Episode Book

EPISODE #5886

From Leviticus to the Kilogram: Honest Scales

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SYNOPSIS

Honest scales, honest weights, honest measures — Leviticus says it, Athens enforced it with a board of ten Metronomoi, and the kilogram depended on a single platinum-iridium cylinder in a French vault for over a century. This episode traces the whole arc: how ancient markets actually policed measurement, why the Hebrew Bible had three different shekels in circulation at once, what lmlk weights reveal about royal enforcement, and why a one-gram calibration weight you can buy online for a few shekels lands you in the deepest recursion in metrology — how do you know the reference itself is right?

TRANSCRIPT



Corn

There's a line in Leviticus that Daniel has been sitting with, and it's the kind of line you read past a hundred times before it stops you.



Herman

Give it to me straight, because I know which one you mean and I want to hear you say it.



Corn

Honest scales, honest weights, honest measures. And Daniel's point is that this is not an ancient curiosity. He lives here, he reads the text in the place it was written, and then he goes and buys things in a market and it's the same problem. He's asking us to trace it: how did the ancient world actually enforce honest measurement, how did we get from a rock in a marketplace to a kilogram defined by a constant, what does traceability mean when you actually pull on it, and then the part I like, the little one-gram calibration weight you can buy online for a few shekels. How do we know the reference itself is right?



Herman

That last question is the whole thing, isn't it. It's the recursion at the bottom of the topic.



Corn

It's the only question. Everything else is scaffolding around it.



Herman

So here's the shape of it. Defining a standard was never the hard part. Any society with a treasury can cast a lump of bronze and say this is the unit. The hard part is enforcement. Somebody has to walk into the market and be allowed to smash a merchant's false measure in front of everybody. That's what makes a standard real. And then the second layer, the one that took us three thousand years, is: who watches the watchmen. How do you know the official lump of bronze hasn't drifted. And the modern answer to that is beautiful, because it's not a better watchman. It's removing the watchman entirely.



Corn

Or removing the artefact.



Herman

Removing the artefact. Define the unit by a constant of nature, and then any competent lab anywhere can realize it independently, and you don't trust one object, you compare results. And that is what Daniel's one-gram weight is really asking. So let's go back to the beginning, because the beginning is better than people expect.



Corn

The beginning has inspectors.



Herman

The beginning has ten of them. Athens had a board of ten Metronomoi, that's the word, inspectors of weights and measures. Chosen by lot, which is very Athenian. Five served in Athens proper and five in Piraeus, because the port was where the cheating was most profitable. And their job, per Aristotle's Constitution of the Athenians, was to be responsible for all weights and measures in the city and to make sure sellers used honest ones.



Corn

Chosen by lot. So you could be a shoemaker on Tuesday and the man who certifies the grain measures on Wednesday.



Herman

That's the Athenian theory of it, yes, and I'd argue it's a feature, not a bug, because a rotating board is harder to buy than a permanent one. And here's the part that gets me. In 1967 they excavated the Agora in Athens and found a stele, a standing stone, set up by the Metronomoi themselves. It names the five Athenian members and two secretaries for 222 over 221 B.C., so a specific year, and it records the handover of the bronze grain measures to the next year's board.



Corn

They published their own annual report on a rock.



Herman

They published their annual report on a rock, and the rock survived two thousand two hundred years, which is more than I can say for most annual reports.



Corn

More than the bronze measures survived.



Herman

Considerably more. And they also found a lead weight countermarked by the Metronomoi, so an actual physical object they had stamped, and pots with lead validating seals on them. So you can hold the enforcement in your hand. Somebody stamped that weight and it said the inspectors had seen it.



Corn

There's something in that. The bronze measures went, the record of who handed them over is still there. The bureaucracy outlasted the weights.



Herman

The paperwork is the durable artefact. Which is going to come back at the end of the episode, so hold onto it.



Corn

Go on to the markets.



Herman

So beyond the Metronomoi, Greek cities appointed agoranomoi, market inspectors, and their remit was broader. They supervised the making of weights and measures, but also product quality and the transactions themselves. And this office gets imported into Eretz Israel in the Hellenistic period and persists straight through the Roman period. We find inscribed lead weights and stone weights, including at Maresha. So this is not a Greek peculiarity, it's the standard machinery of the Mediterranean market.



