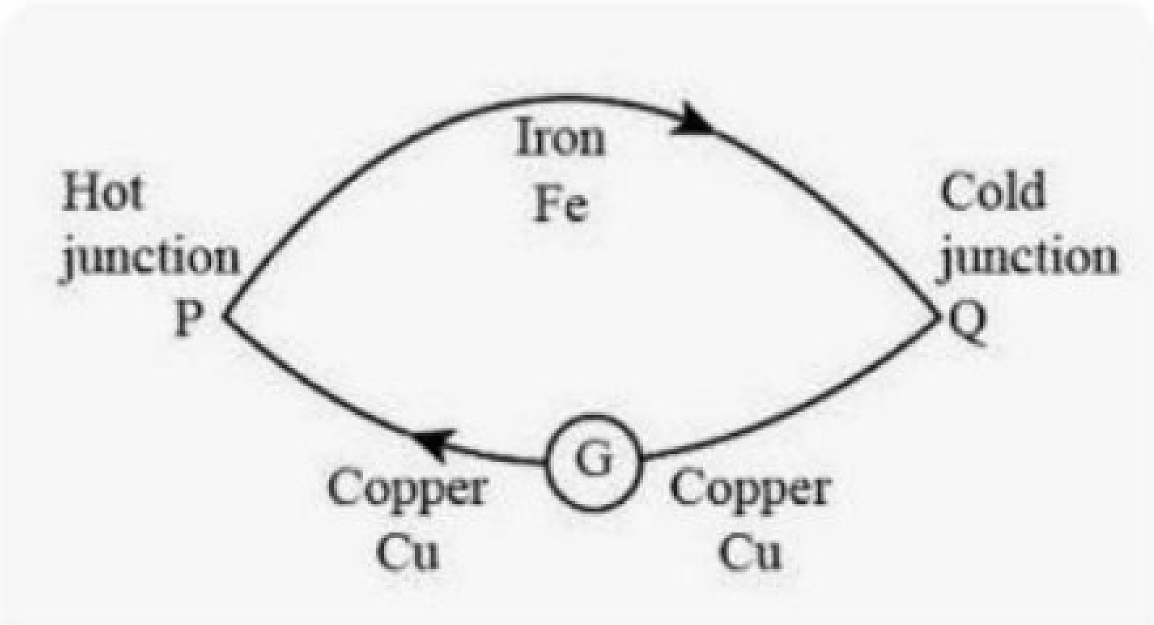
22PHYM12/22: MODULE 3-Thermoelectric materials and devices

When two dissimilar metals are joined at their ends to form two junctions and if these two junctions are maintained at two different temperatures a current is found to flow in the closed circuit and hence emf is produced. The emf is called as thermo emf and current is known as thermo current. Thermo emf is an electromotive force which is generated due to the thermal gradient.

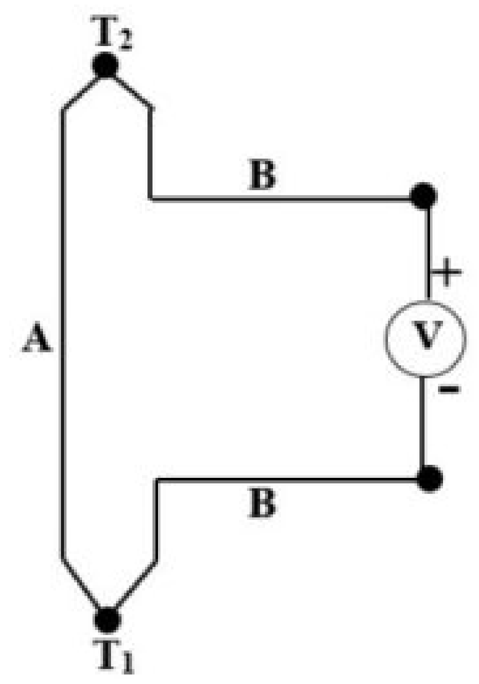


In figure we have 2 thermally and electrically conducting Copper and Ironwires. The 2 wires are attached terminal to terminal to become a closed circuit. A galvanometer is attached to the circuit to detect any current flow through the circuit. A junction P is hot terminal where the temperature is comparatively higher as compared to the cold terminal which is Q. We know that electronsflow from a denser electron metal to a lower electron denser metal, thus creating a gradient. So, if temperature of the junction is maintained at 2 different values, electron diffusion happens, which generates larger potential at the hotter junction when compare to the colder junction. This variation in potential creates a flow of current, which is detected by the galvanometer. The existence of current flow indicates that an emf exists in the circuit.

Seebeck effect:

Definition: The production of electromotive force (emf) and hence current by maintaining the junctions of two dissimilar metals at different temperatures is called Seebeck effect.

In 1821 Thomas Johann Seebeck discovered this phenomenon. The emf is known as thermoelectric emf. The thermoelectric emf causes a continuous current in the conductors, if they form a complete loop and the current is known as thermo electric current. The voltage (thermo electric emf) created is of the order of several micro volts per kelvin difference.



The thermo electric emf will exist and the current will flow in the circuit as long as the 2 junctions, known as the "hot" junction and "cold" junction, are at different temperatures. Thus, the Seebeck effect is the conversion of temperature differences directly into electricity. The magnitude and direction of thermoelectric current depends on the types of metals used and the temperature between the hot and cold ends. It does not depend on the temperature distribution along the conductors.

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The voltage developed in the circuit, is proportional to the temperature difference between the 2 junctions.

$V = \alpha(T_2 - T_1)$ Where $\alpha = \alpha_B - \alpha_A$

α_A *and* α_B are known as the Seebeck coefficients of the metals A and B,

and T_1 and T_2 are the temperatures of the two junctions.

Seebeck effect is observed not only in metals but as well in semiconductors also. It is not necessarily a junction phenomenon, but arises in a single conductor also. If temperature gradient (difference) is caused in conductor, electrons diffuse from the hot side to the cold side. Electrons migrating to the cold side leave behind their oppositely charge and immobile nuclei on the hot side and thus give rise to a thermoelectric voltage.

Seeback coefficient:

Seebeck coefficient or thermo power of a material measures the magnitude of an induced thermoelectric voltage in response to a temperature difference across that material. It is defined as the open circuit voltage produced between two points on a conductor, where a uniform temperature difference of 1K exists between those points.

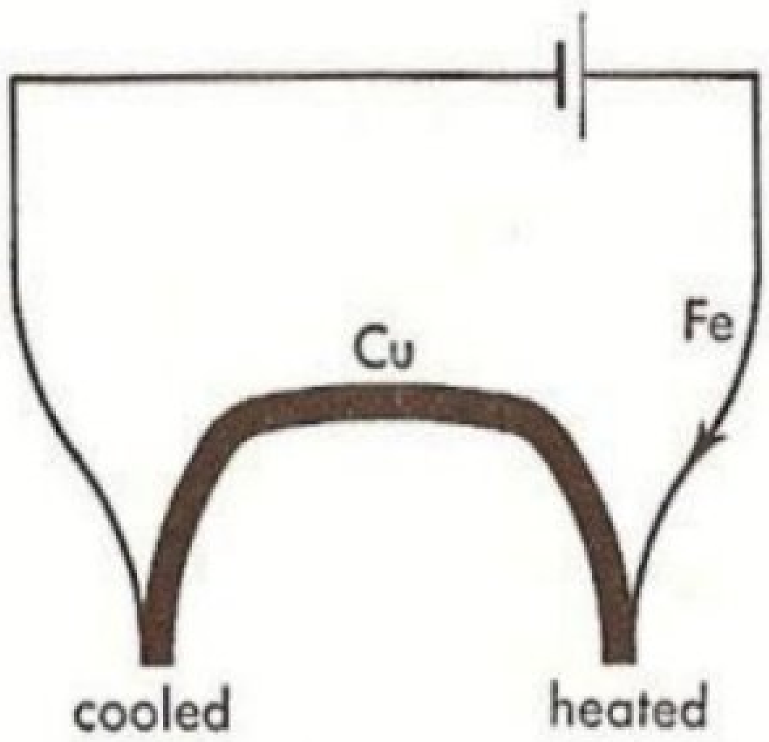
If the temperature difference ΔT between the two ends of a material is small, then the thermo power or Seebeck coefficient of a material may be written as $\alpha = \frac{\Delta V}{\Delta T}$

This can also be expressed in terms of the electric field E and the temperature gradient ∇T,

as $\alpha = \frac{E}{\nabla T}$

The thermo power is an important material parameter the efficiency of a thermoelectric material. A larger induced thermoelectric voltage for a given temperature gradient will lead to a larger efficiency.

