*The 28th International Meeting of Collectors and Researchers of Slide Rules and other Historic Computing Instruments*

*IM2022 — Virtual Meeting*
*17-18 September 2022*

# Fermi's Golden (Slide) Rule

Mike Syphers

THE OUGHTRED SOCIETY

http://followingtherules.info

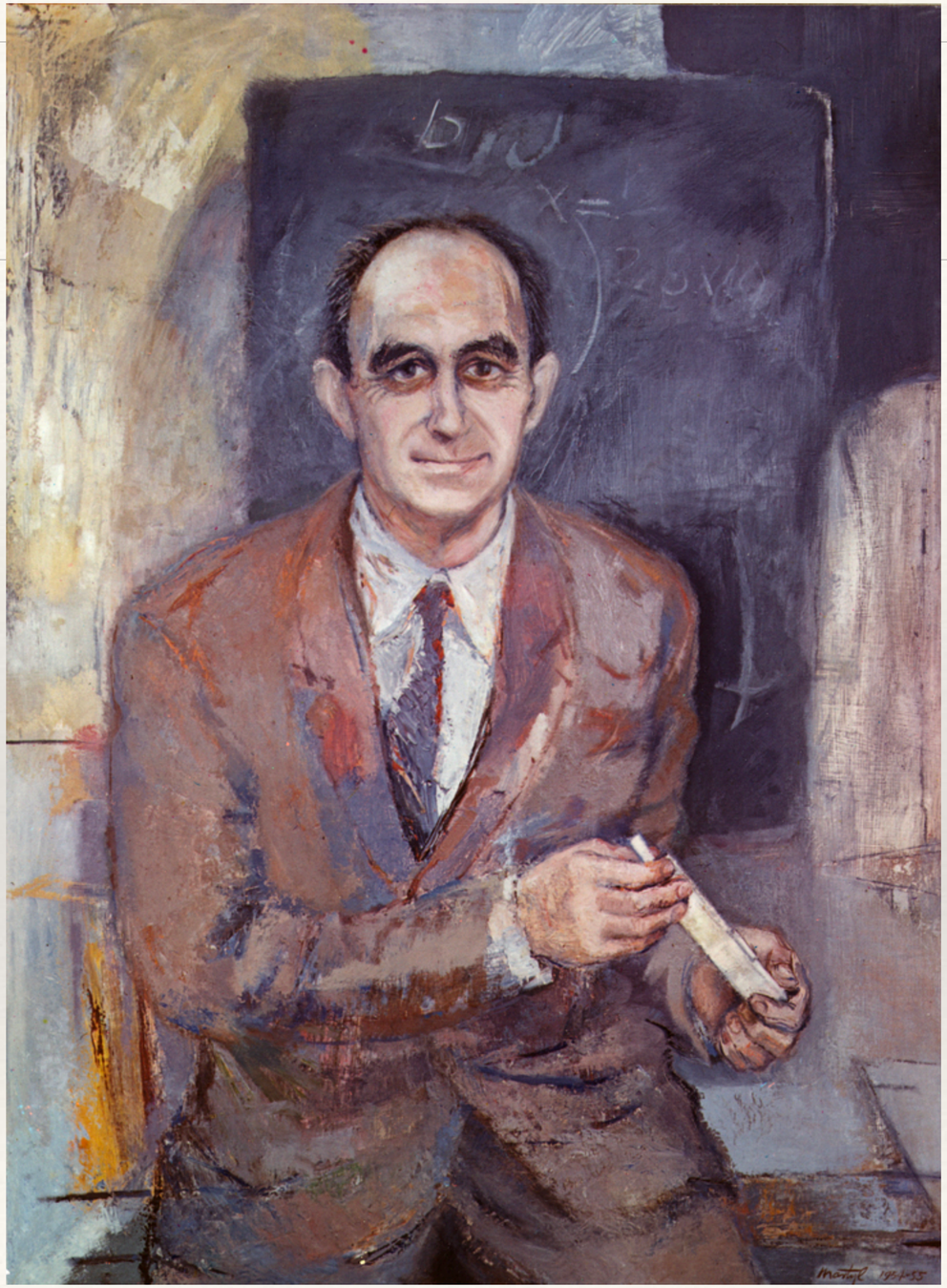
# Life during COVID

- Pandemic time led to many new online connections; for example, Michael Konshak began weekly ISRM video conferences, via Google, for slide rule discussions
- During one of these discussions, in early 2020, we were talking about slide rules used by famous people such as Einstein and van Braun. Michael asked me: What slide rule did Enrico Fermi use?
- Living near Chicago and working at Fermilab, I realized this was a natural question that I should investigate a bit further

# Fermi and His Slide Rules

- Enrico Fermi was one of very few physicists to excel in both theoretical physics and experimental physics. He was noted for always having access to a slide rule, often from his suit coat pocket.


*images from ISRM web site*



Original painting by Martyl (Martyl Schweig Langsdorf), 1955, located at Enrico Fermi Institute, University of Chicago.

