# Thermoelectricity

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## Thermal electromotive forces, Seebeck and Peltier effect:

In 1826, Thomas Johann Seebeck discovered an effect, known as ***Seebeck effect*** that ***a current flows in a circuit consisting of two different metals A and B when a difference of temperature is maintained between the two junctions, as shown schematically in Fig.1.*** There is, therefore, an e.m.f. in such a circuit depends on thermal conditions, called ***thermal electromotive force*** or ***Seebeck e.mf.*** The combination of two different metals in which thermal e.m.f. is produced is called a ***thermocouple***, Seebeck arranged 35 metals in a series in such a way that, when any two comprise a circuit, the current flows across the hot junction from the metal occurring earlier to that occurring later in series. Seebeck's list comprises:

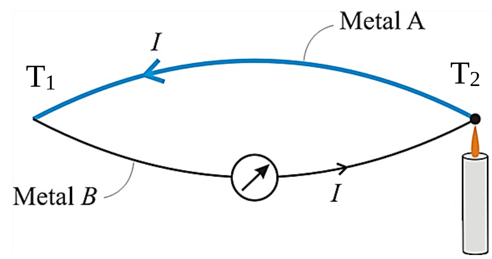


Fig. 1: Thermocouple

***Bi—Ni—Co—Pd—Pt —U —Cu—Mn —Ti—Hg—Pb—Sn—Cr—Mo—Rh—Ir —Au—Ag Zn— W— Cd—Fe—As— Sb—Te.***

The Seebeck e.m.f. arises from the fact that the density of free electrons in a metal differs from one metal to another and, in the same metal, depends on temperature. When two different metals are joined and two junctions are kept at different temperatures, electron diffusions at the junctions take place at different rates. There is a net motion of the electrons, as though the electrons were driven by non-electrostatic field. Energy expended in the current flow is supplied by the absorption of heat from the external source.

A complementary phenomenon to Seebeck effect was discovered by Jean C.A. Peltier in 1834 which is known as ***Peltier effect***. He observed that at constant temperature when current is passed across a junction of two different metals heating or cooling of the junction takes place depending on the direction of the flow of the current and the quantity of Peltier heat is proportional to the charge which crosses the junction, In Fig. 2 when-Current flows in junction from bismuth (Bi) to antimony (Sb), heat is absorbed in the junction which is, therefore, cooled, but on reversing the direction of the current heat is evolved, and the junction is heated. The Peltier e.m.f. of a junction of metals A and B, $\pi_{AB}$ is defined as the heat absorbed or liberated per unit of electricity crossing the junction. Thus

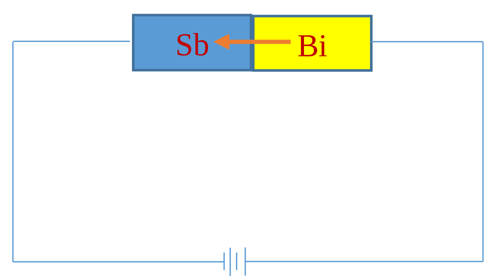


Fig. 2

$$\pi_{AB} = \frac{\text{Peltier heat}}{\text{Charge transferred}} \qquad (1)$$

$\pi_{AB}$ depends on the nature of the two metals and also on the temperature of the junction, but is independent of any other junction that may be present.



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## Laws of addition of thermal electromotive forces:

In measuring thermo e.m.f, it is always necessary to insert some apparatus Li the circuit. This introduces some addition of junctions of different metals in the circuit and it is, therefore, important to define the laws of addition of this extra junctions in the same circuit. There are two such laws:

**(1) Law of Intermediate Metals:** The presence of an additional metal into any Circuit does not alter the whole e.m.f. in the circuit, provided the additional metal is at the same temperature of the point at which it is inserted.