Peltier effect:



In 1834 Peltier discovered that when electric current passed in a circuit consisting of two dissimilar metals, heat is evolved at one junction and absorbed at the other junction. This is known as peltier effect.
It is the inverse of the Seebeck effect. The peltier effect is junction phenomenon.
There is heat absorption or generation at the junctions depending on the direction of current flow.
Heat generated by current flowing in one direction was absorbed if the current was reversed.
As an example, consider the circuit as shown in the figure. Under these conditions it is observed, as indicated in the diagram, that the right-handjunction is heated, showing that electrical energy is being transformed into heat energy. Meanwhile, heat energy is transformed into electrical energy at the left junction, there by causing it to be cooled. When the current is reversed, heat is absorbed at the right junction and produced at the left one.

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Peltier coefficient:

The peltier coefficient is defined as the amount of heat energy absorbed or evolved at the junction of two dissimilar metals when one amper of current flows through it for one second. It is denoted by π and expressed in volts. It is a property that depends on both materials of the junction.

The heat absorbed per second at a junction carrying a current I amperes is given by

Heat absorbed per second = π_{ab} I ----------(1)

Heat absorbed in t seconds, H = π_{ab} I t = π_{ab} q ----------(2)

Where current is from metal 'a' to metal 'b'.

The junction emf, π_{ab} ,is known as Peltier coefficient.

$$\pi_{ab} = \frac{H}{I\,t} \text{ ----------(3)}$$

π_{ab} is positive if metal a is positive with respect to metal b(thus $\pi_{Cu\text{-}Fe}$is positive).

The magnitude of $\pi_{ab}$is a function of the temperature of the junction. For identical temperatures π_{ab}= - π_{ba}. Thus, if the direction of the current in the equation (1) is reversed, the heat absorbed per second is

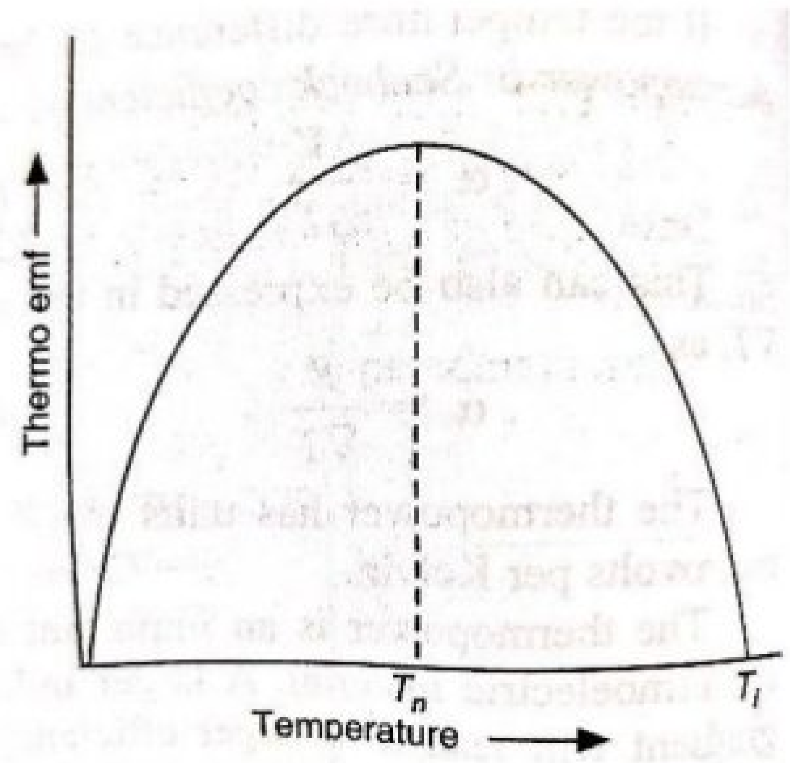
Heat absorbed per second = π_{ab} I, which is opposite in equation (1)

If V is the potential difference applied, then Heat absorbed = V q = V It

Equating the above with equation (2), we get$\pi = V$

Thus, the Peltier coefficient is numerically equal to the applied potential difference expressed in volts.

Variation of Thermoelectric emf with temperature:



If the temperature of the cold junction of athermo couple is kept at 0°C and the thermo electric e.m.f. 'e' is plotted against the temperature T of the hot junction, we obtain a parabolic curve, as shown in Fig. It is seen that the thermo e.m.f. increases with the temperature of the hot junction and becomes a maximum at a particular temperature, T_n. T_n is known as the **neutral temperature** which is a constant for the given pair of metals forming the thermocouple. The temperature of the hot junction at which maximum thermo e.m.f. flows is a constant for a given couple and is known as neutral temperature Tn for that couple. If the temperatureof the hot junction is increased beyond the neutral temperature, the e.m.f.decreases and becomes zero at a temperature T_i, known as the inversion temperature. The temperature at which the thermo e.m.f. is zero, is known as inversion temperature. Beyond the temperature of inversion, the e.m.f. again increases but in the reverse direction.

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The thermo e.m.f. varies with temperature according to the following relation.

$e = at + 1/2bt^2$ -------(1)

where a and b are Seebeck constants for the thermo couple, Eqn.1 is known as Seebeck equation, and $t = T_i - T_n$

Differentiation of eqn.(1) gives $\frac{de}{dT} = a + bt$ -------(2)

At $T = T_n$, e is maximum and hence $\frac{de}{dT} = 0$. Therefore $0 = a + bT_n$

$$T_n = -\frac{a}{b} \quad \text{---------(3)}$$

At $T = T_i$, e = 0. Therefore, it follows from equation (1) that $0 = aT_i + 1/2\, bT_i^2$

OR $T_i\left(a + \frac{1}{2}bT_i\right) = 0$ Therefore $T_i = -2a/b$ ----------(4)

From equation (3) & (4) we get

$$\boxed{T_i = 2T_n}$$

Thermoelectric power:

The rate of change of emf with temperature is called thermoelectric power and is denoted by P. Thus $P = \frac{de}{dt}$

Relation between Peltier coefficient and thermoelectric power is given by $\boldsymbol{\pi = TP}$ where T is the temperature of the junction and P is the thermoelectric power at that temperature.

Figure of -Merit, Z:

The efficiency of conversion of thermal energy into electrical energy is denoted by the parameter called the figure-of-merit of a thermoelectric material. It is denoted as

$$Z = \frac{\alpha^2\sigma}{K}$$

Where α is the Seebeck coefficient of the material (measured in microvolts/K), σ is the electrical conductivity of the material and K is the total thermal conductivity of the material.

Laws of thermoelectricity:

Law of homogeneous circuit

Statement: A thermoelectric current cannot be sustained in a circuit of single homogenous material by the application of heat alone.