*http://photoarchive.lib.uchicago.edu/db.xqy?one=apf1-06049.xml*

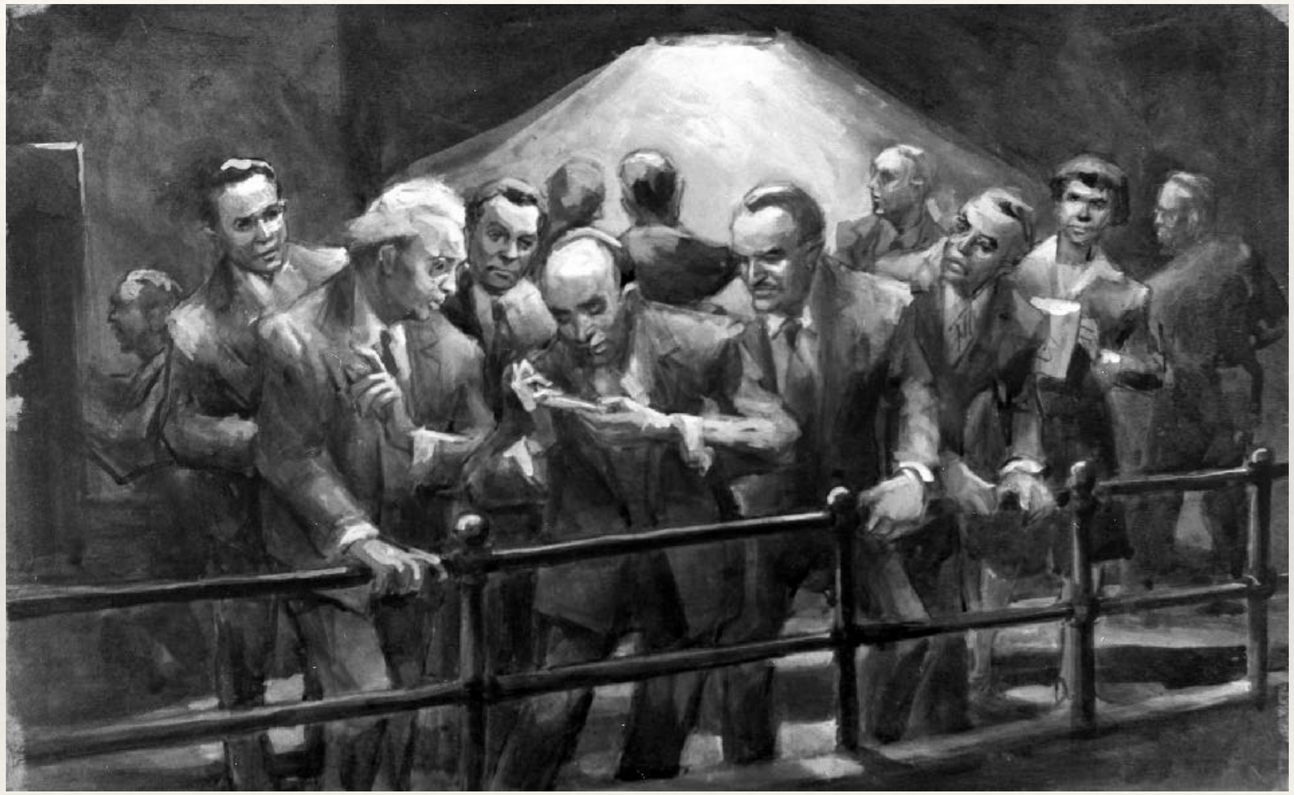
# Enrico Fermi

- Born in Rome, Italy, in 1901. Received his *laurea* (equiv. PhD) at the age of 20. In 1926, Fermi discovered the statistical laws, nowadays known as "Fermi statistics", governing the particles subject to Pauli's exclusion principle. Became Professor of Theoretical Physics, University of Rome in 1927.
- His most significant papers were published in 1934, 1935, and 1936; these earned him the Nobel Prize in Physics in 1938 for his work on induced radioactivity by slow neutrons.
- Fermi left Italy that year with his wife of 10 years, Laura, to receive the award; he never returned to Italy, immigrating to the U.S. to escape Mussolini's fascist dictatorship.
- Arriving in New York in 1939 he was greeted with 5 job offers at competing universities. Accepted position at Columbia University in NYC.
- In 1941, Fermi moved to University of Chicago, primarily to work on the Manhattan Project during WWII. Helped identify a location in Argonne Woods, outside of Chicago, to build the first nuclear reactor; but an industrial dispute halted the work there; convinced the university to build the reactor on campus — underneath the bleachers of the football field! He became a UC professor in 1944.

