

The Physics of the Coin Cradle

Buyandsellbullion.com technical report · 27 September 2026

The Coin Cradle is a pendulum with a strong magnet at the bottom of its swing. A metal coin under the magnet brakes it by eddy currents, and a ratchet dial adds up how far it travels before it stops. This report predicts the reading from first principles: the measured hardware, the magnet's field, the currents induced in the coin, the pendulum's motion and the dial. Nothing continuous is fitted.

Summary

- **Accuracy with nothing fitted.** Over the 38 readings on Coin Cradle #0001 with a known alloy, the error is 12.4% rms in $\ln(\text{reading})$ and the mean bias is -2.4% . 97% of readings fall within $\pm 25\%$, and 66% within $\pm 10\%$.
- **The motion matters.** The magnet swings on a rod: it rises as it moves out and tilts. Treating it instead as sliding horizontally at the speed of its face under-counts the braking by 17–25% and reads about 16% high. The exact rigid-body motion removes that bias with no fitted correction.
- **No overall level error is left, but the error is uneven.** A single fitted scale factor does no better than fitting nothing when whole coins are held out (12.5% against 12.4%). The error is 7.9% on the 17 gold readings, 11.9% on the 12 fine-silver readings and 19.4% on the 8 readings of 90% silver coins. One reading, a Walking Liberty half dollar at 250 (predicted 161), contributes a third of the total squared error. It is kept in every figure.
- **What the device responds to.** At a fixed size and mass, the reading scales almost exactly as one over the coin's conductivity ($\sigma^{-1.00}$ to $\sigma^{-1.07}$). A $\pm 5\%$ acceptance window is therefore about a $\pm 5\%$ conductivity window. That is a threshold, not a demonstrated accuracy: no counterfeit has been measured on the Cradle, and repeatability has not been measured.

Labels: **[measured]** figures measured on the device; **[derived]** physics; **[assumed]** a modelling choice, with its effect tested.

1. Inputs

Quantity	Value	Status
Magnet	N52 ring, axially magnetised, OD 23.4, bore 6.1, height 20 mm, 60.4 g	measured
Br	1.42–1.47 T, central value 1.445 T	N52 grade range
Magnet face to deck	exactly 3S mm (the spacers are 3 mm gauge blocks, removed before testing)	measured
Pivot height above deck	142 mm, fixed	measured
Pivot to magnet centre	$142 - 3S - 10$ mm, i.e. 129, 126, 123 mm	derived
Release	50°	measured
Rod	48.2 g, uniform, from pivot to the top of the magnet	mass measured; shape assumed

Quantity	Value	Status
Cross axle	32.7 g, solid cylinder on the axis, radius 4 mm	mass measured; radius assumed
Side screw	4.27 g point mass, 14 mm from the axis	measured
Coin position	centred under the magnet, resting on its rims	assumed
Coin rim thickness	coin data files, or catalogue figures	measured or catalogue
Metal thickness	$t_{\text{eff}} = m/(\rho\pi R^2)$, a slab centred at half the rim thickness	derived
Conductivity	calibration workbook (section 7)	unverified handbook values

The moment of inertia about the pivot is 1.238, 1.180 and $1.124 \times 10^{-3} \text{ kg} \cdot \text{m}^2$ at one, two and three spacers; the magnet contributes 82%. The release energy is 37.4, 36.5 and 35.6 mJ, and the small-swing period about 0.68 s.

2. Physics

The field [derived]. The ring is the difference of two uniformly magnetised cylinders (radii 11.7 and 3.05 mm, height 20 mm). Each has a closed-form field in terms of Bulirsch's complete elliptic integral (Derby & Olbert, *Am. J. Phys.* 78, 229 (2010)). The field is computed for unit remanence and multiplied by B_r^2 once, in the damping. It agrees with the on-axis closed form and with an independent Hankel-integral calculation to 2×10^{-13} , is divergence-free to 10^{-10} , and, tilted, matches a point dipole at 120–170 mm to 0.1%. At $B_r = 1.445 \text{ T}$ the on-axis field is 0.255 T at 3 mm and 0.176 T at 10 mm; because of the bore it falls again very close to the face (0.08 T at 1 mm).