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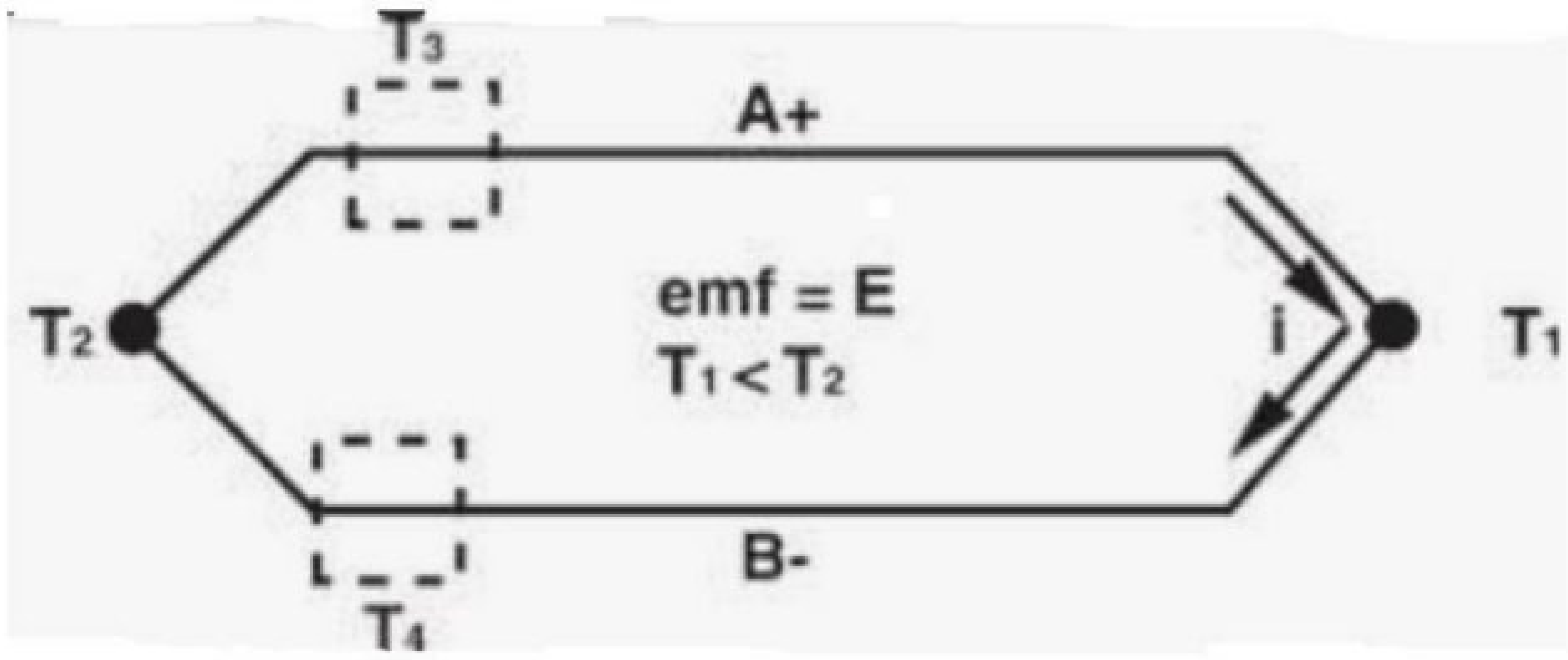
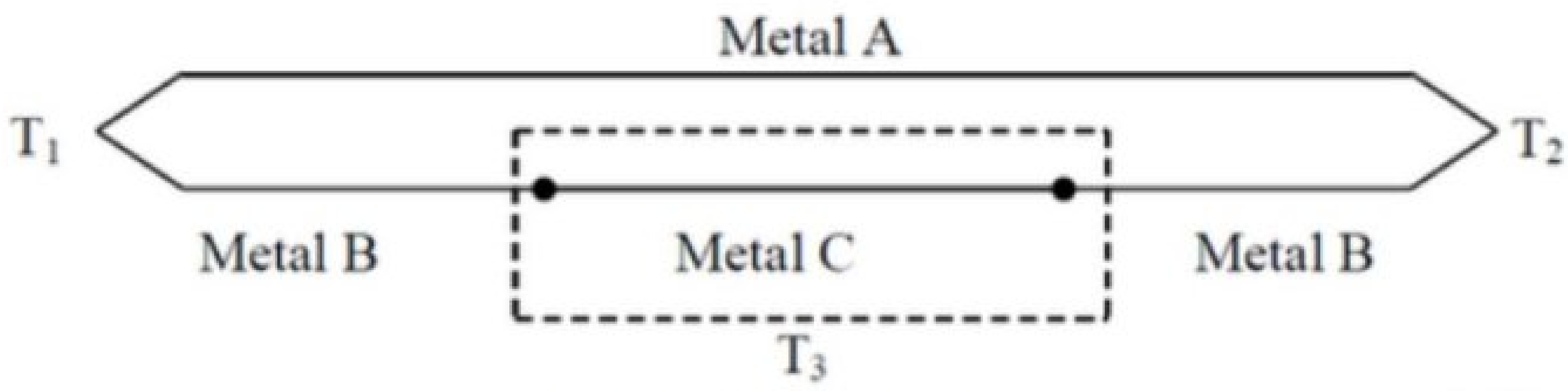
Practical significance: Two different materials are required for any thermocouple circuit to produce thermo emf.



Law of intermediate metals

Statement: A third metal may be inserted into a thermocouple system without effecting the emf generated, if and only if, the junctions with the third metal are kept at the same temperature.



Law of Intermediate Metals

Practical significance:

1. It allows the use of extension wires of metal, different from the metal used to form thermocouples
2. It allows the use of measuring instruments into the circuit without disturbing the emf generated by the thermocouple.
3. It permits the use of joining materials (like soldering) to form thermocouple junctions without effecting the performance of the junction.

Law of intermediate temperature

Statement: the sum of the emf developed by a thermocouple with its junctions at temperatures T_1 and T_2, and with nits junctions at temperatures T_2 and T_3, will be the same as the emf developed if the thermocouple junctions are at temperatures T_1 and T_3.

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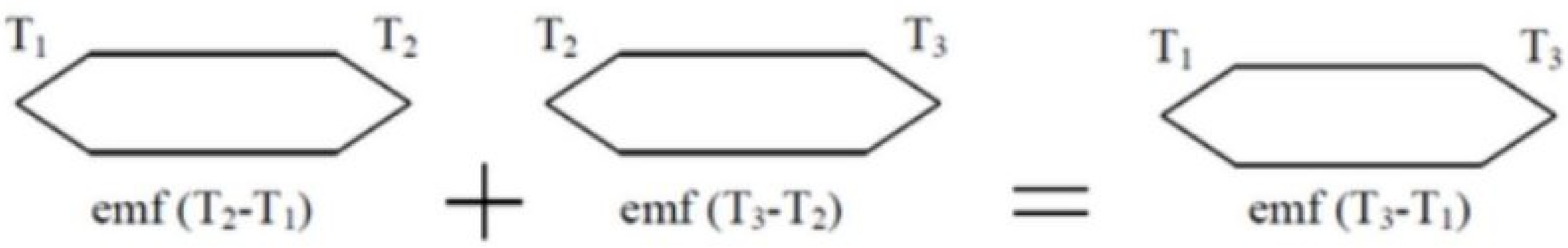
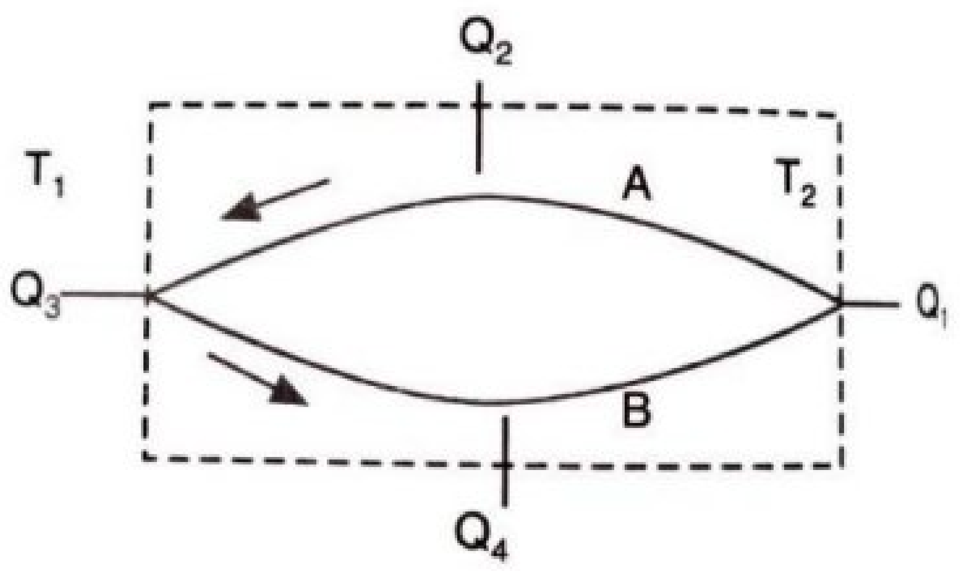


Law of Intermediate Temperatures

Practical significance: This law, illustrated in figure, is useful in practice because it helps in giving a suitable correction in case of a reference junction temperature other than 0°C is employed. For example, if a thermocouple is calibrated with reference junction at 0°C and is with a junction temperature of 20°C, then correction required for the observation would be the emf produced by the thermocouple between 0°C and 20°C

Expression for thermo emf in terms of T1 and T2:

Consider a circuit consisting of two metals A and B as shown in Fig. The hot junction is at a temperature T_2°K and the cold junction is at a temperature T_1°K. Due to the Seebeck effect, i.e., due to temperature difference between the junctions, thermoelectric current flows through the circuit. As the current flows through the hot and cold junctions, heat is absorbed at the hot junction and evolved at the cold junction due to Peltier effect.



Let π_1 and π_2 be the Peltier coefficients at T_1 and T_2.

During the passage of current an amount of heat energy equal to $\pi_2 q$ is absorbed at hot junction and heat energy $\pi_1 q$ is evolved at the cold junction.

Then, the energy $(\pi_2-\pi_1)q$ is used in driving the current through the circuit.

As π_2 and $\pi_1$are equal to the potential differences at hot and cold junctions respectively, the thermo e.m.f. developed is given by

$e= (\pi_2-\pi_1)$

The current in the circuit is small, and the joules heating effect is negligible. As Peltier effect is reversible, a thermocouple may be regarded as a reversible heat engine taking heat from the source at the hot junction at temperature T_2, does work in driving the current through the circuit, and rejecting heat to the sink, the cold junction at temperature T_1.

By the Carnot's engine we have

$$\frac{Q_2}{T_2} = \frac{Q_1}{T_1}$$

Now during the flow of current in the thermocouple, heat absorbed at the hot junction is $Q_2=\pi_2$q joule while the energy given out to the sink is $Q_1=\pi_1$qjoule.

