Content:

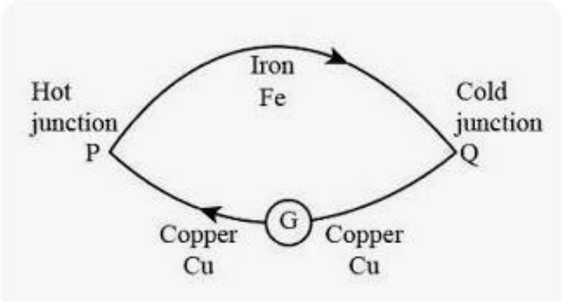
Thermo emf and thermo current, Seebeck effect, Peltier effect, Seebeck and Peltier coefficients, figure of merit (Mention Expression), laws of thermoelectricity. Expression for thermo emf in terms of T1 and T2, Thermo couples, thermopile, Construction and Working of Thermoelectric generators (TEG) and Thermoelectric coolers (TEC), low, mid and high temperature thermoelectric materials, Applications: Exhaust of Automobiles, Refrigerator, Space Program (Radioisotope thermoelectric Generator), Numerical Problems.

Introduction:

Thermoelectricity deals with the direct conversion between heat and electrical energy. When a temperature difference exists across two dissimilar conductors, an electromotive force (thermo emf) is produced, known as the Seebeck effect. Conversely, when an electric current passes through such a junction, heating or cooling occurs, called the Peltier effect. These effects form the basis of thermocouples, thermopiles, thermoelectric generators (TEG), and thermoelectric coolers (TEC). The efficiency of thermoelectric materials is measured using the Seebeck coefficient, Peltier coefficient, and figure of merit (ZT). Depending on their operational range, materials are classified into low, mid, and high-temperature types, with applications in automobile exhaust energy recovery, solid-state refrigeration, and space programs (RTGs).

Thermo-emf and Thermo-electric current:

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 electricallyconducting Copper and Iron wires. The 2 wires are attached terminal to terminal to become a closed circuit. The pair of metals forming the circuit is called a Thermocouple.

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 electrons flow 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.

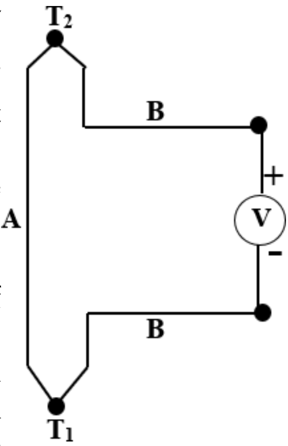
Seebeck effect:

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.

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

$$V = \alpha\,(T_2 - T_1) \quad \text{Where } \alpha = \alpha_B - \alpha_A$$

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.

Seebeck coefficient:

The Seebeck coefficient (also called thermopower, denoted by α) of a material measures the induced thermoelectric voltage generated in response to a temperature difference across that material.

It is defined as the open-circuit voltage developed between two points of a conductor when a uniform temperature difference of 1 K 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

$$\alpha = \frac{\Delta V}{\Delta T}$$

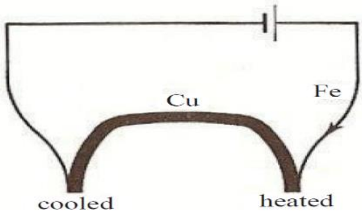
This can also be expressed in terms of the electric field E and the temperature gradient ∇T, $\alpha = \frac{E}{\nabla T}$

Peltier Effect:

It was discovered by **Jean-Charles-Athanase Peltier** in the year 1834 Peltier. If 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. There is heat absorption or generation at the junctions de- pending on the direction of current flow. The Peltier effect depicts the transformation of electrical energy into heat energy. The heating and cooling effect depends on the direction of flow of current.

Example: Consider the circuit as shown in the figure. Under these conditions it is observed, as indicated in the diagram, that the right-hand junction is heated, showing that electrical energy is being transformed into heat energy. Meanwhile, heat energy is transformed into electrical energy at the left junction, thereby causing it to be cooled. When the current is reversed, heat is absorbed at the right junction and produced at the left one.



