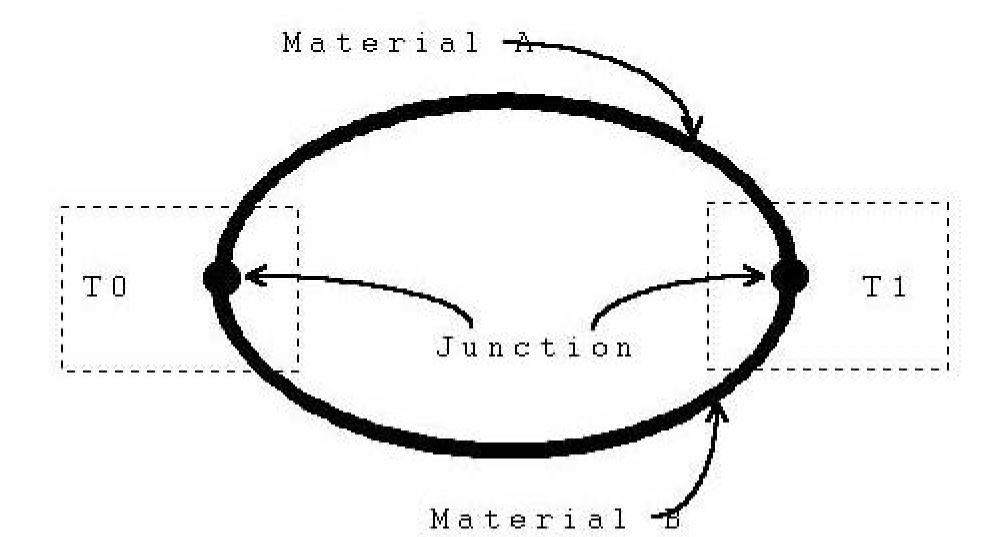
An intuitive introduction to three effects in thermoelectricity:

- The Seebeck effect
- the Peltier effect &
- the Thomson effect.

Usually, when some term involving "thermo" is involved, it invokes the name "thermodynamics" and the famous second law of thermodynamics (at least in me it does!) which basically states that there is no free lunch or in more formal terms, entropy always increases. Perhaps the most familiar phenomena which exemplifies irreversible processes is that known as Joule heating in which energy in the form of heat is lost through resistance proportionally to the square of the current This is commonly expressed in the formula:

$$P_{dissipated} = I^2 R$$

What's interesting is that there are phenomenon (like the 3 mentioned above) that are "reversible". Let me start by describing what I thought was the most curious of the three effects (and the "spark" that got me interested in this topic). Assume that we have 2 materials that are not the same and are not insulating materials. Essentially any two metals or semiconductors will work, even if the 2 materials are the same provided the second piece is strained to some extent, will work. If we were to from these into rods or wires so that we could connect them in a loop as shown:



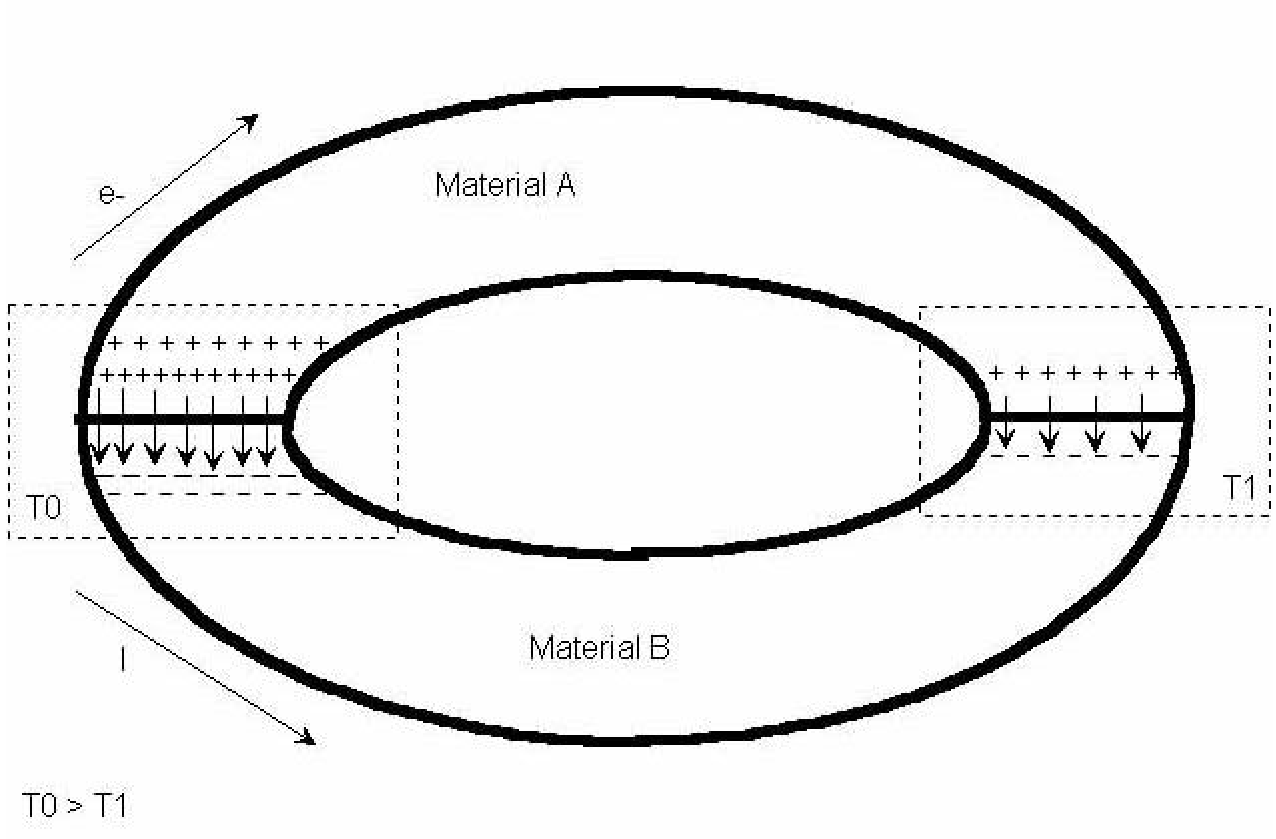
- **Fig. 1: Two materials(could be in the shape of wires) joined at their ends. The junctions are where the interesting things happen.**

and then somehow insert a battery in to the loop so that a current would form, one of the junctions would start to heat up and the other junction would start to cool down. OK, so doesn't seem like that big of a deal, the heating up can be accounted for by Joule heating like in a resistor and the cooling down can be accounted for by...well if it's not heating up it must be cooling down

right? Wrong! In fact even the heating up of one of the junctions has nothing to do with Joule heating(well, almost nothing. In reality, there is a loss and thus a heating up that is from Joule heating but it is not the dominant effect.). In fact the two effects are not related. Joule heating is proportional to the square of the current whereas Peltier heating (as it is known) is directly proportional to the current. What's even more amazing is that the cooling down of the opposite junction is not your "ordinary" cooling down by not heating up; it, in fact can very easily get cold enough to turn water into ice! Now how can that be? How can something that's normally thought of as hot (i.e. electricity, high voltage, electrocution, lightning, sparks...) cool something down that much? Hmmmm....good questions.

Now that I have your curiosity, let me elaborate. The effect I have just described is known as the Peltier effect after Jean Charles Athanase Peltier(1785 - 1845) who was a French watch maker turned physicist. Remember that I mentioned that this effect was reversible on the previous page. The converse of this effect is known as the Seebeck effect after Thomas Johann Seebeck (1770-1831), a German scientist. It is easier to understand if I explain these peculiar effects if I start with the Seebeck effect first.

