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

Research Note — Optical Mechanics

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1. Thesis

A light ray passing through glass and a stone flying through the air count as objects of different fields. The tested baseline model M1 accordingly reads: *"Optics and mechanics are separate fields. Light and matter follow different laws; the similarity of ray path and trajectory is superficial."*

This module's claim: both follow **the same variational calculus**. Fermat's principle (light takes the path of extremal optical path length) and Maupertuis' principle (a body takes the path of extremal action) are not similar but formally identical — with the correspondence refractive index ↔ momentum.

This module has a special feature. The merge rule requires documenting the **limits** of every analogy (merge architecture, section 6). Here the limit is not a restriction but the most valuable part: the analogy breaks at a particular point — and that break led historically to wave mechanics.

2. Assumptions

1. Both principles can be formulated as an extremal problem over the same path parameter.
2. Refractive index n and momentum p are the respective weighting quantities.
3. The extremal condition is numerically findable.
4. From the extremal condition a refraction law follows in both cases.
5. The velocity dependence of n and p is known and different.

3. Mathematical model

M1 — "separate fields": There is no common formulation; agreements are coincidental.

M2 — formal identity. Fermat’s principle: $$\delta \int n \, ds = 0.$$ Maupertuis’ principle (time-independent form of Hamilton’s principle): $$\delta \int p \, ds = 0.$$ The same structure with $n \leftrightarrow p$. From both, a refraction law follows at an interface: $$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad\text{resp.}\qquad p_1 \sin\theta_1 = p_2 \sin\theta_2.$$

M3 — the sign criterion. Here the analogy becomes testable. For light $n = c/v$, for a particle $p = mv$. Hence: $$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{v_1}{v_2} \qquad\text{versus}\qquad \frac{\sin\theta_1}{\sin\theta_2} = \frac{p_2}{p_1} = \frac{v_2}{v_1}.$$ **Exactly inverse.** Same path shape, opposite velocity change.

M4 — the break. Geometrical optics is the limit $\lambda \to 0$ of wave optics (eikonal approximation). If the analogy holds, classical mechanics must be the limit of a wave mechanics, with $$\lambda_{\text{dB}} = \frac{h}{p}.$$

Symbol	Meaning	Unit
n	refractive index	—
p	momentum	kg·m/s
S	eikonal / action function	— resp. J·s
λ_{dB}	de Broglie wavelength	m

4. Parameters

Scenario	Setup
A identity	interface at $x=0$; start $(-2,\,1.5)$, target $(2,\,-1.2)$; $n_1=p_1=1.0$, $n_2=p_2=1.5$; 20,001 sample points
B sign	air → water, $n=1.333$, angle of incidence 45°
C break	six cases from electron to human; two criteria (dominance, measurability)

Tolerance: $\varepsilon = 10^{-6}$ for the path difference in A; otherwise $\varepsilon = 0$.

5. Prediction

Scenario	Expectation
A	both principles yield the same extremal path
B	same path shape, inverse velocity predictions
C	transition classical/quantum where λ_{dB} is comparable to system size

6. Falsification criterion

M1 is refuted as soon as (a) both principles are demonstrably the same calculation, (b) the analogy yields a decidable prediction, or (c) a physical theory emerged from it.

7. Competing models

- **K1 — separate fields (M1):** tested baseline.
- **K2 — formal analogy without substance:** same mathematics but no physical meaning — refuted by scenarios B and C.
- **K3 — Hamilton's programme (1834):** the analogy as a systematic foundation of mechanics.
- **K4 — de Broglie's inference (1924):** taking the analogy seriously yields matter waves.
- **K5 — Schrödinger's route (1926):** the wave equation whose short-wave limit is Hamilton-Jacobi.
- **K6 — Newton's corpuscular theory:** light as classical particles — experimentally decided and refuted by scenario B.

8. Domain of failure

- **The correspondence holds for the time-independent form.** Maupertuis' principle presupposes energy conservation. Full Hamiltonian mechanics contains more: time dependence, phase space, canonical transformations.
- **n and p do not have the same dimension.** In scenario A equal numerical values are used to show the identity of the calculation. This is a mathematical, not a physical identification: n is dimensionless, p has a unit.
- **The analogy is not an identity of the objects.** Light and matter share a structure, not a nature. The merge limit from Module M1 applies here too.
- **Newton's corpuscles are not the photon.** Scenario B refutes classical light particles with $p = mv$. The photon has $p = h/\lambda$ and is thus no counterexample — the irony is treated in section 11.
- **The classical/quantum criterion is not a sharp threshold.** See the correction in section 11.
- **Not treated:** Lagrangian formalism in detail, Noether's theorem, relativistic generalisation, path integral (where the analogy finds its completed form).