**(2) Law of Intermediate Temperatures**: The e.m.f. of a couple with junctions at $T_1$ and T3 is the sum of the e.m.f. of two couples of the same metals, one with junctions at $T_1$ and $T_2$ and other at $T_2$ and $T_3$ as shown in Fig. 3. In other words, e.m.f.

$$[e]_1^3 = [e]_1^2 + [e]_2^3 \tag{2}$$

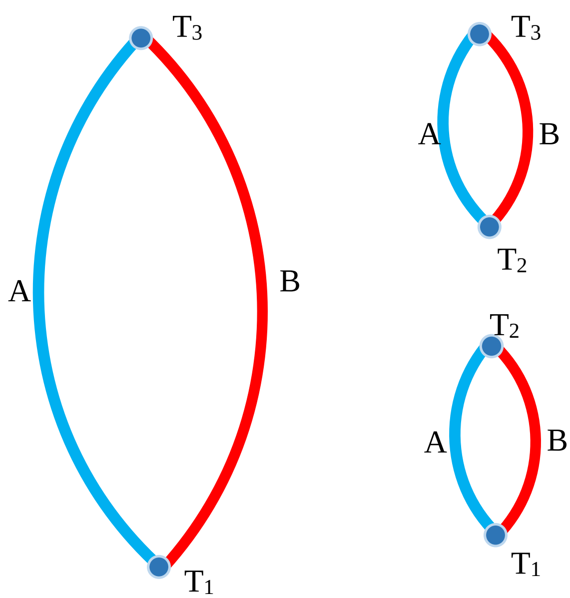


Fig. 3

## Thomson coefficient

From Eq. (1) we know that on carrying a charge q round the circuit the heat absorbed at hot junction at $T_2$ is $\pi_2$q, measured in absolute units, and that given up at $T_1$ is $\pi_1$q. Now the heat absorbed or given up is proportional to the temperature of the junction. Hence



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$$\frac{\pi_2 \mathrm{q}}{\pi_1 \mathrm{q}} = \frac{T_2}{T_1}$$

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

and, therefor

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

Putting $\pi_2 - \pi_1 = e$ (total e.m.f. in the circuit)

$$e = \pi_1 \left( \frac{T_2 - T_1}{T_1} \right) \tag{3}$$

If one junction is kept at constant temperature T$_1$, then $\pi_1$ is constant and, therefore, $e \propto (T_2 - T_1)$. But in actual practice it was found that as a result of licating a junction of two different metals the e.m.f. increased at first, then diminished, and, passing through zero, actually became reversed. Obviously, it indicates that e is not proportional to T$_2$ - T$_1$, This led Lord Kelvin (Prof. Wm. Thomson) to the conclusion that along with Peltier effect there is another source of e.m.f. - existing between the different parts of a metal at different temperatures. Thus if $\sigma$ be the e.m.f. due to unit difference of temperature between two points of it, then $\int_{T_1}^{T_2} \sigma dT$ is the total e.m.f. between points at temperatures T$_1$ and T$_2$. Taking $\sigma_A$ and $\sigma_B$ as the values of a for metal A and B respectively then, our equation of e.m.f. for the whole circuit becomes

$$e = \pi_2 - \pi_1 + \int_{T_1}^{T_2} (\sigma_B - \sigma_A) dT \tag{4}$$

The quantity $\sigma$ is called the Thomson co-efficient. If the current flows in the direction of e.m.f. heat is absorbed to maintain the current in the circuit. But if the direction of current is reversed, heat is liberated for a corresponding reason. The sign of $\sigma$ can, be positive or negative, $\sigma$ is positive for the metals Cd, Zn, Age. Cu and negative for Fe, Pt and Pd.

