Course Name:
IoT & Applications (18EI2T09)

Module-3:

Class-2: Temperature sensor

1. Temperature Sensing Devices

1.1 Resistance Temperature Detector (RTD)

1.2 Thermistors

1.3 Thermocouple

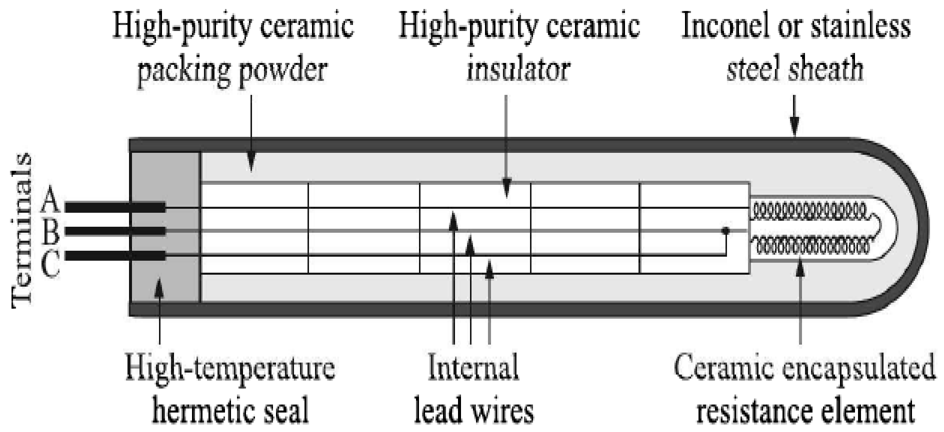
1.4 IC based Temperature Sensor

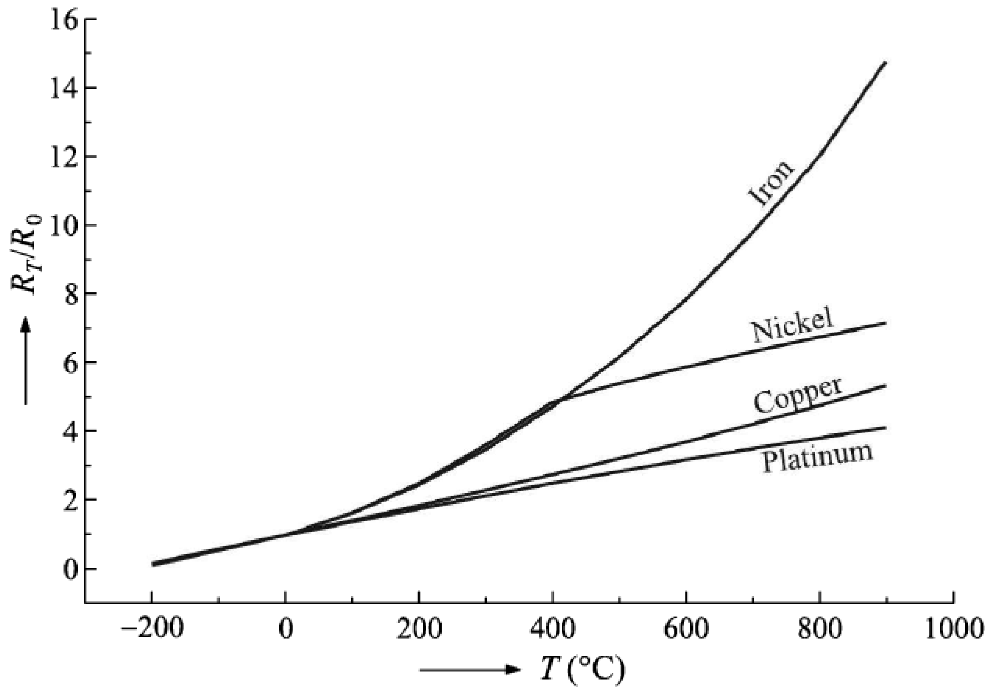
1.1 Resistance Temperature Detector (RTD)

The relation between electrical resistance of a metal R_T and the corresponding temperature T is generally given as

$$R_T = R_0(1 + C_1T + C_2T^2 + \cdots + C_nT^n)$$

where C's are constants and R_0 is the resistance at temperature $T = 0°C$.





