The aim of this unit is to introduce the learner to principles and techniques related to the Performance, Operation and Application of a range of Industrial Transducer Systems.

2 APPLICATION, SELECTION AND OPERATION OF TRANSDUCER TYPES.

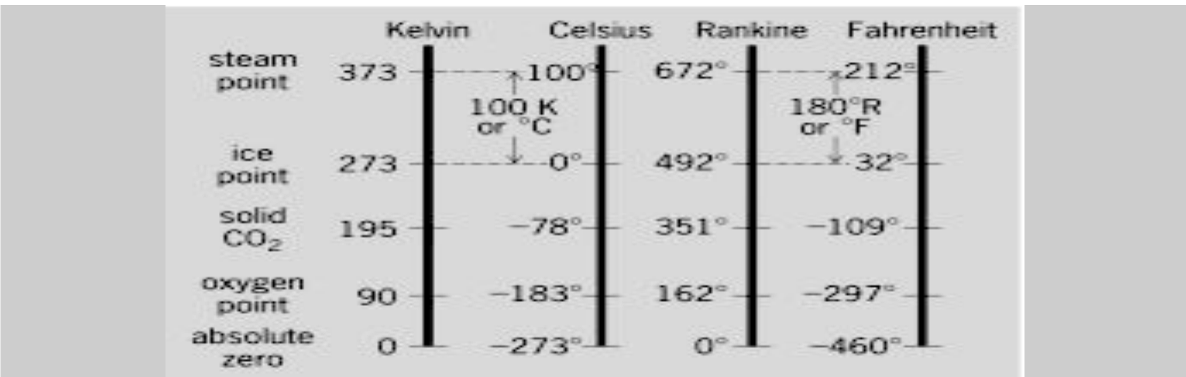
temperature *– thermocouples, metallic resistance thermometers, thermistors;*

What is Temperature?

When we describe something as very hot, or very cold, or just hot or cold, just how hot or cold is that. For this purpose, we use Temperature. Temperature quite literally, is the 'degree of Hotness or Coldness'. Heat on the other hand, refers to the thermal energy, which causes temperature to change. So, Temperature is not a direct measurement of heat, but rather of the impact thermal energy has.

From our school days, we learnt that heat can be transfered in 1 of 3 ways, these are conduction, convection, and radiation. These in some way form the basic techniques and foundations for measurement.

The most common unit of temperature is Celcius, however the Fahrenheit scale is still used and often referred to. Just as pressure has an absolute unit, so to temperature. The absolute version of Celcius is Kelvin, while the absolute version of Fahrenheit is the little heard of scale called Rankine.



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Thermocouples

In electronics and in electrical engineering, **thermocouples** are a widely used type of temperature sensor.

A thermocouple is a sensor for measuring temperature. It consists of two dissimilar metals, joined together at one end. When the junction of the two metals is heated or cooled a voltage is produced that can be correlated back to the temperature. They can measure a wide range of temperatures. The main limitation is accuracy; system errors of less than one degree Celsius (°C) can be difficult to achieve.

In 1821, the German-Estonian physicist Thomas Seebeck discovered that when any conductor (such as a metal) is subjected to a thermal gradient, it will generate a voltage. This is now known as the 'thermoelectric' or Seebeck effect. Any attempt to measure this voltage necessarily involves connecting another conductor to the "hot" end. This additional conductor will then also experience the temperature gradient, and develop a voltage of its own which will oppose the original. Fortunately, the magnitude of the effect depends on the metal in use. Using a dissimilar metal to complete the circuit creates a circuit in which the two legs generate different voltages, leaving a small difference voltage available for measurement. That difference increases with temperature, and can typically be between one and seventy microvolts per degree Celsius (µV/°C) for the modern range of available metal combinations. Certain combinations have become popular as industry standards, driven by cost, availability, convenience, melting point, chemical properties, stability, and output. This coupling of two metals gives the thermocouple its name.

It is important to note that thermocouples measure the temperature ***difference*** between two points, not absolute temperature. In traditional applications, one of the junctions—the cold junction—was maintained at a known (reference) temperature, while the other end was attached to a probe.

