FN-Merge-Oscillatio-EN-v0.1-2026-05-17

Research Note — Oscillation Everywhere

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1. Thesis

A pendulum, a guitar string, a radio resonant circuit and the stretching vibration of a CO molecule count as objects of different subjects. The tested baseline model M1 reads: *"Every oscillation needs its own theory. Pendulum, string, resonant circuit and molecular vibration are different phenomena with different laws; similarities are superficial."*

This module's claim: all four follow **the same differential equation**, and this is no coincidence. The harmonic oscillator is not one model among many but the **generic first approximation for every stable equilibrium**.

The module connects directly to M2 (ANALOGON). There the optical-mechanical analogy broke at the wavelength; here the classical description breaks at $\hbar$. In both cases the break is not the end of the analogy but the transition to the next theory.

2. Assumptions

1. Every system considered has a stable equilibrium.
2. The potential is expandable in a Taylor series about this equilibrium.
3. Restoring and inertial quantities are identifiable.
4. The displacement is small enough that the quadratic term dominates.
5. Damping and external driving are negligible.

3. Mathematical model

M1 — "own theory per oscillation": There is no common equation.

M2 — one formalism. A potential $V(x)$ with stable equilibrium at x_0: $$V(x) = V(x_0) + \underbrace{V'(x_0)}_{=\,0}\,(x-x_0) + \tfrac{1}{2}V''(x_0)(x-x_0)^2 + \dots$$ The linear term vanishes because x_0 is an equilibrium. The quadratic term yields a linear restoring force $F = -V''(x_0)\,(x-x_0)$ and hence $$\ddot{x} + \omega^2 x = 0, \qquad \omega = \sqrt{\frac{\text{restoring quantity}}{\text{inertial quantity}}}.$$

M3 — the limit. For the pendulum the error can be stated exactly: $$\frac{T}{T_0} = \frac{2}{\pi}\,K\!\left(\sin^2\tfrac{\theta_0}{2}\right) = 1 + \frac{\theta_0^2}{16} + \frac{11\,\theta_0^4}{3072} + \dots$$ with K the complete elliptic integral of the first kind.

M4 — quantised. The same potential quantum-mechanically gives $$E_n = \hbar\omega\left(n+\tfrac{1}{2}\right),$$ that is discrete energies and a zero-point energy $E_0 = \hbar\omega/2 \neq 0$.

Symbol	Meaning	Unit
ω	angular frequency	rad/s
θ_0	displacement angle	rad
K	elliptic integral 1st kind	—
E_n	energy level	J
$\hbar$	reduced Planck constant	J·s

4. Parameters

Scenario	Setup
A formalism	five systems: pendulum (1 m), spring-mass (10 N/m, 0.1 kg), string (440 Hz), LC circuit (1 MHz), CO stretching vibration (2143 cm^{-1})
B limit	displacements 1° to 179°, exact versus approximation
C quantum	the same systems quantised; CO at 300 K

Tolerance: $\varepsilon = 10^{-9}$ for the normalised deviation in A; otherwise $\varepsilon = 0$.

5. Prediction

Scenario	Expectation
A	normalised solutions coincide across many orders of magnitude
B	approximation breaks at large displacements, error calculable
C	discrete energies; classical limit for macroscopic systems

6. Falsification criterion

M1 is refuted as soon as physically different systems demonstrably follow the same equation and the commonality is explicable (not merely coincidental).

7. Competing models

- **K1 — own theory per oscillation (M1):** tested baseline.

- **K2 — coincidental similarity:** the same equation without deeper reason — refuted by the Taylor argument.
- **K3 — Taylor argument:** every stable equilibrium yields a quadratic potential to first order.
- **K4 — anharmonicity:** real systems deviate; the question is how much (scenario B).
- **K5 — quantisation:** the same formalism, different physics (scenario C).
- **K6 — quantum field theory:** every field mode is a harmonic oscillator — the furthest-reaching application.

8. Domain of failure

- **Only the one-dimensional, undamped oscillator.** Damping, external driving, resonance (Audio 04), nonlinearity, coupled oscillators and normal modes are absent.
- **The system values are typical orders of magnitude**, not measurements of a concrete setup.
- **The small-angle analysis holds for the mathematical pendulum.** A real pendulum has extended mass, air resistance and suspension friction.
- **Anharmonic effects are real and important.** Molecular vibrations are harmonic only near the ground state; dissociation is a purely anharmonic effect this model does not contain.
- **The quantum/classical comparison in scenario C is qualitative.** The probability distributions are juxtaposed, not the full time evolution.
- **The merge limit from M1 applies.** Shared mathematics does not mean shared nature: a string and a molecule are not “the same”.

