5. Experimental Contents

Experiment 1: Temperature characteristics measurement and application of PN junction temperature sensor

1) Under the condition of constant small current, measure the relationship between the forward voltage and temperature of the PN junction temperature sensor, and find the sensitivity and correlation coefficient of the PN junction temperature sensor;
2) Construct a digital electronic thermometer with PN junction temperature sensor, amplifier circuit and digital voltmeter, and calibrate the digital thermometer (use medical grade mercury thermometer as standard);
3) Use the constructed digital electronic thermometer (PN junction temperature sensor) to measure the temperatures of various parts of the human body (eyebrows; armpits; palms; lower extremities), and understand the temperature differences of different body parts.

Experiment 2: Temperature characteristics measurement and application of voltage integrated temperature sensor (LM35)

1) Measure the relationship between the output voltage of the voltage type temperature sensor (LM35) and the temperature, and find the sensitivity and correlation coefficient of the LM35 temperature sensor;
2) Construct a digital electronic thermometer with LM35 temperature sensor, amplifier circuit and digital voltmeter, and calibrate the digital thermometer (use medical grade mercury thermometer as standard); (Optional)
3) Use the constructed digital electronic thermometer (LM35 temperature sensor) to measure the temperatures of various parts of the human body (eyebrows; armpits; palms; lower extremities) and understand the temperature differences of different body parts. (Optional)

Experiment 3: Temperature characteristics measurement and application of a negative temperature coefficient thermistor (NTC 1K) temperature sensor

1) Use the constant current source method to measure the relationship between the resistance of the negative temperature coefficient thermistor and the temperature, and obtain the sensitivity.
2) Use the thermistor temperature sensor NTC1K (negative temperature coefficient), amplifier and digital voltmeter to construct a digital electronic thermometer, and calibrate the digital thermometer (using a medical-grade mercury thermometer as a standard) (Optional).
3) Measure the temperatures of various parts of the human body (underarms, eyebrows, and palms) (except the oral) and compare them with the measured result in oral by using the mercury thermometer, and understand the cause of the temperature difference of various parts of the human body.

6. Experimental Procedures

Experiment 1: Temperature characteristics measurement and application of PN junction temperature sensor

1) Connect wires as required. Insert the temperature control sensor Pt100 platinum resistance into the central well of the temperature controlled dry-well heater, and the PN junction temperature sensor into another well of the dry-well heater. Start the measurement from room temperature, then turn on the heater, with temperature step size 10.0 ℃ and measure the PN junction forward voltage U_{be} at each temperature value.

2) Construct an electronic thermometer: Use Ur as the input signal, through the amplifier circuit to amplify it to achieve a voltage output of 10 mV/℃ by comparing and calibrating the output voltage with the standard temperature, procedures are as follows:

   Use a mercury thermometer to calibrate the temperature control sensor Pt100 platinum resistance at 37.0 ℃. Perform adaptive tuning of the PID temperature controller at 37.0 ℃.

   Adjust the "Cali." knob (calibration) and "Zero" knob (zero-adjustment) of the circuit to synchronize the output voltage with the temperature change (i.e. the output voltage changes by 10 mV for every 1 °C). Measure the linearity of the electronic thermometer (from 35.0 °C to 42.0 °C with step size 0.5 °C).

3) Perform temperature measurement of various parts of the human body (underarms, eyebrows, and palms, except the oral) and compare them with the measurement value of mercury thermometer in the oral. Understand the cause of the temperature difference among various parts of the human body.

Experiment 2: Temperature characteristics measurement and application of voltage integrated temperature sensor (LM35)

1) Connect wires as required. Insert the temperature control sensor PT100 platinum resistance into the center hole of the dry-well heater, and the LM35 temperature sensor into another well of the dry-well heater. Start measurement from the ambient temperature, then turn on the heater, with temperature step size 10.0 ℃, wait the temperature getting stable for 2 minutes, measure the output voltage of the sensor LM35 at every temperature point.

2) Construct an electronic thermometer: amplify the output voltage of the LM35 sensor through the amplifier circuit and compare and calibrate the output voltage with a standard temperature, procedures are as follows:

   Use a mercury thermometer to calibrate the temperature control sensor Pt100 platinum resistance at 37.0 ℃. Perform adaptive tuning of the PID temperature controller at 37.0 ℃.

   Adjust the "Cali." knob (calibration) of the circuit to synchronize the output voltage with the temperature change (i.e. the output voltage changes by 10 mV for every 1 °C). Measure the linearity of the electronic thermometer (from 35.0 °C to 42.0 °C with step size 0.5 °C).

3) Perform temperature measurement of various parts of the human body (underarms, eyebrows, and palms, except the oral) and compare them with the measurement value of

mercury thermometer in the oral. Understand the cause of the temperature difference among various parts of the human body.

Experiment 3: Temperature characteristics measurement and application of NTC1K temperature sensor

Refer Figure 1 to measure thermal resistance using a constant voltage. Note that, each time the temperature is changed, the current flowing through Rt must be re-measured since the resistance of Rt has changed.

1) Connect wires as required. Insert the temperature control sensor Pt100 into the central well of the heater, and insert the NTC1K thermistor another well. Start measurement from room temperature. Then turn on the heater, with temperature step size 10.0 °C, wait the temperature getting stable for 2 minutes, measure and calculate the resistance of the NTC1K thermistor at every temperature point till 80.0 °C. Use formula (5) and (6), fit the measurement results with the least square method to obtain the constant B.