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 ampere 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

$$\text{Heat absorbed per second} = \pi_{ab} \times I \quad --- (1)$$

Heat absorbed in t seconds,

$$H = \pi_{ab} \times I \times t = \pi_{ab} \times q \quad --- (2)$$

Where current is from metal 'a' to metal 'b'. The junction emf, π_{ab} is known as Peltier coefficient.

$$\pi_{ab} = \frac{H}{I\,t}$$

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

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

Heat absorbed per second = $-\pi_{ba} \times I$, which is opposite in equation (1).

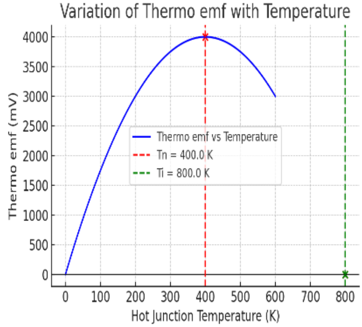
If V is the potential difference applied, then Heat absorbed $= V \times q = V \times I \times t$

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 at thermo couple is kept at 0°C and the thermo electric e.m.f. '***e***' is plotted against the temperature 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 T_n for that couple. If the temperature of 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.

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

$$e = aT + bT^2 \text{ ------------(1)}$$

Here a and b are Seebeck constants, $T = T_i - T_n$, and the above equation (1) is called Seebeck equation.

Differentiating equation (1) with respect to temperature 'T' we get

$$\frac{de}{dT} = a + 2bT \text{ -------------------(2)}$$

At $T = T_n$, e is maximum and hence $de/dT = 0$.

Therefore, from eqn (2), $0 = a + 2bT_n$, hence $T_n = -\frac{a}{2b}$----(3)

At $T = T_i$, $e = 0$. Thus, from equation (1), $e = aT_i + bT_i^2$

or $0 = T_i(a + bT_i)$ $\quad \therefore T_i = -\frac{a}{b}$----------(4)

From equation (3) & (4) $\quad T_i = 2T_n$

Thermo-electric Power

The rate of change of emf with temperature is called Thermo-electric power and is denoted by P.

$$P = \frac{de}{dt}$$

Relation between Peltier coefficient and Thermo-electric power is given by $\pi = TP$, here T is the temperature of the junction and P is the thermometric power at that temperature.

Figure of Merit

The usefulness of a material in thermoelectric systems is determined by its efficiency, which depends on electrical conductivity (σ), thermal conductivity (K), and Seebeck coefficient (α). The efficiency of conversion of thermal energy to electrical energy is denoted by the parameter called figure of merit of a thermo electric material

The performance of a thermoelectric material is expressed using the dimensionless Figure of Merit (ZT):

$$ZT = \frac{\alpha^2 \sigma T}{K}$$

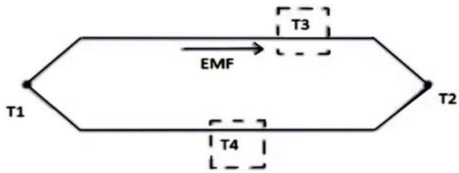
Here, α is the Seebeck coefficient, σ is the electrical conductivity, K is the thermal conductivity, and T is the absolute temperature. Higher ZT values indicate better efficiency of thermoelectric materials.

Laws of Thermo-electricity

Through extensive study of thermoelectric circuits, several fundamental concepts have been established, which can be summarized in three basic laws.

Law of homogeneous circuits

Statement: A Thermo-electric current cannot be sustained in a circuit of single homogeneous material by the application of heat alone. The thermal emf produced by two thermocouples at T_1 and T_2 is independent of and unaffected by any temperature variation down the wires.

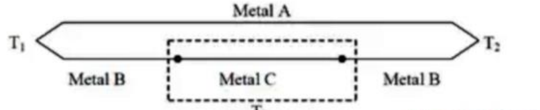


Practical significance: Two different materials are required for any thermocouple circuit to produce thermo emf.

Law of intermediate metals

Statement: The Law of Intermediate Metals states that when a third metal is introduced into a thermocouple circuit, it does not affect the net thermo-emf, provided the two junctions of the third metal are maintained at the same temperature.