# Under the Bleachers in 1942

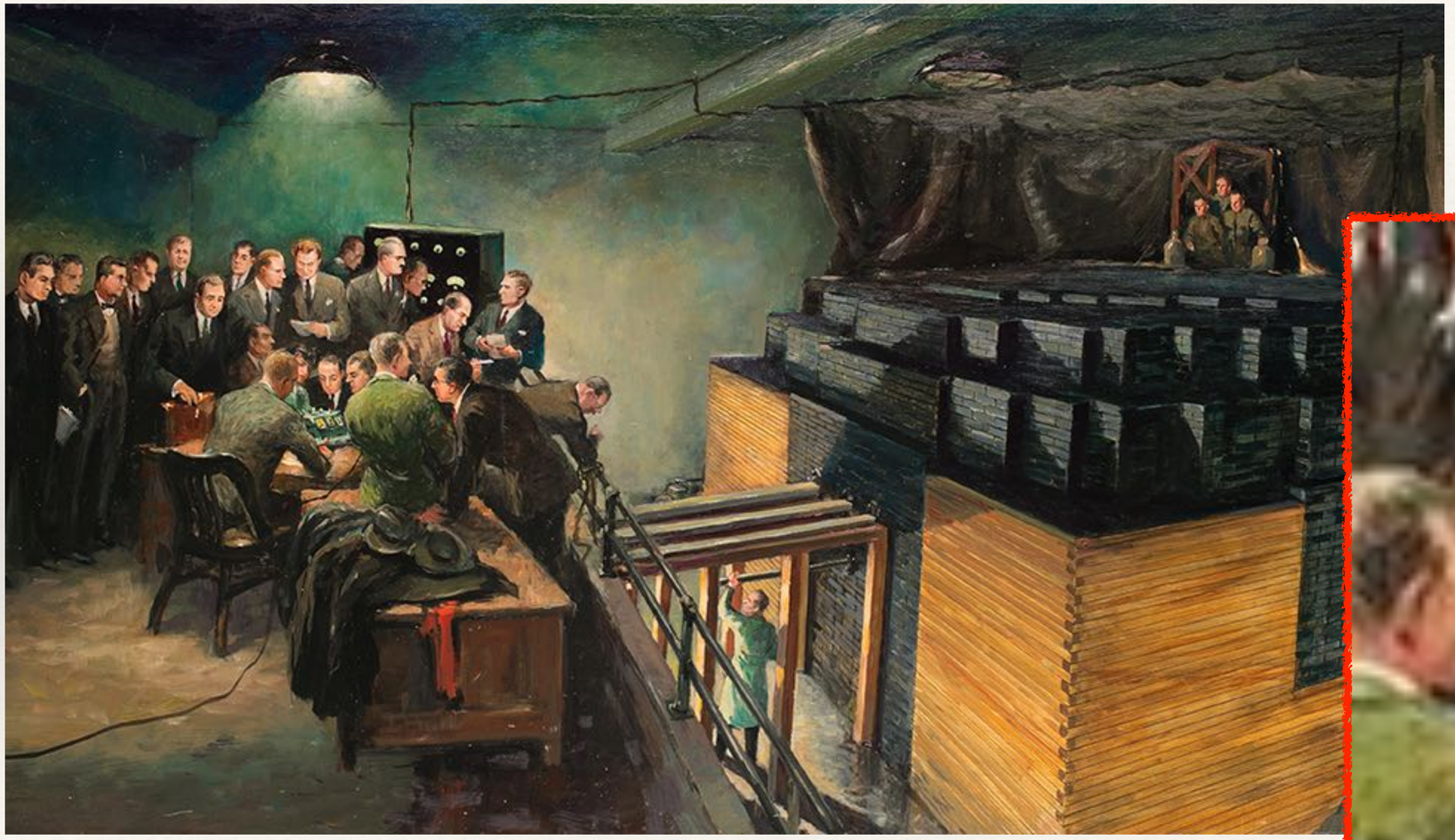
- From Maureen Searcy Ingrid and Gonçalves, *U. Chicago Magazine*, 30 Aug 2017:
  - "At 2:30 p.m. the experiment resumed. Weil again pulled out the remaining main rod in a series of measured increments, and the neutron intensity rose at a steadily increasing rate. Fermi ran calculations on his slide rule before announcing, "The reaction is self-sustaining. The curve is exponential." The rods were replaced at 3:53 p.m. to end the reaction. Quiet applause rippled through the audience."

Note: Power level that day: $\frac{1}{2}$ Watt!



One of 24 John Cadel paintings recreating the Chicago Pile-1 experiment. (Image courtesy Argonne National Laboratory)

# Chicago Pile No. 1

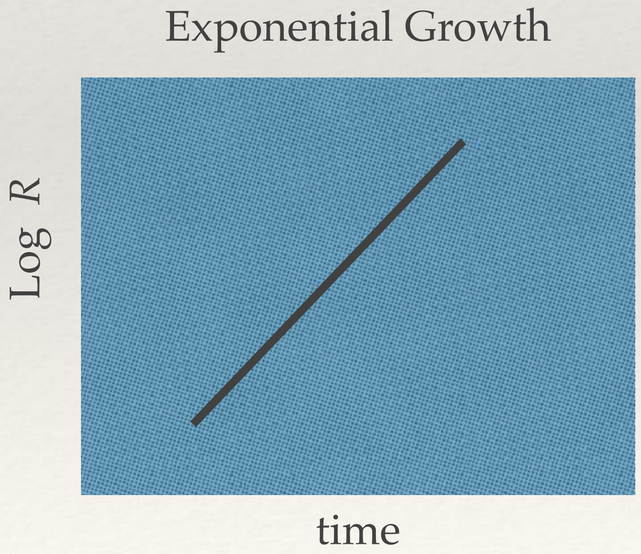


Gary Sheahan, “The Birth of the Atomic Age”, oil painting, 1957. Chicago Historical Society.

# Calculation of Pile Efficiency

- “At the Hanford (Washington state) site in 1944, Fermi inserted the first uranium slug into the “B” pile reactor, just as he had for the first pile in the CP-1 reactor two years earlier. During the "B" reactor test, Fermi was in charge of directing operations. His meticulous calculations, *completed on a slide rule,* determined how much uranium needed to be added to the reactor; measurements confirmed that his calculations were astoundingly accurate.”