Measurements with RTDs

For measuring the resistance, precautions against two interferences need to be taken. They are

1. Self-heating
2. Lead wire resistance

Self-heating. A small current requires to be passed through the RTDs in order to avoid the resistive heating. For example, 1 mA through a 100 Ω RTD generates 100 μW. This may seem insignificant, but it can raise the temperature of some RTDs a significant fraction of a degree.

A typical value for self-heating error is 1°C/mW in free air. The same RTD rises 0.1°C/mW in air flowing at 1 m/s. Using

1. the minimum excitation current that provides the desired resolution, and
2. the largest physically practical RTD

will help reduce self-heating errors.

Lead wire resistance. Because of the rather low resistance of the RTD, the lead wire resistance may also interfere in the measurement. For example, lead wires with a resistance of 1 Ω connected to a 100 Ω platinum RTD cause a 1% measurement error.

Of the two possible sources of error, as mentioned, the self-heating can be avoided by measuring the resistance of the PRT by balancing a bridge circuit when a small current may be allowed to flow through the resistances. The general methods of measuring the RTD resistance by using bridges of different configurations are described below.

Two-wire connection. The simplest resistance measurement configuration uses two wires to connect the thermometer to a Wheatstone bridge [Fig. 10.8(a)].

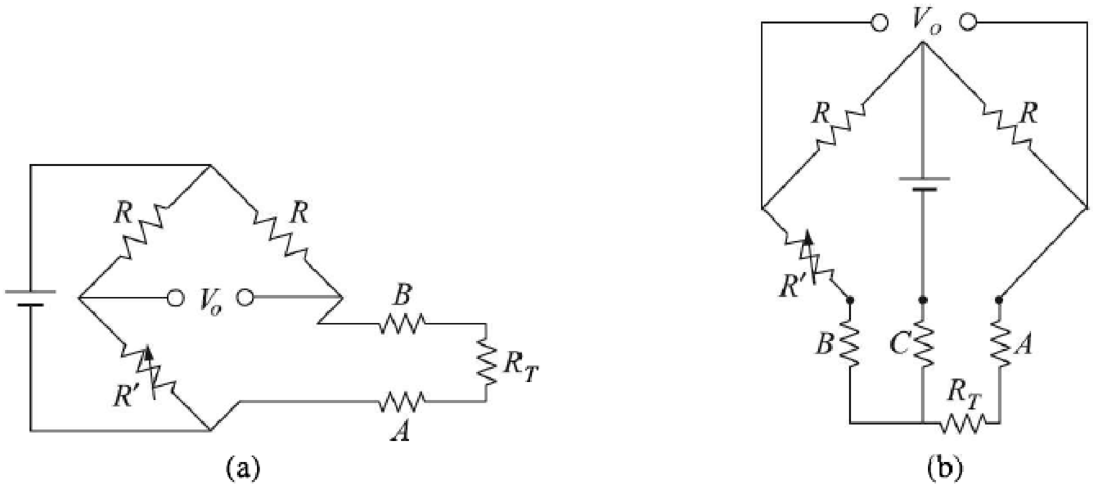


Fig. 10.8 Bridge configurations for the PRT: (a) two-wire, and (b) three-wire connections.

In the balanced condition of the bridge, we have

1.2 Thermistors

Thermistors are thermally sensitive resistors. As a matter of fact the resistance of all resistors vary with temperature, but thermistors are constructed of materials with a resistivity that is especially sensitive to temperature.

$$R(T) = R_0 \cdot \exp\left(B \cdot \left(\frac{1}{T} - \frac{1}{T_0}\right)\right)$$

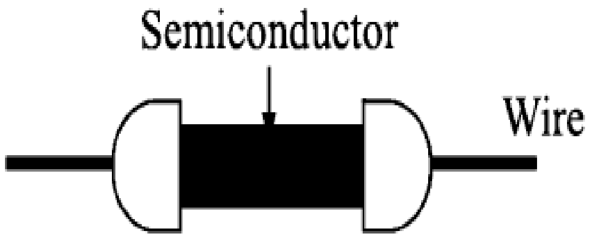
where $R_0 = 4.7k\Omega$ and $T_0 = 298.15K$ (Note that the formula uses Kelvin, and the nominal resistance R_0 is given for 25°C=298.15K)

$B = 3977K$ is a constant specific for your part, and usually listed in the datasheet, or your product page.