For example, in a thermocouple made of metals A and B with junctions at temperatures T_1 and T_2, if a third metal C is inserted between B without creating any temperature difference, the emf of the thermocouple remains unchanged.

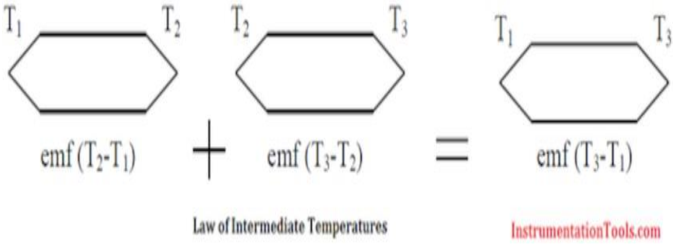


Law of Intermediate Metals

Practical Significance It allows the use of extension wires of metal for measuring instruments and soldering different from the metal used to form Thermocouple.

Law of intermediate temperature

Statement: the sum of the EMFs developed by a thermocouple with its junctions at temperatures T_1 and T_2, and with its 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.

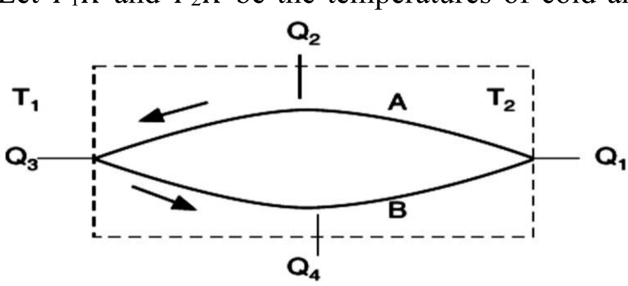


Practical significance: Referring to the figure. This law is useful in practice because it helps in giving a suitable correction in case of a reference junction temperature other than 0°C is employed.

Note: For example, if a thermocouple is calibrated with reference junction a 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 Temperature of Cold (T_1) and Hot (T_2) Junctions

Consider circuit of two dissimilar metals *A* and *B* with two junctions. Let T_1K and T_2K be the temperatures of cold and hot



junctions. The electric current flows in the circuit due to Seebeck effect. Due to the flow of electric current through hot and cold junctions the Peltier effect will be in action which results in the absorption of heat by hot junction and loss of heat at the cold junction. Let π_1 and π_2 be the Peltier coefficients at cold and hot junctions.

Thus $Q = \pi_1 q$ is the heat evolved at cold junction
$Q^{\prime} = \pi_2 q$ is the heat absorbed at hot junction.

The total energy (PD) used in driving the current through the circuit is given by $(\pi_2 - \pi_1)q$.

Since the Peltier coefficient represents voltage the Thermo EMF is given by

$$e = \pi_2 - \pi_1$$

Considering the process as similar to the Carnot's engine, hot junction representing the source and cold junction representing the sink and by the definition of Peltier coefficients we can write

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

We know that $e = \pi_2 - \pi_1$. Thus, the expression for Thermo emf T_1 and T_2 is given by

$$e = \frac{\pi_1}{T_1}(T_2 - T_1)$$

If the temperature of the cold junction T_1 is constant then the Peltier coefficient π_1 is also constant and hence

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

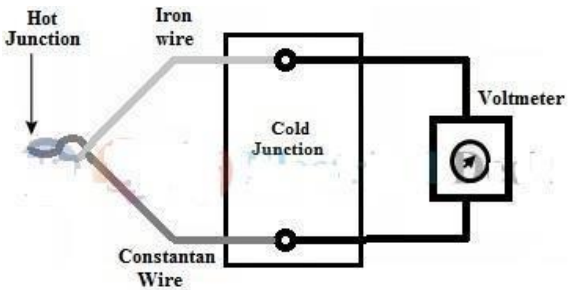
Thermo-couples:

A thermocouple is a transducer that converts thermal energy into electrical energy and it 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 metals i.e, Iron and Constanton. 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.

