

What the Waiting Is For Is Diffusion, Not Reaction

— One millimetre takes **2.7778** hours and a hundred takes **3.17** years — ten times the distance costs **100** times the time — and ten kelvin multiplies the reaction by **4.0553** while multiplying the diffusion by only **1.5220** —

[Paper 445]

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— *From thinking to syncing.* —

Abstract

Ageing is taken to be slow because the reaction is slow. This paper shows that sometimes what one waits for is transport—and that transport barely speeds up when heated. No new theorem or law is claimed. First, this is the core of the paper. The time for diffusion goes as the square of the distance: ten times the distance costs **100** times the time (Section 2). Second, one millimetre takes **2.7778** hours; a hundred takes **3.17** years (Section 2). Third, ten kelvin multiplies the reaction by **4.0553** (Section 3). Fourth, the same ten kelvin multiplies the diffusion by only **1.5220** (Section 3). Fifth, the ratio is **2.6645**, arising from the difference in activation energies (Section 3). Sixth, the separator is whether the reaction or the transport is rate-limiting (Section 4). **Keywords:** diffusion, diffusion-limited process, Fick's law, diffusion length, temperature dependence.

Scope of this paper (scope note): No new theorem or law is claimed—the diffusion equation, the square law for diffusion distance and Arrhenius temperature dependence are all standard. No particular food or material is discussed—how many days a given ageing takes in practice is not the subject. No diffusion coefficient is asserted— $10^{-10} \text{ m}^2/\text{s}$ is representative of a small molecule in water and moves by orders across systems. No activation energies are asserted—100 kJ/mol for reaction and 30 kJ/mol for diffusion are representative. What does not move is that diffusion's is the smaller. Convection is not treated—stirring or flow makes transport far faster than diffusion. Only a still system is treated. One dimension is fixed—spheres and cylinders change the coefficient, not the square law. Relation to earlier papers: Paper 444 showed that emulsifying only makes the slope gentler—there too time was the actor. Paper 300 showed that common root and distinct root can be decided—“the reaction is slow” and “arriving is slow” are distinct roots by that criterion. Paper 443 showed that the effect of temperature is not constant—there it varied within one reaction; here it differs between reaction and transport. Paper 425 showed that a delay leaves the amount and takes the certainty—here too two quantities do not move alike. What is added is giving the diffusion time at three distances, confirming the square law as a factor of 100, setting the temperature factors for reaction and diffusion side by side, giving their ratio as 2.6645, confirming by inversion that equal activation energies give equal factors, and placing the separator at “reaction or transport”.

1. Notation and the Question

Setting: In a system of diffusion coefficient D , the time to travel a distance L is roughly

$$t \sim \frac{L^2}{D}$$

Both reaction and diffusion have Arrhenius temperature dependence.

$$k(T) \propto \exp\left(-\frac{E_a}{RT}\right)$$

Below, $D = 10^{-10} \text{ m}^2/\text{s}$, $E_a = 100 \text{ kJ/mol}$ for reaction, 30 kJ/mol for diffusion, and $T_0 = 15$ degrees.

Observation 1.1

Ageing is taken to be slow because the reaction is slow. Things change gradually—so warming should speed it up.

Observation 1.2

But before molecules react they must meet. And meeting requires transport—two stages, and the slower one governs.

Question: Which is the slow one, and does warming speed both alike.

2. Ten Times the Distance, a Hundred Times the Time

Computation 2.1: Take the diffusion time at three distances.

Distance [mm]	Time [s]	In other units
1	1.0000×10^4	2.7778 hours
10	1.0000×10^6	11.5741 days
100	1.0000×10^8	3.17 years

Observation 2.2

Ten times the distance costs exactly **100** times the time. A square law—not linear, so intuition fails.

Observation 2.3

One millimetre takes **2.7778** hours. Slice it thin and it is done the same day—the other side of the boundary, where there is almost nothing to wait for.

Observation 2.4

A hundred millimetres takes **3.17** years. Left whole, one waits for years—the same material, the same reaction, the same temperature; only the shape differs.

Observation 2.5

So “large things take longer” is not about quantity. It takes time to reach the centre—cut it in half and the time falls to a quarter.

3. Warming Barely Speeds the Transport

Computation 3.1: Take the factor from raising 15 to 25 degrees, for reaction and for diffusion.

Process	Activation energy [kJ/mol]	Factor per ten kelvin
Reaction	100	4.0553
Diffusion	30	1.5220

Observation 3.2

The reaction quadruples. **4.0553**—strongly dependent on temperature.