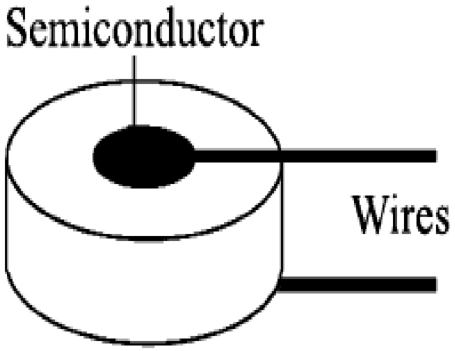
Types of thermistors

1. NTC
2. PTC

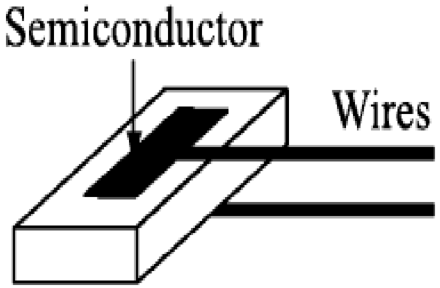
Different forms of thermistors



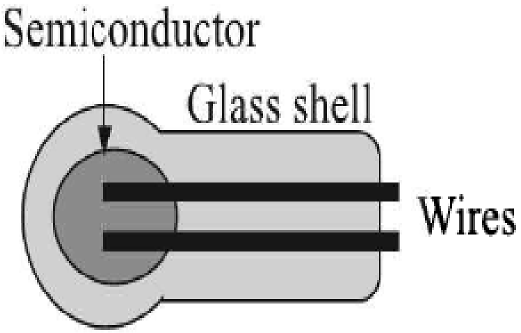
Rod thermistor



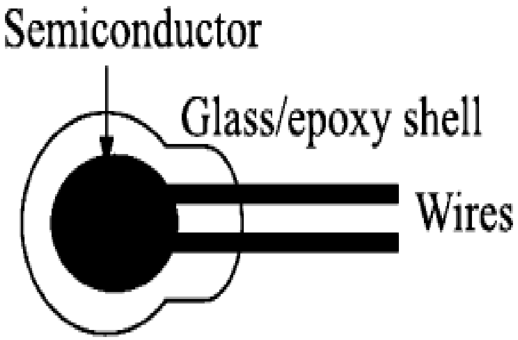
Disc thermistor



Flake thermistor



Glass probe thermistor



Glass/epoxy bead thermistor

Power dissipation. When electrical power is delivered to a thermistor, its temperature will rise. So, when using the thermistor to measure temperature, the temperature rise caused by self-heating is a source of measurement error. The heat dissipation constant D is defined as

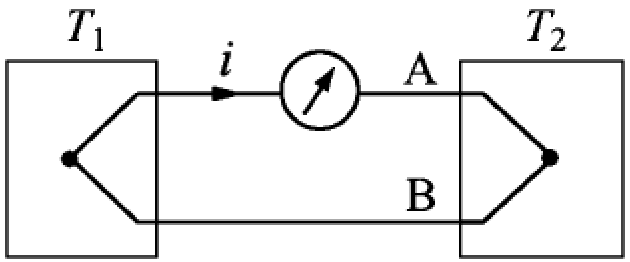
$$D = \frac{Q}{\Delta T}$$

where Q is the power delivered and ΔT is the corresponding rise in temperature.

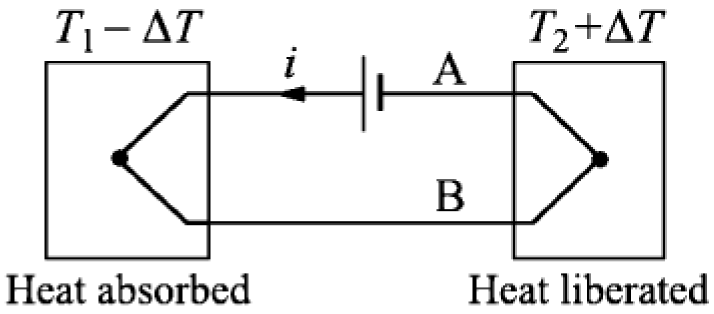
1.3 Thermocouple

Seebeck effect

If two wires or strips of dissimilar metals are welded together at both ends to form a complete circuit and if the two junctions are maintained at different temperatures, an electric current flows through the circuit. The device thus formed is called a *thermocouple* and the phenomenon is called the *Seebeck*[15] *effect* [Fig. 10.17(a)]. A microvoltmeter of very high input impedance may be included in the circuit to measure the resulting emf which is generally called the *thermo-emf*.