*Tour Group, outside the Hanford B Control Room*



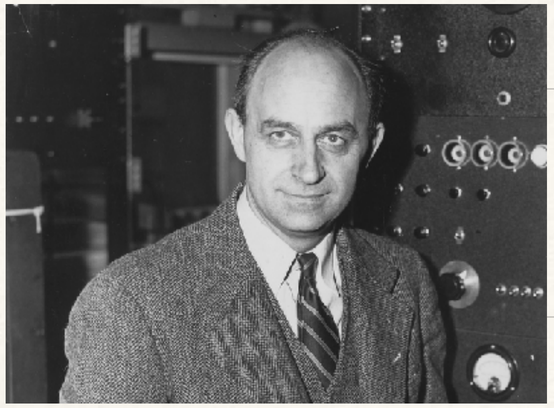

from "Voices of the Manhattan Project”, a joint project by the **Atomic Heritage Foundation** and the **Los Alamos Historical Society**

Fermi would have used a Log-Log rule, no doubt!

# Argonne National Laboratory

- Built at the Argonne Woods site, about 20 miles west of University of Chicago, ANL was the first of the U.S. "National Laboratories", which were established after WWII. ANL was formed in 1946 and was home to the first fully operational nuclear reactor in the U.S.
- Today there is no nuclear reactor on site, but the lab does operate a nuclear physics accelerator facility and one of the world's premier "synchrotron radiation" light source facilities, as well as chemistry and biology labs.
- It is also home to the Argonne Leadership Computing Facility providing supercomputing resources and expertise to the research community.

*1957 ad*



# Enrico Fermi

- Fermi married Laura Capon in 1928. They had one son Giulio and one daughter Nella. His favorite pastimes were walking, mountaineering, and winter sports.[1]
- Fermi died in Chicago on 28th November, 1954 and is buried in the Oaks Woods Cemetery, Chicago.
- The *National Accelerator Laboratory* in Batavia, IL, founded in 1969, was renamed the *Fermi National Accelerator Laboratory (Fermilab)* in 1974. The premier U.S. laboratory for the study of fundamental sub-atomic particles, it was home to the highest-energy particle accelerators in the world until 2008 when the Large Hadron Collider was commissioned in Europe.

[1]From *Nobel Lectures, Physics 1922-1941*, Elsevier Publishing Company, Amsterdam, 1965

# Fermi National Accelerator Laboratory

- Batavia, IL, about 35 mi west of downtown Chicago
- High Energy Physics
  - accelerates protons to “Big Bang” energies
    - have gone up to 1 Trillion “electron volts” per proton

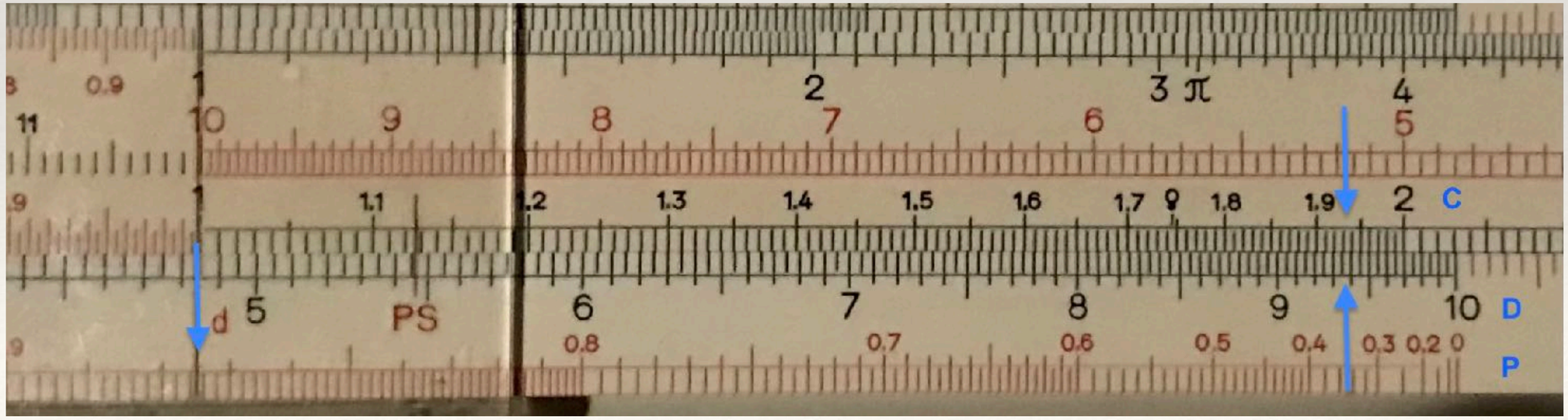
# Speed of a 1 Billion eV ($10^9$ eV ) Proton

- A “relativistic” calculation — proton rest energy ($mc^2$): 0.938 x $10^9$ GeV
  - compute 0.938 / (0.938 + 1.0) = 0.484 on C/D scales
  - use P scale (hopefully your rule has one!) and read off the answer at 1 on C
    - = $v/c$ = *0.875 light speed* *( = 163,000 miles/s = 262,000 km/s )*

$$E = mc^2 + W = \frac{mc^2}{\sqrt{1-(v/c)^2}}$$

$$v/c = \sqrt{1-\left(\frac{mc^2}{mc^2+W}\right)^2}$$

$1\ \text{eV} = 1.6 \times 10^{-19}\ \text{J}$



# Connecting with Fermi

- During my search for information about Enrico Fermi, I came across a photograph and article of his granddaughter, Olivia Fermi.
  - The article was from a Vancouver, B.C., newspaper, a “review” of a talk she had given to the local community

“Calculations for the atomic bomb were made with a slide rule. Here, Olivia Fermi holds the slide rule used by her grandfather, Enrico Fermi.”