Corn

The market inspector travels with the empire.



Herman

The market inspector travels with the empire, and so does the problem he's there to solve. In Roman Gaul, second century B.C. through the fifth century, the standards were often made of stone, which is clever because stone doesn't corrode and it's hard to shave down discreetly. The master standards were kept in the Temple of Jupiter in Rome, which is doing the same work as keeping them in a bank vault, and copies were kept in busy marketplaces. And there was an inspector for checking weights and measures who had the right to destroy false measures. That's the power. Not a fine, not a note in a ledger. Destruction.



Corn

That's a penalty you can watch. A fine is invisible, the confiscation is a public event.



Herman

And that's the design. The whole point is that the next merchant in line sees it happen.



Corn

What did the cheating actually look like. Because I want to know what the inspectors were actually catching.



Herman

This is where it gets wonderfully specific. There's an Athenian decree from the end of the second century B.C. and it goes into detail that borders on the obsessive. Dried fruits were to be sold with a capacity measure of three half-choinikes of grain, levelled off. And then it specifies the choinix, heaped up, quote, with a depth of five fingers and a width at the rim of one finger.



Corn

Five fingers deep and one finger wide at the rim. So the shape of the measure was legislated.



Herman

The shape was legislated, because the shape determines the volume, and the volume determines whether the merchant is cheating. If you let him choose the shape of his own basket, you haven't standardized anything. You've just made him agree on the word.



Corn

How many fingers wide is a finger.



Herman

That is a good question and I do not have a clean answer, because the daktulos, the finger, is a body measure and body measures vary. Which is itself the point. The decree is trying to nail down a variable by reference to another variable, and somewhere in Athens there must have been an official finger. I don't know how they resolved that, honestly.



Corn

An official finger. Somewhere in a drawer.



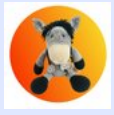
Herman

In a temple, probably, next to the official foot.



Corn

Now bring in the text, because Daniel's whole framing is the biblical layer.



Herman

So Leviticus 19:35 and Deuteronomy 25:13 through 16 are, as the scholarship puts it, the first legislation for economic righteousness. And the prophets keep coming back to it. Amos, Hosea, Micah, Proverbs, over and over, false measures as the emblem of a society that has stopped being honest in the small things. Which is a very sharp instinct, because the small dishonesties are the ones nobody notices. A merchant who skims a gram off every sale is not committing a dramatic crime. He's committing a thousand invisible ones.



Corn

And the text does something interesting. It distinguishes standards.



Herman

It does, and this is the part I find really striking. There isn't one shekel in the Hebrew Bible. There's a merchant's rate shekel, in Genesis 23, when Abraham buys the cave. There's a sanctuary weight shekel, in Exodus 30. And there's a king's weight shekel, in Second Samuel, which is stamped by the royal treasury as proof of perfection. So you've got a commercial standard, a cultic standard, and a royal standard, all called shekel, all in circulation at once.



Corn

Three standards with the same name. That's not a system, that's a negotiation.



Herman

It's a negotiation, and it's exactly why the text has to say honest weights, honest measures, because everybody knows there are three of them and you can pick the one that suits you at the moment of the sale. And then archaeology backs the royal one up. Weights marked lmlk, of the king, and they cluster. Eleven point three grams for the unit, and then twenty two point six, forty five point five, ninety one point two, a hundred and eighty eight and a half, and two hundred and sixty eight point two four. One, two, four, eight, sixteen, twenty four.



Corn

Powers of two, mostly.



Herman

Powers of two with a twenty four stuck on the end, which is a very human thing to do. Arithmetic that's convenient, plus one number that somebody needed for a particular transaction and nobody has explained yet. And the clustering is the evidence. If there were no official standard, you'd find weights scattered across a range. You find them stacked on a value, which means somebody was enforcing it.



Corn

Who, though. Which institution.



Herman

The royal treasury is the best guess, from the stamping. And then the rabbinic layer goes further than the Bible does, which is often the case. The Mishnah and the Talmud demand the periodic cleaning of weights, scales, and measures, lest dirt impair the true standard.



Corn

That's the line. That's the modern insight hiding in the ancient text.



Herman

Say why.



