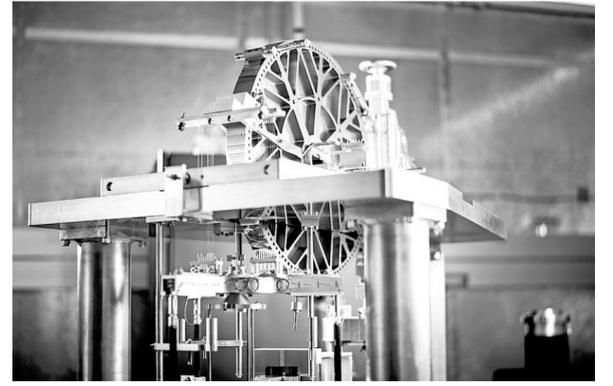


PAGE TWO



PHOTOGRAPHS BY MATT ROTH FOR THE NEW YORK TIMES

Clockwise from above left: a one-kilogram sphere of single-crystal silicon; the Kibble balance, which helped define two units of measurement; and, from left, Stephan Schlamminger, Jon Pratt and David Newell displaying tattoos related to the Planck constant.

The kilogram is dead. Long live the kilogram!

A century of research and an international vote redefine 4 crucial units

BY XIAOZHIM LIM

Since 1889, Le Grand K, a sleek cylinder of platinum-iridium metal, has ruled from its underground vault in Paris. An absolute monarch, it was the very definition of one kilogram of mass. Scientists from around the world made pilgrimages to it, bringing along their national kilogram standards to weigh in comparison.

"The mother ship is never wrong," said Robert Vocke Jr., a chemist at the National Institute of Standards and Technology (N.I.S.T.) in Gaithersburg, Md.

No longer. On Friday, in a small conference center just steps from the Palace of Versailles, several dozen nations voted to overthrow Le Grand K and to redefine the kilogram and three other standard units of measure: the ampere, for electrical current; the kelvin, for temperature; and the mole, which describes the amount of a chemical substance. The vote fulfills an 18th-century dream. Henceforth, all seven units in the International System of Units, otherwise known as the S.I., will no longer be defined by material objects and instead will be defined only by abstract constants of nature.

"This arc of history started before the French Revolution and now, I think we've finished the journey," said Stephan Schlamminger, a N.I.S.T. physi-

calist. The "democratization of the units," he said, is now complete.

The S.I. originated at the end of the 18th century with just the meter and the kilogram. The idea was to standardize the basic units of trade and scientific measurement. After all, for one kilogram of gold coins to hold universal value, everyone has to agree on the exact definition of one kilogram.

By 1875, 17 nations had signed the Treaty of the Meter in Paris, which set international standards for the meter and the kilogram. The meter was defined as the distance between two scratches on a hallowed bar of platinum-iridium metal. The standard kilogram was Le Grand K. Both artifacts would be stored under lock and key at the International Bureau of Weights and Measures, with copies distributed to various countries.

"People called it 'for all times, for all people,'" Dr. Schlamminger said. But it wasn't. A physical object could be scratched, chipped or even destroyed. Scientists began to dream of standard units of measurement that would remain forever constant — standards with definitions built from the fabric of the universe.

The meter achieved this stature in 1983, when it was redefined in terms of the universally constant speed of light. Scientists had been estimating light's speed for centuries, but not until the 1970s, following experiments involving lasers in a vacuum, did they settle on a number: exactly 299,792,458 meters per second.

The meter was defined accordingly, as the distance traveled by a beam of

light in exactly 1/299,792,458th of a second. (The second, another fundamental unit, has been defined since 1967 as the amount of time it takes an atom of cesium-133 to vibrate 9,192,631,770 times.) In effect, a meter no longer needed to be measured; now it could be conjured on demand — "realized," in the parlance of metrology.

THE DECLINE

In 1990, metrologists discovered that Le Grand K had mysteriously become lighter than its six official copies by some 50 micrograms. The kilogram standard was in trouble, and the mission to redefine it took on a new level of urgency. Over the years, two possibilities presented themselves: to measure the exact mass of one kilogram in terms of the electromagnetic force required to lift it, or in terms of the specific number of atoms in its mass. But like the meter before 1983, neither of those experimental ideas linked the kilogram to a fundamental constant.