The Thermoelectric voltages or emf's produced by a thermocouple are very small and at best are just a few tens of microvolts per degree Celsius. In some cases, thermocouples are mainly used at elevated temperatures, above say 100°C and at depressed temperatures, below -50°C; however with appropriate measuring instruments they can be used at any value within their operational range. In some applications, the reference junction may be held at some temperature other than 0°C, for example in liquid gas or a heated enclosure; in any event, the measured "output" will correspond to the difference temperature between the two junctions.

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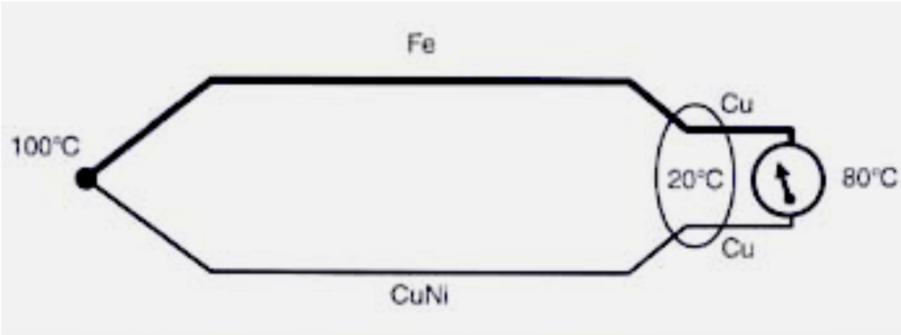

Measuring (Hot) Junction | **Reference (Cold) Junction** | **Measured Output**

Thermocouples are formed when two different metals are connected together (as shown above). For example, when the thermo element conductors are jointed to copper cable or terminals, thermal voltages can be generated at the transition. In this case, the second junction can be taken as located at the connection point (assuming the two connections to be thermally common). The temperature of this connection point (terminal temperature) if known, allows computation of the temperature at the measuring junction. The thermal voltage resulting from the terminal temperature is added to the measured voltage and their sum corresponds to the correct thermal voltage against a 0°C reference.

e.g. if the measuring junction is at 300°C and the terminal temperature is 25°C, the measured thermal voltage for the type K thermo element (Nickel-Chromium v Nickel-Aluminium) is 11.18mV. This corresponds to 275°C difference temperature. A positive correction of 25°C refers the temperature to 0°C; thus 300°C is indicated.

Usually the thermocouple is attached to the indicating device by a special wire known as the compensating or extension cable. The terms are specific. Extension cable uses wires of the same materials as used at the thermocouple itself. These cables are less costly than thermocouple wire, although not cheap, and are usually produced in a convenient form for carrying over long distances—typically as flexible insulated wiring or multicore cables. They are usually specified for accuracy over a more restricted temperature range than the thermocouple wires. They are recommended for best accuracy.

Compensating cables on the other hand, are less precise, but cheaper. They use quite different, relatively low cost alloy conductor materials whose thermoelectric coefficients are similar to those of the thermocouple in question over a limited range of temperatures. The

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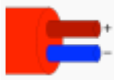
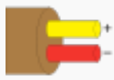
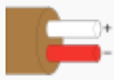
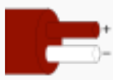
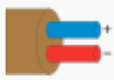
combination develops similar outputs to those of the thermocouple, but the operating temperature range of the compensating cable is restricted to keep the mis-match errors acceptably small.

The extension cable or compensating cable must be selected to match the thermocouple. It generates a voltage proportional to the difference between the hot junction and cold junction, and is connected in the correct polarity so that the additional voltage is added to the thermocouple voltage, compensating for the temperature difference between the hot and cold junctions.

The following table gives 3 examples of commonly used thermocouples, their temperature ranges, and the colour coding used to identify each thermocouple type.

Type	Temperature range ℃ (continuous)	Temperature range ℃ (short term)	IEC Colour code	BS Colour code	ANSI Colour code
K	0 to +1100	−180 to +1300			
J	0 to +700	−180 to +800			
T	−185 to +300	−250 to +400			

Type B, S, R and K thermocouples are used extensively in the steel and iron industries to monitor temperatures and chemistry throughout the steel making process.