Working:



Thermocouple Circuit

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:

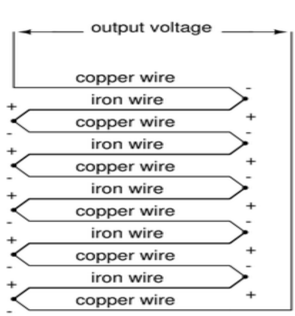
A **thermopile** is an electronic device that converts thermal energy into electrical energy. It is composed of several thermocouples connected usually in series or, less commonly, in parallel.

Principle: Principle is Thermoelectric effect, i.e., generating a voltage when its dissimilar metals (thermocouples) are exposed to a temperature difference i.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 includes a series of thermocouples where each includes two special materials with largethermoelectric power & reverse polarities which are interconnected in series.

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-measuringbodies.
- It has stable response characteristics.
- Thermopile is a non-contact temperature-detecting device that uses IR radiation totransfer heat.
- These are available in small sizes. And 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.

Thermoelectric generators (TEG):

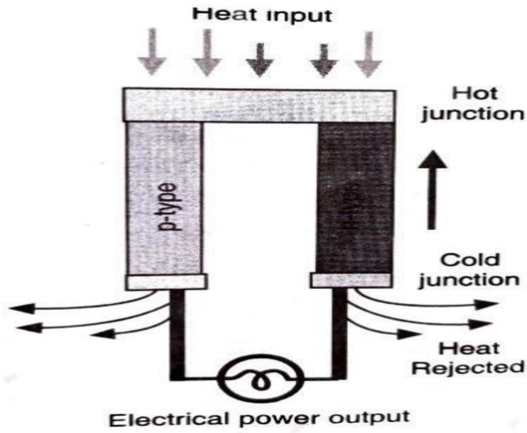
Thermoelectric is the name which is the combination of words electric and thermo. So, the name signifies that thermal corresponds to heat energy and electricity corresponds to electrical energy. And thermoelectric generators are the devices that are implemented in the conversion of the temperature difference 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 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, leadtelluride and silicon-germanium alloys are found to be the best.

Thermoelectric Generator Applications:

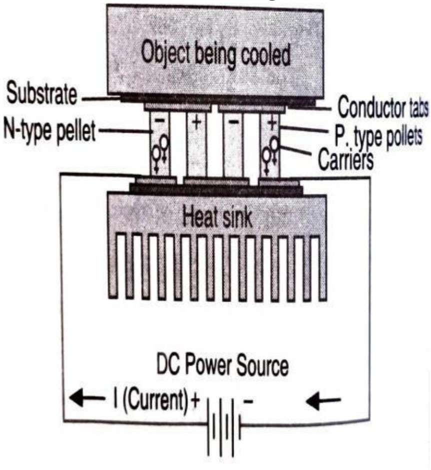
- For enhancing the fuel performance of cars, the TEG device is mostly employed. These generators make use of heat that is generated at the time of vehicle operation
- Seebeck Power Generation is utilized to provide power for the spacecraft.
- Thermoelectric generators to implemented provide power for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

Thermoelectric coolers:

Thermoelectric coolers are solid state heat pump used in applications where temperaturestabilization, 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 atthe 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 the thermoelectric 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 usestacked multi-stage modules.



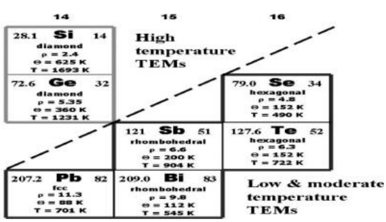
Working: When DC voltage is applied to the module, the positive and negative charge carriers in the pellet array absorb heat energy from one substrate surface and release it to the substrate at the opposite side. The surface where heat energy is absorbed becomes cold the opposite surface where heat energy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

Thermo-electric 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 classified into the following three categories according to their operating temperature. They are low, mid and high temperature thermometric materials.



Low and Near Room Temperature Thermoelectric Materials (<300K and 300K to 500K)

Bismuth Telluride/Antimony Telluride (Bi_2Te_3/Sb_2Te_3). These semiconductors are highly effective for applications below room temperature. Their figure of merit (ZT) ranges from 1.1 to 1.8 in the temperature interval 300–346 K.