The motion [derived]. The coin is at rest and the magnet rotates about the pivot. At each point of the coin, the vertical field of the tilted magnet is $B_z(x, y; \theta)$. A thin conducting layer responds only to $\partial B_z / \partial t = \dot{\theta} \partial B_z / \partial \theta$. Its current has a stream function ψ with

$$\nabla^2 \psi = \partial B_z / \partial \theta, \quad \psi = 0 \text{ on the coin edge}$$

and the damping torque coefficient is

$$D(\theta) = \sigma B_r^2 \left[\sum_k w_k \int (-\psi_k F_k) dA + (t^3/12) \int |\partial B_h / \partial \theta|^2 dA \right], \quad F = \partial B_z / \partial \theta \text{ at } B_r = 1 \text{ T}$$

The sum runs over five Gauss–Legendre depths through the metal thickness t , with weights w_k that sum to t . Integrating by parts, $\int (-\psi \nabla^2 \psi) dA = \int |\nabla \psi|^2 dA \geq 0$, so the braking is positive and exactly proportional to σ . The second term covers currents that loop through the thickness, driven by the horizontal field B_h ; it adds 0.6–1.7%. The pendulum obeys

$$I \ddot{\theta} = -Mg\ell \sin \theta - D(\theta) \dot{\theta} - \tau_f \text{sgn } \dot{\theta}$$

integrated from 50° with a fourth-order Runge–Kutta step of 0.4 ms, stopping when the swing's amplitude falls below 0.02° .

Why the exact motion matters (braking integrated over angle, relative to a magnet sliding horizontally at its face's speed):

Coin	adding the rise	adding the tilt	total
Krugerrand 1 oz, 2 spacers	$\times 1.090$	$\times 1.077$	$\times 1.174$
Philharmonic 1/10 oz, 2 spacers	$\times 1.099$	$\times 1.138$	$\times 1.251$
Morgan dollar, 3 spacers	$\times 1.109$	$\times 1.056$	$\times 1.171$

Directly under the pivot the exact braking is 13–30% lower, because the tilting field partly cancels the translation; it is higher in the wings, which is where the integral gains.

Validity [derived]. For a thin sheet the self-field correction is set by v/w , where $w = 2/(\mu_0 \sigma t)$ is the sheet's characteristic speed. The peak speed is about 1 m/s; across the 38 readings $v/w \leq 0.11$, so the correction is at most 0.9%. The coin's thickness is at most 0.18 of the skin depth at the rate the field sweeps past, so the test reads the whole thickness, not the surface. When tilted, the ring's trailing edge dips by up to about 0.5 mm; the tightest reading keeps 0.56 mm clearance.

3. Pivot friction

The owner reports that the pendulum, released with no coin, kept swinging for about 4.5 minutes. This is a recollection, not a recorded measurement. At a period of 0.68 s that is about 790 half-swings. Coulomb friction removes a fixed $2\tau_f/(Mg\ell)$ of amplitude per half-swing, so falling from 50° to rest in that time gives $\tau_f \approx 5.7 \times 10^{-5} \text{ N} \cdot \text{m}$, and air drag would make the friction alone smaller still. This is an approximate upper estimate, conditional on the recollection and the friction model. The model uses $\tau_f = 0$ and carries the estimate as an uncertainty: it lowers readings by 0.6–23%, most for the small coins, which swing longest.

