**Comment**

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# Comment: "Generalized formula for the electric tunnel effect between similar electrodes separated by a thin insulating film" [J. Appl. Phys. 34, 1793 (1963)]

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In Simmons 1963 paper,[1] he derives an expression for the tunneling current for a low-voltage approximation. An additional factor of $\frac{3}{2}$ is included in his expression that is not explained and appears to be incorrect. This article demonstrates that without the additional factor the correct results are obtained by comparison to the derivation of the intermediate-voltage range tunneling current.

In the original paper[1] by Simmons, he derives approximations for the tunneling current density between two metal electrodes separated by a thin insulating film. One of the approximations [Eq. (25) in Simmons[1]] is when the applied voltage bias across the electrodes is low (i.e., $V \approx 0$) and is reproduced here for clarity

$$J_{sim} = \frac{3(2m\phi_0)^{\frac{1}{2}}}{2s}\left(\frac{e}{h}\right)^2 V \exp\left[-\frac{4\pi s}{h}(2m\phi_0)^{\frac{1}{2}}\right]. \tag{1}$$

In this derivation, Simmons simply substitutes two values for the barrier width, $s$, and barrier height, $\phi_0$, into a previously derived equation [Eq. (24)]. However, the factor of $\frac{3}{2}$ appears without explanation and cannot be understood by the earlier equation. Furthermore, Simmons claims that his derivation is in agreement with the Sommerfeld-Bethe result;[2] however, their derivation [Eq. (21.13) in Sommerfeld-Bethe[2]] also does not contain the additional factor. Thus, Simmons derivation seems to be in error. The corrected expression is then

$$J_c = \frac{(2m\phi_0)^{\frac{1}{2}}}{s}\left(\frac{e}{h}\right)^2 V \exp\left[-\frac{4\pi s}{h}(2m\phi_0)^{\frac{1}{2}}\right]. \tag{2}$$

To verify this, the expression derived by Simmons for the intermediate voltage case [Eq. (27)] can be extrapolated to lower voltages and checked against the low-voltage approximation. Figure 1 demonstrates that at low voltages the intermediate-voltage approximation fails to reproduce the low-voltage approximation given by Eq. (1). However, when the factor of $\frac{3}{2}$ is not included, the intermediate-voltage approximation closely matches the low-voltage approximation at low voltages. These results were produced using an electrode separation of $s = 1$ nm and a mean barrier height of $\phi_0 = 2$ eV.

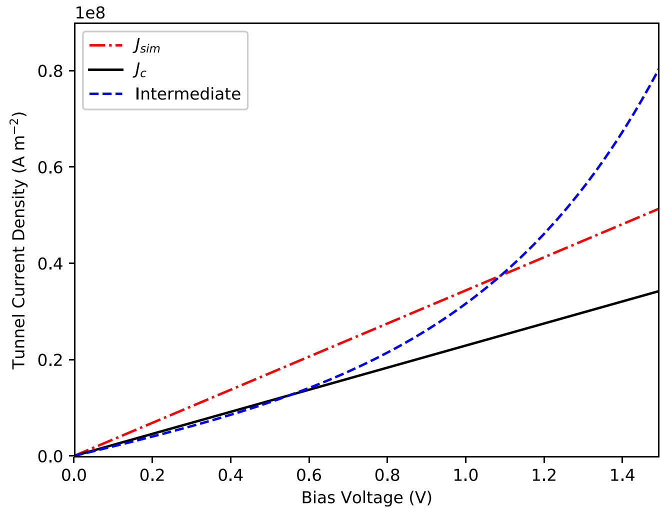


FIG. 1. Comparison between the approximations derived by Simmons in the low and intermediate voltage range, along with the Simmons approximation without the $\frac{3}{2}$ factor.

[1] J. G. Simmons, "Generalized formula for the electric tunnel effect between similar electrodes separated by a thin insulating film," J. Appl. Phys. **34**, 1793–1803 (1963).
[2] A. Sommerfeld and H. Bethe, "Elektronentheorie der metalle," in *Aufbau Der Zusammenhängenden Materie* (Springer Berlin Heidelberg, Berlin, Heidelberg, 1933), pp. 333–622.

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