Electrochemistry and Semiconductors Share One Constant, and It Is No Coincidence

— At 25 degrees Celsius the thermal voltage kT/q is 25.692579 mV, and the voltage needed to multiply the current by ten is $\ln 10$ times that, 59.159350 mV/decade — the separator is what divides the voltage inside the exponent — [Paper 704]

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September 2026

— From thinking to syncing. —

Abstract

A potential difference in solution and the voltage across a junction are taught as separate matters in separate fields. Yet the voltage needed to multiply the current by ten is 59 mV in both.Whether that is a coincidence is decided here by the criterion of Paper 300.No new theorem or law is claimed. First, the numbers agree——the 59.159350 mV/decade of a pn junction is the same number Paper 678 obtained in electrochemistry (Section 2). **Second, the agreement is not at one point——54.198814 mV/decade at 0 degrees, 66.104100 at 60, and even the ratio 1.219660** (Section 2). **Third, and this is the core. The agreement holds in the formulas, not only in the numbers——RT/F and kT/q are two ways of writing one quantity, and the two independent routes differ by only 9.392×10^{-10} mV** (Section 3). **Fourth, so by the criterion of Paper 300 they share a root——not merely agreeing numerically, both come from one source: the coefficient by which a Boltzmann factor converts energy into voltage** (Section 3). **Fifth, a third field carries the same number——the limit on the subthreshold slope of a MOSFET is also 59.159350 mV/decade** (Section 3). **Sixth, the separator is what divides the voltage inside the exponent——writing RT/F or kT/q is a choice of units, and the physical quantity doing the dividing is one** (Section 4). **Keywords**: thermal voltage, pn junction, Nernst slope, shared root, Boltzmann factor, a constant across fields.

Scope of this paper (scope note): **No new theorem or law is claimed——the diode equation, the thermal voltage and the limit on the subthreshold slope are all standard (Shockley 1949, Sze and Ng 2007).Semiconductor physics is not derived——minority-carrier injection and the derivation of the diode equation from diffusion currents are not treated; the exponential form is taken as given.Real devices are not treated——departures caused by an ideality factor or a series resistance are left out.The subthreshold limit is not derived——the 60 mV/decade wall of a MOSFET is mentioned and not derived.Only temperature is varied——differences of doping and material are not discussed.Relation to earlier papers**: **Paper 678 counted, on the electrochemical side, that a tenfold change in concentration moves the voltage by only 59.159350 mV, that the slope is 54.198814 mV/decade at 0 degrees and 66.104100 at 60, and that the ratio is 1.219660——this paper obtains the same numbers from the semiconductor side and shows that the two share a source**. **Paper 300 wrote that whether two things share a root is decidable, and set the criterion that numerical agreement alone does not establish a shared root——this paper applies that criterion to one case.**What is added is **obtaining the same slope independently from the semiconductor side**, **showing the agreement to hold at three temperatures**, **putting the difference between RT/F and kT/q at 9.392×10^{-10} mV**, **naming a third field carrying the same number**, and **placing the separator on what divides the voltage inside the exponent**.

1. Notation and the Question

Setting: **write the thermal voltage two ways: once from the gas constant and the Faraday constant, once from the Boltzmann constant and the elementary charge.**

$$\frac{RT}{F}, \qquad \frac{kT}{q}, \qquad s = \frac{kT}{q}\ln 10, \qquad I = I_s\left(e^{V/(kT/q)} - 1\right)$$

s is the voltage needed to multiply the current by ten.

Question: **is it a coincidence that the same 59 mV appears in electrochemistry and in semiconductors?**

2. The Agreement Is Not at One Point

Computation 2.1: **the thermal voltage and the slope per decade were derived at each temperature.**

temperature	thermal voltage	slope per decade
0 degrees Celsius	**23.538246** mV	**54.198814** mV/decade
25 degrees Celsius	**25.692579** mV	**59.159350** mV/decade
60 degrees Celsius	**28.708646** mV	**66.104100** mV/decade

The ratio between 0 and 60 degrees is 1.219660, matching the ratio of absolute temperatures $333.15/273.15$.

> **Observation 2.2**
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> these three numbers are exactly the table of Paper 678.Paper 678 obtained the same 54.198814, 59.159350 and 66.104100 mV/decade, and the same ratio 1.219660, between concentration and potential in solution——a different field, a different substance and a different instrument.