4. The dial

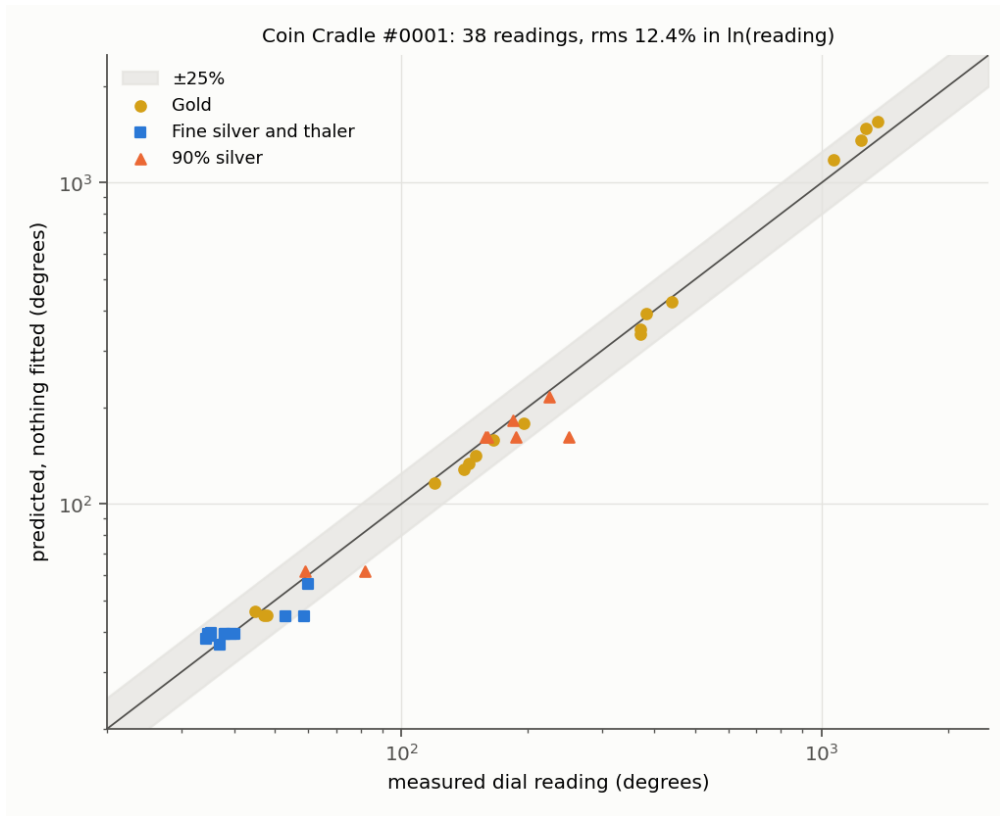
The dial is marked "turn clockwise only" and records cumulative degrees, including full turns, so it is ratcheted. Two separate pieces of evidence fix how it counts:

1. **Outward strokes only.** The owner confirms that the dial ratchets only on the outward swing.
2. **The far side only.** This is inferred from the readings. With a one-to-one drive and nothing fitted:

Dial counts	rms error, 38 readings	Mean bias
outward strokes on the far side	0.124	−0.024
outward strokes on the release side	0.499	−0.401
all return-direction travel	0.534	+0.510
all release-direction travel	0.858	+0.838

Counting outward strokes on both sides would read about 1.6 times too high. The far-side choice is selected with the data, among four rules; it is not an independent test, though the next-best rule is four times worse.

5. Results



The model predicts 38 of the 44 readings in the Cradle #0001 workbook; the other six are 40% silver clad coins with no listed conductivity. For those, the model infers 41–56 MS/m; that depends on the model and is not used as validation.

6. Validation and where the error sits

The 38 readings come from 31 distinct coins and 6 alloy types. Where anything is fitted, whole coins or whole alloys are held out.

	rms of $\ln(\text{reading})$
Nothing fitted	0.124
One scale factor, in-sample	0.121
One scale factor, leave-one-coin-out	0.125
One scale factor, leave-one-alloy-out	0.127

A scale factor gains nothing out of sample: the overall level is right. The error is not uniform, though:

Group	Readings	rms	Mean bias	Dimensions
Gold (fine, 22 ct, 91.67%)	17	0.079	−0.010	all measured
Fine silver coins, rounds, bars	12	0.119	+0.015	5 measured, 7 unsourced
90% silver US coins	8	0.194	−0.109	all catalogue
Maria Theresa thaler (83.3% silver)	1	0.060	−0.060	catalogue

The worst group is also the group whose dimensions and rims come from catalogue figures, so metal and dimension source overlap completely here. That points to checking the geometry first; it does not show that geometry causes the difference.