Type K – Chromel–Alumel

The best known and dominant thermocouple belonging to the chromium-nickel aluminium group is type K. Its temperature range is extended (-200°C up to 1100°C). Its e.m.f./temperature curve is reasonably linear and its sensitivity is 41 microvolt/°C.

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Type J – Iron-Constantan

The conventional type J is still popular 'it is less popular in mineral insulated form' because of its limited temperature range, -40°C to +75°C. Type J is mainly still in use based on the widespread applications of old instruments calibrated for this type. Their sensitivity rises to 55 microvolt/°C.

Many gas-fed heating appliances such as ovens and water heaters make use of a pilot light to ignite the main gas burner as required. If the pilot light becomes extinguished for any reason, there is the potential for un-combusted gas to be released into the surrounding area, thereby creating both risk of fire and a health hazard. To prevent such a danger, some appliances use a thermocouple as a fail-safe control to sense when the pilot light is burning. The tip of the thermocouple is placed in the pilot flame. The resultant voltage, typically around 20 mV, operates the gas supply valve responsible for feeding the pilot. So long as the pilot flame remains lit, the thermocouple remains hot and holds the pilot gas valve open. If the pilot light goes out, the temperature will fall along with a corresponding drop in voltage across the thermocouple leads, removing power from the valve. The valve closes, shutting off the gas and halting this unsafe condition.

Thermocouples are most suitable for measuring over a large temperature range, up to 1800 °C. They are less suitable for applications where smaller temperature differences need to be measured with high accuracy, for example the range 0-100 °C with 0.1 °C accuracy. For such applications, thermistors and resistance temperature detectors are more suitable.

Resistance Temperature Detectors (RTD)

Resistance thermometers, also called resistance temperature detectors (RTDs), are temperature sensors that exploit the predictable change in electrical resistance of some materials with changing temperature. As they are almost invariably made of platinum, they are often called platinum resistance thermometers (PRTs). They are slowly replacing the use of thermocouples in many industrial applications below 600 °C.

There are two broad categories, "film" and "wire-wound" types.

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- *Film thermometers.* Advantages of this type are relatively low cost and fast response. Such devices have improved in performance although the different expansion rates of the substrate and platinum give "strain gauge" effects and stability problems.

- *Wire-wound thermometers* can have greater accuracy, especially for wide temperature ranges. The coil diameter provides a compromise between mechanical stability and allowing expansion of the wire to minimize strain and consequential drift.

The current international standard which specifies tolerance and the temperature to electrical resistance relationship for platinum resistance thermometers is IEC 751:1983. By far the most common devices used in industry have a nominal resistance of 100 ohms at 0 °C, and are called Pt-100 sensors ('Pt' is the symbol for platinum). The sensitivity of a standard 100 ohm sensor is a nominal 0.385 ohm/°C. Resistance thermometers are usually made using platinum, because of its linear resistance-temperature relationship and its chemical inertness.

Resistance thermometers are constructed in a number of forms and offer greater stability, accuracy and repeatability in some cases than thermocouples. While thermocouples use the Seebeck effect to generate a voltage, resistance thermometers use electrical resistance and require a small power source to operate. The resistance ideally varies linearly with temperature.

Advantages of platinum resistance thermometers:

- High accuracy
- Low drift
- Wide operating range
- Suitability for precision applications

Limitations:

- RTDs in industrial applications are rarely used above 660 °C. At temperatures above 660 °C it becomes increasingly difficult to prevent the platinum from becoming contaminated by impurities from the metal sheath of the thermometer. This is why laboratory standard thermometers replace the metal sheath with a glass construction.

- Compared to thermistors, platinum RTDs are less sensitive to small temperature changes and have a slower response time. However, thermistors have a smaller temperature range and stability.

