Contribution ID: **43**

Type: **Virtual Poster**

A tutorial commentary on the Schottky constant

Thursday 11 March 2021 16:05 (20 minutes)

An electron within a piece of condensed matter is held into the material by a surface barrier. In simple basic models, the force preventing electron escape is attributed to an image attraction between the electron and the material surface. This gives rise to an energy barrier of zero-field height H that prevents classical escape. The application of a classical electrostatic field of appropriate polarity and magnitude lowers this barrier, and can reduce it to zero if the field magnitude is sufficiently large. Effects of this general kind were discussed by Kelvin and by Maxwell, in the context of conducting spheres. J. J. Thomson, when discussing (in his 1903 book [1]) electrical discharge effects between closely spaced planar surfaces, suggested that a barrier lowering effect of this kind might enable electron emission to cause the observed phenomena. However, relevant planar-geometry equations were first clearly formulated by Schottky in 1913 [2], and hence the effect is known as the (classical) Schottky effect.

Schottky's original treatment was in terms of "electric potentials", and used the Gaussian equation system. Modern treatments involve the component of electron total energy in the direction (z) normal to the material surface, and use the modern international equation system that has the vacuum electric permittivity ε_0 in Coulomb's Law [3]. For a good conductor, such as a metal, the energy barrier is described by an energy-like quantity M(z) given (for a planar surface) by

$M(z) = H - eFz - e^2/16\pi\varepsilon_0 z$, (1)

where e is the elementary positive charge and F is the magnitude of the linear field outside the planar conductor surface. (My term for M(z) is the motive energy.) This barrier is often now called the Schottky-Nordheim barrier. It can be shown that the maximum height of the barrier is lowered by an energy ΔS called the Schottky reduction (or Schottky lowering) and given by

$\Delta S = c\,F^{1/2}$, (2)

where c is a universal constant given by:

$c \equiv (e^3/4\pi\varepsilon_0)^{1/2} \simeq 1.199985\ \mathrm{eV\ V^{-1/2}\ nm^{1/2}} = 3.794686\times10^{-5}\ \mathrm{eV\ V^{-1/2}\ m^{1/2}}$. (3)

Clearly, the so-called zero-barrier field $F_0(H)$ needed to reduce a barrier of zero-field height H to zero, via the Schottky effect, is

$F_0(H) = c^{-2}H^2$. (4)

where $c^{-2} \simeq 0.6944615\ \mathrm{eV^{-2}\ V\ nm^{-1}} = 6.944615\times10^{8}\ \mathrm{eV^{-2}\ V\ m^{-1}}$. (5)

This universal constant c (alternatively denoted by c_S) has been called the Schottky constant. The numerical value of c (when fields are measured in V/cm) was first given by Schottky in 1914 (see eq. (6) in [2]), with the numerical value of c^{-2} given in his 1923 paper [4] (see Table 1, on p. 83).

Although the Schottky constant plays a central role in the theories of field electron emission, thermal electron emission and ionic field evaporation, particularly since the 1970s reforms in the international system of measurement, it is not widely recognised as a useful universal constant.

This Poster provides a brief "tutorial" introduction to the Schottky constant, primarily for those not familiar with it. It will include: a proof of equations (2) and (3); a demonstration of how the equations need to be modified when the escaping entity is an ion of charge ne (where the chargenumber n is a small integer); statements identifying the scientific contexts and equations in which the Schottky constant is most commonly used; and a demonstration that the Schottky constant is a "property of the world" that is represented by technically different physical quantities in different equation systems (strictly, what is discussed above is the "ISQ Schottky constant" [3]).

[1] J.J. Thomson, Conduction of Electricity through Gases (1st ed., Cambridge Univ. Press, 1903), see p. 386.
[2] W. Schottky, Physik. Zeitschr. 15, 872–878 (1914).
[3] Since 2009, the modern equation system that uses ε0 has been called the "International System of Quantities" (ISQ).
[4] W. Schottky, Z. Phys. 14, 63–106 (1923).

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Session Classification: Poster Session