ELEC 207
Instrumentation and Control

6 – Temperature Measurement

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Temperature measurement

Types of measurement devices

Most common devices employed to measure temperature are based on the following principles:

- Voltage generated by different metals (**thermocouples**);

- Electrical resistance change (**resistance temperature devices**, thermistors);
- Semiconductor characteristic change (semiconductor temperature sensors);
- Radiated energy (optical pyrometer, **infrared sensors**):
  - ➢ Contactless measurement.

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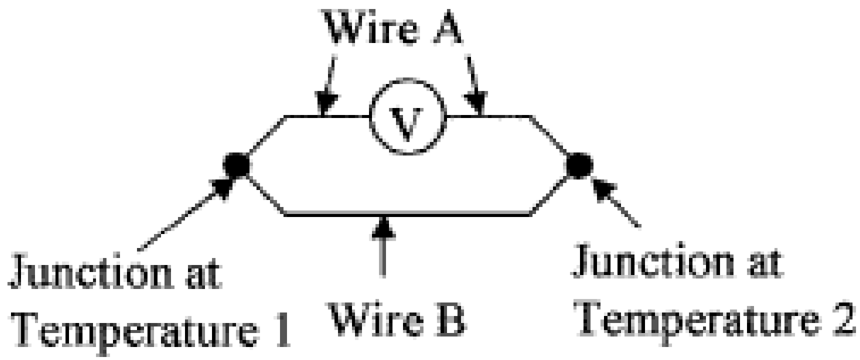
Thermocouple
Principle of operation (1)

Thermocouples are composed of **two different metals**, which are joined together to form **two junctions** in two different parts of the circuit:



- If the two junctions are at different temperatures, a **voltage** will appear, which is proportional to the temperature difference (**Seebeck effect**):
  - ➢ This voltage can be measured.

Thermocouple

Principle of operation (2)

If the temperature at one junction is known, the measured voltage is used to determine the unknown temperature at the other junction:

- The voltage vs temperature for each thermocouple type is tabulated, assuming a specific **reference temperature** (e.g. 0 ºC):

°C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.059	0.118	0.176	0.235	0.294	0.354	0.413	0.472	0.532	0.591
10	0.591	0.651	0.711	0.770	0.830	0.890	0.950	1.010	1.071	1.131	1.192
20	1.192	1.252	1.313	1.373	1.434	1.495	1.556	1.617	1.678	1.740	1.801
30	1.801	1.862	1.924	1.986	2.047	2.109	2.171	2.233	2.295	2.357	2.420
40	2.420	2.482	2.545	2.607	2.670	2.733	2.795	2.858	2.921	2.984	3.048
50	3.048	3.111	3.174	3.238	3.301	3.365	3.429	3.492	3.556	3.620	3.685
60	3.685	3.749	3.813	3.877	3.942	4.006	4.071	4.136	4.200	4.265	4.330
70	4.330	4.395	4.460	4.526	4.591	4.656	4.722	4.788	4.853	4.919	4.985
80	4.985	5.051	5.117	5.183	5.249	5.315	5.382	5.448	5.514	5.581	5.648
90	5.648	5.714	5.781	5.848	5.915	5.982	6.049	6.117	6.184	6.251	6.319