9. Simulation

Numerical evaluation in `oscillatio_simulation.py`:

1. Scenario A: five systems, angular frequencies, periods; comparison of the normalised solutions; span in orders of magnitude.
2. Scenario B: exact pendulum period via the elliptic integral against the harmonic approximation and the series expansion; determination of the 1 % limit.
3. Scenario C: zero-point energies and quantum jumps; quantum number at typical energy; Boltzmann factor for CO at 300 K; probability distributions.

Results in `oscillatio_results.json`, plot as `oscillatio_szenen.svg`.

10. Result

10.1 A — one formalism

System	ω / (rad/s)	Period / s
pendulum (1 m)	3.132	2.006
spring-mass	10.00	0.628
string (440 Hz)	$2.765 \cdot 10^{3}$	$2.273 \cdot 10^{-3}$
LC circuit (1 MHz)	$6.283 \cdot 10^{6}$	$1.000 \cdot 10^{-6}$
CO molecule	$4.037 \cdot 10^{14}$	$1.557 \cdot 10^{-14}$

Span: $1.29\cdot10^{14}$, that is 14.1 orders of magnitude. Maximum deviation of the normalised solutions: $1.78\cdot10^{-15}$ (machine precision).

Assessment M1: refuted.

10.2 B — the small-angle limit

Displacement	T/T_0	Error of the approximation
5°	1.00048	0.048 %
10°	1.00191	0.191 %
20°	1.00767	0.767 %
23°	—	**1.0 % (limit)**
30°	1.01741	1.741 %
60°	1.07321	7.318 %
90°	1.18034	18.03 %
150°	1.76220	76.22 %

Assessment M1: refuted (the commonality is real and quantifiably bounded).

10.3 C — the quantum oscillator

System	E_0 / J	ΔE / eV	quantum number at typical energy
pendulum	$1.65\cdot10^{-34}$	$2.06\cdot10^{-15}$	$3.0\cdot10^{30}$
string 440 Hz	$1.46\cdot10^{-31}$	$1.82\cdot10^{-12}$	$3.4\cdot10^{24}$
LC 1 MHz	$3.31\cdot10^{-28}$	$4.14\cdot10^{-9}$	$1.5\cdot10^{15}$
CO molecule	$2.13\cdot10^{-20}$	0.266	$\Delta E/kT = 10.28$

Frozen-out degree of freedom (CO at 300 K):

Quantity	Value
$\Delta E / kT$	10.28
Boltzmann factor	$3.44\cdot10^{-5}$
fraction of excited molecules	**0.0034 %**

Assessment M1: refuted.

11. Assessment

M1 (“every oscillation needs its own theory”) is refuted in all three scenarios.

Scenario A shows more than an agreement — it shows why it cannot be one. Five systems with entirely different physics — gravity, spring force, string tension, electric field, chemical bond — follow the same differential equation. In normalised coordinates the solutions coincide at machine precision, across **14 orders of magnitude** in angular frequency.

The decisive point is not the numerical agreement but its reason. A potential can be expanded in a Taylor series about any stable equilibrium. The constant term is a choice of energy zero, the linear term **necessarily vanishes** (otherwise it would not be an equilibrium), so the quadratic term dominates. But a quadratic potential **always** yields a linear restoring force — and hence always the same equation.

It follows that the harmonic oscillator is not one model among many but the generic first approximation for every stable equilibrium whatsoever. This explains why the same mathematics carries from the pendulum clock to quantum field theory — and why the workshop strands mechanics, audio and quantum share the same core. Whoever understands the harmonic oscillator has not understood one phenomenon but the first approximation of all stable systems.

Scenario B makes the limit calculable rather than asserting it. A pendulum is not harmonic. The restoring force goes as $\sin\theta$, not θ; only the small-angle approximation makes it harmonic. How good this approximation is can be stated exactly — via the complete elliptic integral of the first kind.

The result is remarkably robust: up to **23°** the period error stays below 1 %. A pendulum clock with ±10° amplitude runs 0.19 % off — about 2.7 minutes per day, which explains historical clockmakers' effort to keep amplitude constant. At 90° it is 18 %, at 150° over 76 %.