(a) Seebeck effect



(b) Peltier effect

Fig. 10.17 Seebeck and Peltier effects.

Explanation of Thermoelectric Effects

The energy band models of two dissimilar metals are shown in Fig. 10.20(a). Here, Φ_A and Φ_B are work functions[18] corresponding to metals A and B respectively. When these two metals are brought in contact, their Fermi levels equalise. As a result some electrons from A flow to B, leaving A and B positively and negatively charged respectively as shown in Fig. 10.20(b).

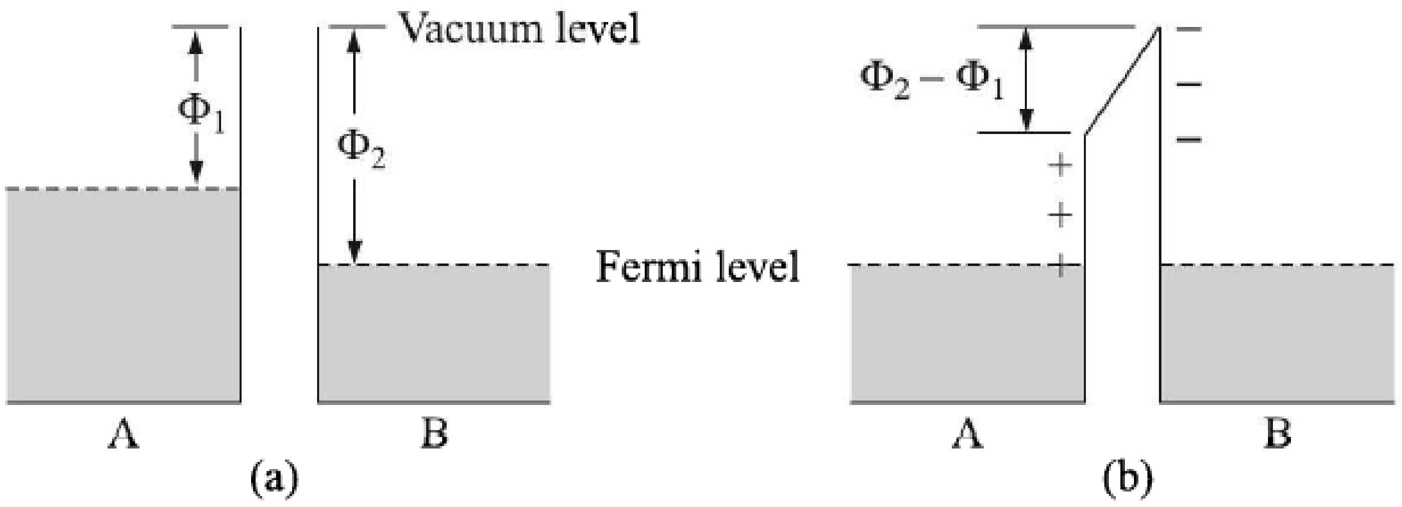


Fig. 10.20 (a) Metals A and B and their energy bands, and (b) metals A and B and their energy bands when A and B are joined together.

This produces a potential difference between the two metals called the *contact potential V* defined by