## Thermo-electric power:

Eq. (4) can be written in the following form

$$e = \pi_2 - \pi_1 + \int_{T_1}^{T_2} (\sigma_B - \sigma_A) dT \tag{5}$$



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$\frac{d\pi}{dT}$ is the rate of change of Peltier co-efficient with temperature for two metals $\pi_2$ and $\pi_1$ are the upper and lower limits of integral $\int \frac{d\pi}{dT} dT$. Again, Eq. (5) can be written as

$$e = \int_1^2 \left\{\frac{d\pi}{dT} - (\sigma_A - \sigma_B)\right\} dT \quad (6)$$

Differentiating with respect to T, we get

$$\frac{de}{dT} = \frac{d\pi}{dT} - (\sigma_A - \sigma_B)$$

$\frac{de}{dT}$ is called thermo-electric power for two metals. This is the rate of change of e.m.f. in the couple with the change of temperature in one junction. The thermo-electric power $\frac{de}{dT}$ has plotted against temperature T as shown in Fig. 4. In this diagram the elementary area PQ gives the e.m.f. acting round the couple, temperature difference being dT. Total electro-motive force in the couple is the sum of the elementary areas such as PQ and this is the area of the whole figure ABCD for temperature difference $T_2 - T_1$.

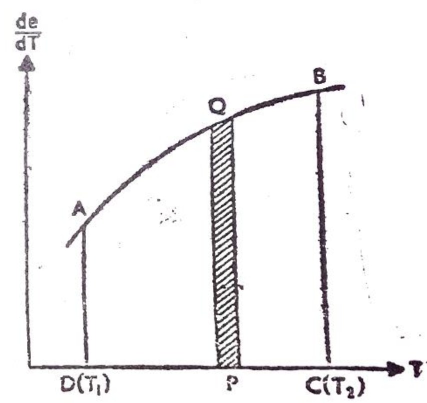
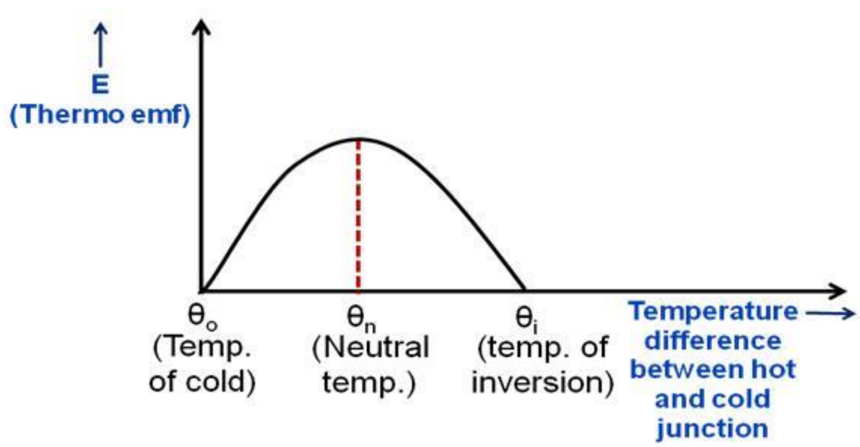



Fig. 4

## Neutral Temperature and Temperature of Inversion

If we increase the temperature of the hot junction of a thermocouple keeping the temperature of the cold junction constant, the thermo emf will increase with the temperature. The thermo emf rises to a maximum at a temperature ($\theta n$) called **neutral temperature**.

Again if we further increase the temperature then the emf gradually decreases and eventually becomes zero at a particular temperature ($\theta i$) called **temperature of inversion**.



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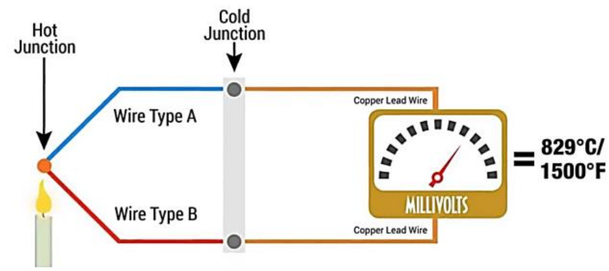
**<u>Home work:</u> The emf of a thermocouple, one junction of which is kept at $\mathbf{0}$ ℃ is given by $\boldsymbol{E = 1784\, t - 2.4\, t^2}$. Find the neutral temperature.**
**Hints: at neutral temperature, the slope ( dE/dt) is zero.**

## Application of Thermal Electromotive Force:

### (1) Thermocouple:




Thermo e.m.f. produced in a thermocouple can be used for measuring the amount of radiant heat. One of these measuring devices is a thermocouple. As the effect produced in one couple is very low, a number of them is arranged in series to multiply the effect. A more sensitive device is Boy's radio-micrometer. The galvanometer and the couple are combined in one instrument. The loop connected to an antimony-bismuth couple hangs in between the poles of a horse-shoe magnet. When current flows in the loop due to heating of the thermocouple junction there will be deflection of the loop. The magnitude of the deflection gives indication about the amount of heat.