That link appeared in the form of the so-called Planck's constant, which converts the macroscopic wavelength of light to the energy of individual photons of light. Only highly accurate experiments could provide an agreeable number for Planck's constant, paving the way for a new definition of the kilogram.

"If you can't do that, your definition is useless," Dr. Robinson said.

One method of redefining the kilogram sprang from an effort to better realize the ampere, the standard measure of electrical current. In 1975, Bryan Kibble, a physicist at the National Physical Laboratory (N.P.L.) in London, was

handed the unenviable job of improving an instrument called the ampere balance. The device could measure electrical current in terms of weight, but only poorly. "It was a devil to work with," said Anne Kibble, a retired N.P.L. scientist and the widow of Dr. Kibble, who died in 2016.

Dr. Kibble dreamed up a different apparatus, renamed the Kibble balance following his death, that eliminated many of the sources of inaccuracy and error that plagued the original.

"All of the difficult things just melt away," said Dr. Robinson, who worked closely with Dr. Kibble. Together, Dr. Kibble and Dr. Robinson built the world's first Kibble balance, named the N.P.L. Mark I, in the 1970s.

"This arc of history started before the French Revolution and now, I think we've finished the journey."

At around the same time, physicists elsewhere discovered two new quantum mechanical effects, which linked Planck's constant with electrical voltage and resistance. Dr. Kibble's instrument, invented as a way to measure electric current in terms of weight, inadvertently became a way to also measure Planck's constant. Just as with the experiments that measured the speed of light, once Planck's constant was measured with extreme accuracy and agreed upon, the role of the Kibble balance could be reversed, to define a kilogram in electromagnetic terms.

THE AVOGADRO PROJECT

In the 1990s, a few hundred miles to the east, Horst Bettin, a physicist at the Physikalisch-Technische Bundesanstalt in Germany, was working on realizing the kilogram in a very different way, by counting atoms.

Another standard unit used by scientists, the mole, roughly describes how many particles are contained in a given amount of mass. Dr. Bettin figured that if he could create an exceptionally perfect silicon crystal — ultrapure, spherical and with a very orderly atomic structure — that weighed exactly one kilogram, and counted the atoms with the unit moles, he could essentially define a kilogram as a specific number of silicon atoms.

"That was our idea," Dr. Bettin said. "It would be far more simple than with the Planck constant."

In effect, Dr. Bettin had devised an experiment that would precisely measure a constant known as Avogadro's number, which for many years dictated that one mole of a substance contains 6.022×10^{23} particles such as electrons, atoms, ions, or molecules.

Avogadro's number had been estimated but, like the speed of light, never precisely measured and agreed upon. (As of today, Avogadro's constant has been set at the value $6.02214076 \times 10^{23}$.)

Crucially, Avogadro's constant and the Planck constant are intertwined in the laws of physics. Having measured Avogadro's constant, Dr. Bettin could derive the Planck constant. And with a precise measure of the Planck constant, he could validate the results of Dr. Kibble's work, and vice versa.

AN HEIR TO THE THRONE

But the kilogram could not be redefined until the scientists had derived the same answer for the Planck and Avogadro constants within seven decimal places.

"What we call 'measurement' is an estimate," Dr. Schlamminger said. "Basically you can estimate what the true value is. The true value, only the universe knows."

That accomplishment took twenty years. In 2008, the N.P.L. shut down the Kibble balance effort and sold the instrument to Canada's National Research Council (N.R.C.). By 2014, the Kibble balances from N.I.S.T. and N.R.C. produced numbers for the Planck and Avogadro constants that agreed with the results from Dr. Bettin's work for the first time.

Friday's vote cements the values of the Planck and Avogadro constants, and releases the kilogram from its earthly form.

The four new definitions — for the kilogram, ampere, kelvin and mole — will officially take effect after World Metrology Day, next May 20. The transition will only be felt at the frontiers of science and technology; the everyday world will not notice.