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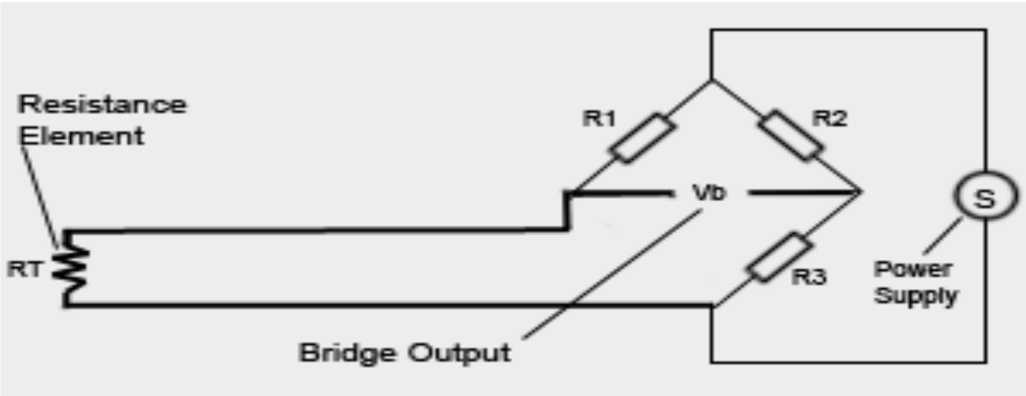
Two-wire configuration



The simplest resistance thermometer configuration uses two wires. The wiring arrangement utilises a wheatstone bridge, it comprises of 4 equal value resistors. When all 4 resistances are the same, the bridge is said to be 'in-balance', resulting in no output through Vb. However, when one of the arms of the bridge changes in resistance, the bridge becomes unbalanced, and an output is the detected in Vb, proportional to the out of balance of the circuit.

In the diagram, the resistance which would be labelled R4, has been removed from the bridge, and this is replaced with the RTD measuring element, which is to be placed in the process to be measured.

The 2 wire arrangement is only used when high accuracy is not required as the resistance of the connecting wires between the RTD element and the bridge add themselves to the resistance of the RTD itself, therefore increasing the overall resistance amount on that arm, leading to errors in the signal, and making the output higher than it should be.

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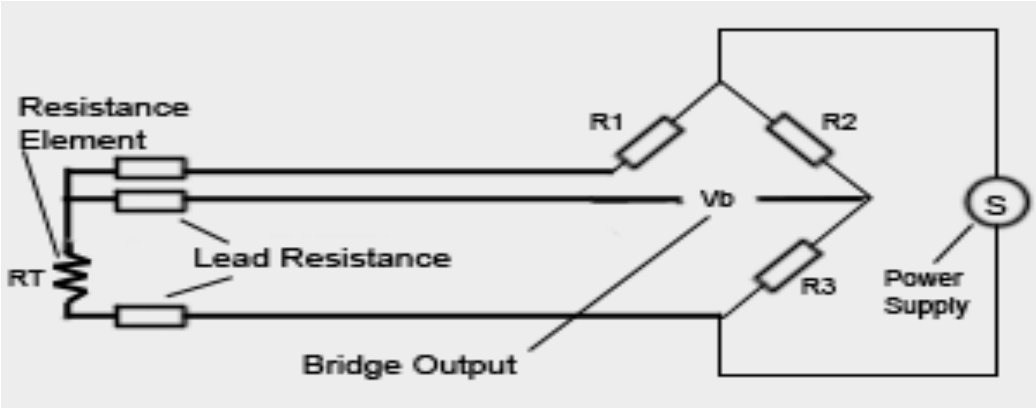
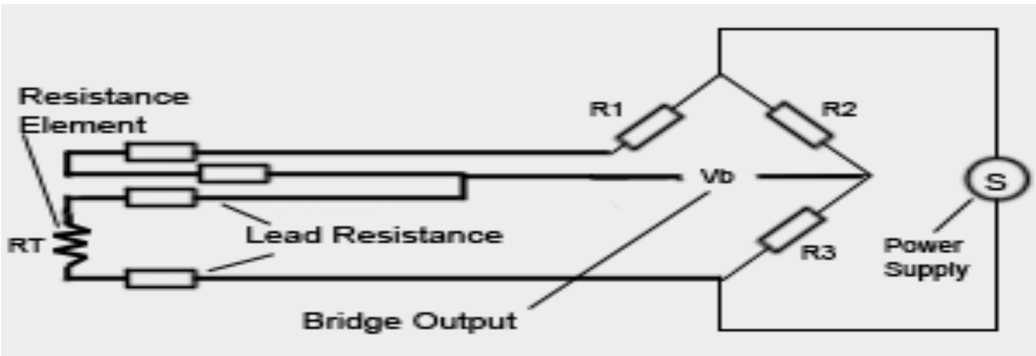
Three-wire configuration