mV

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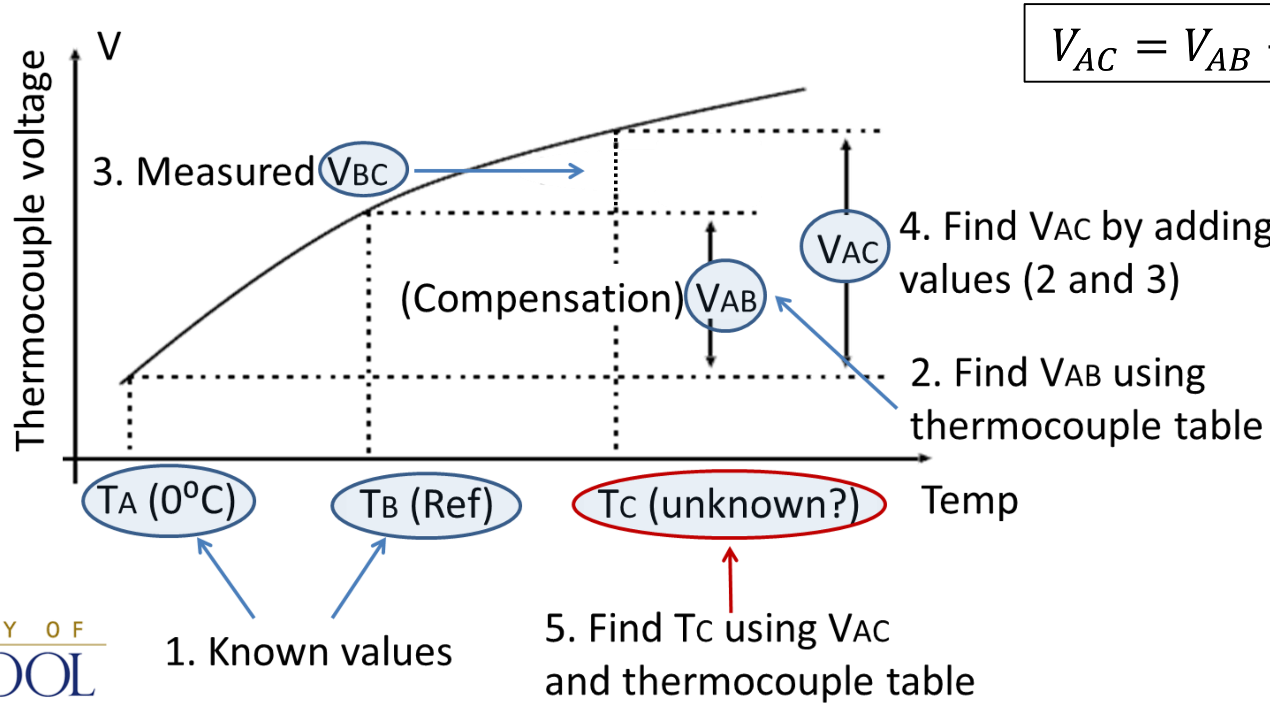
Thermocouple

Reference junction compensation

In many cases the reference junction is not a the specified reference temperature (e.g. not a 0 °C):

- The effect of a different temperature can be **compensated** by using the same thermocouple table:

$$V_{AC} = V_{AB} + V_{BC}$$



Thermocouple
Materials and thermocouple types (1)

The two metals used for the thermocouple determine the **thermocouple type**:

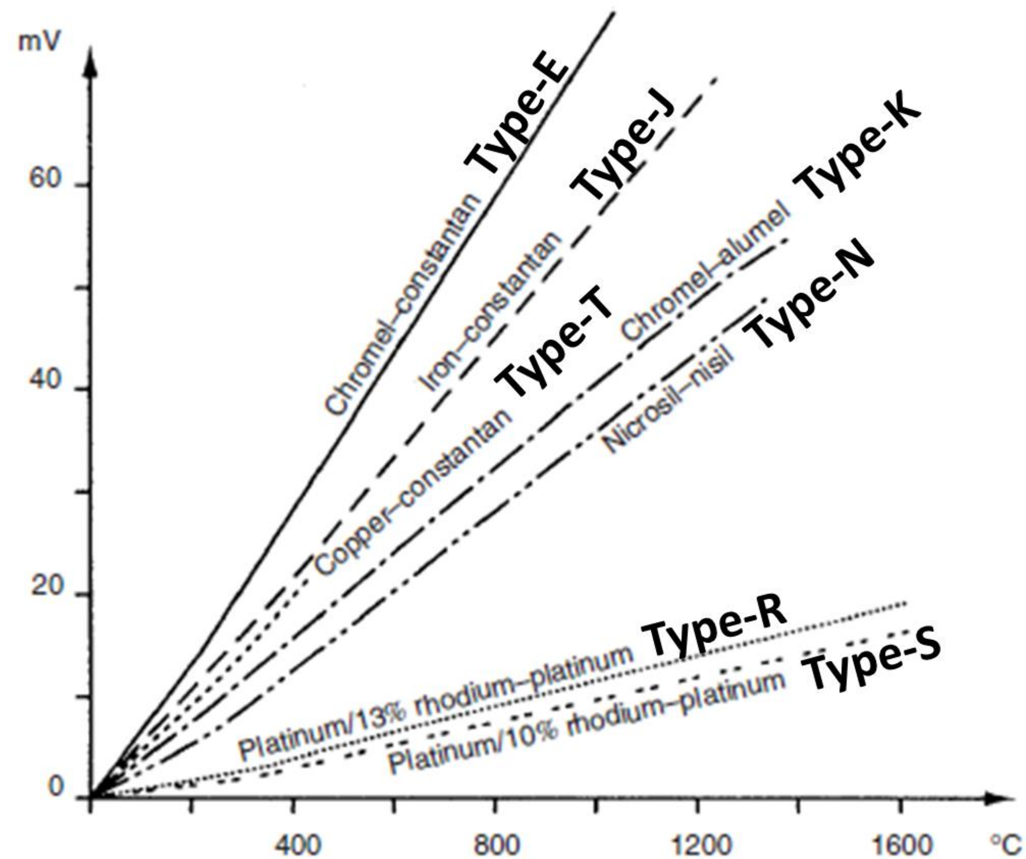
- Different types have different **temperature ranges**:

Type	Temperature°C	Conductor A	Conductor B
B	0 to +1700	Pt-Rh (30% Rh)	Pt-Rh (6% Rh)
C	0 to +2320	W-Re (5% Re)	W-Re (26% Re)
E	-200 to +900	chromel (Ni, Cr)	constantan (Cu, Ni)
J	0 to +750	iron	constantan (Cu, Ni)
K	-200 to +1250	chromel (Ni, Cr)	alumel (Ni, Al)
N	-270 to +1300	nicrosil (Ni, Cr, Si)	nisil (Ni, Si, Mg)
R	0 to +1450	platinum	Pt-Rh (13% Rh)
S	0 to 1450	platinum	Pt-Rh (10% Rh)
T	-200 to +350	copper	constantan (Cu, Ni)

Thermocouple

Materials and thermocouple types (2)

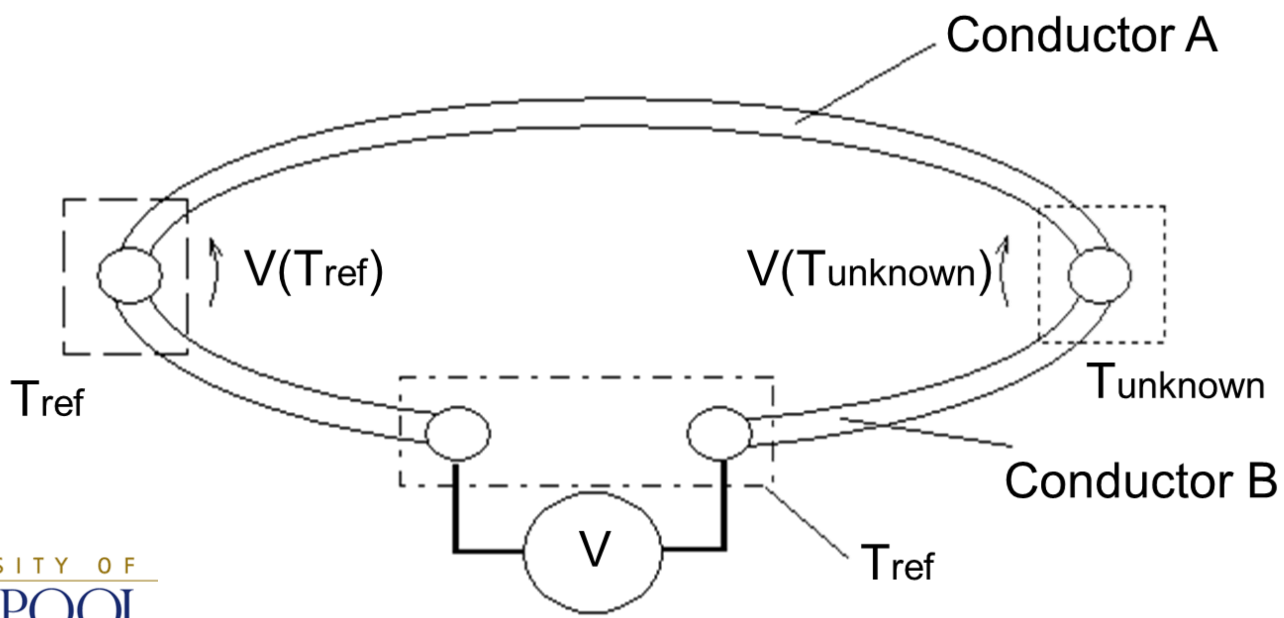
- They also have different **sensitivities** (and different costs):