> **Observation 2.3**
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> an agreement at one point could be a coincidence.But all three temperatures agree, and so does the ratio——coincidence does not hit three points at once.

3. The Formulas Agree Too

Computation 3.1: the slope from RT/F is 59.159350 mV/decade and the slope from kT/q is 59.159350 mV/decade; the difference is 9.392×10^{-10} mV.

> **Observation 3.2**
>
> this is the core: the two are one quantity written differently.R is k times the Avogadro number and F is q times the same, so the Avogadro number cancels in the ratio——one counts by the mole and the other one particle at a time.

> **Observation 3.3**
>
> so by the criterion of Paper 300 they share a root.Paper 300 set the criterion that numerical agreement alone does not establish a shared root——here, beyond the numbers, the two formulas can be shown to come from one source, the coefficient by which a Boltzmann factor converts energy into voltage. The criterion is met.

Computation 3.4: in a diode the factor at $+0.5$ V is 2.829759×10^{8}, while at -0.5 V it saturates near -1, so the currents differ in magnitude by 2.829759×10^{8}.

Observation 3.5

rectification itself comes from the same coefficient.Half a volt is 19.460872 times the thermal voltage, and the exponential turns that into eight decades——“the current differs by orders with direction” is a restatement of 59 mV being small.

Observation 3.6

a third field carries the same number.In the subthreshold region of a MOSFET, the gate voltage needed to multiply the current by ten cannot fall below 59.159350 mV/decade——electrochemistry, the pn junction and the field effect share one coefficient.

4. The Separator

Observation 4.1

the separator is what divides the voltage inside the exponent.Writing RT/F or kT/q is only a choice between counting by the mole and counting one at a time——the physical quantity doing the dividing is one, and that is why different fields return the same number.

Observation 4.2

beside Papers 678 and 300.Paper 678 counted what this slope demands of measurement, within electrochemistry——there it was a matter inside one field; here the same slope crosses fields, and the decision Paper 300 set out is applied to an actual case.

Observation 4.3

what is not said.Semiconductor physics is not derived, and neither real-device departures nor the subthreshold limit are treated——what is shown is that three fields share one coefficient, and that the agreement is not a coincidence.

5. Roll Call and Closing

1. **thermal voltage 25.692579 mV** (Computation 2.1): **kT/q at 25 degrees.**
2. **slope 59.159350 mV/decade** (Computation 2.1): **the number of Paper 678.**
3. **54.198814 at 0 degrees** (Computation 2.1): **not one point.**
4. **66.104100 at 60 degrees** (Computation 2.1): **three of three agree.**
5. **ratio 1.219660** (Computation 2.1): **the ratio of absolute temperatures.**
6. **routes differ by 9.392×10^{-10} mV** (Computation 3.1): **the core.**
7. **the Avogadro number cancels** (Observation 3.2): **one quantity, two spellings.**
8. **rectification 2.829759×10^{8}** (Computation 3.4): **from the same coefficient.**
9. **the MOSFET limit is the same** (Observation 3.6): **a third field.**
10. **what divides the voltage** (Observation 4.1): **the separator; Papers 678 and 300.**

Closing: **Electrochemistry and semiconductors share one constant.The 59.159350 mV/decade that follows from a thermal voltage of 25.692579 mV is the number Paper 678 obtained in electrochemistry, and the agreement holds at 54.198814 mV/decade at 0 degrees, 66.104100 at 60, and in the ratio 1.219660——different fields, different substances, different instruments, and three points out of three.The agreement is not merely numerical: RT/F and kT/q are one quantity written differently, the Avogadro number cancelling between them, and the two independent routes differ by 9.392×10^{-10} mV——one counts by the mole, the other one particle at a time.So the criterion of Paper 300, that numerical agreement alone does not establish a shared root, is met.The same coefficient appears in a third field——the subthreshold slope of a MOSFET cannot fall below 59.159350 mV/decade.Even the rectification ratio 2.829759×10^{8} follows from half a volt being 19.460872 thermal voltages.The separator is what divides the voltage inside the exponent.Placed among the earlier papers——Paper 678 counted the slope within one field; here the same slope crosses fields and the decision of Paper 300 is applied.To be honest——semiconductor physics is not derived and real-device departures are not treated.**

References

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