9. Simulation

Numerical evaluation in `optmech_simulation.py`:

1. Scenario A: numerical minimisation of both functionals over 20,001 sample points; comparison of the extrema; back-calculation of the refraction law.
2. Scenario B: refraction angle from Snell's law; velocity predictions of both theories; factor between them.
3. Scenario C: de Broglie wavelengths for six cases; separate tests for dominance and measurability.

Results in `optmech_results.json`, plot as `optmech_szenen.svg`.

10. Result

10.1 A — formal identity

Quantity	Value
extremum optics (∫n ds)	$y = -0.2305$
extremum mechanics (∫p ds)	$y = -0.2305$
difference	**0.0**
Snell check $n_1\sin\theta_1$	0.654319
Snell check $n_2\sin\theta_2$	0.654303
deviation	$1.6\cdot10^{-5}$ (grid resolution)

Assessment M1: refuted.

10.2 B — the sign criterion

Air → water, angle of incidence 45°, refraction angle 32.04°:

Theory	v_2/v_1	Statement
wave theory	0.7502	**slower** in the denser medium
corpuscular theory (Newton)	1.3330	**faster** in the denser medium
factor between the predictions	**1.777**	

Foucault and Fizeau (1850): light in water is **slower**. Newton's corpuscular theory refuted.

Assessment M1: refuted.

10.3 C — the productive break

Case	λ_{dB}	λ/L	Regime
electron in atom (1 eV)	1.23 nm	12.3	wave mechanics needed
neutron (thermal)	0.18 nm	0.60	wave mechanics needed
electron in TEM (100 keV)	4.4 pm	0.044	wave mechanics needed
C60 (Arndt 1999)	**2.8 pm**	**$2.8\cdot10^{-5}$**	**classical dynamics, interference measurable**
dust grain (1 µg)	$6.6\cdot10^{-22}$ m	$6.6\cdot10^{-16}$	classical limit
human walking	$6.8\cdot10^{-36}$ m	$6.8\cdot10^{-36}$	classical limit

C60 in detail: diffraction angle $2.77\cdot10^{-5}$ rad, spread over 1.25 m flight path **34.6 µm** — measurable.

Assessment M1: refuted.

11. Assessment

M1 (“optics and mechanics are separate fields”) is refuted in all three scenarios — and the three refutations operate at ascending levels: formal, experimental, historical.

Scenario A shows identity, not similarity. Both principles yield the same extremal path at equal numerical values, with a difference of exactly zero. This is no numerical coincidence but the consequence of it being the same calculation: a functional of the form $\int f \, ds$ is made extremal, where f is called n in one case and p in the other. The back-calculation confirms a refraction law of the same form in both cases.

The correspondence reaches further than the refraction law: eikonal ↔ action function, wavefronts ↔ surfaces of constant action, light rays ↔ particle trajectories, eikonal equation ↔ Hamilton-Jacobi equation. This is not a catalogue of similarities but a continuous structural correspondence.

Scenario B shows that the analogy has teeth. A common objection to formal analogies is that they are mathematical curiosities without physical content (K2). Here this can be tested — and the finding is remarkable.

The analogy is precisely **not** trivial, because n and p depend **oppositely** on velocity: $n = c/v$ increases when v decreases; $p = mv$ decreases. Both pictures therefore predict the same path shape — but inverse velocity changes. For air → water at 45°: wave theory requires $v_2/v_1 = 0.75$, Newton’s corpuscles 1.33. A factor of 1.78 between the predictions, at an identical observed ray path.

This made the question decidable. For over a century and a half it could not be settled whether light is wave or particle, because both pictures explained the same refraction. Foucault and Fizeau measured the speed of light in water **directly** in 1850 — and found it slower. Newton’s corpuscular theory was thereby refuted. A formal analogy had delivered an *experimentum crucis*.

The irony belongs here: light today is both, wave and quantum. But Newton’s corpuscles were **classical** particles with $p = mv$, and those are refuted. The photon has $p = h/\lambda$ — a relation containing the wavelength and thus leading back to the wave description. Scenario B refutes not “light is particle-like” but “light consists of classical mass points”.