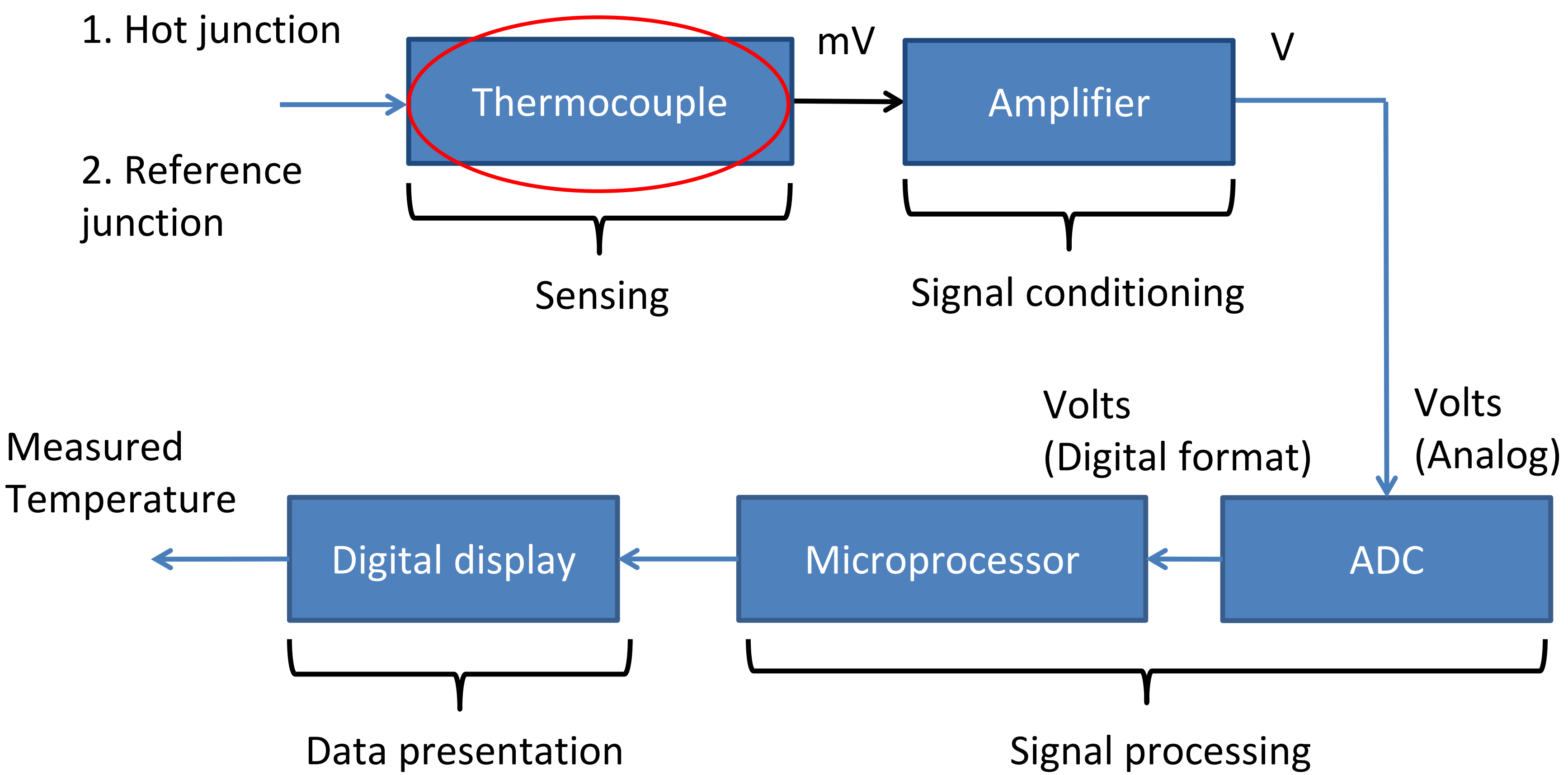
Thermocouple
Additional junctions

It is possible to add other metals (therefore other junctions) to the thermocouple circuit as long as these **additional junctions are at the same temperature**:

- This property can be used to add extension leads to connect the voltage measurement instrument (e.g. a voltmeter).



Temperature measurement
Thermocouple in a measurement system



Varying resistance devices

Metal vs semiconductor devices

There are two types of devices that experience changes in resistance due to changes in temperature:

- Metal devices (**Resistance Temperature Devices/Detectors**):
  - ➢ Usually composed of platinum, copper, nickel or tungsten;
  - ➢ Wide temperature range (e.g. from -200 ^{o}C to 850 ^{o}C).
- Semiconductor devices (**Thermistors**):
  - ➢ Usually composed of oxides of chromium, iron, manganese or nickel;
  - ➢ Narrower temperature range (e.g. from -50 ^{o}C to 300 ^{o}C).

Resistance Temperature Device (RTD)

Principle of operation

The electrical resistance of a metal changes with a change in temperature:

- The relationship between resistance and temperature is not linear but it can be **linearized for small variations**:

$$R(T) = R_0(1 + a\Delta T)$$

- The coefficient a depends on the material:

- A more accurate conversion from resistance to temperature is usually provided by the manufacturer as a table (similar to the thermocouple table).