Observation 3.3

The diffusion rises by half. **1.5220**—not even doubling.

Observation 3.4

The ratio is **2.6645**. It comes from the 70 kJ/mol difference in activation energies—and equal activation energies give equal factors, confirmed by inversion.

Observation 3.5

So if transport limits, warming barely shortens anything. Ten kelvin buys a factor of 1.5—3.17 years becomes 2.08.

Observation 3.6

Whereas if the reaction limits, ten kelvin quadruples the speed. Entirely different behaviour—which of the two limits decides whether warming is worth anything.

4. The Separator

The separator: is the reaction rate-limiting, or the transport.

Observation 4.1

If the reaction limits, changing the shape does nothing. Cut it or crush it, the same—the time is set by temperature.

Observation 4.2

If transport limits, changing the shape works. Half the thickness, a quarter of the time—the time is set by distance.

Observation 4.3

These are distinct roots by the criterion of Paper 300. Both are called “ageing takes time”—one a function of temperature, one of distance.

Observation 4.4

And there are two ways to tell them apart. Cut it, or warm it—if cutting speeds it, transport; if warming speeds it, reaction.

Observation 4.5

Stirring speeds the transport side at once. Convection is far faster than diffusion—so “does stirring change it” asks the same question.

Observation 4.6

To be honest— $D = 10^{-10} \text{ m}^2/\text{s}$ and both activation energies are representative. They move by orders across systems—what does not move is that diffusion’s activation energy is the smaller.

Observation 4.7

One last thing—only a still system has been treated. With flow, transport is far faster—the figure of 3.17 years is a consequence of choosing not to move it.

5. Roll Call and Closing

1. **2.7778 hours at 1 mm** (Computation 2.1): **done the same day.**
2. **11.5741 days at 10 mm** (Computation 2.1): **under a fortnight.**
3. **3.17 years at 100 mm** (Computation 2.1): **years of waiting.**
4. **Ten times gives a hundred** (Observation 2.2): **a square law.**
5. **Half the thickness, a quarter of the time** (Observation 2.5): **not about quantity.**
6. **Reaction: 4.0553 per ten kelvin** (Computation 3.1): **strongly dependent.**
7. **Diffusion: 1.5220** (Computation 3.1): **not even doubling.**
8. **The ratio is 2.6645** (Observation 3.4): **from the activation energies.**
9. **Transport-limited: 3.17 → 2.08 years** (Observation 3.5): **warming hardly helps.**
10. **The separator is reaction or transport** (Observation 4.3): **distinct roots by Paper 300.**

Closing: Ageing is taken to be slow because the reaction is slow, so warming should speed it up—but before molecules react they must meet, and meeting requires transport. There are two stages, and the slower one governs. The transport side goes as the square of the distance—one millimetre takes **2.7778** hours, ten takes **11.5741** days and a hundred takes **3.17** years, so ten times the distance costs exactly **100** times the time. It is not linear, so intuition fails. Sliced thin it is done the same day; left whole one waits for years—the same material, the same

reaction, the same temperature, only the shape differing. So “large things take longer” is not about quantity but about reaching the centre, and cutting it in half brings the time to a quarter. And warming barely speeds the transport—ten kelvin multiplies the reaction by **4.0553** and the diffusion by only **1.5220**, which does not even double it. The ratio is **2.6645**, arising from the 70 kJ/mol difference in activation energies, and equal activation energies give equal factors, as inversion confirms. If transport limits, ten kelvin takes 3.17 years only to 2.08; if the reaction limits, it quadruples the speed. Which of the two limits decides whether warming is worth anything. One thing separates them—is the reaction rate-limiting, or the transport. If the reaction limits, cutting or crushing does nothing and the time is set by temperature; if transport limits, half the thickness gives a quarter of the time and the time is set by distance. They are distinct roots by the criterion of Paper 300, one a function of temperature and one of distance. There are two ways to tell them apart—cut it or warm it—and if cutting speeds it, transport; if warming speeds it, reaction. Stirring speeds the transport side at once, since convection is far faster than diffusion, so “does stirring change it” asks the same question. To be honest— $D = 10^{-10} \text{ m}^2/\text{s}$ and both activation energies are representative and move by orders across systems. What does not move is that diffusion’s activation energy is the smaller. One last thing—only a still system has been treated. With flow, transport is far faster, and the figure of 3.17 years is a consequence of choosing not to move it.

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