Corn

Because it's not about cheating. Nobody's shaving the weight. It's about the fact that a standard degrades through ordinary use. Grime accumulates. The bronze wears at the edge. And over a year of honest handling, your honest measure has quietly stopped being honest, and nobody did anything wrong.



Herman

That is exactly what we're going to come back to with the one-gram weight, and it's a two thousand year old observation. The reference is not a fixed thing. It's a thing in the world that gets dirty.



Corn

Which is the ancient version of the problem we're about to describe with the kilogram.



Herman

And that's the pivot, because for over a century the kilogram had exactly this problem, in its purest form. The kilogram was defined as the mass of a single object. The International Prototype of the Kilogram, a platinum iridium cylinder, conserved at the BIPM, at Sèvres, outside Paris. For over a hundred years, the kilogram was that cylinder. Not a definition that pointed at the cylinder. That cylinder was the kilogram.



Corn

One object. The world's unit of mass was a lump of metal in a French suburb.



Herman

And the BIPM's own description of it is honest about the cost. It ensured a common reference for the whole world, and it also meant the definition of the kilogram depended on one physical object. I know they keep it in a vault under three nested bell jars, and I



Herman (continued)

know about the ritual, the keys, the two people who have to be present.



Corn

Under glass, touched twice a century.



Herman

Which sounds like reverence, and it is, but reverence is what you do when you're afraid. And the fear was justified, because the copies drifted. The IPK and its official national copies, made from the same ingot at the same time, diverged over the decades, on the order of tens of micrograms over a century. So the question became: which one moved. Is the prototype losing mass, or are the copies gaining it, and how would you know, when the prototype is the definition of the thing you're using to check it.



Corn

You can't check it. There's nothing above it to check it against.



Herman

There's nothing above it. That's the terminal case of the watchman problem. And I'll tell you why this is the ancient problem in modern dress, and I think it's the single best connection in the whole topic. Rabbinic law said clean your weights because they drift through use. The IPK is the same statement, at a hundred thousand times the precision. The reference is unstable, and no amount of care fixes it, because the instability is in the nature of a physical object.



Corn

So you stop having a reference.



Herman

You stop having a reference. On the twentieth of May, 2019, the revised SI came into force, and the kilogram stopped being defined by an object. It's now defined by fixing the numerical value of the Planck constant. Six point six two six zero seven zero one five, times ten to the minus thirty four, joule seconds.



Corn

And what happens to the cylinder.



Herman

It's conserved. It sits in the vault as history. It's an artefact now, not a definition.



Corn

That's a strange retirement. The most important object in the world, and one day it's a museum piece.



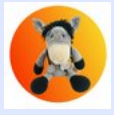
Herman

Walter, I think it's the most dignified retirement a lump of metal has ever had.



Corn

It got to be the kilogram for a hundred years and then it got to stop.



Herman

And the point of replacing it was not precision, it was independence. Any competent lab can now realize the kilogram from the constant. There are two primary ways. The Kibble balance, which links a mechanical mass measurement to electrical measurements tied to quantum electrical standards. And the X-ray crystal density method, which essentially counts atoms in a silicon crystal that's been characterized to astonishing precision. The BIPM runs its own Kibble balance. Two methods, and the BIPM says they can realize the kilogram to within a few parts in ten to the eighth. For a kilogram, that's a few tens of micrograms.



Corn

Tens of micrograms on a kilogram. I want to sit with the scale of that for a second.



Herman

Go ahead, because it's hard to feel.



Corn

A microgram is a speck you could lose by breathing. And they're arguing about tens of them on a kilogram, which is a bag of sugar.



Herman

That is the whole achievement, yes. And there's a lovely human story attached to it. At NIST, in December 2013, before the redefinition, the group working on the NIST-4 Kibble balance did a prediction exercise. They predicted what value of the Planck constant they would measure. A guest researcher named Shisong Li came closest. He was off by about five parts per billion.



Corn

Five parts per billion, as a guess, at something they hadn't built yet.



Herman

As a prediction of a measurement they were about to make. That's not luck. That's understanding your instrument to the level where you can forecast it. And the reason I bring it up is that it's the exact opposite of trusting an object. You know your apparatus so well you can tell me what it's going to say before it says it.



