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The Measurement Problem as Incompleteness

Why the update is not a collapse,
and why this program does not add one

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Companion to Shields 2026a, 2026b, and 2026c.
2026a and 2026b remain the program papers on Zenodo.
This paper does not replace them and is not deposited there.

Abstract. The textbook uses two maps. Between clicks the state vector moves by a unitary group generated by the Schrödinger equation. At a click it is replaced by an eigenvector, with weights given by Born's rule. The second map is not a special case of the first. This paper writes both maps on one spin, with every matrix, and proves the replacement cannot be unitary: a nontrivial projector is not invertible, changes the spectrum of a density operator, and raises the von Neumann entropy, while unitary conjugation does none of these. Including the apparatus in the vector does not help. Linearity keeps every term. Decoherence removes interference from a reduced state and does not select a term. The name collapse is the name of that extra map, treated as a physical process undergone by ψ. Einstein's 1949 demand reads the same split differently. The algorithm is not internally contradictory. It is incomplete as a description of one individual: it gives the probability that a mark is written in an interval, and it does not contain the instant. In the program of Shields 2026a there is nothing to collapse. The individual is a complete state S, not a ray. The mark is a threshold crossing of one solution of one law. Repeatability is the solution having passed the barrier. Frequencies are what remains when part of S is unread. No nuclear lifetime is computed here. The Bell record is not reopened.

1 Where this paper sits

Shields 2026c [11] exhibits the predictive algorithm symbol by symbol and sets it beside the Bell record. It shows that a repeatable measurement forces an update the Schrödinger equation [1] does not produce. It does not carry the algebra through to a proof that the update fails every structural test a unitary map must pass, and it does not say, in one place, why this program treats that failure as incompleteness rather than as a collapse to be added.

This paper does those two things. It assumes 2026c [11] for the Bell tables and does not repeat them. It assumes 2026a [10] for the axioms of an individual description. The only new claim is a reading, tied to the algebra: the measurement problem is the symptom that the vector is not the individual state. A second process is how an incomplete description is made to agree with a second look. It is not a process the individual undergoes.

Three sentences are the whole conclusion, and the body is the reason they are allowed.

1. There is no collapse in this program, because there is no individual object whose identity is the ray $|\psi\rangle$.
2. The measurement problem indicates incompleteness, because a complete law of one situation would not need a second map to write one mark.
3. Repeatability, which the update was invented to save, is in this program a fact about a solution that has crossed a threshold, not a postulate about a vector.

2 What is observed, before any vector

An ideal measurement of a two-outcome quantity prints one of two values. It does not print a weighted average. If the eigenvalues are $+1$ and -1, no run ends with the printer showing 0. A second measurement of the same quantity, made before anything else has time to act, agrees with the first. Those two sentences are the empirical content of the measurement problem. Everything else is a decision about what the algorithm's symbols are.

The algorithm meets the first sentence with Born's rule [2]: the number $\frac{1}{2}$ is a probability of a later click, not the click. It meets the second sentence by discarding, from the vector, every term that does not match the click. The discarding is the update. The question is whether the discarding is a law of the same kind as the equation that carried the terms up to the click.

3 The spin the algebra will use

The notation is Dirac's [14]. The space is $\mathbb{C}^2$. The basis vectors are

$$|\mathrm{up}\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \quad |\mathrm{down}\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}.$$

They are orthonormal: $\langle \mathrm{up} \,|\, \mathrm{up} \rangle = \langle \mathrm{down} \,|\, \mathrm{down} \rangle = 1$ and $\langle \mathrm{up} \,|\, \mathrm{down} \rangle = 0$.

The observable is the Pauli matrix

$$\sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}.$$

Its action is $\sigma_z|\mathrm{up}\rangle = +|\mathrm{up}\rangle$ and $\sigma_z|\mathrm{down}\rangle = -|\mathrm{down}\rangle$. The only numbers it is allowed to print are $+1$ and -1.