The Walking Liberty reading. Two readings of a Walking Liberty half dollar at 3 spacers were recorded, 187.5 and 250. The model predicts 161, as for the Kennedy (160 measured) and Franklin (158.7 measured) halves of the same specification. The 250 reading contributes 33% of the total squared error; without it the error would be 10.2%. It may be a transcription error, a different specimen, a different release, or a model failure; the data cannot say which.

Repeats. Three coins were read twice at the same setting: 2%, 33% and 39% apart. The larger two may be different specimens, so measurement repeatability is not known.

7. Uncertainty

Nothing is refitted in any row. Each shift is the change in $\ln(\text{reading})$, across the 38 readings.

Change	Median shift	Range	rms after
Br 1.42 / 1.47 T	+3.5% / -3.5%	3.0–4.1%	0.121 / 0.135
conductivity $\pm 3\%$ (all coins)	$\mp 3.0\%$	2.5–3.6%	0.121–0.133
rod inertia $\pm 15\%$	$\pm 1.4\%$	1.0–1.6%	0.122–0.128
axle radius 2–6 mm	$< 0.1\%$		0.124
release angle $\pm 2^\circ$	$\pm 7\%$	6.1–7.5%	0.129–0.155
coin clearance ± 0.1 mm	$\pm 3\%$	2.6–6.2%	0.123–0.134
rim thickness ± 0.1 mm	$\mp 1.5\%$	1.3–3.1%	0.122–0.128
coin 2 mm off-centre, along the swing	-0.3%	-2.6 to +0.4%	0.123
coin 2 mm off-centre, across the swing	+2.4%	1.6–3.4%	0.120
friction at the bound	-2.2%	-23% to -0.6%	0.136

The release angle is the largest single input: $\pm 2^\circ$ moves every reading by $\pm 7\%$. The clearance under the magnet comes next, with the magnet face assumed to sit exactly 3S mm above the deck.

Combined. All inputs are drawn together: 20,000 draws, linearised on per-reading sensitivities computed with the exact model. Four full joint runs of the exact model agree with the linearisation to within 1.1% on every reading. The draws are split by what each error is shared across. The distributions are assumptions, not measured noise; nothing here comes from repeated releases.

Component	Assumed distribution	Shared across	Per-reading sd (median / max)	rms over the 38, 5–95%
Device	Br U(1.42, 1.47) T; rod $\pm 15\%$; axle 2–6 mm; friction U(0, 5.7×10^{-5}) N · m; clearance ± 0.1 mm	every reading	2.9% / 7.0%	0.116–0.155
Alloy	conductivity $\pm 3\%$ per alloy type	readings of one alloy	1.8% / 1.9%	0.120–0.130
Coin	rim ± 0.1 mm (measured dimensions) or ± 0.2 mm (catalogue or unsourced dimensions)	readings of one coin	1.6% / 3.5%	0.120–0.129
Release	angle U($\pm 2^\circ$); centring uniform within a 2 mm radius	one release	4.0% / 4.3%	0.118–0.138
			5.4% / 8.1%	0.117–0.162

Component	Assumed distribution	Shared across	Per-reading sd (median / max)	rms over the 38, 5–95%
All together				

The uniform ranges are assumptions; none is independently measured.

What this says. The inputs as assumed account for about 5% per reading. The observed error is 12.4%, which leaves roughly 11% unexplained by any listed input (in quadrature). That remainder is some mix of real measurement noise, geometry errors larger than assumed (see the 90% silver group in section 6) and model error. Without repeated releases of one coin they cannot be told apart.

Conductivity provenance. The conductivities are taken from the Cradle's calibration workbook, which does not cite sources:

Type	σ (MS/m)
A	44.7
B	35.2
C	25.5
D	9.7
E	11.1
F	11.8
G	8.9
H	61.0
I	52.5
J	51.0
K	50.2
L	48.5
M	47.0

They are plausible handbook figures for fine gold, the 22-carat and 91.7% gold alloys, fine silver and 90% silver, but they are unverified until matched to a cited table. The six 40% silver clad coins have no σ . The model infers 41–56 MS/m for them. That depends on the model, is not a validation, and is not used anywhere else.