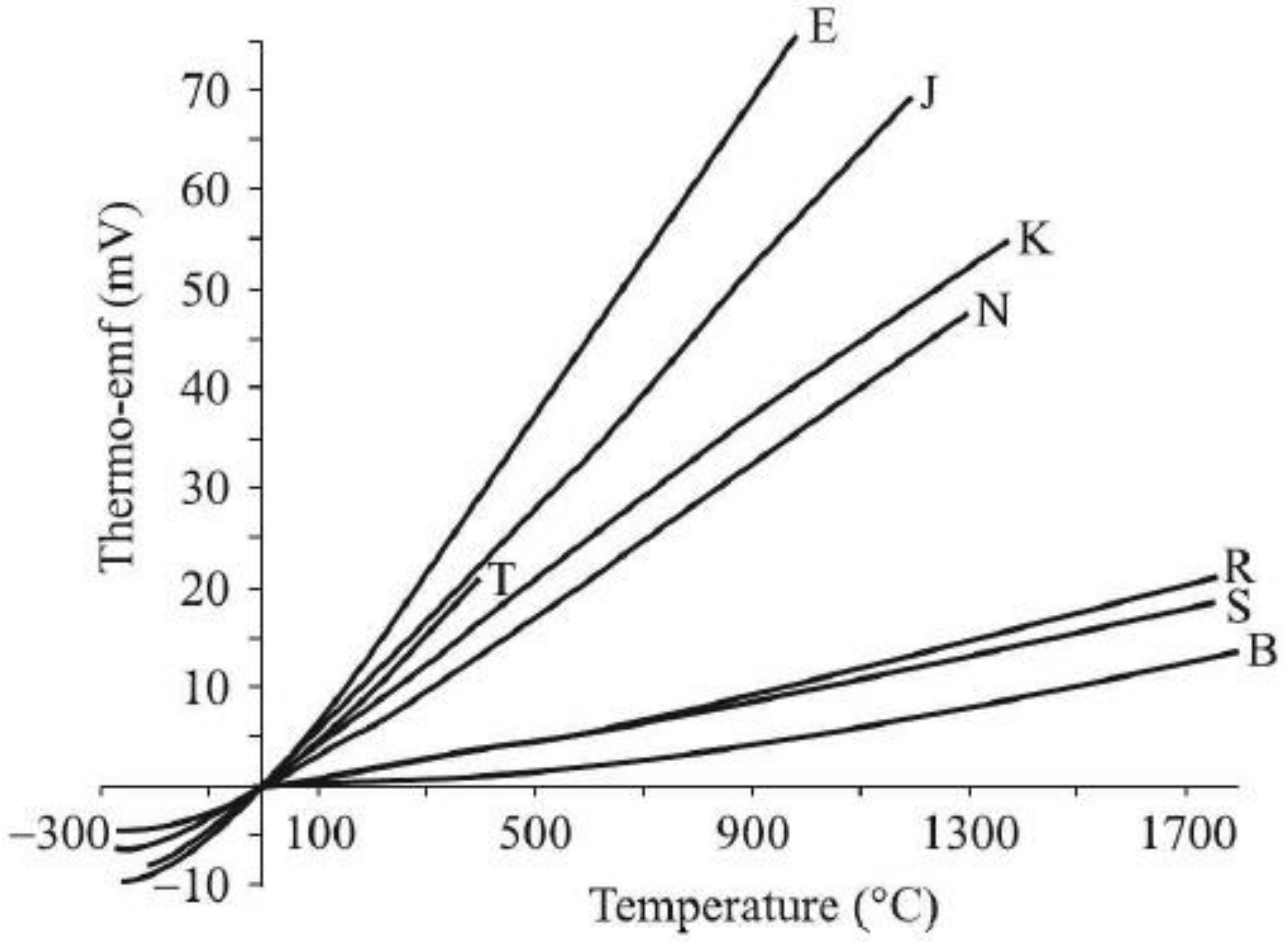
$$eV = \Phi_A - \Phi_B$$

Common Thermocouples

A variety of thermocouples today cover a range of temperatures from $-270°C$ to $+1800°C$. They are given letter designations of B, E, J, K, N, R, S and T. Table 10.5 gives an idea about their composition, and typical attributes. The letter type identifies a specific temperature-voltage relationship, not a particular chemical composition. Manufacturers may fabricate thermocouples of a given type with variations in composition; however, the resultant temperature versus voltage relationships must conform to the thermoelectric voltage standards associated with the particular thermocouple type.

ANSI type	*Junction materials (+/−)*	*Typical range (°C)*	*Nominal sensitivity (μV/°C)*	*Atmospheric media*[f] I	R	O	V
E	Chromel[a]/Constantan[b]	0 to 900	76	Yes	No	Yes	No
	Highest sensitivity among thermocouples commonly used. Low drift. Good corrosion resistance. Use is less widespread than other base-metal thermocouples owing to their low useful range.						
J	Iron/Constantan	−200 to 760	55	Yes	Yes	Yes	Yes
	Iron oxidises rapidly above 540°C. Should not be used above 760°C due to an abrupt magnetic transformation at the Curie point of iron (~770°C) which changes its characteristic and can cause permanent de-calibration. Widely used in industry due to their high sensitivity and low cost.						
K	Chromel/Alumel[c]	−200 to 1260	39	Yes	No	Yes	No
	Not recommended in sulphur environments. Cycling at high temperatures can cause calibration drift. Most commonly used base-metal thermocouple.						
T	Copper/Constantan	−200 to 400	45	Yes	Yes	Yes	Yes
	Rust and corrosion resistant. Best for sub-zero temperatures.						