In order to cancel out the effects of the lead resistance and increase the accuracy of the measuring system, a three wire configuration can be used. Using this method the two leads to the sensor are on adjoining arms, there is a lead resistance in each arm of the bridge and therefore the lead resistance is cancelled out. High quality connection cables should be used for this type of configuration because an assumption is made that the two lead resistances are the same. This configuration allows for up to 600 meters of cable.

This setup, is probably the most commonly used version.

Four-wire configuration



The four wire resistance thermometer configuration even further increases the accuracy and reliability of the resistance being measured. In the diagram above a standard two terminal RTD is used with another pair of wires to form an additional loop that cancels out the lead resistance. The above Wheatstone bridge method uses a little more copper wire and is not a perfect solution. Below is a better alternative four-wire configuration that should be used in all RTDs. It provides full cancellation of spurious effects and cable resistance of up to 15 Ω

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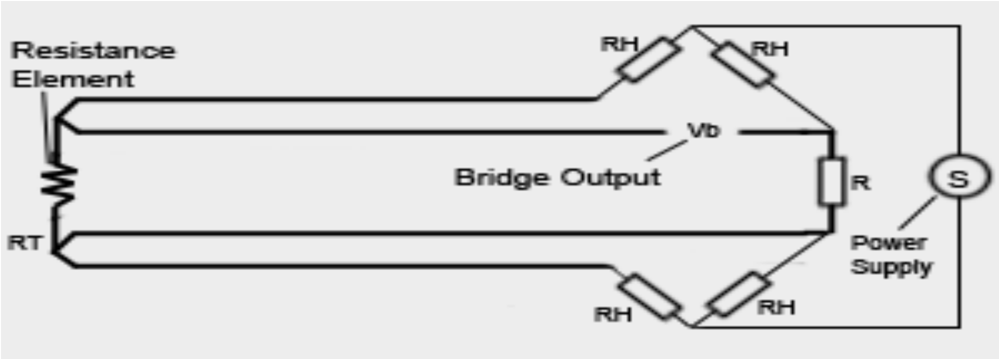
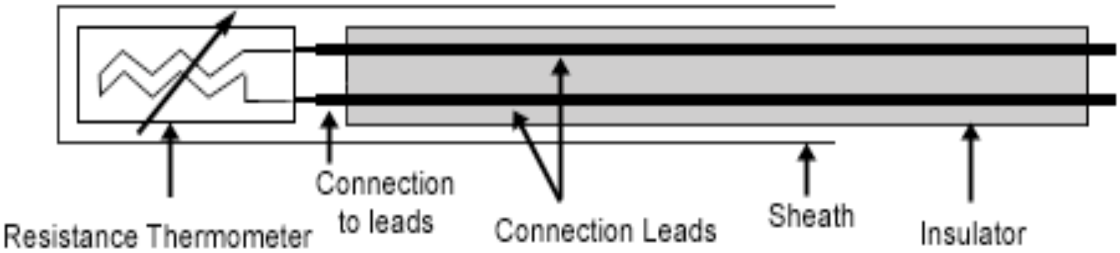
can be handled. Actually in four wire measurement the resistance error due to lead wire resistance is zero.