8. Numerical and independent checks

Check	Change
grid 0.25 $\rightarrow$ 0.125 mm	+0.9% (1.9 mm gap), -0.04% (5 mm gap)
angle step 0.125° $\rightarrow$ 0.0625°	+0.2% / +0.07%
depth nodes 5 $\rightarrow$ 8	$< 10^{-6}$
angle range 40° $\rightarrow$ 60°	$< 10^{-5}$
time step 0.4 $\rightarrow$ 0.2 ms	$\leq 0.23\%$ on any reading

The first four checks are on integrated D; the time step is on the readings. The integration stops when a swing's energy amplitude falls below 0.02°. The worst numerical error, about 1% on the smallest gaps, is in the direction of slightly more braking.

An independent audit of the code checked the kinematics against the analytic rigid-rotation derivative $\partial B_z / \partial \theta = B_x - Z_p \partial_x B_z - X \partial_z B_z$ and found agreement to 10^{-4} . The four defects it found were fixed before the figures in this report were computed.

9. Telling fakes apart

- **Solid substitutes.** A solid tungsten, lead or brass piece of the same size reads 2–10 times differently from fine gold.
- **Constructed fakes.** The braking comes from the whole thickness, so a thin gold layer changes little, and a core whose effective $\sigma \cdot t$ matches the genuine coin's would pass. The Cradle tests conductivity times thickness, not composition. 22-carat coins (9.7–11.1 MS/m) are the weak point, because their conductivity lies among cheap dense metals.
- **Reference coin.** An eddy-current pass on this site needs a genuine reference coin of the same type measured on the same unit; a comparison with the formula alone is inconclusive.
- **Not established.** False-accept and false-reject rates need the repeatability of one coin over many controlled releases and a defined set of counterfeit constructions with measured responses. Neither exists yet.

10. What further measurements would settle

- Predictions for fresh coins, made before they are measured.
- A recorded no-coin decay, turning the friction estimate into a value.
- The dial moved by hand through known angles on each side.
- Ten releases of one coin, for the noise floor.
- The release angle and the clearance under the magnet, measured directly: they are the two largest inputs.
- Calliper rims and dimensions for the catalogue-dimensioned coins, and a check of the Walking Liberty reading.

Appendix: data

Predictions in degrees on the dial, far-side rule, nothing fitted. t_{eff} is the volume-equivalent metal thickness; rim is the maximum thickness; Dimensions is the source of the coin's dimensions and rim.

Coin	Alloy type	σ (MS/m)	Spacers	Shape (mm)	t_{eff}	Rim	Dimensions	Measured	Predicted
South African Krugerrand (1oz)	D	9.7	2	Ø32.77	2.30	2.84	measured	196	179
South African Krugerrand (1/2 oz)	D	9.7	1	Ø27.07	1.68	2.22	measured	150	141
South African Krugerrand (1/4 oz)	D	9.7	1	Ø22.06	1.27	1.80	measured	382	392
South African Krugerrand (1/10 oz)	D	9.7	1	Ø16.5	0.91	1.35	measured	1278	1473
American Gold Eagle (1 oz)	E	11.1	2	Ø32.7	2.27	2.87	measured	166	158