"They mustn't notice, because if they do, we haven't done our jobs right," said Dr. Robinson, of the N.P.L.

Le Grand K will join its counterpart, the meter bar, in the archives of metrology. Dr. Bettin will retire next year. Dr. Schlamminger has set his sights on big G, the universal gravitational constant.

"If we love to measure things," he said, "there's tons of stuff out there that can be measured."

Louis Armstrong's life, in letters, music and art

ARMSTRONG, FROM PAGE 1

pletely aware of his importance and wanting to be in control of his own story."

And it wasn't just posterity. The same things that drove him as a performer — faith in unfettered communication, an irreverent approach to the strictures of language, the desire to wrap all of American culture in his embrace — course through his writings, collages and home recordings.

Armstrong had been largely responsible for shaping jazz into the worldly, youth-driven music it became in the 1930s. He emerged as a symbol of racial pride, crossing Tin Pan Alley gentility with street patois, and sometimes singing directly about black frustrations. But as his career went on, his grinning stage persona — an expansion on the minstrel shows and New Orleans cabarets of his youth — fell out of step with most African-American listeners' tastes. ("I loved the way Louis played trumpet, man, but I hated the way he had to grin in order to get over with some tired white folks," Miles Davis wrote in his autobiography.)

With jazz's identity solidifying as an art music in the 1950s, Armstrong became especially unfashionable to the critical establishment. The autumnal hits he scored in the mid-1960s, "Hello, Dolly!" and "What a Wonderful World," seemed only to confirm the media consensus that the times had passed him by.

But these archives contain the tools to better understand Armstrong: He was as idiosyncratic an artist as any, one whose creative instincts only grew deeper and broader over time.

In part, we see a man attuned to race and politics, who took his role seriously as a global ambassador for American culture and kept a close eye on the achievements of fellow African-Americans. When he spoke out against school

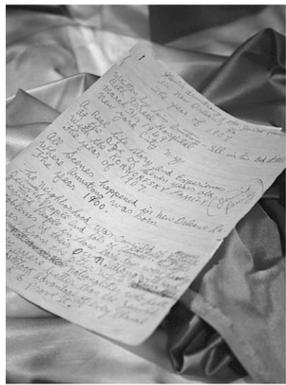
segregation in Little Rock, Ark., in 1957, he surprised the nation. Some activists said it was too little, too late. The archive, however, shows that he considered it both a proud moment in his career and wholly of a piece with his life up to that point. In the collection is a telegram he wrote to President Dwight Eisenhower on the day Eisenhower announced he would be sending Army troops into Little Rock, urging him "to take those little Negro children personally into Central High School along with your marvelous troops."

And as solicitous as he was, Armstrong was unwilling to let critical judgments define him. He kept a close eye on reviews, but he wrote acerbically about music critics and sometimes taped his interviews with them — perhaps for evidence, in case they misreported something. On one tape, from 1959, he barks at a journalist after being asked about changes afoot in jazz. "I just live what I play, and I can't vouch for the other fellow. As long as I feel and hit the notes and I've got my own audience, then no critic in the world can tell me how I should play my horn," he says.

LOOKING AT US LOOKING AT HIM

Raised in New Orleans, Armstrong came to fame in his early 20s after joining King Oliver's Creole Jazz Band in Chicago; his early recordings as a leader, with his Hot Five and Hot Seven, established jazz as a soloist's music, and made him one of the first pop musicians of the radio era. By the 1940s and '50s he was regularly included on lists of the most admired Americans.

Starting in his 20s, Armstrong frequently clipped newspaper articles about himself and bundled them into scrapbooks. The books began as a tool to convince club owners of his legitimacy, but they turned into a historical record. The dozens of scrapbook binders con-



Left, a page from a long essay Louis Armstrong began in 1969 about his early life in New Orleans. Right, a photo of Armstrong with a teenage trumpet player.



tained in the archive are a window into his self-image as a celebrity: Armstrong looking at us looking at him.