# Olivia Fermi on the Neutron Trail

https://neutrontrail.com/

- Continuing, I found that Olivia had a web site, and on the site was another photograph of the same slide rule, resting on a copy of a book written by her grandmother, Laura Fermi

Laura Fermi 1962, Courtesy Special Collections, University of Chicago

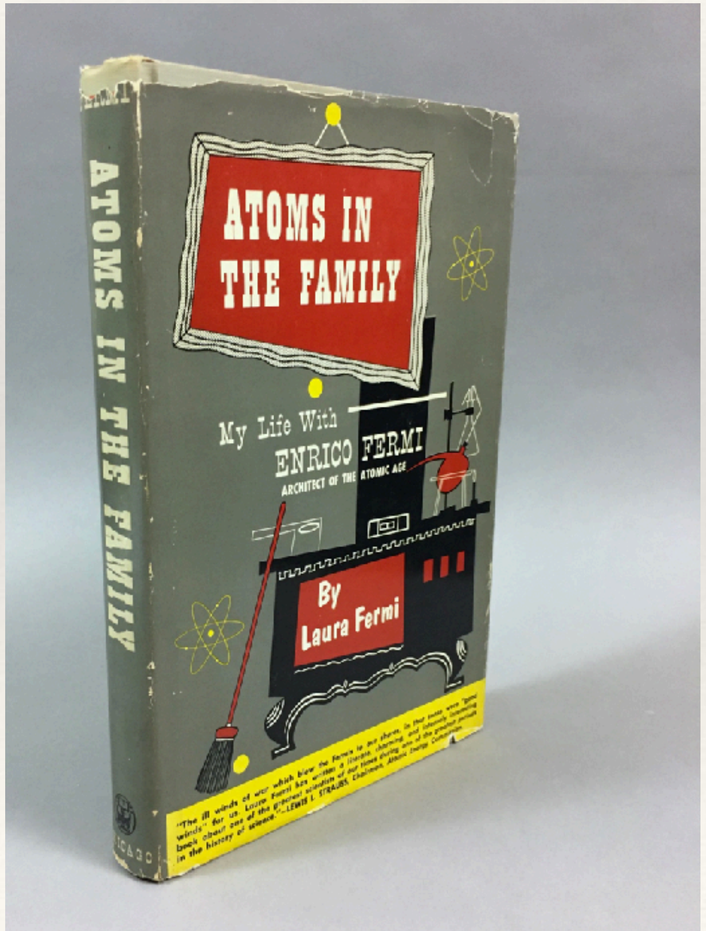



photo by Olivia Fermi


Laura and Enrico Fermi at the Institute for Nuclear Studies, Los Alamos, 1954

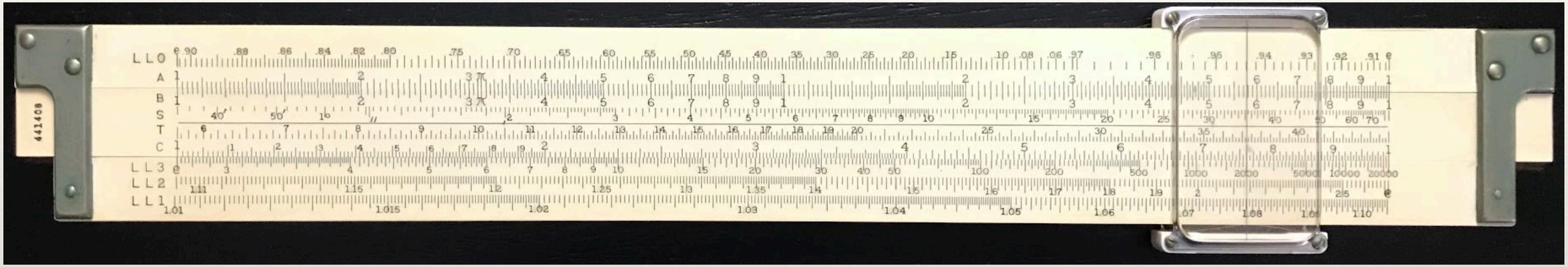
# Rule No. 1

- Finally, a Fermi slide rule picture in which I can discern detail!  The model number is hard to read in the image, but…


- K&E 4092-3  (only K&E model with this scale set  —  K DF [ CF CIF CI C ] D L  )

# The K&E 4092-3

The back side of a 4092-3 (from my collection):




The original 4092, introduced in 1909, was the first K&E rule which had Log-Log scales

