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Comments on the presentation of field emission theory in the SLAC report

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This Poster forms part of a quiet campaign by the author to bring the theory of field electron emission (FE), as used in technological contexts, into a common form based on: (a) the "new" rules for writing scientific equations introduced as part of the 1970s reforms associated with the introduction of SI units; and (b) modern formulations [1,2] of the 1956 FE theory of Murphy and Good (MG) [3]. Murphy-Good FE theory is based on an underlying physical model—the "smooth planar metal-like emitter" (SPME) model" that disregards the effects of atomic-level structure and models the emitter as if it had a smooth planar surface of large lateral extent. Better models and formulations do now exist (e.g., [4]), but the author's view is that it will be easier for technological FE to move on to using a better underlying approach (if desired, in due course) if we first move to a common modern method of formulating and using MG FE theory.

As of 2021, the author's preferred method (in the context of modern MG theory) of writing an expression for the local emission current density J in terms of the local work function φ and the magnitude F of the local barrier field is

$J = \lambda a \varphi^{-1} F^2 \exp[-v(f) \cdot b \varphi^{3/2}/F]$, (1)

where a [≅ 1.541434 μA eV V^{-2}] and b [≅ 6.830890 $eV^{3/2}$ V nm^{-1}] are the Fowler-Nordheim constants. The exponent correction factor v(f) is a particular value of the principal field emission special mathematical function v(x) [5], and is obtained by setting x equal to the scaled field f (for a barrier of zero-field height equal to the local work function) given by

$f \equiv (e^3/4\pi\varepsilon_0)\ \varphi^{-2}F \cong (1.439965\ eV^2\ V^{-1}\ nm)\ \varphi^{-2}F = (1.439965\times10^{-9}\ eV^2\ V^{-1}\ m)\ \varphi^{-2}F$. (2)

An exact series expansion is now known for v(x), but many different algebraic approximations for v(x) have been used in the literature. Approximation (5) below was in fact suggested by Charbonnier and Martin in 1962 [6]. The pre-exponential correction factor λ formally takes into account physical effects disregarded in the SPME model, and is regarded as an "uncertainty factor", whose functional form and values are not currently known (and are unlikely to be accurately known for many years to come). In MG 1956 theory a correction factor that I would now write as $t^{-2}(f)$ appears instead of λ, but this difference between eq. (1) and the 1956 formulation is not of major interest for this Poster.

In a 1997 report [7] from the Stanford Linear Accelerator Centre, sometimes referred to as the "SLAC Report" and often cited, the following expression is given for local emission current density

(J =) $j_F = [1.54\times10^{-6}E^2/t^2(s)\ \varphi]\ \exp[-6.83\times10^9\ \varphi^{1.5}\ v(s)/E]$ (A/m^2) , (3)

where E is stated to be the surface electric field measured in V/m, φ is stated to be in eV, and

$s = 3.79\times10^{-5}\ E^{0.5}/\varphi$, (4)

$v(s) = 0.956 - 1.062\ s^2$. (5)

By substituting these into (3) and letting $t^2(s)\approx1$, the SLAC report derives (after some further algebraic manipulation) the "all-in-one" approximate formula

$j_F = [1.54\times10^{-6} \times 10^{(4.52/\sqrt{\varphi})}\ E^2/\varphi]\ \exp[-6.53\times10^9\ \varphi^{1.5}/E]$ (A/m^2) . (6)

This Poster will comment on the format differences between eq. (1) and the SLAC report equations, suggest that format (1) has advantages, and assess the accuracy of approximation (5).

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