Coin	Alloy type	σ (MS/m)	Spacers	Shape (mm)	t_eff	Rim	Dimensions	Measured	Predicted
American Gold Eagle (1/2 Oz)	E	11.1	1	Ø27	1.66	2.15	measured	141	128
American Gold Eagle (1/4 Oz)	E	11.1	1	Ø22	1.25	1.78	measured	370	351
American Gold Eagle (1/10 Oz)	E	11.1	1	Ø16.5	0.89	1.26	measured	1240	1354
American Gold Eagle (1/4 Oz)	E	11.1	2	Ø22	1.25	1.78	measured	1065	1181
Austrian Philharmonic (1/10 oz)	A	44.7	1	Ø16	0.80	1.20	measured	440	425
Austrian Philharmonic (1/10 oz)	A	44.7	2	Ø16	0.80	1.20	measured	1360	1548
South African Elephant (1 Oz safari Series)	A	44.7	3	Ø32.69	1.93	2.80	measured	120	116
South African Elephant (1 Oz safari Series)	A	44.7	2	Ø32.69	1.93	2.80	measured	45	46
Canadian Maple Leaf (1/2 Oz)	A	44.7	3	Ø25	1.65	2.23	measured	370	338
Canadian Maple Leaf (1/2 Oz)	A	44.7	2	Ø25	1.65	2.23	measured	145	134
Australian Kangaroo	A	44.7	2	Ø32.6	1.94	2.95	measured	47	45
Australian Kangaroo	A	44.7	2	Ø32.6	1.94	2.95	measured	48	45
Canadian Maple Leaf	H	61	3	Ø38	2.62	3.29	measured	34	38
Austria Philharmonic	H	61	3	Ø37	2.76	3.20	measured	35	39
American Silver Eagle	H	61	3	Ø40.6	2.30	2.98	measured	40	39
Australian Kangaroo	H	61	3	Ø40.9	2.26	3.50	measured	37	36
UK Britannia (since 2013)	H	61	3	Ø38.61	2.54	3.00	measured	35	40
Generic Round .999 fine	H	61	3	Ø39	2.49	2.99	unsourced	38	39
Silver Trade Unit (.999 fine round)	H	61	3	Ø39	2.49	2.99	unsourced	38	39
Englehard Prospector . 999 fine	H	61	3	Ø39	2.49	2.99	unsourced	40	39
Silver Buffalo .999 fine	H	61	3	Ø39	2.49	2.99	unsourced	35	39
Scottsdale Silver OMNIA round	H	61	3	Ø39	2.49	2.99	unsourced	35	39
Scottsdale bar	H	61	3	50×28	2.12	2.62	unsourced	53	45
Silvertowne bar	H	61	3	50×28	2.12	2.62	unsourced	59	45
Morgan Silver Dollar (90%)	K	50.2	3	Ø38.1	2.28	2.40	catalogue	59	62
Morgan Silver Dollar (90%)	K	50.2	3	Ø38.1	2.28	2.40	catalogue	82	62
90% Washington Quarter	K	50.2	2	Ø24.26	1.31	1.75	catalogue	184	182
	K	50.2	1	Ø17.91	0.96	1.35	catalogue	225	215

Coin	Alloy type	σ (MS/m)	Spacers	Shape (mm)	t_eff	Rim	Dimensions	Measured	Predicted
90% silver US dime, type unverified									
90% Half Dollar (Kennedy 1964)	K	50.2	3	Ø30.61	1.65	2.15	catalogue	160	161
90% Half Dollar (Franklin 1963)	K	50.2	3	Ø30.61	1.65	2.15	catalogue	159	161
90% Half Dollar (Walking Liberty 1917-1939)	K	50.2	3	Ø30.61	1.65	2.15	catalogue	188	161
90% Half Dollar (Walking Liberty 1917-1939)	K	50.2	3	Ø30.61	1.65	2.15	catalogue	250	161
Thaler (M Theresia D.g)	J	51	3	Ø40	2.15	2.50	catalogue	60	57

Clad coins (no listed σ ; σ inferred by the model, not used as validation):

Coin	S	measured	σ inferred (MS/m)
Bicentennial Eisenhower Dollar (40% Ag, 60% Cu)	3	63	48
Bicentennial Kennedy Half Dollar (40% Ag, 60% Cu)	3	187	43
Bicentennial Washington Quarter (40% Ag, 60% Cu)	3	510	43
Bicentennial Eisenhower Dollar (40% Ag, 60% Cu)	2	21	56
Bicentennial Kennedy Half Dollar (40% Ag, 60% Cu)	2	74	44
Bicentennial Washington Quarter (40% Ag, 60% Cu)	2	215	41