N	Nicrosil[d]/Nisil[e]	0 to 1100	10.4	Yes	Yes	Yes	Yes
	Not recommended in sulphur environments. Improved resistance to drift and better stability over K and E at elevated temperatures.						
R	Platinum-13% Rhodium/ Pure Platinum	0 to 1593	6	Yes	No	Yes	Yes
	High temperature use. Usually with a ceramic sheath. Granular precipitation from metal protection tubes can cause failure or calibration drift.						
S	Platinum-10% Rhodium/ Pure Platinum	0 to 1538	10.4	Yes	No	Yes	Yes
	Because of its high stability, used as the standard for calibrating the melting point of Gold.						
B	Platinum-30%Rhodium/ Platinum-6% Rhodium	50 to 1800	7.7	Yes	No	Yes	Yes
	Owing to its increased Rhodium content, it is not so stable as the R or S types.						



Thermo-emf vs. temperature curves for common thermocouples.

Cold Junction Compensation

The emf generated by a thermocouple, as shown by Eq. (10.18), is dependent not only on the temperature of the measuring junction but also on that of the cold junction. So, if we make an arrangement as shown in Fig. 10.26(a) for temperature measurement of T_1, it may generate different emf at different times although T_1 may be steady, because we have unwittingly left the other junction to an uncertain temperature T. In industry, it is not practical to maintain

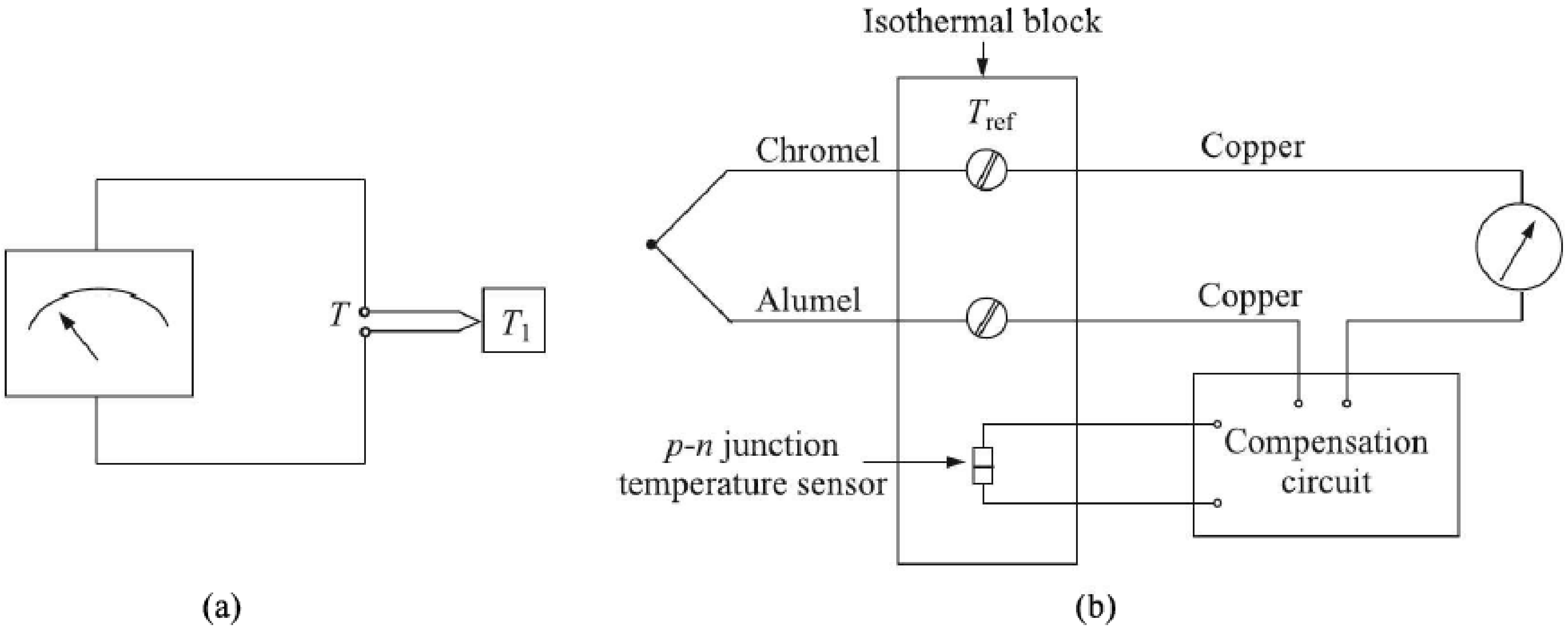


Fig. 10.26 Temperature measurement by thermocouple: (a) cold junction left at an arbitrary temperature, (b) cold junction temperature compensated for.

