Example C concerns the temperature within a film in a symmetric contact with metallic members. The film is assumed to be thick enough that the tunnel current through it is small. Let the voltage across the film be $2Y$ and across the mono-constriction, $U$ volt; cf. Eqs. (16.19 and 16.20). With $\varrho \lambda$ belonging to the metal, the supertemperature $\Theta_m$ in the contact surface between metal and film satisfies

$$
2 \int_0^{\Theta_m} \varrho \lambda d\Theta = (U + Y)^2 - Y^2 \quad (17.06)
$$

or

$$
\int_0^{\Theta_m} \varrho \lambda d\Theta = U Y \quad (17.07)
$$

if $U^2$ can be neglected against $2UY$. Eq. (17.07) gives $\Theta_m$.

The maximum supertemperature $\Theta - \Theta_m$ in the film above $\Theta_m$ of the metal is according to (13.06)

$$
\Theta - \Theta_m = \frac{Y^2}{2 (\varrho \lambda)_f} \quad (17.08)
$$

where $(\varrho \lambda)_f$ that belongs to the film, is of the order of $10^2$ with $\alpha > 1$. Even with a considerable $Y$, of for example $5$ V, $\Theta - \Theta_m$ is small. In other words, the film is practically isothermal up to high $Y$-values. This surprising conclusion results from the fact that the high value of $(\varrho \lambda)_f$ is based on a high $\varrho$ that keeps the current and $U$ very small; $\lambda$ is of the order of $1$ watt per m °K.

§ 18. The (equilibrium) temperature distribution in the constriction of a contact between two metals with different conductivities, both obeying Wiedemann-Franz law.

Thermoelectric effects

A. Features of the thermoelectric effects. Consider a current carrier that is moved from position (1) to another one (2) whereby the carrier in (1) was on an energy level higher than it meets in (2). To restore equilibrium it has to give off the surplus energy at (2). Thermoelectric effects are such energy transports.

It is relatively simple to explain both Peltier and Seebeck effects between semiconductors. Fig. (18.01) demonstrates features of a contact between semiconductors $B_1$ and $B_2$, where $B_1$ has a higher density of free electrons than $B_2$. In order to restore equilibrium (i.e., equal density on equal energy levels) the conducting band of $B_2$ is lifted so that $B_2$ assumes a higher negative potential than $B_1$. Such voltage
§ 18. The (equilibrium) temperature distribution in the constriction...

differences constitute the Seebeck effect; see below. Now let a current move electrons from \( B_2 \) to \( B_1 \). These electrons evidently belong to higher average niveau than the average niveau in \( B_1 \). In order to be adapted to the average level in \( B_1 \), they give off energy in the form of heat. In other words, the electric potential energy is converted into heat at the junction. An opposite current produces a corresponding cooling. This is the Peltier effect.

In the case of metals, the distribution of electrons on energy levels is of the Fermi type, which complicates the picture although the effects still resemble the description above. However, in metals, both Peltier and Seebeck effects are relatively weak because, owing to the degenerated partition\(^1\), the carriers change their average energy very little with the temperature.

It is evident from the foregoing that the Peltier and Seebeck effects are related to each other. The relationship shows up in the formulas (18.02) and (18.03) which refer to Fig. (18.04).

The conductors \( a \) and \( b \) of different materials constitute a circuit that contains a voltmeter \( v_b \). If the junctions are held at different temperatures \( T \) and \( T_1 \^\circ \text{K} \) with \( T > T_1 \), the voltmeter indicates a Seebeck voltage that may be written

\[
TE_{ba}(T) - T_1E_{ba}(T_1)
\]  

(18.02)

\( E_{ba} \) is a slowly varying function of \( T \) and is called the differential Seebeck coefficient. It is termed positive when \( E_{ba} \) is directed to move a positive current from the lower temperature \( T_1 \) to the higher temperature \( T \) in the conductor \( a \).

The Peltier heat at a junction having a temperature \( T \) has the amount

\[
|IT E_{ba}(T)| \text{ watt}
\]  

(18.03)

This junction is cooled when the Seebeck voltage \( TE_{ba}(T) \) tries to move its own current in the direction of the circuit current\(^2\) \( I \). With respect to the Peltier effect, \( TE_{ba}(T) \) is labeled \( \Pi_{ba}(T) \) the Peltier coefficient.

The Thomson effect appears when the carriers are moved along a temperature gradient within a conductor, if the distribution of carriers

\(^1\) See §II. \(^2\) I can come essentially from a battery, not sketched in Fig. (18.04).