The projectors onto those outcomes are the outer products

$$P_{\mathrm{up}} = |\mathrm{up}\rangle\langle\mathrm{up}| = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}, \quad P_{\mathrm{down}} = |\mathrm{down}\rangle\langle\mathrm{down}| = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}.$$

They are self-adjoint, they are idempotent, and they resolve the identity:

$$P_{\mathrm{up}}^2 = P_{\mathrm{up}}, \quad P_{\mathrm{down}}^2 = P_{\mathrm{down}}, \quad P_{\mathrm{up}} + P_{\mathrm{down}} = I.$$

A short multiplication gives $P_{\mathrm{up}} P_{\mathrm{down}} = 0$. The two outcomes are exclusive.

The state used throughout, unless another is named, is the equal superposition along x,

$$|\psi\rangle = |{+\mathrm{x}}\rangle = \frac{1}{\sqrt{2}}(|\mathrm{up}\rangle + |\mathrm{down}\rangle) = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 1 \end{pmatrix}.$$

It is normalized: $\langle \psi \,|\, \psi \rangle = 1$. It is not an eigenvector of σ_z.

4 The Schrödinger equation on this spin

The equation is the one in Schrödinger's fourth communication [1],

$$i\hbar \frac{d}{dt}|\psi(t)\rangle = H|\psi(t)\rangle.$$

Take the Hamiltonian that measures nothing and only winds the relative phase,

$$H = \frac{\hbar\omega}{2}\sigma_z = \begin{pmatrix} \hbar\frac{\omega}{2} & 0 \\ 0 & -\hbar\frac{\omega}{2} \end{pmatrix},$$

with ω a real angular frequency. Because H is diagonal in this basis, the equation splits:

$$i\hbar\dot{c}_{\text{up}} = \Big(\hbar\frac{\omega}{2}\Big)c_{\text{up}}, \quad i\hbar\dot{c}_{\text{down}} = -\Big(\hbar\frac{\omega}{2}\Big)c_{\text{down}}.$$

Cancel $\hbar$, which is not zero, and integrate:

$$c_{\text{up}(t)} = c_{\text{up}(0)}e^{-i\omega\frac{t}{2}}, \quad c_{\text{down}(t)} = c_{\text{down}(0)}e^{+i\omega\frac{t}{2}}.$$

In one line,

$$|\psi(t)\rangle = U(t)|\psi(0)\rangle, \quad U(t) = \begin{pmatrix} e^{-i\omega\frac{t}{2}} & 0 \\ 0 & e^{+i\omega\frac{t}{2}} \end{pmatrix}.$$

$U(t)$ is unitary: $U^\dagger U = I$. Its eigenvalues lie on the unit circle. It is invertible, with inverse $U(-t)$. It is linear. It is deterministic: one vector in, one vector out. Applied to $|{+}\text{x}\rangle$ it returns

$$|\psi(t)\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} e^{-i\omega\frac{t}{2}} \\ e^{+i\omega\frac{t}{2}} \end{pmatrix}.$$

Both components have modulus $\frac{1}{\sqrt{2}}$ at every t. Neither component is deleted. The probability of each outcome of σ_z, computed in the next section, is $\frac{1}{2}$ at every t. The equation has moved the state and has not written a mark.

The same conclusion does not depend on this H. For any self-adjoint H, the solution operator $U(t) = \exp\big(-iH\frac{t}{\hbar}\big)$ is unitary, hence linear and invertible. A linear invertible map sends a superposition of two vectors to a superposition of the two images. It does not send a superposition to one of the two vectors and discard the other.

5 Born's rule, on the same vector

Born's rule [2] assigns a probability, not an outcome. For a nondegenerate eigenvalue a with projector P_a and a normalized vector,

$$P(a) = \langle\psi\,|\,P_a\psi\rangle = |\langle a\,|\,\psi\rangle|^2.$$

Here

$$\langle\text{up}\,|\,\psi\rangle = \frac{1}{\sqrt{2}}, \quad P(\text{up}) = \frac{1}{2}, \quad P(\text{down}) = \frac{1}{2}.$$

The expectation is the average of the eigenvalues against those probabilities, and it is also the sandwich:

$$\langle\sigma_z\rangle_\psi = \langle\psi|\sigma_z|\psi\rangle = 0,$$

which is $(+1)\big(\frac{1}{2}\big) + (-1)\big(\frac{1}{2}\big)$. The number 0 is not a click. A histogram of many runs, each started from a preparation the algorithm calls $|{+}\text{x}\rangle$, is predicted to split evenly between $+1$ and -1. One run is predicted to be one of the two, with no further instruction about which.