### (2) Pyro-electricity:

Certain crystals, especially tourmaline, if heated at one end becomes positively charged and the other negatively charged but on being cooled the polarity changes. Heating or cooling can be done with reference to atmospheric or any other temperature. This phenomenon is known as Pyro-electricity. If the crystals are broken up, each part exhibits pyro-electricity. If heating or cooling is done to tourmaline powder, the particles arrange themselves in chains, owing to the polar charges, just as iron filings do when magnetized. Boracite, quartz and fluor are among the pyro-electric materials.

### (3) Piezo-electricity

It is discovered by J. Curie and P. Curie that if the crystals which exhibit pyro-electricity are t3ubj-2cted to compression or tension, opposite charges of electricity appear at ends of the crystals. This phenomenon is known as Piezo-electricity. The sign of the charges produced at the end of the crystal under compression is similar to those produced by cooling the crystal, while tension produces the charges with -similar sign as those produced by heating the crystal.

## Practical Thermocouple

1. Type K Thermocouple (Nickel-Chromium / Nickel-Alumel): The type K is the most common type of thermocouple. It's inexpensive, accurate, reliable, and has a wide temperature range.

   Temperature Range:
   Thermocouple grade wire, –454 to 2,300F (–270 to 1260C)
   Extension wire, 32 to 392F (0 to 200C)

Accuracy (whichever is greater):

- Standard: +/- 2.2C or +/- .75%
- Special Limits of Error: +/- 1.1C or 0.4%

2. Type J Thermocouple (Iron/Constantan): The type J is also very common. It has a smaller temperature range and a shorter lifespan at higher temperatures than the Type K. It is equivalent to the Type K in terms of expense and reliability.

   Temperature Range:

- Thermocouple grade wire, -346 to 1,400F (-210 to 760C)
- Extension wire, 32 to 392F (0 to 200C)

Accuracy (whichever is greater):

- Standard: +/- 2.2C or +/- .75%
- Special Limits of Error: +/- 1.1C or 0.4%

3. Type T Thermocouple (Copper/Constantan): The Type T is a very stable thermocouple and is often used in extremely low temperature applications such as cryogenics or ultra-low freezers.

   Temperature Range:

- Thermocouple grade wire, -454 to 700F (-270 to 370C)
- Extension wire, 32 to 392F (0 to 200C)

Accuracy (whichever is greater):

- Standard: +/- 1.0C or +/- .75%
- Special Limits of Error: +/- 0.5C or 0.4%

4. Type E Thermocouple (Nickel-Chromium/Constantan): The Type E has a stronger signal & higher accuracy than the Type K or Type J at moderate temperature ranges of 1,000F and lower. See temperature chart (linked) for details.

   Temperature Range:

- Thermocouple grade wire, -454 to 1600F (-270 to 870C)
- Extension wire, 32 to 392F (0 to 200C)

Accuracy (whichever is greater):

- Standard: +/- 1.7C or +/- 0.5%

- Special Limits of Error: +/- 1.0C or 0.4%

5. Type N Thermocouple (Nicrosil / Nisil): The Type N shares the same accuracy and temperature limits as the Type K. The type N is slightly more expensive.

   Temperature Range:

- Thermocouple grade wire, -454 to 2300F (-270 to 392C)
- Extension wire, 32 to 392F (0 to 200C)

Accuracy (whichever is greater):

- Standard: +/- 2.2C or +/- .75%
- Special Limits of Error: +/- 1.1C or 0.4%

NOBLE METAL THERMOCOUPLES (Type S,R, & B):
Noble Metal Thermocouples are selected for their ability to withstand extremely high temperatures while maintaining their accuracy and lifespan. They are considerably more expensive than Base Metal Thermocouples.

