CONSTRICTION THERMAL EFFECTS. When current is passed through a constriction or a-spot in an electrical contact system, the current causes joule heating (I^2R heating) in the tiny spot. To understand the manner in which this heating affects overall contact performance a classical *crossed-rod* experiment will be described, as pictured in Fig. l-8. Clean contact members will be assumed in order to eliminate some extraneous variables, and a mechanical load "P" will be applied .

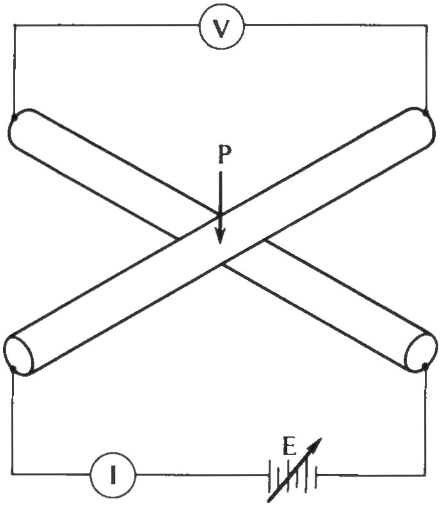

Fig. 1-8. Four wire crossed-rod experiment.

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The voltage V is measured across points where no current flows, which means that the voltmeter will measure the voltage drop across the constriction resistance alone, eliminating the drop across any bulk resistance of the members. This provides a means of calculating Rc from ohms law, vc = I Rc, as will be discussed later.

Thermal currents in the constriction follow the same paths as electrical currents. Also, the Wiedemann-Franz-Lorenz law establishes a relationship between electrical resistivity and thermal conductivity. Mathematical combination of the above two facts provides a distinct relationship between temperature in the constriction and voltage drop across a constriction, as follows:

$$V_c^2 = 4\,L\,(T_c^2 - T_o^2) \qquad \text{Eq. 1.10}$$

where V_c = Voltage drop across the constriction, volts
L = Lorenz constant, $\text{Volts}^2/{}^\circ\text{Kelvin}^2$,
$\cong 2.4 \times 10^{-8}\ \text{volts}^2/{}^\circ\text{Kelvin}^2$ for most metals
T_c = Temperature in a constriction, °Kelvin = °C + 273
T_o = Bulk temperature, °Kelvin = °C + 273

With temperature-voltage relationship now established, the behavior of R_c, the constriction resistance, can be explained. As current is increased and the temperature within the constriction increases due to I^2R heating, resistance would be expected to increase because of the metal's positive temperature coefficient of resistance, α. The original R_{co} at T tends to increase to a value of R_{ct} when its temperature is T_c, so that

$$\mathbf{R_{ct} = R_{co}\left[1 + \frac{2}{3}\,\alpha(T_c - T_o)\right]} \qquad \textbf{Eq. 1.11}$$

And this equation will be found to hold true *until* a temperature is reached at which softening of the metal starts to occur. If we were now to recalculate R_c from $V_c = IR_c$ we would find that the constriction resistance had *decreased* slightly from the value it had just before this softening occurred The joule heating in the asperity has raised the asperity temperature to such a value that the metal has softened.

We have already seen (Sec. 1.5) that constriction resistance is dependent on hardness. The softening means that the real contact area must increase in order to support whatever gram load has been applied. The voltage observed in the first region of resistance decrease is called the *softening* voltage. It is not a sharp, well defined voltage, but rather is a fairly narrow spread of voltages at which relaxation of the metal asperities occurs. In practice, however, it is assigned a single value.

A typical plot of constriction voltage drop versus Rc is shown in Fig. 1-9. The resistance decrease described is quite evident. Softening voltage values for Ney alloys and several unalloyed materials are given in Table 1-2.

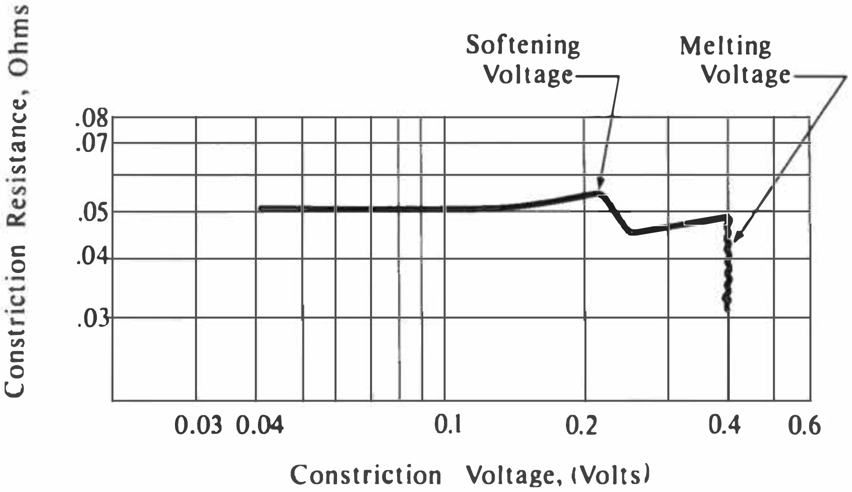

Fig. 1-9. Voltage across a constriction vs. resistance of the constriction.

Material*	Material Condition	Approximate Softening Voltage, Millivolts	Melting Voltage, Millivolts
Paliney® 6	Age Hardened	200	390
Paliney 7	Annealed	220	385
Paliney 7	Age Hardened	220	400
Paliney 8	Age Hardened	200	390
Paliney M	Work Hardened	180	460
Neyoro® G	Annealed	230	350
Neyoro G	Age Hardened	150	360
Neyoro 28	Work Hardened	90	370
Neyoro 28A	Work Hardened	100	340
Neyoro 28B	Work Hardened	100	340
Neyoro 69	Work Hardened	100	340
Neydium® 90	Work Hardened	50	290
24K Gold	Work Hardened	80	400
Silver	Work Hardened	90	370
Platinum	Work Hardened	250	710
Palladium	Work Hardened	—	570

Table 1-2. Softening and melting voltages for various contact materials

**Paliney, Neyoro and Neydium are registered tradenames of The J. M. Ney Company.*

It is important to realize that the temperature rise mentioned takes place primarily in the asperities and that bulk temperature of the contact members is not significantly changed from ambient conditions.

If current were increased well beyond that necessary to produce softening, it follows that I^2R heating can raise the temperature of a-spots to such an extent that melting occurs. The asperities collapse and increase their area to a size necessary to cause cooling. The voltage drop has reached a limiting value, which indicates that Rc has decreased abruptly. Any further increase in current will cause additional melting, refreezing and further decrease of Rc. See Table 1-2 for melting voltage values.

In the region between softening and melting the resistance assumes a gradually increasing value if long term stress relaxation properties of the materials are not allowed to influence the experiment.

Equation 1.10 is useful for calculating melting voltages of materials from the metallurgical properties of liquidus and solidus which often are known, whereas the cross-rod experiment may not be convenient. The value of $2.4 \text{ X } I0^{-8}$ for the Lorenz constant does not apply for iron, nickel, platinum or tungsten.