Corn

Alright. So the kilogram is now a constant. But Daniel's actual question is downstream of that. How does it get from a constant realized in a lab to a certificate that says this piece of metal weighs one kilogram.



Herman

That's traceability, and the definition is worth hearing in full because every word in it is doing work. Traceability is the property of a measurement result, whereby the result can be related to a reference through a documented, unbroken chain of calibrations, each contributing to the measurement uncertainty.



Corn

The property of a result.



Herman

Of a result. And this is the counterintuitive part, and NIST is very firm about it. Only measurement results are traceable. Not instruments, not laboratories, not organizations. Merely having an instrument calibrated at NIST is not enough to make your measurement result traceable. Under their own policy.



Corn

So the calibration certificate in the drawer means nothing on its own.



Herman

It means nothing on its own. It's one link. What has to exist is the chain, documented, dated, unbroken, with the uncertainty stated at every link. And a lab can have a beautifully calibrated instrument and still produce an untraceable result, if they can't show the chain from that result back to a reference.



Corn

So if you find a certificate in a drawer that says calibrated to NIST, and nothing else, you have a piece of paper about a piece of equipment. Not a fact about a measurement.



Herman

That's the distinction, exactly. The instrument got calibrated. The result is a different animal. And this is what makes the international system work, because every national lab is producing results, and those results all have to be comparable. So how do you check a hundred national standards against each other when there's no master standard anymore.



Corn

The same way the Athenians did. You put them in front of each other.



Herman

You put them in front of each other, and that's the actual mechanism. It's the CIPM Mutual Recognition Arrangement. The framework through which national metrology institutes recognize each other's standards and calibration certificates. And the outputs of that arrangement are Calibration and Measurement Capabilities, published in a database at the BIPM, which covers more than fifteen hundred scientific comparisons. About two thirds of them key comparisons, one third supplementary.



Corn

And a key comparison is what. Two labs measuring the same thing and publishing both numbers.



Herman

That's exactly what it is. Each participant's results are published in the database, identified by name, so you can see who agrees with whom and by how much. The whole point is that the agreement is not asserted. It's demonstrated in public, and it's visible. And when a lab disagrees, that's the mechanism. It gets published. It doesn't get buried. Which is a remarkable thing for an international system to do.



Corn

Publicly disagreeing with your peers is not the usual institutional behaviour.



Herman

It isn't, and I think it's why it works. And to have your capabilities listed at all, there are three requirements. You have to have taken part in reviewed scientific comparisons. You have to have an approved quality management system. And you have to pass international peer review. So it's not a claim you make about yourself. It's a claim other people have checked.



Corn

Which is the modern Metronomoi. Peer review instead of a man with the power to smash a basket.



Herman

Same function. Different machinery. And I'll say the thing I keep noticing, which is that the ancient method may have been more effective at the point of sale, and the modern method is more effective at the point of comparison. They're optimized for different failure modes.



Corn

I'd like to go back to something you said about the Athenians. The stele outlasted the bronze.



Herman

The record outlasted the object.



Corn

That's the CIPM MRA. It's a database of records. It's the same instinct. The thing that survives is the documentation of what was compared to what.



Herman

That is a good observation, and I hadn't put it that way. The durable artefact is the record of the comparison.



Corn

Alright. So now let's actually do what Daniel asked. One gram, bought online, a few dollars plus shipping. What's on it, and what would it take.



Herman

So there's a standard for these things. OIML R one eleven, part one, defines seven accuracy classes, from tightest to widest, E one, E two, F one, F two, M one, M two, M three. And what most people don't know is where the top class sits in the system.



Corn

The E one weights.



Herman

The E one weights have a specific job. They exist to ensure traceability between national mass standards and weights of class E two and lower. So the top class is not the everyday working standard. It's the thing whose purpose is to anchor everything below it. And an E one weight must be accompanied by a calibration certificate. Not a sticker. A certificate.



Corn

So if you're buying an E one weight and it doesn't come with a certificate, somebody has misunderstood the category.



Herman

Somebody is selling you the word E one, not the class. And the class is defined by what accompanies it.



Corn

What does a real certificate say.