6
Type S Thermocouple (Platinum Rhodium - 10% / Platinum): The Type S is used in very high temperature applications. It is commonly found in the BioTech and Pharmaceutical industries. It is sometimes used in lower temperature applications because of its high accuracy and stability.

Temperature Range:

- Thermocouple grade wire, -58 to 2700F (-50 to 1480C)
- Extension wire, 32 to 392F (0 to 200C)

Accuracy (whichever is greater):

- Standard: +/- 1.5C or +/- .25%
- Special Limits of Error: +/- 0.6C or 0.1%

6. Type R Thermocouple (Platinum Rhodium -13% / Platinum): The Type R is used in very high temperature applications. It has a higher percentage of Rhodium than the Type S, which makes it more expensive. The Type R is very similar to the Type S in terms of performance. It is sometimes used in lower temperature applications because of its high accuracy and stability.

   Temperature Range:

- Thermocouple grade wire, -58 to 2700F (-50 to 1480C)
- Extension wire, 32 to 392F (0 to 200C)

Accuracy (whichever is greater):

- Standard: +/- 1.5C or +/- .25%
- Special Limits of Error: +/- 0.6C or 0.1%

7. Type B Thermocouple (Platinum Rhodium – 30% / Platinum Rhodium – 6%): The Type B thermocouple is used in extremely high temperature applications. It has the highest temperature limit of all of the thermocouples listed above. It maintains a high level of accuracy and stability at very high temperatures.

   Temperature Range:

- Thermocouple grade wire, 32 to 3100F (0 to 1700C)
- Extension wire, 32 to 212F (0 to 100C)

Accuracy (whichever is greater):

- Standard: +/- 0.5%
- Special Limits of Error: +/- 0.25%

## Illumination Laws

i) Illumination is directly proportional to the luminous intensity of the source.

ii) Inverse square law – The illumination of a surface receiving its flux from a point source is inversely proportional to the square of the distance between the surface and the source.

iii) Lambert's cosine law – The illumination of a surface at any point is proportional to the cosine of the angle between the normal at the point and the direction of the luminous flux.

***Luminous intensity*** is a measure of the wavelength-weighted power emitted by a light source in a particular direction per unit solid angle, based on the luminosity function, a standardized model of the sensitivity of the human eye. The SI unit of luminous intensity is the candela (cd), an SI base unit

## Various Kinds of Lamps

1) Incandescent lamps.
2) Compact fluorescent lamps.
3) Halogen lamps.
4) Metal halide Lamps.

5) Light Emitting Diode.
6) Fluorescent tube.
7) Neon lamps.
8) High intensity discharge lamps.

**1) Incandescent lamps:**

Incandescent bulbs are standard bulbs and many people are quite familiar with these bulbs. These incandescent bulbs are available in a broad range of sizes and voltages. An incandescent bulb glows and produces heat when electricity passes through the tungsten filament present inside the bulb. The filament of this bulb is placed either in a mixture of nitrogen gas or in a vacuum. These bulbs are being gradually replaced by LEDs, fluorescent lamps, and other service based new technologies.


The reason for this is that when this bulb is switched on, the sudden flow of current, energy and heat penetrate the thin areas, which in turn heat up the filament; once the filament heats up, it tends to break and burns out the bulb. Incandescent bulbs can last for 700 – 1000 hours and can also be used with a dimmer. Incandescent bulbs generate steady heat, which is quite good for house hold applications. Luminous efficiency of incandescent lamp is about 15 lumens per watt.

**2) Compact Fluorescent Lamps**

A compact fluorescent lamp is a modern type of light bulb that works like a fluorescent lamp. It contains mercury, which cause difficulties to its disposal. A CFL is designed to replace an Incandescent lamp. Generally, CFLs use less power, produce same amount of light and have long lifespan. Most of the compact fluorescent lamps consist of two or three tubular loops. Sometimes they even look quite similar to incandescent bulbs. These lamps cannot be used with dimmers, and usually they can last for 10,000 hours. Luminous efficiency of a compact fluorescent lamp is about 60 lumens per watt.