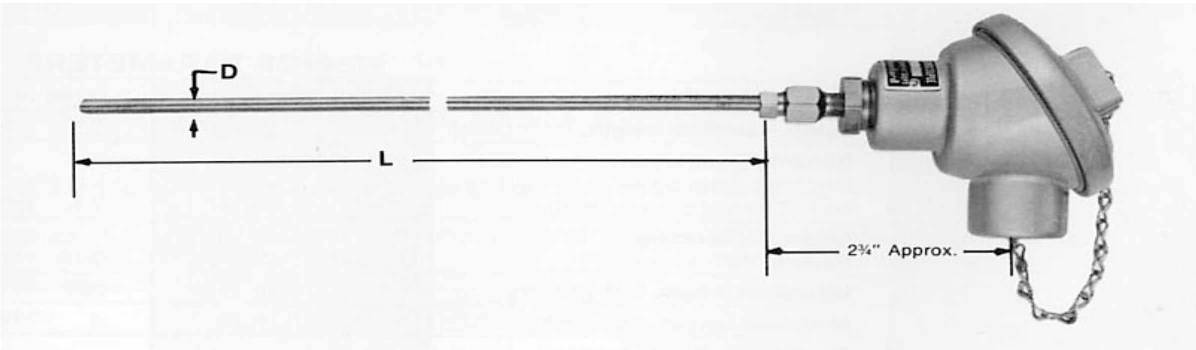
Resistance thermometer construction

The measuring point and usually most of the leads require a housing or protection sleeve. This is often a metal alloy which is inert to a particular process.

The diagram below shows a typical construction of an RTD element.



These elements nearly always require insulated leads. At low temperatures PVC, silicon rubber or PTFE insulators are common to 250°C. Above this, glass fibre or ceramic are used. Often more consideration goes in to selecting and designing protection sheaths than sensors as this is the layer that must withstand chemical or physical attack and offer convenient process attachment points. The final diagram below shows a typical RTD element.



Thermistors

A **thermistor** is a type of resistor used to measure temperature changes, like RTD's relying on fact that its resistance changes with temperature. The word is a combination of *thermal* and *resistor*.

Using the assumption that the relationship between resistance and temperature is linear, then:

$$\Delta R = k\Delta T$$

where

$\Delta R =$ change in resistance
$\Delta T =$ change in temperature
$k =$ temperature coefficient of resistance

From the above, Thermistors can be classified into two types depending on the sign of k. If k is positive, the resistance increases with increasing temperature, and the device is called a positive temperature coefficient (**PTC**) thermistor, or **posistor**. If k is negative, the resistance decreases with increasing temperature, and the device is called a negative temperature coefficient (**NTC**) thermistor. Resistors that are not thermistors are designed to have the

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smallest possible *k*, so that their resistance remains nearly constant over a wide temperature range.

Thermistors differ from resistance temperature detectors in that the material used in a thermistor is generally a ceramic or polymer, while RTDs use pure metals. The temperature response is also different; RTDs are useful over larger temperature ranges.

Accuracy

Thermistors are one of the most accurate types of temperature sensors. Some thermistors have an accuracy of ±0.1°C or ±0.2°C depending on the particular thermistor model. However thermistors are fairly limited in their temperature range, working only over a nominal range of 0°C to 100°C .

Stability

Finished thermistors are chemically stable and not significantly affected by aging.

Comparison of Thermistor and RTD element resistances

Using data points for a typical thermistor from "The Temperature Handbook" (Omega Engineering, Inc., 1989), the following table compares the resistances of a thermistor and RTD element between 0 and 50°C

T (°C)	RTD resistance (Ω)	Thermistor resistance (Ω)
0	100	16,330
25	109.7	5000
50	119.4	1801

Applications of Thermistors

- PTC thermistors can be used as current-limiting devices for circuit protection, as replacements for fuses. Current through the device causes a small amount of resistive heating. If the current is large enough to generate more heat than the device can lose to its surroundings, the device heats up, causing its resistance to increase, and

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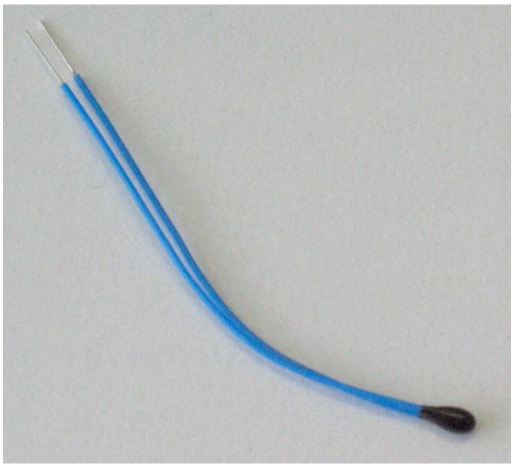
therefore causing even more heating. This creates a self-reinforcing effect that drives the resistance upwards, reducing the current and voltage available to the device.