— exponential function ($e^x$), natural logarithms ($\ln x$), powers ($x^y$)

— scales were reconfigured in about 1922: 4092-3 and 4092-5

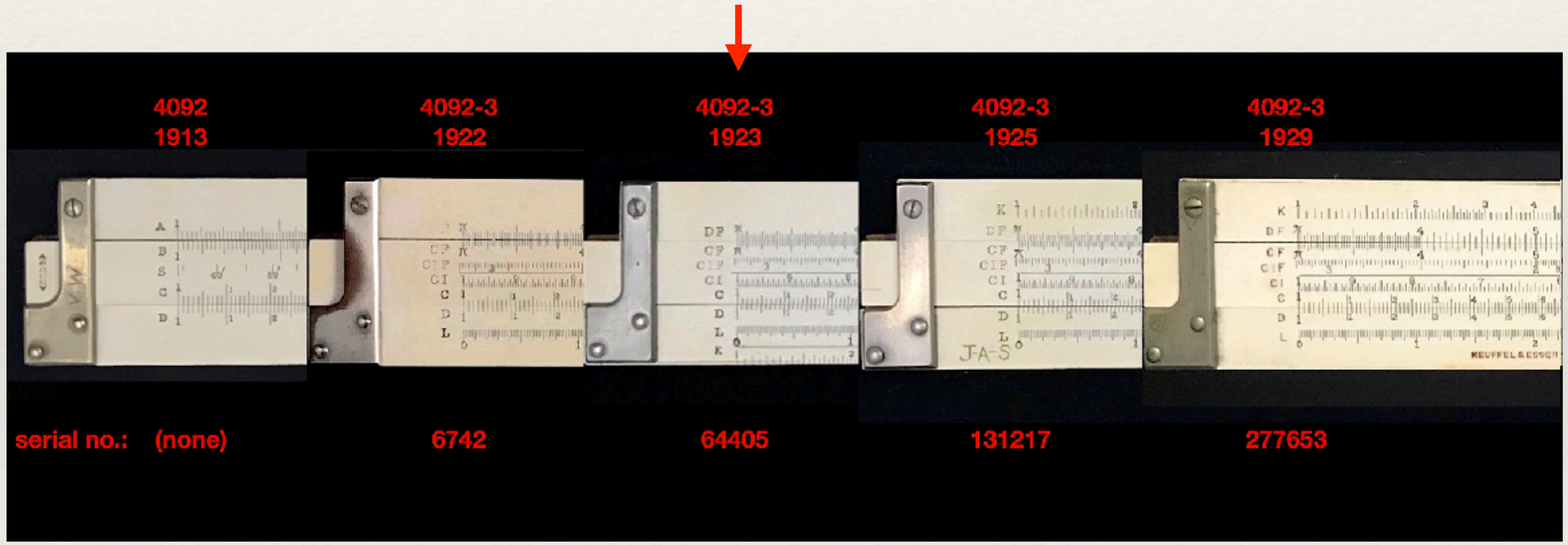
The 4092-3 and 4092-5's were discontinued in about 1937

Would have been very useful to Fermi during this time frame

# K&E 4092-3 Scale Sets

- It was my investigations of Fermi's K&E 4092-3 that led me to take another look at the four in my collection (at that time), in which I discovered I had a unique version — a *transitional* rule with a unique scale layout.

(See JOS 30:2 and OS2021 talk)




- Fermi's rule was from the final scale set — *sans serif* font, K scale on top
  - a serial number would help fix the date — sometime about 1925-1937

# Connecting with Fermi [2]

- After finding the above photos of the 4092-3, I wrote a short *vignette* for the web site I had started in 2020 during the pandemic. (followingtherules.info)
- In Jan 2021 I decided that since I had found the photo on Olivia Fermi's web site, and she had an email address there, that I'd send her a short message.
  - she responded, almost immediately!
  - within a week Olivia sent me an image of the other side of the 4092-3, yielding the serial number of the slide rule…

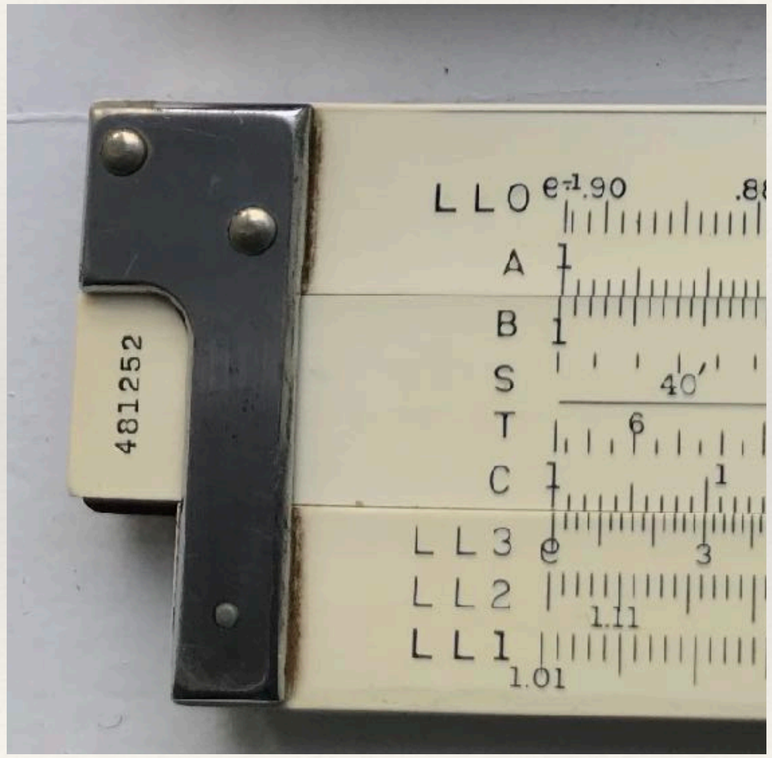
# Enrico Fermi's 4092-3

- photo from Olivia Fermi:

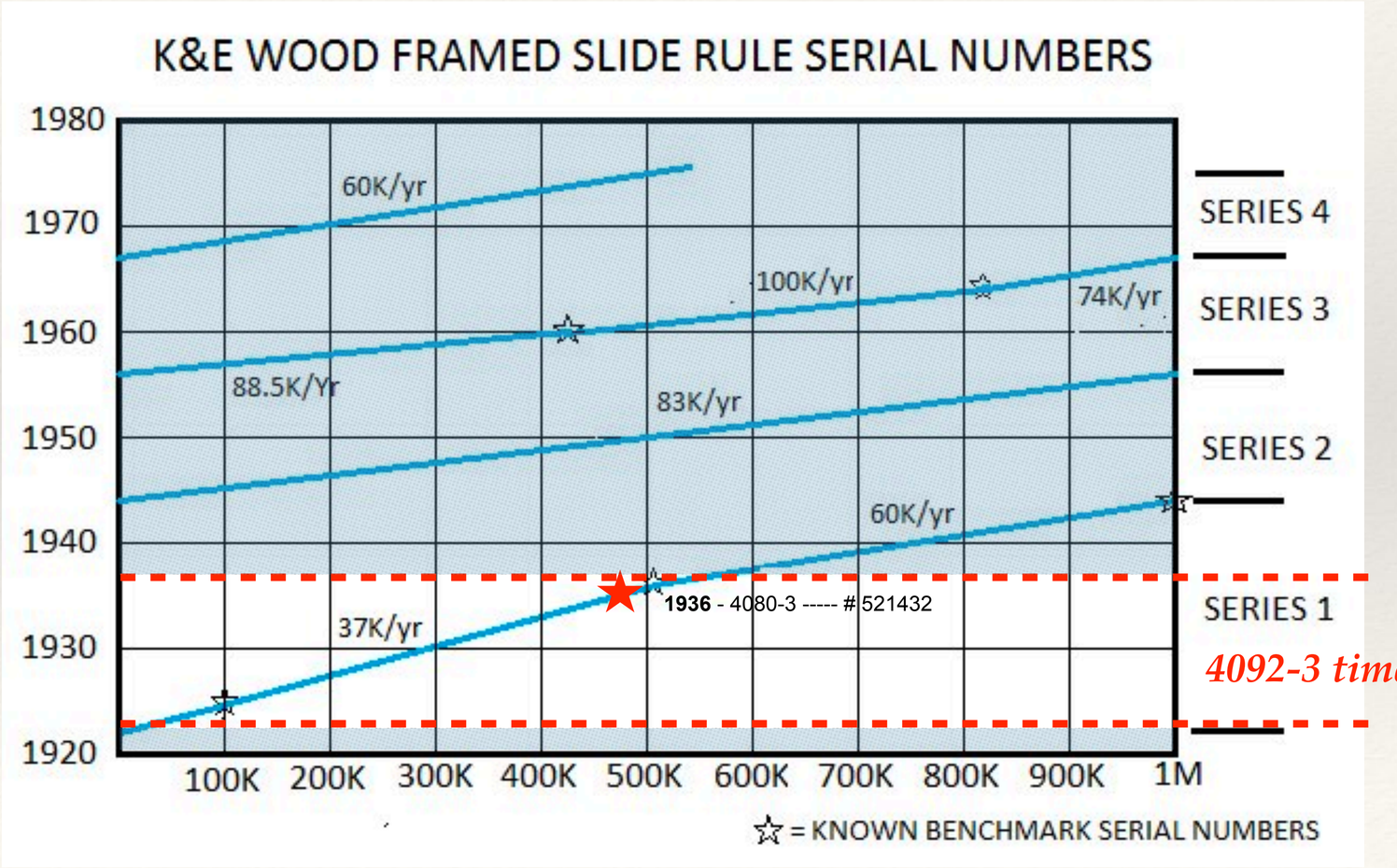

Serial Number: 481252

# Dating of Fermi's 4092-3

- https://www.mccoys-kecatalogs.com/keserialnumbers/KESerialNumberChart.jpg

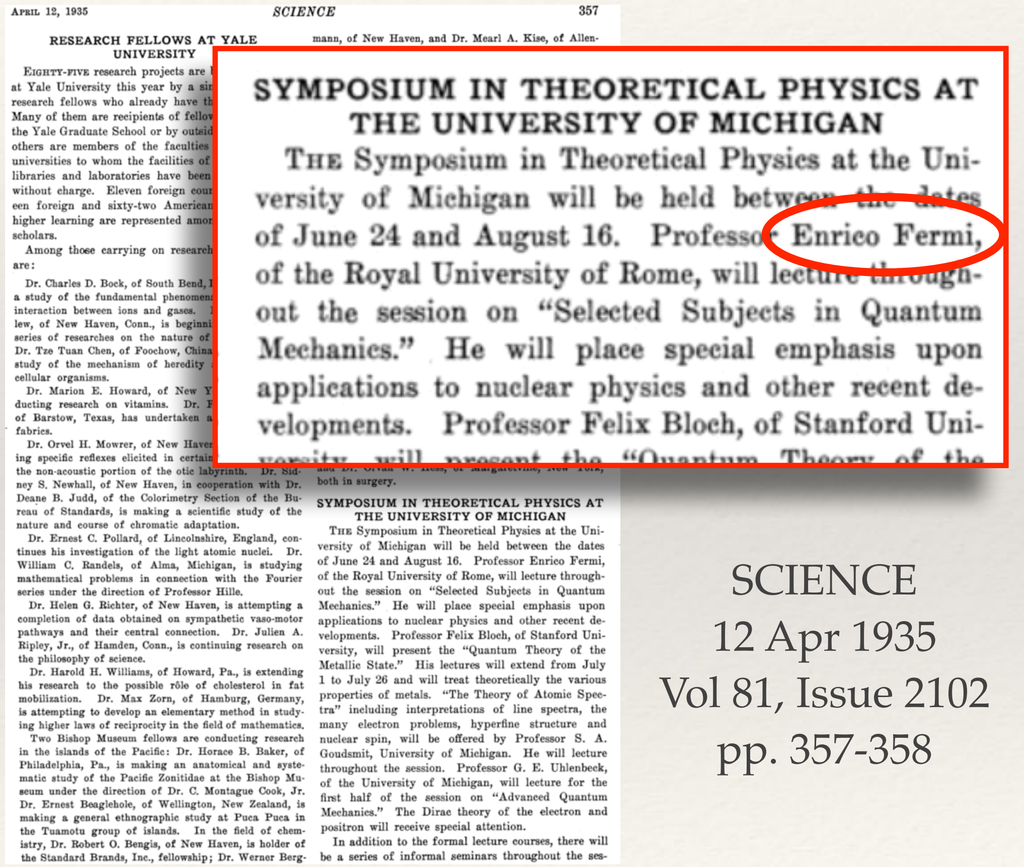



most likely very early 1935



# Where was Fermi in 1935?

- Fermi didn't move to the US until 1939. Could he have owned and used this 1935 K&E 4092-3 from the USA during the years leading up to his award of the 1938 Nobel Prize?
  - University of Michigan's Department of Physics held Summer Symposia in Theoretical Physics from 1928 to 1941. Fermi lectured at these events or taught classes (or both) during five extended stays during those years. His first visits were in 1930 and 1933. [1,2]
    - **reminder**: Nobel-related publications began in 1934
  - In particular, Fermi's next visit to Ann Arbor was during the **summer of 1935**, accompanied by his mentee Emilio Segrè (1959 Nobel laureate!) [3] — just a few months after the time when this slide rule was manufactured!



APRIL 12, 1935 SCIENCE 357

RESEARCH FELLOWS AT YALE UNIVERSITY

EIGHTY-FIVE research projects are
at Yale University this year by a sir
research fellows who already have th
Many of them are recipients of fellow
the Yale Graduate School or by outsid
others are members of the faculties
universities to whom the facilities of
libraries and laboratories have been
without charge. Eleven foreign cour
een foreign and sixty-two American
higher learning are represented amor
scholars.

Among those carrying on research
are:

Dr. Charles D. Bock, of South Bend, I