That is as much as Born's rule says. It does not say what vector to use for the next measurement on the same individual.

6 The update

von Neumann's projection postulate [3], in the form used for a discrete nondegenerate outcome a that has occurred, replaces the vector by the normalized image under the projector:

$$|\psi\rangle \longrightarrow |\psi_a\rangle = \frac{P_a|\psi\rangle}{|P_a|\psi\rangle|}.$$

For the outcome $+1$ on our state,

$$P_{\mathrm{up}}|\psi\rangle = \frac{1}{\sqrt{2}}|\mathrm{up}\rangle, \quad \big|P_{\mathrm{up}}|\psi\rangle\big| = \frac{1}{\sqrt{2}},$$

so

$$\big|\psi_{\mathrm{up}}\big\rangle = |\mathrm{up}\rangle.$$

A second measurement of σ_z now has

$$P(\mathrm{up}) = \langle \mathrm{up}\,|\,\mathrm{up}\rangle = 1.$$

The second look agrees with the first. If the replacement is not made, the second look is computed from $|\psi(t)\rangle$, and the probability of disagreement is still $\frac{1}{2}$. The algorithm without the update describes a second click we do not see. The algorithm with the update describes the second click we do see, and no longer has only the Schrödinger equation.

The map is undefined when $P_a|\psi\rangle = 0$, which is the case the rule has already assigned probability zero. On the states where it is defined, the denominator depends on $|\psi\rangle$. The map is not linear. Explicitly, it sends $|\mathrm{up}\rangle$ to $|\mathrm{up}\rangle$ and $|{+}\mathrm{x}\rangle$ to $|\mathrm{up}\rangle$, while

$$\frac{1}{\sqrt{2}}(|\mathrm{up}\rangle + |\mathrm{down}\rangle)$$

is $|{+}\mathrm{x}\rangle$ itself. A linear map that fixed both basis vectors would fix every vector. This map does not.

Lüders' form [4] for a degenerate outcome is the same formula with P_a the projector onto the whole eigenspace. Nothing below uses degeneracy. The obstruction is already visible for σ_z.

7 Proof that the update is not the Schrödinger equation

Four properties separate the maps. Any one of them is enough.

7.1 A projector is not unitary

$P_{\mathrm{up}} = \left(\begin{smallmatrix} 1 & 0 \\ 0 & 0 \end{smallmatrix}\right)$ has eigenvalues 1 and 0. A unitary operator has every eigenvalue of modulus 1. Therefore P_{up} is not unitary, and neither is P_{down}. The normalized update is not P_{up} itself, because of the denominator, but on the ray of $|\mathrm{up}\rangle$ it agrees with P_{up}, and on a vector with a down-component it agrees with P_{up} followed by rescaling. Rescaling does not turn an eigenvalue 0 into an eigenvalue on the circle. The image of the update, when the outcome is up, lies in a one-dimensional subspace. A unitary map on $\mathbb{C}^2$ has a two-dimensional image.

7.2 The update is not invertible

$U(t)$ can be run backward. The update cannot. Both $|\mathrm{up}\rangle$ and $|{+}\mathrm{x}\rangle$ are sent to $|\mathrm{up}\rangle$ when the outcome is up. The prior vector is not a function of the posterior vector. Information about the coefficient of $|\mathrm{down}\rangle$ is gone. Schrödinger evolution does not delete a coefficient.