Iron Antimonide ($FeSb_2$): $FeSb_2$ is a promising candidate for low-temperature thermoelectric devices, especially due to its colossal Seebeck coefficient of about 45,000 μV K^{-1}at ~10 K, with ZT ≈ 0.71 at 55 K.

Applications:

- Thermoelectric cooling (Peltier modules) for electronics, CPUs, and laser diodes.
- Portable refrigeration units and beverage coolers.
- Sensitive low-temperature sensors and medical cooling devices.

Mid Temperature Thermoelectric Materials (500 to 800K)

- **Lead Telluride (PbTe) and its Alloys**: One of the most widely used TE materials in generators, with an optimal operating range near **1000 °C**.
- **Magnesium Stannide (Mg_2Sn)** Considered a potential candidate for mid-range power generation due to its favorable thermoelectric properties.

Applications:

- Industrial waste heat recovery (steel plants, glass industries).
- Thermoelectric generators in automobiles to convert exhaust heat into electricity.
- Power generation in remote or off-grid systems.

High Temperature Thermoelectric Materials (>800K)

Lanthanum Telluride (Rare Earth Telluride ($La_{3-x}Te_4$)

First investigated in the late 1980s for TE generator applications, this n-type material exhibits high efficiency at extreme temperatures, with a ZT of about 1.2 at 1275 K.

Silicon-Germanium Alloys ($Si_{1-x}Ge_x$):

These solid solution semiconductors with cubic diamond-type structure are highly durable and efficient. With ZT values of **0.7–1.0 around 1200 K**, SiGe alloys can operate up to **1300 K** without significant degradation.

Applications:

- Radioisotope Thermoelectric Generators (RTGs) for space missions (e.g., Voyager, Mars rovers).
- High-temperature power generation in aerospace and defense systems.
- Energy harvesting in furnaces and nuclear power systems.

Applications: Exhaust of Automobiles – ATEG

Principle An automotive thermoelectric generator (ATEG) is a device that converts some of the waste heat of an internal combustion engine (IC) into electricity using the Seebeck Effect. ATEGs can convert waste heat from an engine's coolant or exhaust into electricity.

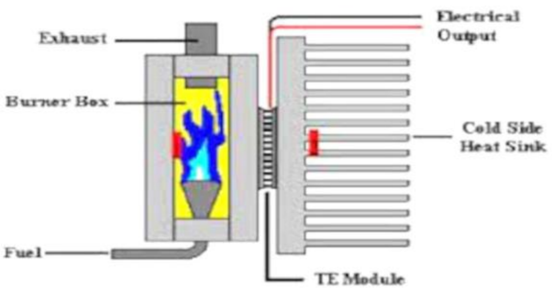


Figure: Automobile Thermoelectric Exhaust Generator

Construction A typical ATEG consists of four main elements: A hot-side heat exchanger, a cold-side heat ex- changer, thermoelectric materials, and a compression assembly system. In ATEGs, thermoelectric materials are packed between the hot-side and the cold-side heat exchangers. The thermoelectric materials are made up of p- type and n-type semiconductors, while the heat exchangers are metal plates with high thermal conductivity.

Working 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 the cold side exchanger. The buildup of charge carriers results in a net charge, producing an electrostatic potential while the heat transfer drives a current. The temperature difference of several hundred degrees (700°C) is capable of generating 500 to 750W of electricity.

Thermoelectric Refrigeration

Thermoelectric Refrigeration System works on the principle of Peltier effect according to which heat energy is evolved at one junction and absorbed at the other one when direct current is passed through a junction of two dissimilar metals like antimony and bismuth. It consists of a number of thermoelectric module assemblies in series joined by copper strips, as shown in figure. Each thermoelectric module is built up of a large number of thermocouples

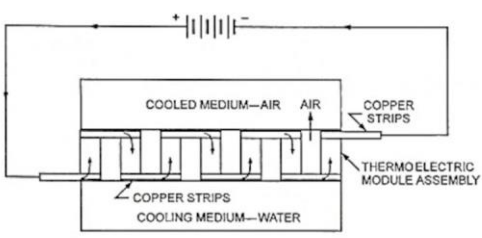


Figure: Thermoelectric Refrigerator

Working When the direct current is passed through the thermoelectric module assemblies in the direction shown in figure, junctions at the top of the assembly are cooled and those at the bottom are heated up. Thus, top junctions abstract heat from the surroundings and produce refrigerating effect and bottom junctions require cooling by water. Module assembly, therefore, abstracts heat from the medium at top and rejects the same to the medium at bottom.