Scenario C shows where the analogy ends — and why that is the most important part. Geometrical optics is the limit $\lambda \to 0$ of wave optics. If the analogy is more than coincidence, classical mechanics must likewise be the limit of a wave theory whose wavelength becomes vanishingly small for macroscopic objects.

Hamilton formulated the analogy in 1834 without knowing of matter waves; it remained a mathematical curiosity for ninety years. **De Broglie (1924) took it seriously** and postulated $\lambda = h/p$. **Schrödinger (1926) took the final step** and sought the wave equation whose short-wave limit yields the Hamilton-Jacobi equation. The result was wave mechanics.

For the merge architecture this is a special case. The rule requires documenting the limits of every analogy so that the merge idea does not slide into arbitrariness. Here the **domain of failure is the most productive part**: the analogy fails exactly where wavelength becomes relevant, and this failure was the trail to quantum mechanics. A documented domain of failure is not merely a restriction — it can be the place where the next theory begins.

On the correction in scenario C. The first version used a single criterion, λ_{dB} relative to system size, with a threshold of 10^{-3}. This classified **C60 as a classical limit** — of all things the molecule with which Arndt et al. demonstrated matter-wave interference in 1999. The classification thus contradicted one of the best-known experiments in the field.

The error lay in the criterion itself. Two different questions must be distinguished: **dominance** (do quantum effects determine the dynamics?) and **measurability** (is interference detectable with a given apparatus?). For C60 the two come apart: at a grating period of 100 nm, $\lambda/L = 2.8\cdot10^{-5}$, so the dynamics are clearly classical — but the diffraction angle of $2.8\cdot10^{-5}$ rad yields a spread of 34.6 µm over a 1.25 m flight path, and that is measurable.

“Classical” is thus not a sharp threshold but depends on what one measures and how precisely. The error is documented here rather than silently fixed (workshop line); the correction sharpened the statement rather than merely repairing it.

12. Next test

Module M3 Oscillation Everywhere (OSCILLATIO) as the obvious continuation: the harmonic oscillator from pendulum through string and electromagnetic wave to the quantum oscillator — one formalism, five contexts, twenty orders of magnitude. Or **L6 Gestalt Laws**, which completes the perception strand.

Possible extension v0.2: Lagrangian formalism and Noether’s theorem; the path integral as the completed form of the analogy; relativistic generalisation; the brachistochrone as a shared example; gradient media (mirage) alongside the trajectory in a gravitational field.

Appendix A — Cross-references

- Practice explanation: `PRAXIS-OptMech-EN.md` · Companion paper: `BEGLEITPAPIER-OptMech-EN.md`
- Tool: `ANALOGON.html`
- Code: `optmech_simulation.py` · Plot: `optmech_szenen.svg` · Data: `optmech_results.json`
- **Modules used:** M1 signal chain (merge rule), 05 lenses, 06 prisms (refraction), Mechanics 01/03, 01 double slit (wave optics)
- **Planning document:** `MERGE-ARCHITEKTUR-v0.1-2026-05-17.md`

Appendix B — External stocktaking

- **Hamilton (1834/35)** — the optical-mechanical analogy.
- **Foucault (1850), Fizeau (1850)** — speed of light in water.
- **de Broglie (1924)** — matter waves.
- **Schrödinger (1926)** — wave mechanics from the analogy.
- **Arndt et al. (1999)** — interference of C60.
- **Goldstein, *Classical Mechanics*** — standard treatment of the analogy.

What the workshop note adds: the numerical verification of the identity rather than mere assertion; the sign criterion as a worked-through *experimentum crucis*; the separation of dominance and measurability at the classical/quantum transition; the framing of the domain of failure as a productive part of the analogy.

Appendix C — Sources

- Hamilton, W. R. (1834). On a General Method in Dynamics. *Phil. Trans. R. Soc.* 124:247–308.
- Foucault, L. (1850). Méthode générale pour mesurer la vitesse de la lumière. *Comptes Rendus* 30:551–560.
- de Broglie, L. (1924). *Recherches sur la théorie des quanta*. Dissertation, Paris.
- Schrödinger, E. (1926). Quantisierung als Eigenwertproblem. *Annalen der Physik* 384:361–376.
- Arndt, M. et al. (1999). Wave–particle duality of C60 molecules. *Nature* 401:680–682.
- Goldstein, H.; Poole, C.; Safko, J. (2002). *Classical Mechanics*. 3rd ed., Addison-Wesley.

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