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$$\frac{\pi_2 q}{T_2} = \frac{\pi_2 q}{T_1} \qquad \therefore \ \frac{\pi_2}{\pi_1} = \frac{T_2}{T_1} \qquad \therefore \frac{\pi_2}{\pi_1} - 1 = \frac{T_2}{T_1} - 1$$

Or $$\frac{\pi_2 - \pi_1}{\pi_1} = \frac{T_2 - T_1}{T_1}$$

Or $$\pi_2 - \pi_1 = \pi_1 \left(\frac{T_2 - T_1}{T_1}\right)$$

But $\pi_2 - \pi_1 = e$ $\qquad \therefore e = \frac{\pi_1}{T_1}(T_2 - T_1)$

If the cold junction temperature is held constant, the Peltier coefficient π_1 will also be constant. Then

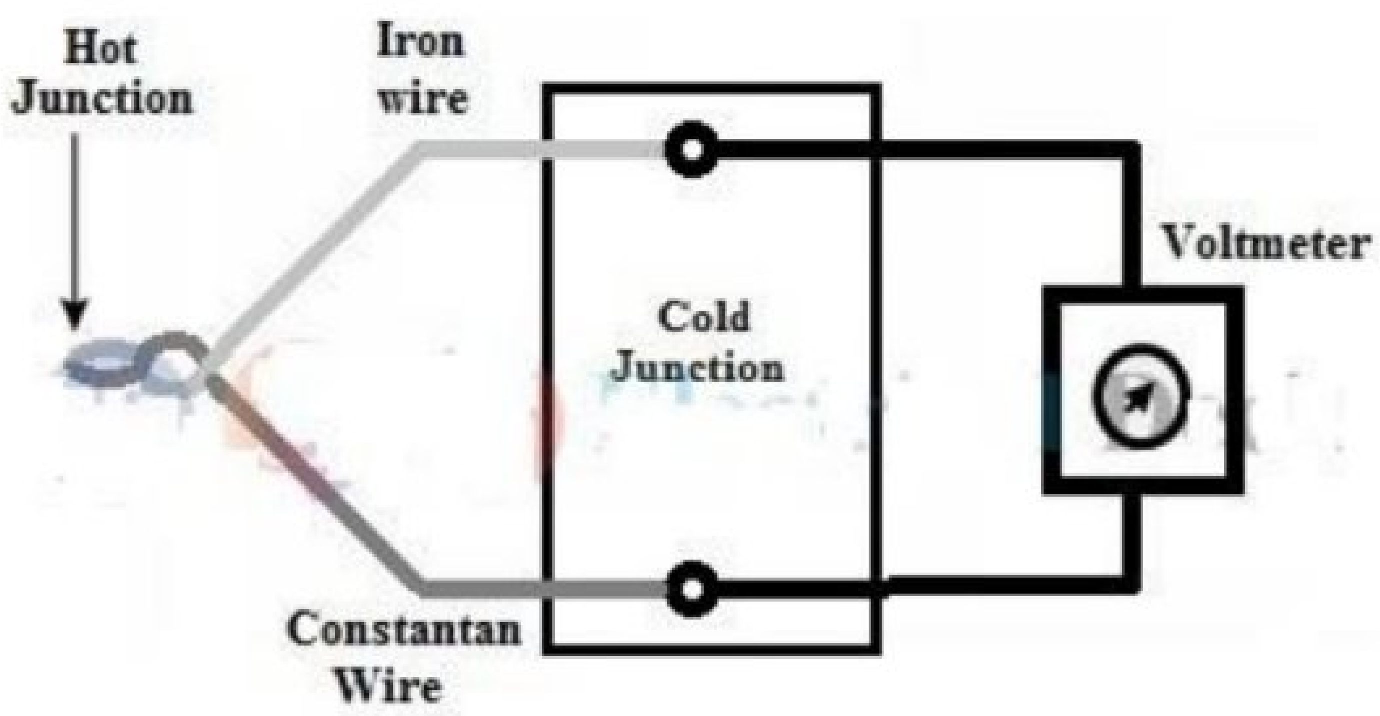
$$e \propto (T_2 - T_1)$$

Thermo couple:

Description:A thermocouple is a transducer that converts thermal energy into electrical energy and is constructed by joining wires made from dissimilar metals to form a junction. Voltage is produced when the temperature at the junction changes.

Principle: The concept of the thermocouple is based on the Seebeck Effect, which states that if dissimilar metals are joined at a point, they will generate a small measurable voltage when the temperature of the point of connection changes. The amount of voltage depends on the amount of temperature change and the characteristics of the metals.

Construction: Thermocouples are constructed by two different metals that exist in the form of wires. The two ends are joined by twisting the two wires and welded them together. The figure shows the thermocouple formed by two dissimilar metalsi.e, Iron andConstanton.A protective sealing is provided around the junction and a portion of extension leads. Generally, a diameter of wire ranging from 1.5 to 3mm is used for base metals and a diameter of 0.5mm wire is used for noble metals.



Thermocouple Circuit

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Working:

In a thermocouple transducer, out of two junctions, one junction is referred to as hot junction or measuring junction, which is placed at the process media where the temperature is to be measured. Another junction is referred to as a cold junction or reference junction is maintained at a constant reference temperature.

When there exists a temperature difference between hot and cold junctions an emf will be set up at the free ends due to temperature gradient and is measured by millivoltmeter. The amount of induced emf depends upon the difference in temperature between two junctions and the material used to build the thermocouple.

The temperature is determined by calibrating the millivoltmeter. Since the cold junction is at 0°C, the induced emf measured by the voltmeter is the function of the temperature of the hot junction. It is essential to keep the reference junction at 0°C to avoid errors due to change in room temperature.

Advantages of Thermocouple:

- It is an active transducer i.e., it operates without any external power source.
- Measurement of wide ranges of temperature from -200°C to 2800°C.
- The response time is fast, which can measure fast-changing temperatures.
- The cost of thermocouples is low compared to thermistors.
- Able to measure temperatures at desired points.

Disadvantages of Thermocouple:

- The output voltage produced is low.
- The stray magnetic field can introduce errors in output voltage.
- Accuracy is low.

Thermopile:

Description: A **thermopile** is an electronic device that converts thermal energy into electrical energy. It is composed of several thermocouples connected usually in series or, less commonly, in parallel.

Principle: Principle is Thermoelectric effect, i.e., generating a voltage when its dissimilar metals (thermocouples) are exposed to a temperature differencei.e Seeback effect

Construction:

The structure of the thermopile is shown in figure. The output voltage of a single thermoelectric cell is extremely small. So a number of these cells is connected in series/parallel to get a larger signal output. **The arrangement of this thermocouple stack is called "thermopile".**

To make a thermopile, we need to connect more thermocouple pairs in series, so that it increases the output voltage. Thermopiles are designed with a set of thermocouples which includes dual thermocouple junctions otherwise various thermocouple pairs. A thermopile

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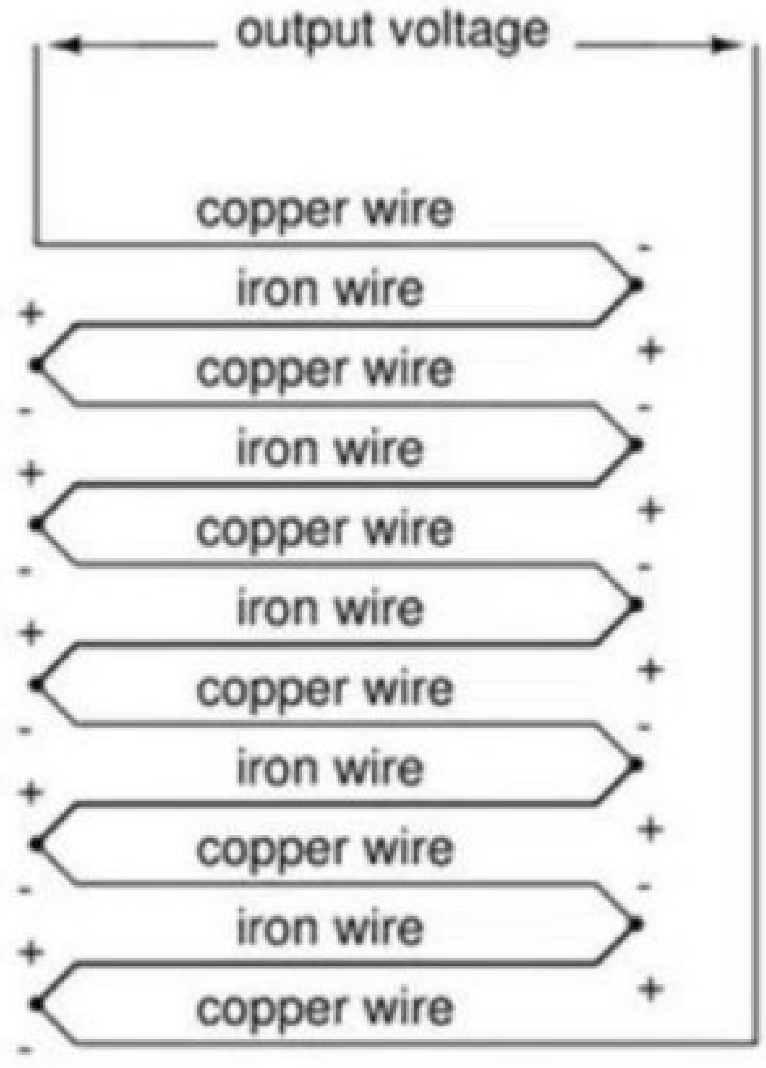
includes a series of thermocouples where each includes two special materials with large thermoelectric power & reverse polarities which are interconnected in series.