Advantages The main advantages of this thermoelectric refrigeration system are absence of moving parts and ease of automatic control by controlling the magnitude of current.

Disadvantages The only drawback of this system of refrigeration is its very high initial cost.

Space Program - Radioisotope Thermoelectric Generator (RTG)

Radioisotope Thermoelectric Generators (RTGs) are lightweight, compact spacecraft power systems that are extraordinarily reliable. RTGs provide electrical power using heat from the natural radioactive decay of plutonium-238, in the form of plutonium dioxide. The large difference in

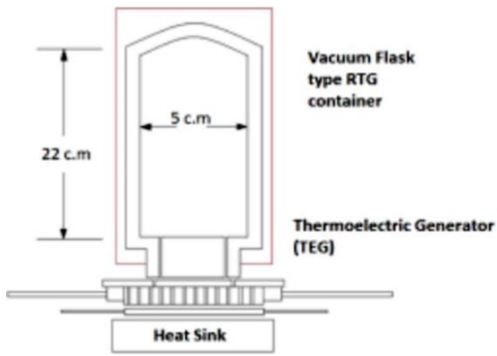


Figure: Radioisotope Thermoelectric

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 using no moving parts.

The design of an RTG is simple by the standards of nuclear technology: the main component is a sturdy container of a radioactive material (the fuel). Thermocouples are placed in the walls of the container, with the outer end of each thermocouple connected to a heat sink. Radioactive decay of the fuel produces heat. It is the temperature difference between the fuel and the heat sink that allows the thermocouples to generate electricity.

SI No	Sample Questions and Numerical
1.	State and Explain Seebeck Effect and hence define Seebeck coefficient.
2.	State and Explain Peltier Effect and hence define peltier coefficient.
3.	Discuss the variation of Thermo EMF with respect to temperature
4.	Define neutral temperature and inversion temperature and hence deduce the relation between them.
5.	Elucidate the laws of Thermo electricity.
6.	Derive an expression for Thermo EMF in terms of temperatures of hot and cold junctions.
7.	Explain the principle, construction and working of thermocouple with a neat sketch.
8.	Mention the advantages and disadvantages of thermocouples.
9.	Mention the need for thermopile and hence describe its construction and working.
10.	Enumerate the advantages and disadvantages of thermopile.
11.	Discuss the principle construction and working of Thermo Electric Generator.
12.	Explain the principle, construction, working and application of thermoelectric coolers.
13.	Discuss Low temperature, Moderate temperature and High Temperatures with suitable examples and mentions their ZT.
14.	Describe the application of thermoelectrics in Auto- mobile Thermo Electric Generators.
15.	Explain thermoelectric refrigeration.
16.	Describe Radioisotope Thermometric Generator and its applications.
17.	Calculate the neutral and inversion temperature for an iron - silver thermo couple. The values of *a* and *b* are 16.65 and –0.096 for iron and 2.86 and 0.017 for silver respectively. **Solution:** $a = a_{\text{iron}} - a_{\text{silver}} = 16.65 - 2.86 = 13.79$ $b = b_{\text{iron}} - b_{\text{silver}} = -0.096 - 0.017 = -0.113$

