

“Ten Degrees Halves the Life” Holds, Under the Arrhenius Law, Only in One Temperature Band for One Activation Energy

— with the activation energy fixed, the lifetime ratio per ten degrees shrinks as temperature rises, and the ratio is independent of temperature only when written as an exponential in temperature itself — the separator is whether the exponent is taken in inverse temperature or in temperature itself — [Paper 930]

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Abstract

For electronic components, the rule of thumb that “life halves for every ten degrees of temperature” is widely used. This paper counts the lifetime ratio per ten degrees under the Arrhenius law, where life depends exponentially on inverse temperature, for four activation energies and four temperature bands, and sets it beside the view that writes the exponential in temperature itself. No new theorem or law is claimed. First, with one activation energy fixed, the ten-degree ratio changes with the temperature band: at 0.7 eV it is 2.420937 for 25 → 35 degrees Celsius, 2.079348 for 55 → 65, 1.851651 for 85 → 95 and **1.648510** for 125 → 135, and for all four activation energies it shrank as temperature rose (Section 2). Second, the activation energy giving exactly a factor of two per ten degrees differs by band. It was **0.548776** eV for 25 → 35 degrees, 0.662796 eV for 55 → 65, 0.787568 eV for 85 → 95 and **0.970655** eV for 125 → 135 (Section 2). Third, stacking “ten degrees halves” misses by an order of magnitude: using 0.548776 eV, which doubles for 25 → 35 degrees, the lifetime ratio from 25 to 125 degrees is **213.7152**, about a fifth of the 1024 from halving ten times. Using the value that doubles for 85 → 95 degrees gives 2206.1160 (Section 3). Fourth, with the exponential in temperature itself, the ratio does not depend on temperature: under $Q_{10} = 2$, that is $Z = 33.219281$ degrees, the ratio is 2.000000 for every ten degrees and 1024.0 from 25 to 125 degrees (Section 3). Fifth, the separator is whether the exponent is taken in inverse temperature or in temperature itself: in the Arrhenius law, which takes it in inverse temperature, the same ten degrees makes a smaller difference in inverse temperature at higher temperature, so the ratio shrinks. Taken in temperature itself, the ratio is constant, and “ten degrees halves” is a rule of thumb of that form (Section 4). **Keywords:** Arrhenius law, activation energy, acceleration factor, temperature coefficient, component lifetime, Z value.

Scope of this paper (scope note): No new theorem or law is claimed: the Arrhenius law, obtaining acceleration factors from activation energies, and the Q_{10} and Z-value views are all known. Which law is right is not judged: whether component life follows the Arrhenius law or an exponential in temperature itself is not stated; it is only counted that the two forms give different ratios for the same ten degrees. Activation energies are set values: 0.3, 0.5, 0.7 and 1.0 eV are values for comparison, not those of particular components or failures. Failure mechanisms are not entered. What chemical or physical process sets the life is not treated. Relation to earlier papers: Paper 717 showed that, trading temperature for time in the Z-value view, the rate of exchange does not depend on absolute temperature. Here it is counted that writing the same exchange with the Arrhenius law makes the ratio shrink with absolute temperature. Paper 523 showed that even sharing the same exponential, the prefactor comes from three different roots. Here it is not the prefactor but the form of the exponent that is changed, and the effect on the ten-degree ratio is examined. Paper 457 showed that trading flavour for speed works only when two temperature coefficients differ. Here it is counted that even a single temperature coefficient takes different values across bands depending on how it is written. What is added: setting out the ten-degree ratio for four activation energies and four bands, finding for each band the activation energy that gives exactly a factor of two, finding the miss when the rule is stacked ten times, setting it beside the ratio with the exponential in temperature itself, and placing the separator on “the exponent in inverse temperature, or in temperature itself”.

1. Notation and the Question

Setting: when life follows the Arrhenius law, the ratio of lifetimes (the acceleration factor) on raising the absolute temperature from T_1 to T_2 is as follows. In the view writing the exponential in temperature itself, the ratio per ten degrees is a constant Q_{10} .

$$\text{AF} = \exp \left[\frac{E_a}{k_B} \left(\frac{1}{T_1} - \frac{1}{T_2} \right) \right], \quad \text{AF}_{Q_{10}} = Q_{10}^{(T_2 - T_1)/10}$$

The activation energy giving exactly a factor of two per ten degrees is $E_a = k_B \ln 2 / (1/T_1 - 1/T_2)$, and $Q_{10} = 2$ corresponds to a Z value of $10 / \log_{10} 2$ degrees. The check uses $k_B = 8.617333262 \times 10^{-5}$ eV/K.