Thermopile Structure

Working: These thermocouples are arranged throughout the cold & hot areas of the arrangement where the hot junctions are isolated thermally from the cold junctions. In reply to the temperature variation across the material, the output voltage of the thermopile is called a **Seebeck coefficient or thermoelectric coefficient.** So it is measured per kelvin (V/K) otherwise mV/K in volts.

Thermopile advantages

- It doesn't need an external power supply.
- It gives a stable response to radiation which is gone from temperature-measuring bodies.
- It has stable response characteristics.
- Thermopile is a non-contact temperature-detecting device that uses IR radiation to transfer heat.
- These are available in small sizes.
- It is less costly.
- It generates larger o/p voltage because of the usage of several thermocouple devices.

Thermopile disadvantages

- These are static, so not used ones should be stored within conductive material to defend them from static discharges & static fields.
- These can be damaged due to stress and reverse the polarity of the supply.
- These should not be directly exposed to moisture or sunlight because this may harm or will have corrosion on the device's performance.
- This device should not be operated with dirty or oily fingers because this dust will affect the device's performance. For superior performance, we need to clean with cotton swabs or alcohol.
- For precise temperature measurement, an object should fill the field of view completely of the thermopile device.

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Thermoelectric generators (TEG):

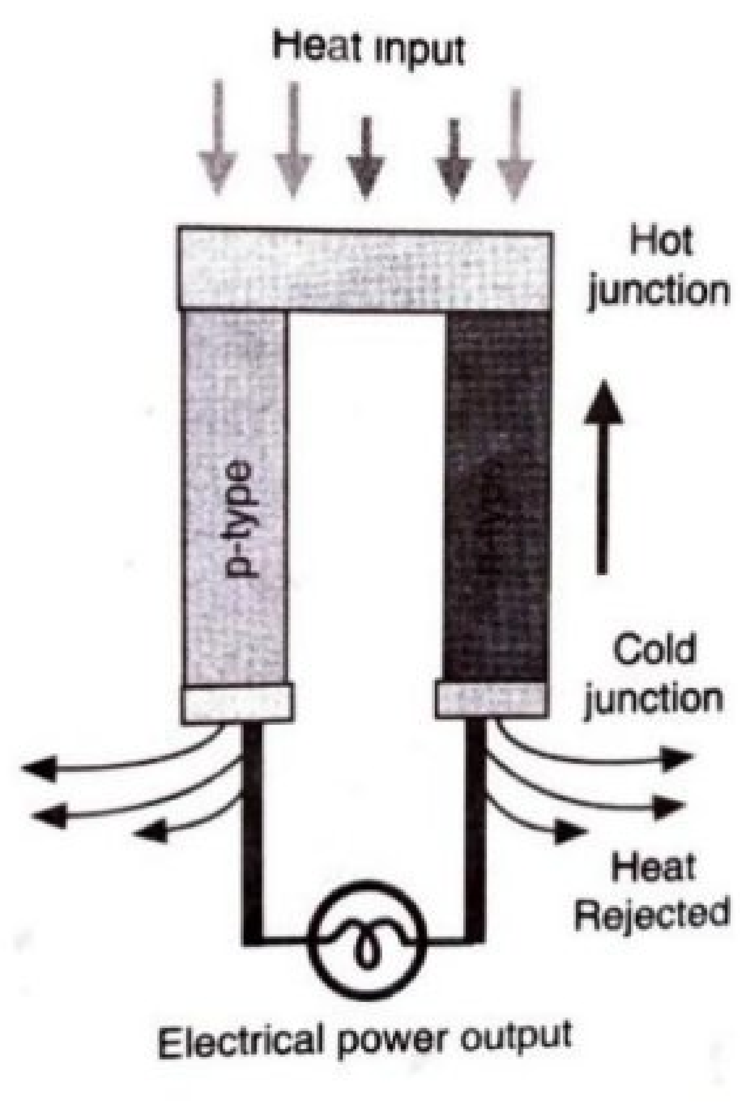
Thermoelectric is the name which is the combination of words electric and thermo. So, the name signifies that thermal corresponds to heat energy and electricity corresponds to electrical energy. And thermoelectric generators are the devices that are implemented in the conversion of the temperature difference that is generated between the two sections into the electrical form of energy. This is the basic thermoelectric generator definition.

These devices are dependent on the thermoelectric effects which involve interface that happens between heat flow and the electricity through solid components.

Principle: The Seebeck effect forms the basis for power generation. Thermoelectric generators convert heat energy to electricity. When a temperature gradient is created across the thermoelectric device, a DC voltage develops across the terminals. When a load is properly connected, electrical current flows. Typical applications for this technology include providing power for remote telecommunication, navigations, and petroleum installations.

As early as 1929, A. F. Iofe (1880-1960) showed that a thermoelectric generator utilizing semiconductors could achieve a conversion efficiency of 4%, with further possible improvement in its performance.

Construction: The simplest thermoelectric generator consists of a thermocouple, comprising a p-type and n-type thermo-element connected electrically in series and thermally in parallel (Fig).The P-type and N-type semiconductors are interconnected through a metal. Load is connected to free end of P and N type semiconductors.To design such thermoelectric generators, semiconductors are used which have high electrical conductivity and low thermal conductivity.



Working:

Heat is pumped into one side of the couple and rejected from the opposite side.The electrons present at the hot end would be at a high energy level as compared to electrons present at the cool end side. This means that the hot electrons will tend to move towards the cool end due to the temperature gradient. When a temperature gradient is produced between two ends, the

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electrons start flowing from one end to another end and create a potential difference. An electrical current is produced, proportional to the temperature gradient between the hot and cold junctions.

Of the great number of materials studied, semiconductors based on bismuth telluride, lead telluride and silicon-germanium alloys are found to be the best.

Thermoelectric Generator Applications:

- For enhancing the fuel performance of cars, the TEG device is mostly employed. These generators make use of heat that is generated at the time of vehicle operation
- Seebeck Power Generation is utilized to provide power for the spacecraft.
- Thermoelectric generators to implemented provide power for the remote stations such as weather systems, relay networks, and others

THERMOELECTRIC COOLERS

Thermoelectric coolers are solid state heat pump used in applications where temperature stabilization, temperature cycling, or cooling below ambient are required.

Principle: The principle used in this is Peltier effect. i.e: ‘when electric current passed in a circuit consisting of two dissimilar metals, heat is evolved at one junction and absorbed at the other junction.’

Construction: A thermoelectric cooling arrangement is a shown in figure. It consists of a thermoelectric module, a heat sink and the object to be cooled. A typical thermoelectric module consists of an array of bismuth telluride semiconductor pellets that have been “doped” so that one type of charge carrier-either positive or negative carriers the majority of current. The pairs of P/N pellets are configured so that they are connected electrically in series, but thermally in parallel.Metalized ceramic substrates provide the platform for the pellets and the small conductive tabs that connect them.The ceramic material on both sides of thethermoelectric adds rigidity and the necessary electrical insulation.The pellets, tabs and substrates thus form a layered configuration.Module size varies from less than 0.25” by 0.25” to approximately 2.0” by 2.0”.Thermoelectric modules can function singularly or in groups with either series, parallel, or series/parallel electrical connections.Some applications use stacked multi-stage modules.