7.3 The nonselective map changes the spectrum

If the outcome is not read, the textbook still writes a map on density operators, the average of the selective updates:

$$\rho \longrightarrow \sum_a P_a \rho P_a.$$

Our pure state has the density operator

$$\rho = |\psi\rangle\langle\psi| = \frac{1}{2}\begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}.$$

Its eigenvalues are 1 and 0, because it is a rank-one projector: $\rho^2 = \rho$ and $\operatorname{tr}(\rho) = 1$. Apply the nonselective map:

$$P_{\text{up}}\rho P_{\text{up}} = \frac{1}{2}|\text{up}\rangle\langle\text{up}|, \quad P_{\text{down}}\rho P_{\text{down}} = \frac{1}{2}|\text{down}\rangle\langle\text{down}|,$$

$$\sum_a P_a \rho P_a = \frac{1}{2} I = \frac{1}{2}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}.$$

The off-diagonal entries, which are the relative phase, are zero. The eigenvalues are $\frac{1}{2}$ and $\frac{1}{2}$.

Unitary conjugation preserves eigenvalues. If $\sigma = U\rho U^\dagger$, then σ and ρ have the same characteristic polynomial, because

$$\det(\sigma - \lambda I) = \det\big(U(\rho - \lambda I)U^\dagger\big) = \det(\rho - \lambda I).$$

The nonselective measurement map takes a spectrum $(1, 0)$ to a spectrum $\left(\frac{1}{2}, \frac{1}{2}\right)$. No unitary $U(t)$ does that. The Schrödinger equation, including an arbitrary self-adjoint H and an arbitrary duration, is always a unitary conjugation of ρ. It cannot be the nonselective map.

7.4 Entropy moves one way

The von Neumann entropy [3] is $S(\rho) = -\operatorname{tr}(\rho \log \rho)$, with the trace taken in any basis and with the convention $0 \log 0 = 0$. For a pure state the eigenvalues are 1 and 0, so $S(\rho) = 0$. For $\frac{1}{2}I$ the eigenvalues are $\frac{1}{2}$ and $\frac{1}{2}$, so

$$S\left(\frac{1}{2}I\right) = -2 \cdot \left(\frac{1}{2}\log\frac{1}{2}\right) = \log 2.$$

Entropy has gone from 0 to $\log 2$. Unitary conjugation preserves S, because it preserves the eigenvalues. The nonselective update does not. A law that preserves entropy cannot be the map that produces the diagonal mixture.

The selective update is not an entropy calculation of this kind: conditioning on the outcome returns a pure state, $|\text{up}\rangle\langle\text{up}|$, whose entropy is again 0. What it costs is linearity and invertibility, already shown. Either way, the map that secures agreement of a second look is not $U(t)$.

8 The chain does not find a place to stop

Couple the spin to an apparatus with ready state $|A_0\rangle$ and two record states $|A_{\text{up}}\rangle$ and $|A_{\text{down}}\rangle$, orthonormal. The linear interaction von Neumann wrote [3] is a unitary on the joint space with

$$|\text{up}\rangle|A_0\rangle \longrightarrow |\text{up}\rangle|A_{\text{up}}\rangle, \quad |\text{down}\rangle|A_0\rangle \longrightarrow |\text{down}\rangle|A_{\text{down}}\rangle.$$

By linearity, the superposition is sent to a superposition:

$$|\psi\rangle|A_0\rangle \longrightarrow \frac{1}{\sqrt{2}}\big(|\text{up}\rangle|A_{\text{up}}\rangle + |\text{down}\rangle|A_{\text{down}}\rangle\big).$$

Both records are in the joint vector. The equation has correlated the spin with the apparatus. It has not selected a record. If a second apparatus measures the first, linearity writes a second correlation and still does not select. The chain can be carried to a cat, or to a friend, or to the ink on a strip. At every finite stage the joint state, evolved by a unitary, contains every term that was present at the start, transferred onto some degree of freedom. There is no stage at which the Schrödinger equation, by itself, contains only one mark.

Schrödinger's 1935 argument [5] is this algebra with the mark made biological. Einstein's 1949 argument [7] is the same algebra with the mark made a spot on a strip and the question made a time. Neither argument requires the equation to be numerically wrong. Both require it to be short of the individual fact.

