oblique direction, as this will cause the glass to break. If the bubble does not move, or if it moves toward the bulb, try another method.

(2) Repair by centrifugal force

Grip the thermometer at the head tightly and shake it forcefully. The mercury in the capillary tube will be forced toward the bulb by centrifugal force, and as a result the bubble will be expelled to the top of the mercury column.

(3) Repair by temperature difference

Cool alcohol with dry ice to a temperature below the scale range of the thermometer. Immerse the bulb of the thermometer in the alcohol so that all the mercury flows into the bulb, and the bubble will be eliminated.

If a thermometer has a safety chamber at the top of the capillary tube, warm the bulb in lukewarm water. When the bubble reaches the safety chamber and the lower mercury unites with the upper mercury, cool the bulb slowly and the bubble will disappear. Remember that too much warming may cause the mercury to burst through the top of the capillary tube.

2.6.2.4 Breakage in the Spirit Column

Perform repair as outlined in (2) and (3) of Section 2.6.1.3.

2.6.3 Bimetallic Thermographs (see Figure 2.9.)

2.6.3.1 Adjustment of Indication

(1) Large shifts in indication

When the indication position needs to be shifted significantly for seasonal changes, turn the indicator adjustment screw ① near the temperature sensor.

(2) Small shifts in indication

To shift the indication position slightly for small corrections of instrument error, turn the pen arm adjustment screw near the pen arm rotation axis.

When the indication position is shifted, tap the instrument body, observe the movement of the pen and make sure its position is stable. To adjust the indication, place the bulb of a reliable liquid-in-glass thermometer close to the bimetallic strip of the thermograph when the temperature is practically constant. Leave them for several minutes and then make the adjustment. Leave them for several minutes again and check that both indicate the same temperature.

(3) Unstable indication

Inspect for looseness of the indicator adjustment screw ①, the sensor attachment screw ②, the set-screw ③, the pen arm attachment nut ④, the pen arm spring ⑤, the pen arm attachment screw, the pen arm-supporting pivot, and the attachment of the pen tip. Tighten any loose parts. Adjust the pivots at both ends of the pen arm rotation axis so that the bottom of the steel strip ⑥ touches the bimetal lever ⑦ lightly when the top of the link is held and allowed to hang down.

2.6.3.2 Irregular Movement of the Pen

Irregular movement of the pen during its up and down motion may occur if excessive friction is exerted between the pen tip and the recording chart or if rotating parts are faulty. Typical causes of such irregular movement are as follows:

(1) Defective pen tip

Irregular movement often occurs when a pen tip is replaced. Polish the tip a little on an oilstone. If a pen tip is damaged, replace it.

(2) Improper pen pressure

If the instrument has a pen pressure adjustment screw, change the pressure so that the tip separates from the recording chart when the instrument body is inclined by about 30 degrees to the front. Repeat this adjustment with the pen tip position in the upper and lower parts of the recording chart.

If irregular movement of the pen occurs in particular parts of the recording chart, the shaft of the clock-driven drum may be inclined or the distance between the drum shaft and the pen arm rotation axis may not be correct.

- Inclined clock-driven drum shaft

  Bring the drum shaft to the correct position by loosening the fixing nut ⑫ and the rotating washer ⑬, or by inserting a piece of paper between the washer ⑬ and the lower plate ⑭.

- Improper pen arm length

  Measure the distance from the pen arm rotation axis (the center of the nut ④) to the pen tip, and move the tip to the correct position.

(3) Loosened screws in various parts

It is difficult to specify the play of various parts and the tightening of screws quantitatively. An instrument that operates well should be examined to get a feel of the situation.

(4) Soiled pivot rotation parts

If dust accumulates on pivot rotation parts, friction develops and the movement becomes dull. Clean pivots from time to time. If rust develops on them, clean them and oil lightly. When cleaning pivots, always clean one pivot rotation part at one end, reassemble and adjust the play before cleaning the other part on the opposite side. Otherwise, operation may deteriorate further.

2.6.4 Clock-driven Drums

(1) Clock stoppage

If a clock-driven drum comes to a standstill due to oil shortage or deterioration, dismantle and clean it. As the rotation-driving part contains minute components and performs precision operation, consult a technical expert or the manufacturer for repair.

(2) Clock inaccuracy

Detach the drum and adjust the clockwork using the pace adjustment lever.

2.7 Transport

Transport liquid-in-glass thermometers with the bulb in a low position to prevent breakage of the liquid column. Mercury is widely used for liquid-in-glass thermometers, but is toxic if swallowed or inhaled in vapor form. The International Air Transport Association (IATA) restricts the transportation of mercury by aircraft. Seek advice from the appropriate institution or common carriers.