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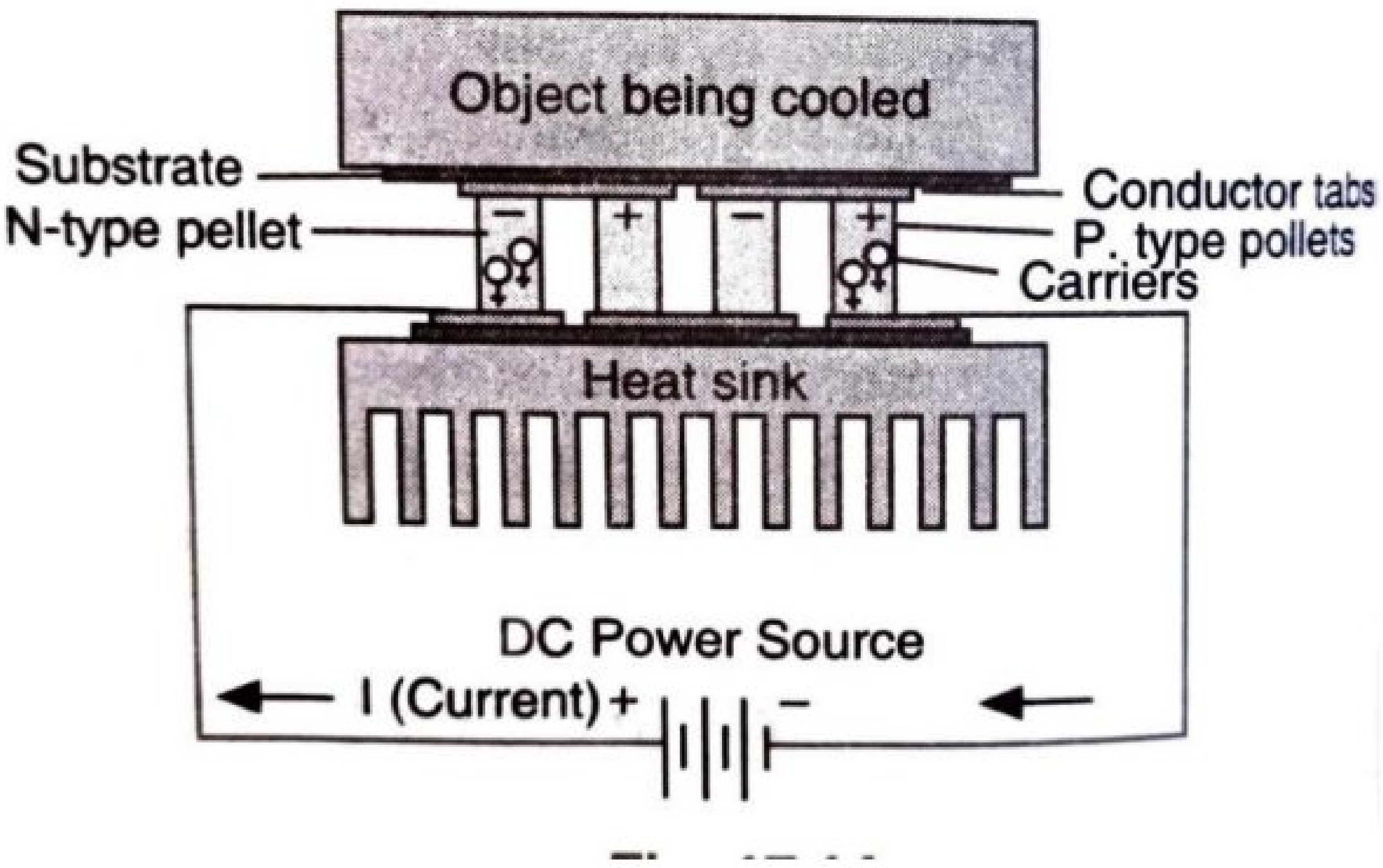

Working: When DC voltage is applied to the module, the positive and negative charge carriers in the pellet array absorb heat energy from one substrate surface and release it to the substrate at the opposite side.The surface where heat energy is absorbed becomes cold the opposite surface where heat energy is released, becomes hot.

These devices cannot only pump appreciable amount of heat, but with their series electrical connection, are suitable to be used as DC power supplies. Thus, the most common **thermoelectric devices** now in use connecting 254 alternating P and N-type pellets can run from a 12 to 16 VDC supplyand draw only 4 to 5 amps. A means to mechanically hold everything together is to mount the conductive tabs to thin ceramic substrates (Fig) the outer faces of the ceramics are then used as the thermal interface between **Peltier device** and the 'outside world'. Ceramic materials represent the best compromise between mechanical strength, electrical resistivity, and thermal conductivity.

Thermoelectric materials:

Thermoelectric (TE) materials have the capability of converting heat into electricity, which can improve fuel efficiency as well as provide a robust alternative energy supply in multiple applications by collecting wasted heat, and therefore assist in finding new energy solutions.

Classification:

The thermoelectric materials can be divided into the following three categories according to their operating temperature. They are low, mid and high temperature thermoelectric materials.

1.Low temperature thermoelectric materials:

Bismuth telluride and its alloys. This is a material widely used in thermoelectric coolers, and its optimal operating temperature is<450°C.

Bismuth (Bi), Antimony (Sb), and the Bi–Sb alloys form a complete class of thermoelectric semiconductors that are particularly suited to thermoelectric applications below room temperature.

Thermoelectric materials allow direct conversion of waste heat energy into electrical energy, thus contributing to solving energy related issues. Polymer-based materials have been considered for use in heat conversion in the temperature range from 20 to 200 °C, within which conventional materials are not efficient enough, whereas polymers due to their good

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electronic transport properties, easy processability, non-toxicity, flexibility, abundance, and simplicity of adjustment, are considered as promising materials.

2. Mid temperature thermoelectric materials:

Lead telluride and its alloys. This is a material widely used in thermoelectric generators, and its optimal operating temperature is about 1000°C.

Mg_2Sn is a potential mid-temperature thermoelectric material.

3.High temperature thermoelectric materials:

Silicon-germanium alloy. This type of material is also commonly used in thermoelectric generators, and its optimal operating temperature is about 1300°C. Thermoelectric materials, which can be applied in highly efficient cooling and refrigeration, energy scavenging, sensing, and thermo power systems, can make significant contributions to solve the global energy crisis by providing a sustainable energy solution. Metal oxides have become important thermoelectric materials due to their high-temperature stability, tunable electronic and phonon transport properties, and well-established synthesis techniques. In this chapter, $NaxCoO_2$, $Ca3Co4O_9$, $SrTiO_3$, $CaMnO_3$, and ZnO are reviewed as promising metal oxide-based thermoelectric materials.

Applications: Exhaust of Automobiles, Refrigerator, Space Program (RTG):

Application in exhaust of Automobiles

Automotive thermoelectric generator (ATEG) technology involves **converting the waste heat available in the exhaust gas in internal combustion engine into electricity using Seebeck effect. That electricity can be stored and utilized for various electrical inputs of a vehicle so that the fuel efficiency can be improved**.ATEG is gaining significant importance since a direct conversion of exhaust waste heat into electricity allows for a reduction in fuel consumption. The role of exhaust flow rate, temperature and heat exchanger will affect on the performance of ATEG.

A typical ATEG consists of four main elements.A hot-side heat exchanger,a cold side heat exchanger, thermoelectric materials and a compression assembly system. In ATEG, thermoelectric materials are packed between the hot-side and cold-side heat exchangers. The thermoelectric materials are made up of p-type and n-type semiconductors. The heat exchangers are metal plates with high thermal conductivity. The temperature difference between the two surfaces of the thermoelectric modules generates electricity using Seebeck effect. When hot exhaust from the engine passes through an exhaust ATEG, the charge carriers of the semiconductors within the generator diffuse from the hot-side heat exchanger to cold-side exchanger. The build-up of charge carriers results in net charge, producing an electrostatic potential while the heat transfer drives a current. With exhaust temperature of 700^0c or more, the temperature difference between exhaust gas on the hot side and coolant on the cold side is several hundred degrees. This temperature difference is capable of generating 500-750 W of electricity.

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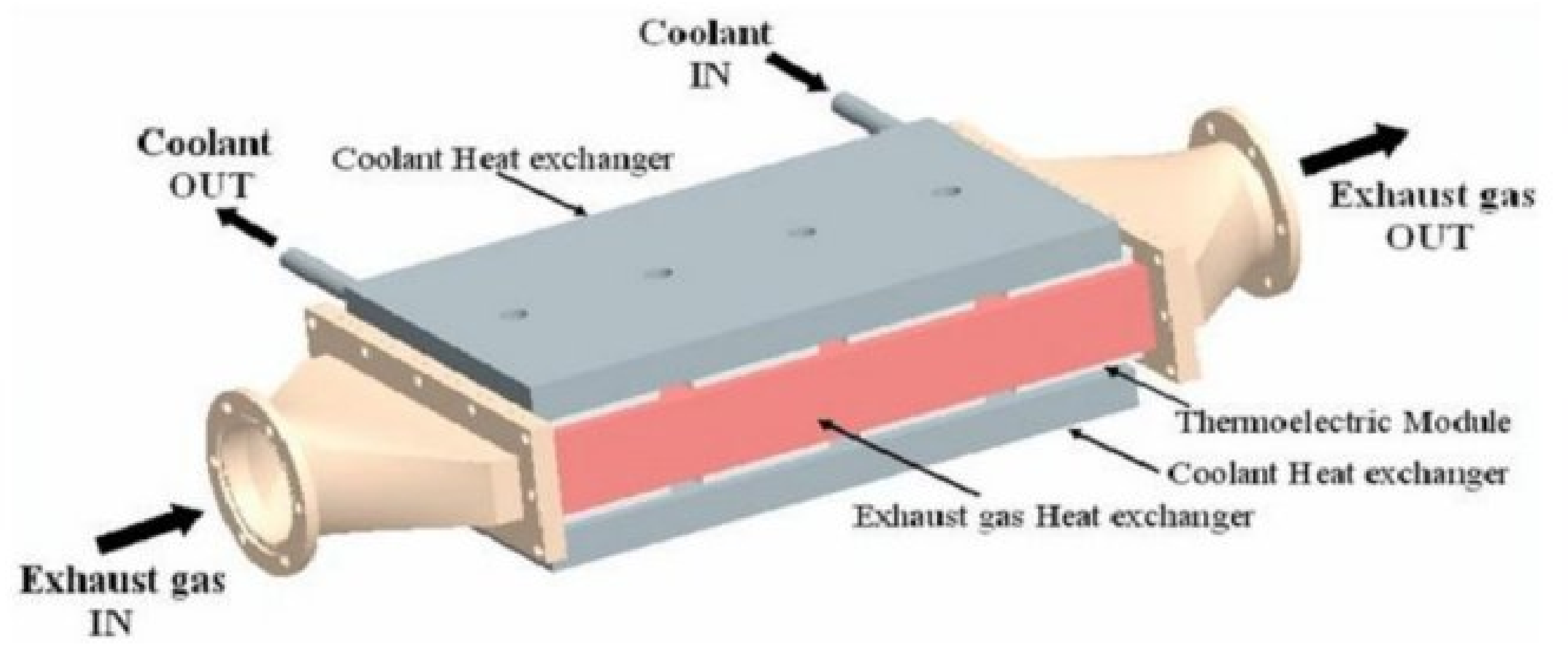