9 Decoherence is not a selection

Trace out the apparatus. The reduced state of the spin is

$$\rho_S = \mathrm{tr}_A(|\Psi\rangle\langle\Psi|) = \frac{1}{2}|\mathrm{up}\rangle\langle\mathrm{up}| + \frac{1}{2}|\mathrm{down}\rangle\langle\mathrm{down}|,$$

the same $\frac{1}{2}I$ as the nonselective map. Local expectation values of spin operators no longer show interference. That is a theorem about partial traces, and it is why a macroscopic record is hard to unscramble. The joint vector is still the sum of both branches. The partial trace is a way of refusing to write the apparatus down. It is not a way the apparatus chooses. Zeh's 1970 statement of the point [6] does not claim otherwise. A calculation that begins by discarding degrees of freedom cannot be cited as the physical act that discards a term in the vector one refused to discard.

10 Einstein's reading

The 1949 Reply [7] does not say the quantum algorithm contradicts itself. It says that ψ gives the probability that the mark on the strip is written in a given interval, and does not say of this atom when the mark is written. A complete description of the individual situation would have laws that, by themselves, have nothing to do with statistics. The statistical theory would stand to that description as statistical mechanics stands to mechanics.

The measurement problem is that demand, seen from inside the algorithm. Statistical mechanics does not contain a second process that deletes microstates when a thermometer is looked at. The macroscopic variables are incomplete. The underlying variables are not. Quantum theory, as a theory of the vector alone, has no underlying variables in that sense. When the vector fails to contain the mark, the textbook adds a process that puts a mark in by hand. The addition works, as a rule for computing the next probability. It is the confession that the vector was not the whole situation. Calling the confession a collapse relocates the problem into the ontology of ψ: one then has to say when the vector jumps, why the jump is not in the equation that was supposed to be the law of the vector, and where along the chain the jump occurs. Those questions are manufactured by the decision to keep ψ as the individual.

Bohr's reply to EPR [12, 15] refuses the decision differently. There is no individual situation apart from the whole arrangement, and the update is the account of a phenomenon, not a process in a system. That is a consistent refusal of Einstein's demand. It is not a completion of it. Heisenberg's potentia [13] is a third wording of the same refusal: the vector is a tendency, and the event is the transition from tendency to fact, still without a law of the instant. Everett's relative state [9] keeps the linear equation and denies that one term, rather than the sum, is the fact. Each of these is a decision about what to do with a vector that will not select. None of them is the 1949 request [7], which was for a description in which the selection is not an extra decision.

11 Why this program has no collapse

Shields 2026a [10] takes the individual to be a complete state S, split only epistemically into what the preparation fixes and what it does not:

$$S = S_{\mathrm{coarse}} \oplus S_{\perp}.$$

The symbol $\oplus$ is not a direct sum of Hilbert spaces and not an exclusive or. It is the cut between the read part and the unread part of one individual. The ray $|\psi\rangle$ is not S. It is, at best, the catalog of what follows when $S_{\perp}$ is unread and many individuals are pooled. A catalog is not the kind of thing that collapses. Updating a catalog after a click is bookkeeping. It is what any statistical theory does when one more fact about the individual comes in. The fact came from the individual. It did not come from the catalog jumping.

The mark, in that paper, is a first-event time

$$T^*(S) = \inf\{t > t_0 : E[\varphi_S](t) \geq E_c\},$$

the first time a positive functional of one solution crosses a threshold fixed with the solution. One law, the law of φ_S. No second map. After the crossing, the configuration is on the far side of the threshold. A second look finds it there because that is where the solution is, not because a projector was applied. Repeatability is ordinary determinism plus a threshold that has already been passed.

The Born weights are recovered, where they are recovered at all, as the distribution of T^*, or of an outcome, over the unread remainder. They are not properties of one S. A preparation that leaves $S_\perp$ unread is predicted to produce a spread of instants. A preparation that fixes S is predicted to produce one instant. The sentence "the outcome was half up and half down" does not occur, because one solution crosses or it does not. The sentence "the probability was one half" occurs only as a statement about the unread ensemble.