This calculability is the difference between a load-bearing analogy and a figure of speech. "Everything oscillates alike" would be a phrase. "Everything oscillates alike as long as the displacement is small, and the error at 30° is exactly 1.74 %" is a statement. The merge rule requires precisely this (merge architecture, section 6): no analogy without calculation, and the limits belong in the write-up.

Scenario C yields the furthest-reaching finding — and it is historically tested. The same formalism, quantised, gives entirely different physics: discrete energies, a zero-point energy (the oscillator **never** comes to rest, whereas classically $E=0$ would be allowed), and a probability distribution **opposed** to the classical one. In the ground state the particle is most likely in the middle — classically it is fastest there and spends the least time.

For macroscopic systems the quantum nature is invisible: the pendulum sits at quantum number $n \approx 3\cdot10^{30}$, the steps are immeasurably fine. For the CO molecule this reverses — and here lies the most interesting point.

For CO at 300 K, $\Delta E/kT = 10.28$, the Boltzmann factor $3.4\cdot10^{-5}$: **only 0.0034 % of molecules are excited.** The vibration is frozen out and contributes almost nothing to the heat capacity.

This was an unsolved problem of classical physics. The equipartition theorem demands $kT/2$ per degree of freedom — a fixed contribution of every degree of freedom to the molar heat, independent of temperature. This was not what was measured: for diatomic gases the vibrational contribution was missing at room temperature, and the molar heat of solids fell off towards low temperatures. Maxwell called it one of the greatest difficulties of kinetic theory.

Einstein (1907) and Debye (1912) solved it with the quantised oscillator: if $\hbar\omega \gg kT$, the degree of freedom cannot be excited and drops out. Heat capacity becomes temperature-dependent. This was one of the earliest successes of quantum theory outside the radiation laws — and it rests on exactly the oscillator that classically describes the pendulum clock.

The connection to M2 is exactly parallel. There the optical-mechanical analogy broke at the wavelength, and the break led via de Broglie and Schrödinger to wave mechanics. Here the classical description breaks at $\hbar$, and the break led via Einstein and Debye to quantum statistics. **In both cases the domain of failure was the most productive part.** This is by now a pattern in the merge strand, not an isolated case.

12. Next test

L6 Gestalt Laws (GESTALT) to complete the perception strand, or the **quantum cluster (wishlist B)**, for which this module lays the groundwork: the quantised harmonic oscillator is the only exactly solvable potential of quantum mechanics and the basis of quantum field theory.

Possible extension v0.2: damping and resonance (connection to Audio 04); coupled oscillators and normal modes; anharmonic potentials (Morse potential, dissociation); parametric driving; the oscillator in quantum field theory.

Appendix A — Cross-references

- Practice explanation: `PRAXIS-Oscillatio-EN.md` · Companion paper: `BEGLEITPAPIER-Oscillatio-EN.md`
- Tool: `OSCILLATIO.html`
- Code: `oscillatio_simulation.py` · Plot: `oscillatio_szenen.svg` · Data: `oscillatio_results.json`
- **Modules used:** M2 optical mechanics (break pattern), M1 signal chain (merge rule), Mechanics 01/03, Audio 02/03/04, 01 double slit
- **Planning document:** `MERGE-ARCHITEKTUR-v0.1-2026-05-17.md`

Appendix B — External stocktaking

- **Einstein (1907)** — heat capacity with quantised oscillators.
- **Debye (1912)** — refinement for solids.
- **Feynman, *Lectures* I-21/23** — the oscillator as universal model.
- **Landau & Lifshitz, *Mechanics*** — small-angle approximation and anharmonicity.
- **Morse (1929)** — anharmonic molecular potential.

What the workshop note adds: the numerical verification of coincidence across 14 orders of magnitude; the exact determination of the small-angle limit instead of the usual rule of thumb; the connection of classical and quantised oscillator to the historical heat-capacity problem; the parallel to the break pattern from M2.

Appendix C — Sources

- Einstein, A. (1907). Die Plancksche Theorie der Strahlung und die Theorie der spezifischen Wärme. *Annalen der Physik* 327:180–190.
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- Feynman, R. P.; Leighton, R. B.; Sands, M. (1963). *The Feynman Lectures on Physics*, Vol. I. Addison-Wesley.
- Landau, L. D.; Lifshitz, E. M. (1976). *Mechanics*. 3rd ed., Butterworth-Heinemann.
- Morse, P. M. (1929). Diatomic molecules according to the wave

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