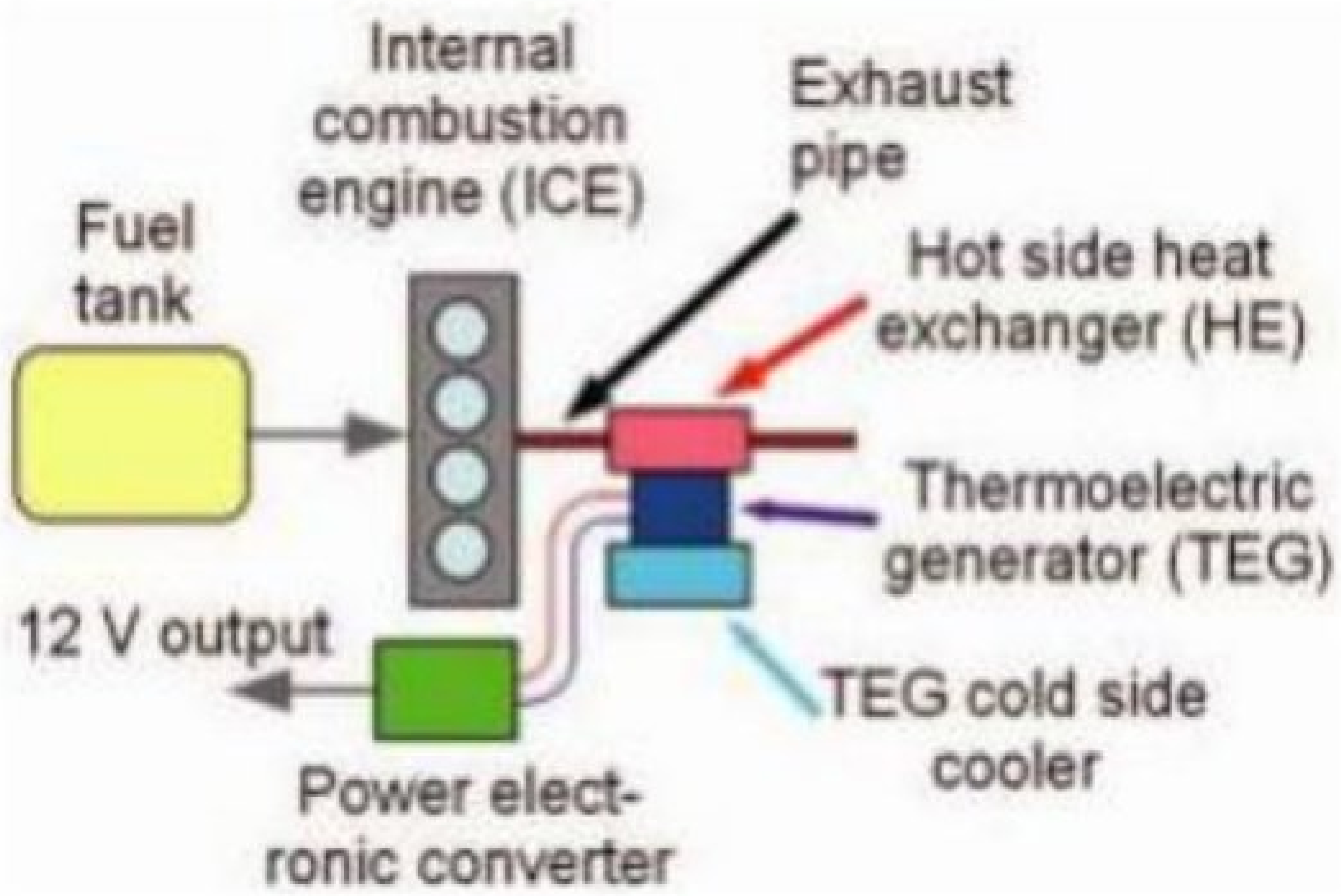

Fig: Layout of the main components of Exhaust gas Heat recovery system with TEG

Refrigerator

Thermoelectric cooling is a way to remove thermal energy from a medium,device or component by applying a voltage of constant polarity to a function between two dissimilar semiconductors or electrical conductors.Thermoelectric cooling uses the **Peltier effect** to create a heat flux between the junction of two different types of materials. This effect is commonly used in camping and portable coolers and for cooling electronic components and small instruments. The device has two sides, and **when a DC electric current flows through the device, it brings heat from one side to the other, so that one side gets cooler while the other gets hotter.** The major components of the refrigerator are given below.

The thermoelectric devices used in thermoelectric refrigeration (or thermoelectric coolers) are based on the Peltier effect to convert electrical energy into a temperature gradient [1]. A conventional thermoelectric cooler is composed of a number of N-type and P-type semiconductor junctions connected electrically in series by metallic interconnects (conducting strips, in general made of copper) and thermally in parallel, forming a single-stage cooler. If a low-voltage DC power source is applied to a thermoelectric cooler, heat is transferred from one side of the thermoelectric cooler to the other side. Therefore, one face of the thermoelectric cooler is cooled and the opposite face is heated.

Fig. 1 depicts a thermoelectric cooling module considered as a thermoelectric refrigerator, in which the electrical current flows from the N-type element to the P-type element. The temperature Tc of the cold junction decreases and the heat is transferred from the environment to the cold junction at a lower temperature. This process happens when the transport electrons

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pass from a low energy level inside the P-type element to a high energy level inside the N-type element through the cold junction. At the same time, the transport electrons carry the absorbed heat to the hot junction which is at temperature Th. This heat is dissipated in the heat sink, whilst the electrons return at a lower energy level in the P-type semiconductor (the Peltier effect). If there is a temperature difference between the cold junction and hot junction of N-type and P-type thermoelements, a voltage (called Seebeck voltage) directly proportional to the temperature difference is generated.