Integrated Circuit Sensors

Integrated circuit (IC) temperature sensors are ubiquitous nowadays. Apart from household body temperature measuring thermometers, PC and automotive applications, they are used as temperature sensors in many electronic gadgets. Mobile phones usually include one or more sensors in the battery pack, and notebook computers might have four or more sensors for checking temperatures in the CPU, battery, ac adapter, and PCMCIA card cage. These applications do not cover the enormous number of thermal-shutdown and thermal-protection circuits that designers build i nto all sorts of ICs as a final defence against short circuits and over-clocking (exceeding the IC's specified clock speed).

Of course, they cannot always replace the traditional temperature sensors like RTDs, thermistors and thermocouples, but IC temperature sensors offer many advantages. They require no linearisation or cold-junction compensation, for instance. Rather, they often provide cold-junction compensation for thermocouples. They generally provide better noise immunity through higher-level output signals, and some provide logic outputs that can interface directly to digital systems.

These ICs generate electrical output proportional to the temperature. Their principle of operation is as follows.

Principle of operation

The sensor works on the principle that the forward voltage of a silicon diode depends on its temperature. The following simplified equation shows the voltage-temperature relationship:

$$V_F = \frac{kT}{e} \ln \frac{I_F}{I_S} \quad \text{for } I_F \gg I_s \tag{10.19}$$

where T is the ambient temperature in degrees kelvin
k is the Boltzmann's constant (1.3807×10^{-23} J/K)
e is the charge of an electron (1.602×10^{-19} coulomb)
I_F is the forward current
I_S is the saturation current

I_S is a constant defined by the diode size.

LM335. The LM335 is a precision temperature sensor which can be easily calibrated. It operates as a 2-terminal Zener diode with a voltage output of 10 mV/K. That means, at 25°C (298.2 K) it acts like a 2.982 V Zener (Fig. 10.27).

It comes with an accuracy of ±1°C and it can be externally trimmed. A single point calibration improves its accuracy to ±0.5°C over a range of −55°C to +125°C. Unlike other sensors, the LM335 has a linear output.

LM35. The output voltage of LM35 is linearly proportional to the Celsius (centigrade) scale of temperature.

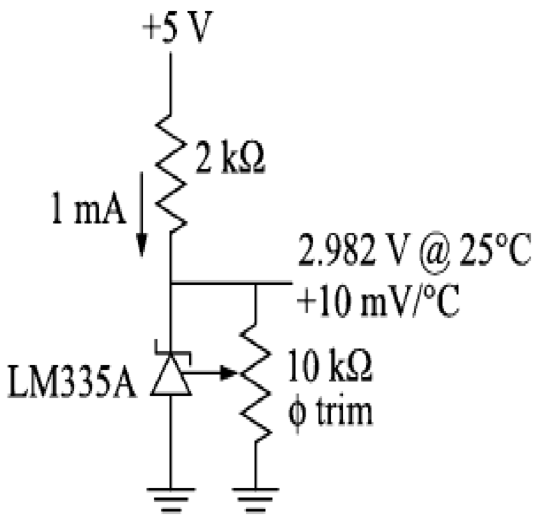


Fig. 10.27 LM335 Zener diode temperature sensor.

Device	*Advantages*	*Disadvantages*
RTD	Linear. High stability. Wide range of operating temperature. Interchangeable over wide temperature range.	Rather low sensitivity. Relatively slow response. Low resistance requires three- or four-wire measurement. Sensitive to shock and vibration. Voltage source required. Expensive.
Thermistor	High stability. Fast response. High sensitivity. High resistance eliminates the need for four-wire measurement. Small size. Interchangeable.	Nonlinear. Limited operating temperature. Interchangeable over relatively narrow temperature ranges. Voltage source required. Inexpensive.
Thermocouple	Simple. Wide range of operating temperature. No external power supply required. Rugged. Inexpensive.	Nonlinear. Relatively low stability. Low sensitivity. Low voltage output can be affected by RI and EMI. Cold junction compensation required.
IC	Linear. High sensitivity. Inexpensive.	Limited range of operating temperature. Power supply required. Subject to self-heating. Limited configurations.