Material	a (per ^oC)
Iron	0.006
Nickel	0.005
Tungsten	0.0045
Platinum	0.00385

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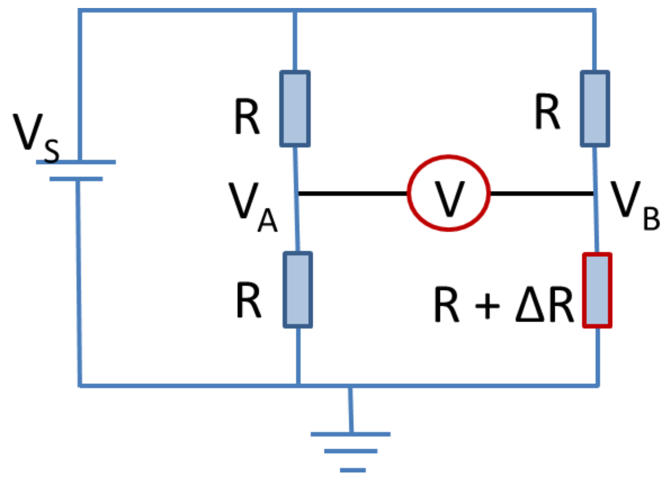
Resistance Temperature Device (RTD)

Deflection bridge

The resistance change of a RTD is usually measured by a **deflection bridge**, similarly to what done for the strain gauge.

- The **self-heating** of the RTD due to the current flowing in it may give rise to significant errors:

  - Therefore the voltage source should be carefully chosen (not too high) in order to limit this effect.



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Thermistor

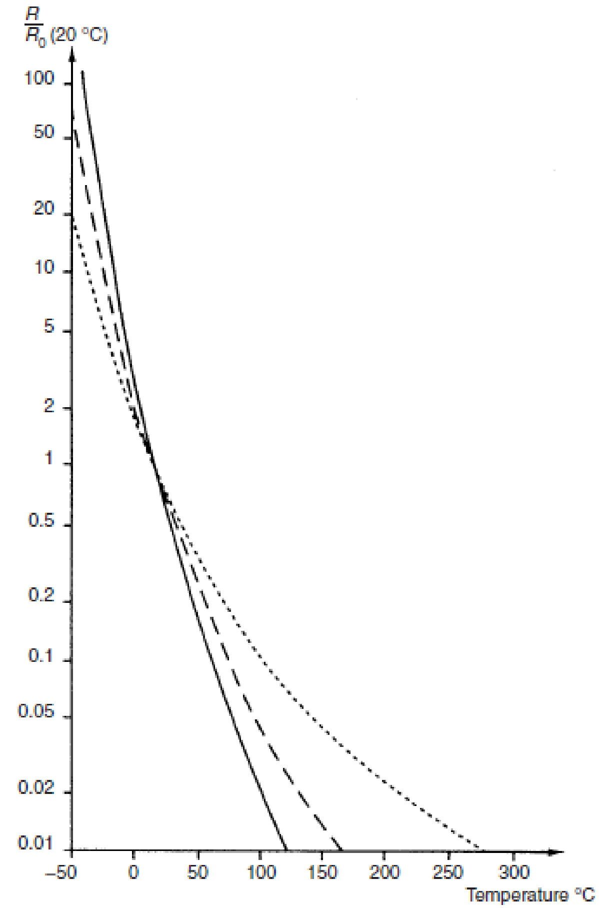
Principle of operation

In semiconductor devices, typically (but not always) the resistance decreases as the temperature increases (**negative temperature coefficient**):

$$R(T) = R_0 e^{\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)}$$

(T and T_0 are measured in K)

- The coefficient β depends on the material;
- The **sensitivity is high** (a small change in temperature corresponds to a large change in resistance);
- They are small in size and low-cost.



References

Textbook: Principles of Measurement Systems, 4th ed.

For further explanation about the points covered in this lecture, please refer to the following chapters and sections in the **Bentley** textbook:

- Chapter 8, Sec. 8.5: **Thermoelectric sensing elements**;
- Chapter 8, Sec. 8.1.2: **Resistive metal and semiconductor sensors for temperature measurement**.

<u>NOTE</u>: Topics not covered in the lecture are not required for the exam.

References

Textbook: Measurement and Instrumentation, 2nd ed.

For further explanation about the points covered in this lecture, please refer to the following chapters and sections in the **Morris-Langari** textbook:

- Chapter 14, Sec. 14.1: **Introduction [of temperature measurement]**;
- Chapter 14, Sec. 14.2: **Thermoelectric effect sensors (thermocouples)**;
- Chapter 14, Sec. 14.3: **Varying resistance devices**.

NOTE: Topics not covered in the lecture are not required for the exam.