Herman

A defensible NIST-traceable claim requires a calibration certificate from an ISO/IEC 17025-accredited lab, stating a measurement uncertainty, and a documented, dated, unbroken chain. That's the whole test. The CASRAI procurement guide puts it about as bluntly as it can be put. A weight certified as one gram with no stated uncertainty and no traceability statement, quote, is not a calibration certificate in any defensible sense, it's a label.



Corn

A label. That's the exact word for it.



Herman

A label. And the manufacturer knows this, which is why the marketing is careful. NIST-traceable is a phrase with no legal force in that context. It's a vibe.



Corn

It's a vibe with a font.



Herman

A very confident font. And here's the bit that makes the entire business circular. Suppose you want to check. You have a one-gram weight, you don't trust it, you want to know. You can't check it against anything you own, because everything you own is calibrated against something you also don't trust. You have to send it out. To an ISO/IEC 17025-accredited lab, to be calibrated against a higher-class weight, an E two or an E one, traceable to a national standard. And then the chain runs: your weight, the lab's E two, the lab's E one, the national metrology institute's primary standard, the realization of the kilogram by Kibble balance or by the silicon sphere method, and then the Planck constant itself.



Corn

So the chain from a cheap weight on my desk to a fundamental constant is about six links long.



Herman

About six, and every one of them has to be documented and dated, and each one contributes uncertainty, which is stated. And I should say, the reason you'd bother is usually not the weight itself. It's that whatever you measure with that weight inherits its uncertainty. If the weight is off, everything downstream is off, and you'll never see it, because the whole point of a bad standard is that it silently makes everything consistent and wrong.



Corn

Consistent and wrong. That's the failure that scares me.



Herman

It should. It's the reason the whole apparatus exists.



Corn

And what about the thing the rabbis noticed. Dirty weights.



Herman

Weights drift. Handling, contamination, surface wear. Bare-hand contact deposits oils onto the surface, and over time that changes the mass. So even a certified weight is not certified forever. It needs periodic recertification. Which is the Mishnah's point, arriving two thousand years late in a lab manual.



Corn

You can't do the cleaning yourself, though. You can't take a certified E two weight and polish it.



Herman

You cannot. The moment you touch it, you've invalidated the certificate. So a certified weight is an object you own and are not allowed to use. It's a reference, not a tool. You keep it in a case, in a room, and you look at it occasionally.



Corn

It's a pet.



Herman

It is functionally a pet. And the ancient equivalent was the temple standard, the stone measure in the Temple of Jupiter that everybody copied and nobody transacted with.



Corn

So there's this lovely thing where the modern system and the ancient system converge again. Both of them end up with an object that sits untouched in a protected place and is used only to generate copies.



Herman

And then the copies are what everyone actually touches, and the copies are what drift.



Corn

Alright, quick one. If I buy a one-gram weight online and I send it off to be calibrated, roughly what am I looking at.



Herman

It depends on the lab, but the calibration typically costs an order of magnitude more than the weight. And for that money you get a number with an uncertainty attached. Which may well tell you the weight is fine. But you'll have paid to learn that, which is the point. Confidence has a price, and it always did, and the ancient version of that price was the tax that paid the inspector.



Corn

There it is.



Herman

So where does that leave Daniel's question. How far up the chain can you trace it. The honest answer is: as far as the paperwork goes, and no further. If you have a certificate, you can trace it all the way to the constant. If you have a label, you can trace it to a warehouse.



Corn

That's a clean way to put it. And it's the same distinction the Athenians were making when they stamped a lead weight. The stamp wasn't the weight being honest. The stamp was somebody standing behind it.



Hilbert

It was a Tuesday, and I notice this because I was the one doing it.



Hilbert

Second Tuesday of every month, I'd go round the eleven sites with the case and the reference set. Six weights in a mahogany case with the felt cutouts, and each one had its own certificate in a plastic wallet, and the certificates went back eleven years to the same lab in Zurich. I never once opened a certificate. That wasn't the job. The job was to put the reference set on the slab, and put the working set next to it, and look at the zero drift on the comparator, and if the drift was over the line I tagged the scale out of service and signed the tag with the date and the time.



Corn

How big was the case, out of interest.



Hilbert

About the size of a briefcase, and it weighed eleven kilos, which is more than a briefcase has any business weighing, and I carried it on the train because the firm wouldn't pay for the van. Two hundred and forty pounds a year travel allowance, and the van quote was four hundred and ten, so the arithmetic was done for me. I did that route for six years.