- NTC thermistors are used as resistance thermometers in low-temperature measurements of the order of 10 K.



- NTC thermistors can be used as inrush-current limiting devices in power supply circuits. They present a higher resistance initially which prevents large currents from flowing at turn-on, and then heat up and become much lower resistance to allow higher current flow during normal operation. These thermistors are usually much larger than measuring type thermistors, and are purpose designed for this application.

- NTC thermistors are regularly used in automotive applications. For example they monitor things like coolant temperature and/or oil temperature inside the engine and provide data to the ECU and indirectly the dashboard.

- Thermistors are also commonly used in modern digital thermostats and to monitor the temperature of battery packs while charging.

Radiation Thermometers

The theory

Any object with a temperature above the absolute zero (-273.15°C = 0 Kelvin) emits electromagnetic waves or radiation from its surface, the frequency of which is directly proportional, and an accurate measure of its temperature. Measurement of this radiation, allows us to determine the body (object) temperature without actual contact.

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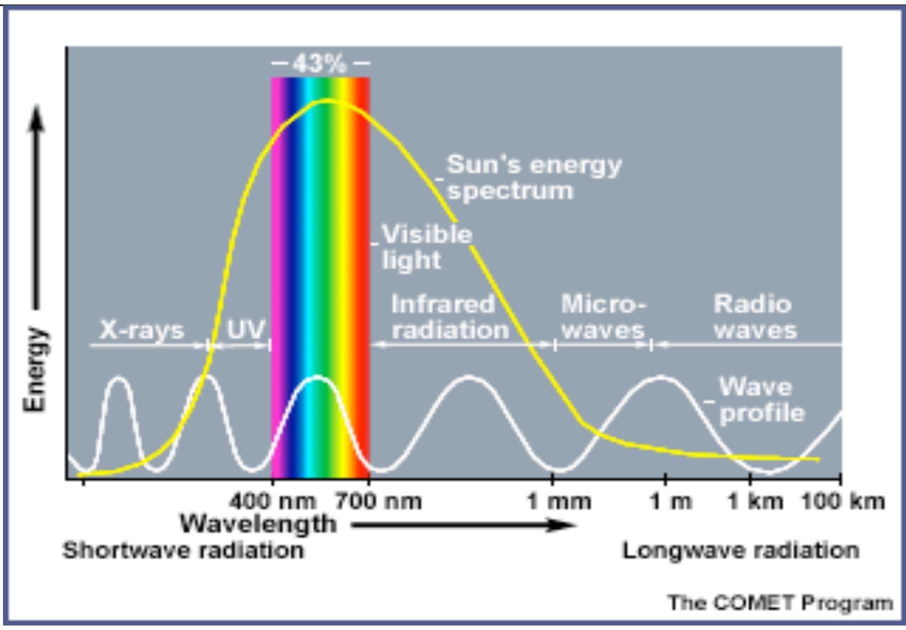
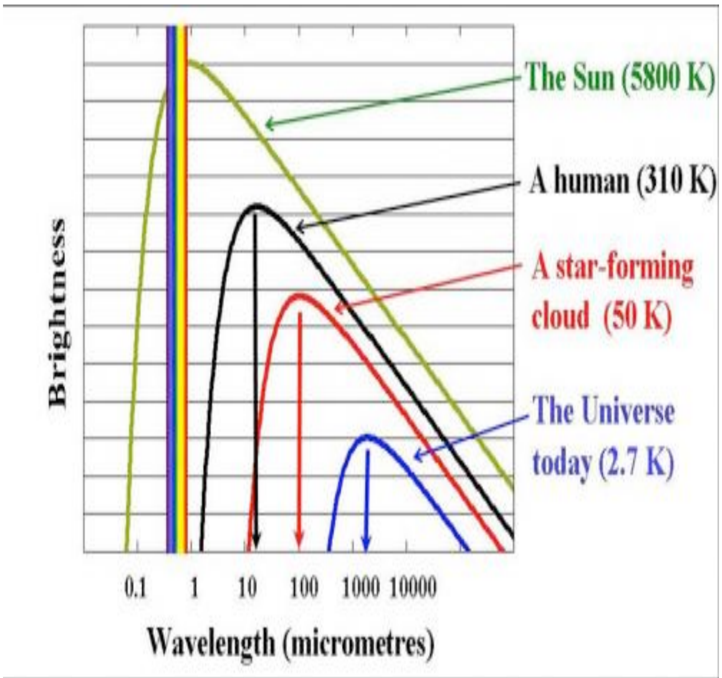