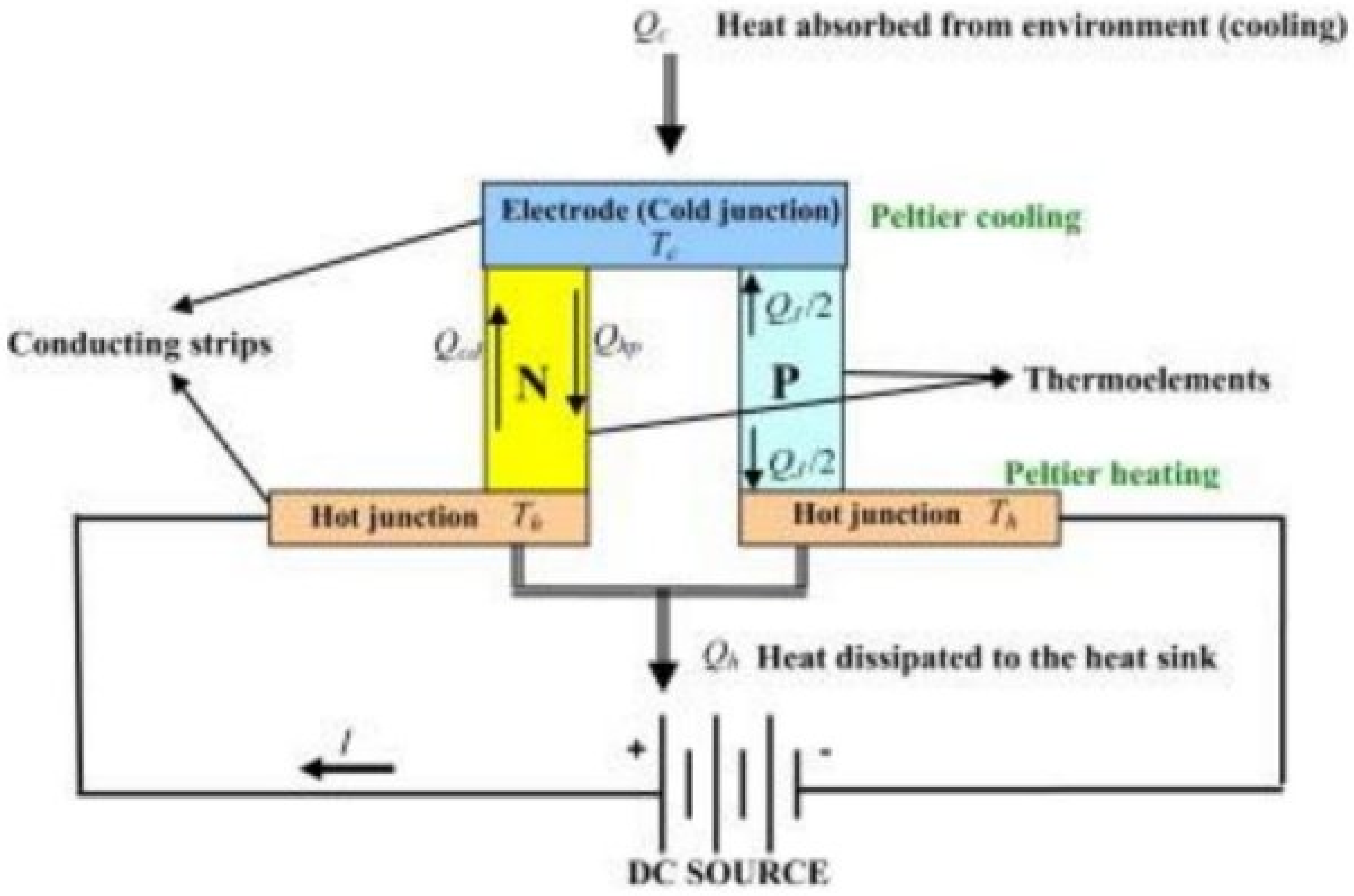


Fig. 1. Scheme of a thermoelectric refrigerator.

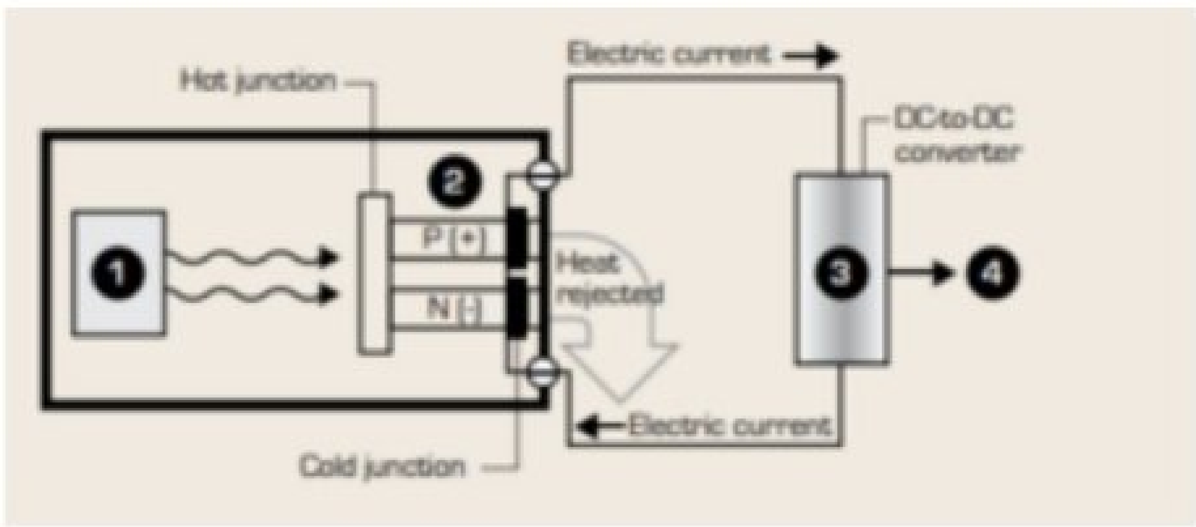
The quality of a thermoelectric cooler depends on parameters such as the electric current applied at the couple of N-type and P-type thermoelements, the temperatures of the hot and cold sides, the electrical contact resistance between the cold side and the surface of the device, the thermal and electrical conductivities of the thermoelement, and the thermal resistance of the heat sink on the hot side of the thermoelectric cooler. The number of thermoelements in a thermoelectric module mainly depends on the required cooling capacity and the maximum electric current .

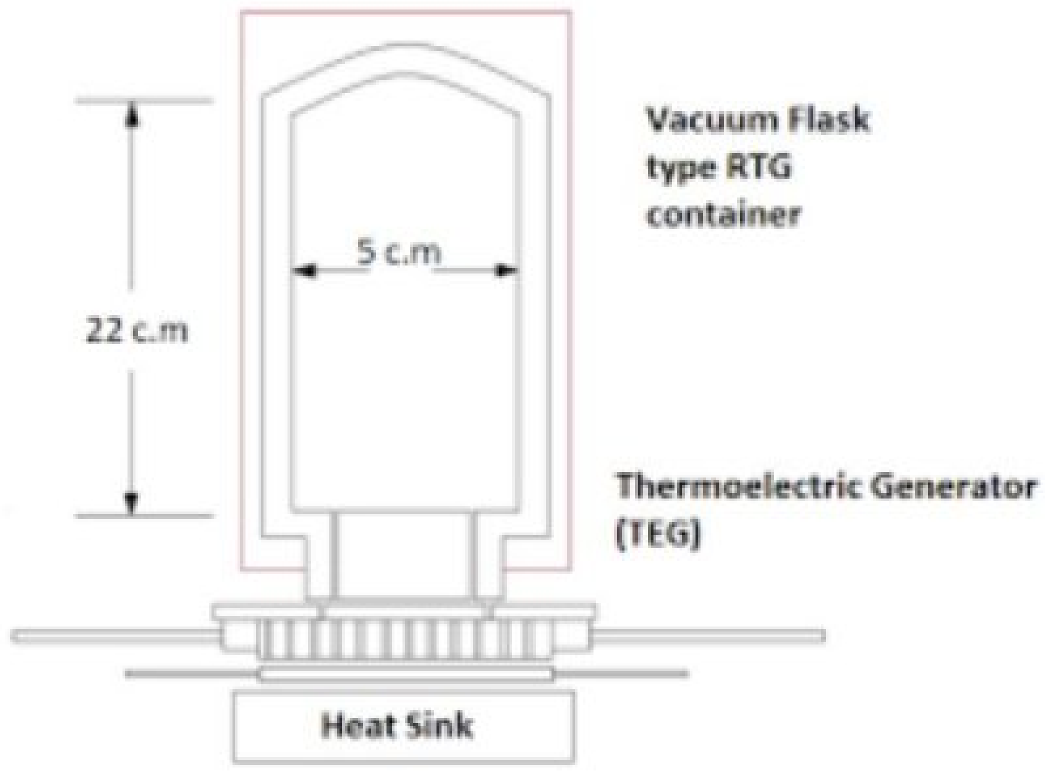
The characteristics and performance of a thermoelectric refrigerator are described by parameters like the figure of merit, the cooling capacity, and the coefficient of performance. This review is specifically focused on these parameters, addressing the concepts in a different way with respect to various review papers appearing on thermoelectric cooling in the past years. Specific aspects such as thermoelectric cooling system design, experimental assessment, numerical analysis and simulation are outside the scope of this review.

Space Program (Radioisotope Thermoelectric Generators)

A major practical application of thermoelectric generators has been in the space program, where the need is for an electric generator with no moving parts and which will supply power for the long duration of the space missions. A **radioisotope thermoelectric generator** (**RTG**, **RITEG**), sometimes referred to as a radioisotope power system (RPS), is a type of nuclear battery that uses an array of thermocouples to convert the heat released by the decay of a suitable radioactive material into electricity by the Seebeck effect. RTGs provide electrical power using heat from the natural radioactive decay of plutonium-238, in the form of plutonium dioxide.In the isotopic decay process, alpha particles are released which bombard the inner surface of the container. The energy released is converted to heat and is the source of heat to the thermoelectric converter. The large difference in temperature between this hot fuel and the cold environment of space is applied across special solid-state metallic junctions called thermocouples, which generates an electrical current.This type of generator has no moving parts.

RTGs have a long operating life, are reasonably lightweight, and require little or no maintenance once assembled and tested. However, because RTGs contain significant quantities of radioactive materials, normally plutonium^{238} and its decay products, they must be transported in packages.RTG is made up of a radioisotope heat source, a thermoelectric converter, a gas pressure venting system, temperature transducers, connectors, a heat rejecting cylindrical container, and bracketry.





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