Question: does “ten degrees halves the life” hold alike at every temperature?

2. The Ten-Degree Ratio Under the Arrhenius Law

Computation 2.1: lifetime ratio per ten degrees.

activation energy	25 → 35 C	55 → 65 C	85 → 95 C	125 → 135 C
0.3 eV	1.460711	1.368531	1.302171	1.238909
0.5 eV	1.880502	1.686906	1.552793	1.429109
0.7 eV	2.420937	2.079348	1.851651	1.648510
1.0 eV	3.536289	2.845651	2.411167	2.042353

Computation 2.2: the activation energy giving exactly two per ten degrees is 0.548776 eV for 25 → 35 degrees, 0.662796 eV for 55 → 65, 0.787568 eV for 85 → 95 and 0.970655 eV for 125 → 135, and with these values the ratio differed from 2 by at most 2.2×10^{-16} .

Observation 2.3

with one activation energy fixed, the ten-degree ratio shrinks as temperature rises. For all four activation energies the ratio was largest for 25 → 35 degrees and smallest for 125 → 135: to keep “two per ten degrees”, the activation energy would have to change by band from 0.548776 to 0.970655 eV.

3. The Miss When Stacked, and the Exponential in Temperature Itself

Computation 3.1: using 0.548776 eV, which doubles for 25 → 35 degrees, gives 1.620904 for 85 → 95 degrees, 1.479764 for 125 → 135, and a lifetime ratio of 213.7152 from 25 to 125 degrees. Using 0.787568 eV, which doubles for 85 → 95, gives 2.704075 for 25 → 35 and 2206.1160 from 25 to 125.

Computation 3.2: under $Q_{10} = 2$ ($Z = 33.219281$ degrees), the ratio was 2.000000 for every ten degrees and 1024.0 from 25 to 125 degrees.

Observation 3.3

stacking “ten degrees halves” ten times can miss the Arrhenius estimate by an order of magnitude. Against 1024, an activation energy fitted in the low band gives 213.7152, one fitted in the high band 2206.1160: the same hundred-degree extrapolation differs by more than tenfold depending on which band the rule was fitted in.

4. The Separator

Observation 4.1

the separator is whether the exponent is taken in inverse temperature or in temperature itself. The Arrhenius law takes the exponent in the difference of inverse temperatures, so the same ten degrees gives a smaller difference at higher temperature and the ratio shrinks: in the Q_{10} and Z-value views, which take the exponent in the difference of temperatures themselves, the ten-degree ratio is the same at every temperature. “Ten degrees halves” is a rule of thumb of that form.

Observation 4.2

what is not said. Which law component life follows, activation energies of real components, and failure mechanisms are not treated. What is shown is that the two forms give different ratios for the same ten degrees, and that under the Arrhenius law the ratio changes by band.

5. Roll Call and Closing

1. $AF = \exp[E_a/k_B \cdot (1/T_1 - 1/T_2)]$ (Section 1): **exponential in inverse temperature.**
2. at 0.7 eV, from 2.420937 to **1.648510** (Computation 2.1): **shrinks by band.**
3. activation energy for a factor of two, **0.548776 to 0.970655 eV** (Computation 2.2): **differs by band.**
4. 25 → 125 degrees: **213.7152 or 2206.1160** (Computation 3.1): **can miss the stacked 1024 by an order.**
5. $Q_{10} = 2$: 2.000000 for every ten degrees (Computation 3.2): **independent of temperature.**
6. inverse temperature, or temperature itself (Observation 4.1): **the separator; Papers 717, 523, 457.**

Closing: “Ten degrees halves the life” holds, under the Arrhenius law, only in one temperature band for one activation energy. With one activation energy fixed, the ten-degree ratio shrank as temperature rose, and the value giving exactly two moved from 0.548776 eV for 25 → 35 degrees to 0.970655 eV for 125 → 135: fitted in the low band, the lifetime ratio from 25 to 125 degrees was 213.7152, about a fifth of the 1024 from stacking ten times. The ratio is independent of temperature only when written as an exponential in temperature itself, as with Q_{10} or Z values: the separator is whether the exponent is taken in inverse temperature or in temperature itself. Placed among the earlier papers: the rate of exchange shown by Paper 717 to be temperature-independent in the Z-value view was rewritten with the Arrhenius law and counted as shrinking, and beside the prefactor of Paper 523 and the two

temperature coefficients of Paper 457, another dividing line, the form of the exponent, was set. To be honest, which a component follows is not said. On which form the rule of thumb stands, and no further.

References

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