The diagram above shows the frequency ranges against the band or type of radiation being measured. In the next diagram we see frequency values against approximate temperatures.



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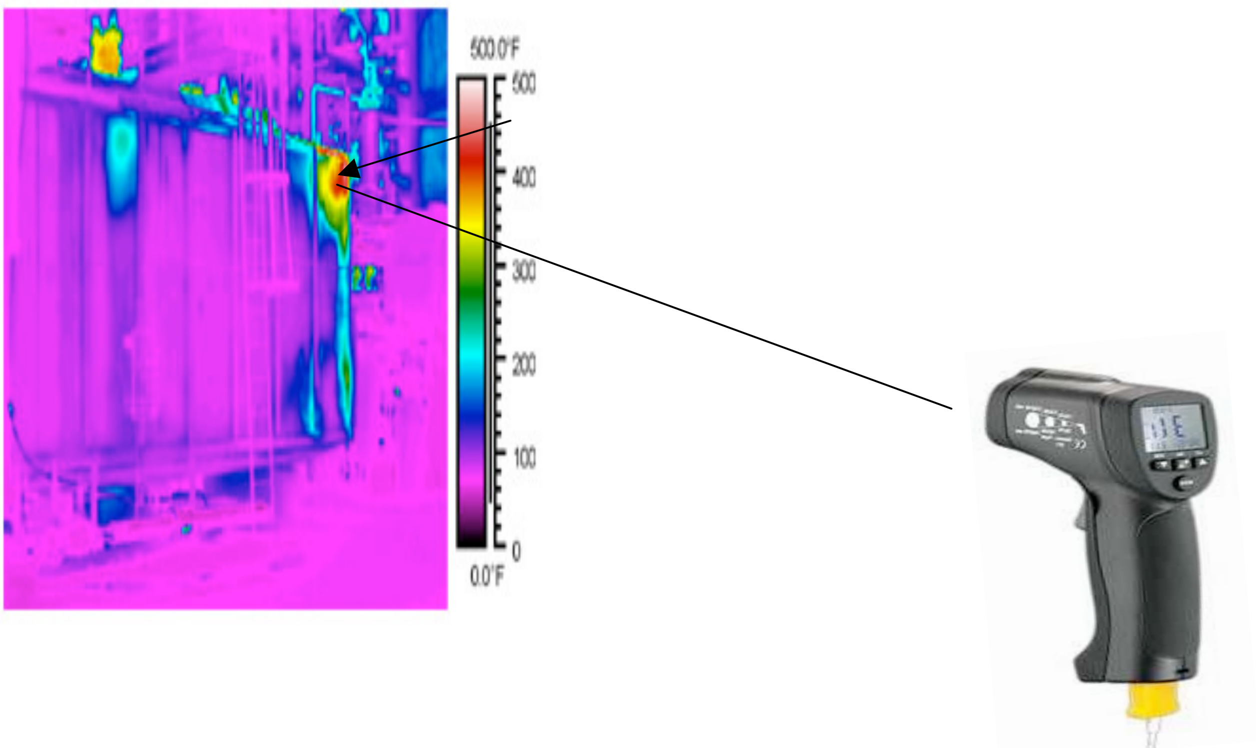
This method has no influence on the object being measured, which enables you to take measurements on High temperature and pressure situations, or on sensitive surfaces or sterile products. It is also good for measuring hazardous points or places that are difficult to access.

The next image shows a hand held radiation temperature measuring device.



Alternatively, a radiation thermometer, may be installed into the plant structure, as this next example shows. So this system may be used where metallic based thermometry reaches its temperature limitations. One example being in high temperature furnaces.

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