2) Construct electronic thermometer (optional): Use U_{Rt} as the input signal, through the amplifier circuit to amplify it to achieve a voltage output of 10 mV/°C by comparing and calibrating the output voltage with the standard temperature, procedures are as follows:

   Use a mercury thermometer to calibrate the temperature control sensor Pt100 platinum resistance at 37.0 °C. Perform adaptive tuning of the PID temperature controller at 37.0 °C.

   Adjust the "Cali." knob (calibration) and "Zero" knob (zero-adjustment) of the circuit to synchronize the output voltage with the temperature change (i.e. the output voltage changes by 10 mV for every 1 °C). Measure the linearity of the electronic thermometer (from 35.0 °C to 42.0 °C with step size 0.5 °C).

3) Perform temperature measurement of various parts of the human body (underarms, eyebrows, and palms, except the oral) and compare them with the measurement value of mercury thermometer in the oral. Understand the cause of the temperature difference among various parts of the human body.

7. Examples of Data Recording and Processing

Note: the following data are for reference purposes only, not the criteria for apparatus performance.

Experiment 1: Temperature characteristics measurement and application of PN junction temperature sensor

Table 1 Data of forward voltage U_{be} and temperature of PN junction sensor

t (°C)	20.0	30.0	40.0	50.0	60.0	70.0	80.0
Ube (V)	0.5856	0.5636	0.5427	0.5212	0.4989	0.4768	0.4548

Use the least square method to fit the straight line, and obtain the result:

Temperature coefficient K = -0.0022 V/°C. The correlation coefficient r = 0.9999.

Table 2 Compare the constructed thermometer using PN junction with the standard thermometer

t (°C)	35.0	35.5	36.1	36.6	37.2	37.7	38.2	38.6	38.9	39.3	39.9	40.6	41.2	41.7	42.2

t_1(°C)	35.0	35.4	35.9	36.4	37.0	37.5	38.0	38.5	39.1	39.5	40.1	40.7	41.1	41.5	42.2
Δt (°C)	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.1	-0.2	-0.2	-0.2	-0.1	0.1	0.2	0.0

* $\Delta t = t_1 - t$, t is measured by the constructed thermometer, t_1 is measured by the standard thermometer (in oral)

Experiment 2: Temperature characteristics measurement and application of voltage integrated temperature sensor (LM35)

Table 3 Data of output voltage and temperature of LM35 sensor

t (°C)	20.0	30.0	40.0	50.0	60.0	70.0	80.0
Uo (V)	0.1934	0.3006	0.4020	0.5035	0.6020	0.7036	0.8046

Use the least square method to fit the straight line Uo=Kt+A, and obtain the result:

Sensitivity K=0.0102 V/°C, correlation coefficient r = 0.99989.

Table 4 Compare the constructed thermometer using LM35 with the standard thermometer

t (°C)	35.0	35.5	36.0	36.5	37.0	37.5	38.0	38.5	39.0	39.5	40.0	40.5	41.0	41.5	42.0
U_0 (V)	0.3500	0.3552	0.3604	0.3652	0.3712	0.3753	0.3808	0.3856	0.3912	0.3956	0.4008	0.4050	0.4011	0.4155	0.4200
t_1(°C)	34.9	35.4	35.9	36.4	37.0	37.5	38.0	38.5	39.0	39.5	40.2	40.5	41.0	41.7	42.1
Δt (°C)	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	-0.2	-0.1

* $\Delta t = t_1 - t$, t is measured by the constructed thermometer, t_1 is measured by the standard thermometer (in oral)

Experiment 3: Temperature characteristics measurement and application of NTC1K temperature sensor

Table 5 Data of NTC1K resistance and temperature

No.	t(°C)	T (K)	RT (Ω)	$1/T \times 10^{-3}$ (K^{-1})
1	20.0	293.15	1364	3.411
2	25.0	298.15	1137	3.354
3	30.0	303.15	923.5	3.299
4	40.0	313.15	614.5	3.193
5	50.0	323.15	419.2	3.095
6	60.0	333.15	291.5	3.002
7	70.0	343.15	206.5	
8	80.0	353.15	151.2	
9				

From equation (6), find the straight-line relationship of lnRT - (1/T) and perform straight-line fitting, we obtain: $B = 3.807 \times 10^{-3} K$, and Correlation coefficient r = 0.9997.

The relationship between the thermistor resistance RT and the temperature T satisfies the exponential relationship of $R_T = Ae^{B/T}$.

* Generally from 20.0 ～ 60.0 ℃ in winter, from 40.0 ～ 80.0 ℃ in summer, and freezing point can be measured at 0 ℃

* If you need to save time, you can set the temperature control system every 5.0 ℃.

Table 6 Compare the constructed thermometer using NTC1K with the standard thermometer

t (℃)	35.0	35.5	36.0	36.5	37.0	37.5	38.0	38.5	39.0	39.5	40.0	40.5	41.0	41.5	42.0
U_0 (V)	0.3501	0.3550	0.3595	0.3653	0.3699	0.3752	0.3801	0.3852	0.3901	0.3952	0.4002	0.4050	0.4092	0.4147	0.4192
t (℃)	35.0	35.5	36.1	36.6	37.1	37.6	38.2	38.7	39.3	39.8	40.4	40.9	41.4	42.0	42.5
Δt (℃)	0	0	0.1	0.1	0.1	0.1	0.2	0.2	+0.3	+0.3	+0.4	+0.4	+0.4	+0.5	+0.5