Herman

And the tag on the scale. What did the tag say.



Hilbert

It said out of service, and the date, and my initials. Three things. Nothing about why. The why went in the log at the site, in the back of the folder, and the folder lived in the site office and got water in it twice.



Corn

The folder gets water in it, the tag survives.



Hilbert

The tag survives because the tag's the thing that stops somebody using it. The folder's for the auditors, and the auditors were informed, but they were informed later and in a different building. Anyway, the detail I wanted to raise with you two. You said the prototype and the copies diverged, tens of micrograms over a century. Fine. But the thing I'd want on the record is what a comparative weigh looks like in practice. You don't put the prototype on a scale. You can't. You use a comparator, and the comparator doesn't tell you what anything weighs. It tells you the difference between what you put on the left and what you put on the right, and that's a much easier instrument to build than a scale, and it's been the same instrument at the bottom of the whole business since before either of you were born. The BIPM was doing that with the prototype from 1889, and the fundamental instrument hasn't changed. The electronics have, the rest of it hasn't. You want to compare two masses, you use a comparator, and you compare them against a third one if you're sensible, and you do it twice with them swapped over, and that's it.



Herman

You're right, and I should have said it that way.



Hilbert

Swapped over. That was the bit I came out here for, actually.



Corn

Swapped over is the whole trick. You're cancelling the instrument's own bias by measuring it in both directions.



Hilbert

You're measuring the instrument as much as the weights.



Herman

Which is the same instinct as the CIPM arrangement, done with a piece of brass on a bench instead of a database. Compare, swap, compare again, and publish both numbers.



Hilbert

That's it. And the case. Eleven kilos. I've still got the case.



Herman

So the thing I'm taking from that is that the whole international system is a comparator scaled up. The comparison is the primitive operation. Everything else, the database, the certificates, the peer review, is bookkeeping on top of the fact that at the bottom, somebody does a comparison, swaps the sides, and does it again.



Corn

And the swap is the part nobody sees. The published number is one figure. The swap is what makes it trustworthy.



Herman

Which is the correct place to leave it, because it means Daniel's one-gram weight is not actually asking a question about weight. It's asking who did the swap, and whether anybody bothered.



Corn

And the answer for the thing in the envelope is almost certainly nobody.



Herman

Almost certainly nobody, and it's not a scandal. It's a product at a price point. The label is the product. If you want the comparison, you buy the comparison.



Corn

Which is honest, in its way. The seller isn't lying. They're selling a label, and you're buying one.



Herman

And the ancient inspectors would have had a very clear view on a merchant who sold the stamp instead of the measure.



Corn

They'd have smashed it.



Herman

They'd have smashed it, and they'd have put it in the annual report on a rock. So the arc, if you look at it whole: a bronze weight in an Athenian market and a platinum cylinder in a vault in Sèvres are the same solution to the same problem, and both of them failed in the same way, which is that the reference was a thing, and things drift. The modern fix is to take the reference out of the world entirely. The kilogram is now a number, and the number is exact, and anybody with the apparatus can build it. What's left is not the definition. It's the comparison and the paperwork.



Corn

And as the catalogue of certified standards gets more precise, the gap between the certified chain and the consumer grade instrument on your desk gets wider. Not because the cheap thing got worse. Because the good thing got better, and the label stayed the label.



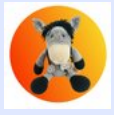
Herman

Which is the shape of it, and it's not going to resolve, because the problem was never the definition. It was whether the man across the table is standing behind his number.



Corn

If this was your kind of episode, go back for episode twelve thirty-nine, Why Can't We All Use the Same Screw; episode eleven seventy-seven, The Race Against the Digital Dark Age; and episode sixteen, On Deepfakes, SynthID, And AI Watermarking. This has been My Weird Prompts. Thanks to Hilbert Flumingtop, who produces the show, and who has a case.



Herman

If you enjoyed this one, leave us a review on your podcast platform of choice. It helps other listeners find the show.



Corn

If you've got a question about honest weights, or anything else, send us your own prompt on Telegram at t dot me slash MWP listener bot.



Herman

We'll be back soon. See you then.