	The neutral temperature for an iron – silver is $$T_n = -\frac{a}{2b} = -\frac{13.79}{-0.226} = 61.02°\text{C}$$ The inversion temperature for an iron – silver is $T_i=2T_n=2\times 61.02°\text{C} =122.04°\text{C}$
18.	The neutral temperature of a thermocouple is 300 °C. When its junctions are kept at temperatures 0°C and 100 °C, the e.m.f. generated is 1300 mV. Calculate the values of the coefficients a and b. **Solution:** Temperature T =100 °C Neutral temperature Tn =300 °C e.m.f. generated = 1300 mV The thermo e.m.f. varies with temperature according to the following relation $e = aT + bT^2 ----------------(1)$ $\frac{de}{dT} = a + 2bT$ At $T = T_n= 300^{°C}$, e is maximum, hence de /dT = 0. $0 = a + 2b\text{T}n$ $a = -600b ------ (2)$ Substitute for a and T in (1), we get $T = 100^{°C}$ $1.3 = -60000b + 10{,}000b$ $1.3 = -50000b$ $b = -2.6 \times 10^{-5}$ From equation (2), we have $a = -600(-2.6 \times 10^{-5}) = 0.0156$
19.	For Fe-Cu thermocouple it is observed that the thermo e.m.f is zero when one of the junctions is at 20 °C and the other one is at some higher temperature. If the neutral temperature is 285°C, calculate the higher temperature. Hence find out the temperature of inversion, if the cold junction temperature is at –20°C. **Solution:**

	Temperature T_1 =20 °C Temperature T_2=T Neutral temperature Tn =285 °C e.m.f. generated = 0 $e = aT + bT^2$ ---------------(1) $\frac{de}{dT} = a + 2bT$ At $T = T_n$= 285°C, e is maximum, hence de /dT = 0. $0 = a + 2b\mathrm{T}n$ $a = -570b$ ------ (2) Condition for zero thermo-emf e(T_2) − e(T_1) =0 $a(T_2 - T_1) + b(T_2^2 - T_1^2) = 0$ $(T_2 - T_1)[a + b(T_2 + T_1)] = 0$ $a + b(T_2 + T_1) = 0$------(3) Substitute $a = -570b$ into (3): $-570b + b(T_2 + 20) = 0$ $b(T_2 - 550) = 0$ $\boxed{T_2 = 550°\mathrm{C}}$ The inversion of temperature is $T_i = 2T_n$ =570°C
20.	The e.m.f of Fe-Pb thermocouple when one junction is at 0°C and the other at 100 °C is 1185 mV. When the second junction is at 300°C the e.m.f. is 675 mV. Similar readings with Ag-Pb thermocouple are 371 mV and 1623 mV respectively. Calculate the neutral temperature for Fe-Ag thermocouple. [Ans: 122°C]
21.	The thermoelectric and zero at 400 °C. That for cop- per is 6 mV / °C at 500 °C and zero at –50 °C. Find the e.m.f. for steel-copper thermocouple with one junction at its neutral temperature and other at 0 °C.[Ans:2.7 mV]
22.	The thermoelectric power of iron is 1734 – 4.87 t and that of copper is 136–0.95t, where t is the temperature in °C. Show that the e.m.f. of thermocouple of iron- copper, the junctions of which are at 0 °C and 100 °C is 0.14 V.
23.	The Seebeck coefficient of a thermocouple is 25 $\mu V/K$.

	Find the thermo-emf when the junction temperatures are 400 K and 300 K. **Solution:** $\boldsymbol{V = 25 \times 10^{-6}(400 - 300)}$ $\boldsymbol{V = 2.5 \times 10^{-3}\ V = \boxed{2.5\ mV}}$
24.	The neutral temperature of a thermocouple is 250°C. Find the inversion temperature. **Solution:** T_i=2T_n=2×250=500°C
25.	The Peltier coefficient of a junction is 0.02 V. Find the heat absorbed in 10 s when a current of 2 A flows. **Solution:** $Q=\pi It=0.02\times 2\times 10$ $\boldsymbol{Q = \boxed{0.4\ J}}$
26.	The thermo-electric constants of iron are $a = 14.20$ and $b = -0.082$, while those of silver are $a = 3.10$ and $b = 0.018$. Determine the neutral temperature and inversion temperature of the iron–silver thermocouple. **Solution:** $a = a_{iron} - a_{silver} = 14.20 - 3.10 = 11.10$ $b = b_{iron} - b_{silver} = -0.082 - 0.018 = -0.100$ The neutral temperature for an iron – silver is $T_n = -\frac{a}{2b} = -\frac{11.10}{-0.20} = 55.5°C$ The inversion temperature for an iron – silver is T_i=2T_n=2×55.5°C =111°C