The Seebeck effect is described as the "creation" of a current when 2 different conducting materials are joined in a loop such that the two junctions are maintained at different temperatures(T0 and T1 in Fig. 1 on the previous page). When you have two different materials you may assume that their respective free electron densities are different while they're both at the at the same temperature. A temperature difference merely gives the free electrons more kinetic energy to move around in. When you join the two materials the more energetic electrons from one material will migrate over to the other material in an attempt to establish a new equilibrium of the junction and balance out the charge difference. Naturally, this disturbs each of the two materials own individual equilibriums (that is, their equilibrium states before they were joined together). The disturbance as mentioned previously is caused by the migration of energetic free electrons which as a result leaves exposed positive charges on one side and an excess of negative charges on the other from the point of view of each material. As we've seen before, this causes an electric field to be formed across the junctions. Since the temperature determines how much more energetic the free electrons will be and their migration determines how many exposed positive and excess negative charges are on the two sides of the junction, it follows that the magnitude of the electric field is a function of the temperature. Since the setup of the 2 materials is in a loop, a current forms from the electric field and circulates the loop. At one junction where the electric field "goes along" with the direction of the generated current, the current has "an easy time" but at the other junction, the current must go against the electric field. (see fig. 2)



- **Fig. 2: A zoom-in on the "wires" of Fig.1. This shows the net charges after the respective electron densities in the two materials have reached equilibrium. The thing to note is that the electric fields point in the same general direction so that a current "goes with" one E-field and "goes against" the other.**

This design is not just any old design. The current, known as the Seebeck current has an "easy time" at the junction which is maintained at the higher temperature and thus absorbs heat in an effort to cool the junction down to the equilibrium temperature at which it is "comfortable". Likewise at the other junction, the Seebeck current has to go against the electric field thus having to do work and thus heating up the junction in an effort to bring the temperature up to the equilibrium temperature. In summary, the Seebeck current comes about to try to bring the system back to it's equilibrium conditions.

We saw how the Seebeck effect works but we still haven't answered the question of how one junction would heat up and the other cool down if they were at the same temperature to begin with and an artificial current was forced into the loop. Well, you can look at it this way, the introduction of an artificial current "tricks" the systems into thinking that the two junctions are at different temperatures and therefore the current was generated. The current's direction with respect to the Seebeck current determines which of the junctions will heat up and cool down. In other words, the current tries to do what it was originally designed to do, to cool down the hot junction and heat up the cool junction. But in this case, the junctions are already at their equilibrium temperatures so in effect the artificial current makes one junction hotter and hotter and the other cooler and cooler, thus the Peltier effect.

The Thomson effect is actually the same as the Seebeck and the Peltier effects except that it doesn't need two materials to make a junction and an electric field. Instead it depends on a temperature gradient which by itself causes an electric field which causes a current to flow to try

to nullify that gradient. So it is as if we were talking about the Seebeck effect where the two junctions were very close to each other.

While there isn't much practical application of the Thomson effect, the Seebeck and Peltier effects have been put to use in thermocouples which can be used to measure temperatures and air conditioning and refrigeration units. Power generation is feasible but due to the low efficiency of the thermoelectric effects this is not in widespread use. Overall, use has been limited to places where quick heat and refrigeration is needed and efficiency is not of utmost importance.

A brief list of Materials that have been experimented with for the Peltier Seebeck and Thomson effects:

- **ZnSb**
- **PbTe**
- **Bi2Te3**
- **PbSe**
- **Bi2Se3**
- **Sb2Te3**
- **MnTe**
- **GeTe**
- **III-V Compounds**

Bibliography

- **Blatt, Frank J. and Schroeder, Peter A and Foiles, Carl L. and Denis, Greg; Thermoelectric power of metals; 1976 Plenum Press**
- **Heikes, Robert R. and Ure Jr. Roland W.; Thermoelectricity: Science and Engineering; 1961 Interscience Publishers, Inc.**
- **MacDonald, D.K.C.; Thermoelectricity: an introduction to the principles; 1962 John Wiley & Sons, Inc.**
- **Ioffe, A.F.; Semiconductor Thermoelements and Thermoelectric Cooling; 1957 Infosearch Ltd.**
- **Pollack, Daniel D.; Thermoelectricity : theory - thermometry - tool 1985 ASTM**
- **The New Ilustrated Science and Invention Encyclopedia ; 1989 H.S. Stuttman Inc.**

Written by Felix Lu for presentation in ECE 135B Winter 1994 at the University of California at San Diego.