Armstrong began his career as an idol to many African-Americans. Watch the well-circulated video clip of him performing in Copenhagen in 1933 — bountiful and aggressive as he scats over "Dinah," then carves his way through "Tiger Rag" with a sweltering trumpet solo — and you'll get why. But as time wore on, many younger people, particularly musicians of the bebop generation, expressed misgivings about his genuflecting stage persona.

Armstrong's scrapbooks make it clear that he kept a close eye on how he was perceived, as an artist and as a black statesman. When he traveled to Baltimore in the winter of 1931, he donated 300 bags of coal to residents of a needy black neighborhood, and privately

saved the news clipping from The Baltimore Afro-American. When his band was arrested in Arkansas simply for traveling in the same bus as its white manager, he saved the article reporting it.

ORIGINALITY MATCHED ON THE PAGE

Armstrong wrote constantly — mostly letters and short stories about his life, but also in the form of limericks and pages-long jokes. He wrote in a galloping, oddly punctuated style, treating literature almost as an outsider art. Commas turned into apostrophes; jive talk collided with standard English; words were underlined all over. His musical originality is matched on the page.

When Armstrong joined King Oliver's famed band, he brought along a typewriter. By 1936, when he was in his mid-30s, he had already published an

autobiography. Over the course of his career he wrote more than 10,000 letters to fans, hundreds of pages of personal memoirs and enough lengthy jokes to fill an entire book.

In 1969 and '70, with his health failing, Armstrong set about writing a long essay about his relationship with the Karnofskys, a Jewish family in New Orleans. When he was 7, he worked as a servant in their house, and they recognized his musical talent early, advancing him a small amount of money to buy his first cornet.

In this essay, which stretches on for 77 pages, Armstrong enshrines a number of other elements of his personal mythology. He reports his birthday as July 4, 1900, an apocryphal but symbolic date he was fond of using. And he describes the importance of the Storyville neighborhood where he was raised, and where much of early jazz was developed.

Just months after he wrote this piece, he died in his sleep at age 69. This story would be collected in a posthumous book, "Louis Armstrong, in His Own Words," that featured essays from across his career, many of which are included in the Armstrong archive in their original, handwritten form.

Armstrong's creative hobbies outside writing were less easily wrangled for posterity or publication. One example: the hundreds of collages that he made over the course of his life, cutting out and combining photographs, illustrations and text.

Starting in the early 1950s, few pieces of paper were safe from the blade of Armstrong's scissors: magazines, risqué photographs, even a Christmas card from Richard Nixon wound up cut and collaged. Most of the time, he taped his collages onto reel-to-reel tape boxes; they were purely decorative. Elsewhere, he turned larger pieces of paper

into what amounted to a personal hall of fame.

In one such collage, he crammed a page with almost a dozen photos of Jackie Robinson. On another, Duke Ellington and Kermit Parker, the first black man to run for governor as a Democrat in Louisiana, gaze toward each other from across the page.

ON THE RECORD

Starting in December 1950, Armstrong used a tape recorder to capture casual conversations, road hangouts, interviews with journalists, radio broadcasts he liked and more. Most often, though, he would simply record his shellac and vinyl discs to tape, consolidating the music and making it easier to carry. He kept careful documentation of the track lists, and together the tapes and their accompanying lists provide a revealing glimpse into his broad music tastes.

On a disc marked "Reel 24," he is listening mostly to the bebop musicians that had succeeded him in the jazz spotlight of the 1940s and '50s. On the audio of the tape itself, you can hear him announcing the tunes like a radio D.J.

After that tape plays, Armstrong introduces another: a bootleg recording of a jam session at Minton's, the venue where bebop was born. After he plays it, he expresses approval. "Cats jumpin' man," he says, apparently unperturbed by the beboppers' sometimes-ambivalent relationship to his own legacy. Later on, he jumps to a track of his own, "Among My Souvenirs." In the handwritten playlist, Armstrong closely notes each turn in the tape, including the moment when he pauses to mention the children playing outside.

These are the children that Armstrong said he was thinking of when he sang his most famous song, "What a Wonderful World." Here we have their very voices, documented for all time.