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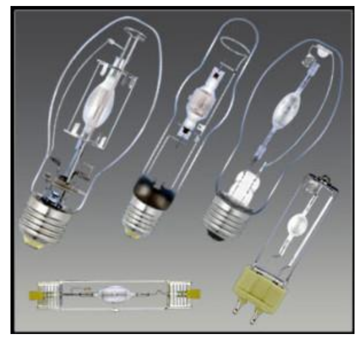
### 3) Halogen Lamps

A halogen lamp consists of a tungsten filament, which is sealed with a compact transparent envelop and filled with an inert gas and small amount of halogen (bromine or iodine). These lamps are smaller than the conventional lamps. Halogen increases the lifetime and brightness of the lamps. Luminous efficiency of a halogen lamp is about 25 lumens per watt.

### 4) Metal Halide Lamps

Metal halide lamps consist of a discharge tube or arc tube within a bulb. This tube can be made from either ceramic or quartz and contains mercury, Metal Halide salts and a starting gas. Metal halide lamps produce a great amount of light for their size, and these lamps are one of the most efficient lamps. These lamps are most commonly used in halls, traffic lights, on stages and in outdoor lighting systems for commercial purposes



### 5) Light Emitting Diode

LED lamp is an electrical component that emits light through the movement of electrons in a semiconductor device. It lacks a filament, uses less power and has a long lifespan. LEDs produce more light than incandescent lamps and help save energy in energy-conserving devices. LEDs are usually assembled into a light bulb to be used as a LED lighting system. These diodes can emit light of an intended color without the use of color filters. The initial cost of a LED is generally high and these are used to build electronic projects.

### 6) Fluorescent Tube

A fluorescent tube is a gas discharge tube that uses a fluorescence to produce visible light. Luminous efficiency of a fluorescent tube is about 45 to 100 lumens per watt. Compared with the incandescent bulbs, fluorescent tubes use less power for the same amount of light, and are usually more complex and expensive than the incandescent lamps. Fluorescent lamps do not have good color representation ability, but these tubes are cool in appearance and color. Fluorescent tubes can be used in many places around a home, but cannot be used with dimmers.



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### 7) Neon Lamps

A neon lamp is a gas-discharge lamp that contains gas at low pressure. It is assembled by mounting two electrodes within a small glass envelop. Standard brightness bulbs are filled with an argon or neon gas mixture, and high-brightness lamps are filled with a pure neon gas. When a voltage is applied, then the gas ionizes and starts to glow allowing a very small current to travel from one electrode to the other electrode. Once the gas ionizes, the operation of the lamp can be maintained at a lower voltage, and the maintaining voltage may vary between 10-20 volts depending on the lamp and operating current.

### 8) High Intensity Discharge Lamps

Metal halide, mercury vapor, self-ballasted-mercury lamps and high-pressure-sodium lamps all are high intensity discharge lamps. These lamps are specially designed with inner glass tubes that include tungsten electrodes with electrical arc. This inner glass tube is filled with both metals and gas. With the immunity of the self-ballasted lamps, auxiliary equipment (starters and ballasts) must be provided for proper operation of each bulb. These lamps produce a large quantity of light compared to the fluorescent and incandescent lamps. High-intensity-discharge lamps are normally used when high levels of light are required over large areas which include outdoor activity areas, gymnasiums, large public areas, pathways, roadways and parking lots.

### 9) Low Pressure Sodium Lamps

Low-pressure-sodium lamp is the first sodium lamp which has the maximum efficiency than all the other lighting systems. These lamps operate much like a fluorescent lamp and there is a brief heat up period for the lamp to reach full brightness. Low pressure sodium lamps are commonly used in places like roads, pathways, outdoor areas and parking lot wherein color is not important as such.



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