This is why the measurement problem indicates incompleteness inside the program, and why the indication is not a call for a collapse theory. A collapse theory, of the kind Ghirardi, Rimini, and Weber wrote in 1986 [8], modifies the Schrödinger equation by a stochastic hit so that one term dies. The hit is a second law, now written as dynamics, and the instant is random by construction. That can be made to agree with frequencies. It is the opposite of a demand that the law of the individual have nothing to do with statistics. Everett [9] keeps one linear law and gives up the single mark. This program keeps the single mark and gives up the claim that the linear vector was the individual. The update remains in the textbook, as the rule for rewriting the catalog. It is not promoted to a process in S.

12 A crossing already does the work the projector was doing

The closed Hamiltonian obtained by repairing the harmonic series, recorded in the History tab and not part of 2026a, is enough to see the pattern on a system small enough to integrate. The crest q sits in

$$V(q) = \frac{1}{2}q^2 - \Big(\frac{0.85}{3}\Big)q^3 - 0.15q^4,$$

with a barrier of height about 0.114 near $q = 0.764$. The radiation is a sum of ordinary oscillators, coupled by one term $-\kappa q \sum_n \xi_n$. The equations are Hamilton's equations of that one function. For one stated remainder, eight phases $(0.2, 1.1, 2.4, 3.7, 4.0, 5.2, 0.9, 1.8)$, with the radiation energy started at 0.13 and $\kappa = 0.55$, the crest reaches 1.35 at $T^* = 4.841$. A second look at q after that time finds q past 1.35. No projector was required for the agreement. Unread phases do not give 4.841. They give an interval. Reading the phases collapses the interval onto the number. That last verb is epistemic. The solution did not jump when a phase was written into the initial condition. The initial condition was completed.

The number 4.841 is not a lifetime in seconds, and the well is not a nucleus. It is the existence proof the measurement problem was missing inside this program: one law, one solution, one instant, and a second look that agrees because the threshold is behind the solution rather than because a vector was replaced. Scaling that pattern to a nuclear configuration is step 6 of 2026a and is not done in this paper.

13 What is not being claimed

The Schrödinger equation is not being accused of a wrong eigenvalue. Hydrogen and the spin precession are inside $U(t)$, and they stay there. Born's rule is not being accused of a wrong frequency, on the preparations for which it has been checked. The update is not being accused of a wrong conditional probability. It is the right rule for a catalog. It is the wrong object to call the life of one system.

Nothing here reproduces a Bell table from a local remainder. 2026c [11] records that a remainder of the sort defined in 2026a [10] does not reach $2\sqrt{2}$. That constraint is untouched. Incompleteness of the vector is not a license to ignore factorization.

Nothing here is a hidden-variable dressing of ψ. A λ added so that the Born weights come back as averages is the scheme Bell classified. S is supposed to be a successor description, with its own law. The catalog is what you have when you cannot read S. Collapse is what you write if you insist that the catalog was S all along.

14 Conclusion

The measurement problem is a theorem about two maps, not a mood about observers. On a single spin the Schrödinger equation preserves both components, preserves the spectrum of ρ, preserves entropy, and stays invertible. The update that makes a second click agree with the first does none of those things. Extending the vector through the apparatus preserves the theorem, because linearity preserves every term. Decoherence changes the bookkeeping of the partial trace and does not repeal it.

Einstein's program reads the theorem as incompleteness. The mark is real. The vector does not contain it. A second map is added so that the probabilities after the mark match the mark. This program accepts the theorem and refuses the second map as a law of the individual. There is no collapse, because the individual was never the ray. The measurement problem indicates incompleteness because a complete individual law writes one mark by itself, and the textbook law does not. The work that remains is to write that law for a system whose threshold is not a demonstration well. The algebra that shows the textbook cannot be that law is already closed.

15 References

The bracketed numbers in the text are these entries, in this order.

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Not a Zenodo deposit. Read with Shields 2026a, 2026b, and 2026c. The crossing at 4.841 is a check on the repaired harmonic Hamiltonian in the History tab. It is not an entry in the frozen analog archive, and it is not a measured lifetime.