a study of the fundamental phenomen
interaction between ions and gases.
lew, of New Haven, Conn., is beginni
series of researches on the nature of
Dr. Tze Tuan Chen, of Foochow, China
study of the mechanism of heredity
cellular organisms.

Dr. Marion E. Howard, of New Y
ducting research on vitamins. Dr. F
of Barstow, Texas, has undertaken a
fabrics.

Dr. Orvel H. Mowrer, of New Haver
ing specific reflexes elicited in certain
the non-acoustic portion of the otic labyrinth. Dr. Sid-
ney S. Newhall, of New Haven, in cooperation with Dr.
Deane B. Judd, of the Colorimetry Section of the Bu-
reau of Standards, is making a scientific study of the
nature and course of chromatic adaptation.

Dr. Ernest C. Pollard, of Lincolnshire, England, con-
tinues his investigation of the light atomic nuclei. Dr.
William C. Randels, of Alma, Michigan, is studying
mathematical problems in connection with the Fourier
series under the direction of Professor Hille.

Dr. Helen G. Richter, of New Haven, is attempting a
completion of data obtained on sympathetic vaso-motor
pathways and their central connection. Dr. Julien A.
Ripley, Jr., of Hamden, Conn., is continuing research on
the philosophy of science.

Dr. Harold H. Williams, of Howard, Pa., is extending
his research to the possible rôle of cholesterol in fat
mobilization. Dr. Max Zorn, of Hamburg, Germany,
is attempting to develop an elementary method in study-
ing higher laws of reciprocity in the field of mathematics.

Two Bishop Museum fellows are conducting research
in the islands of the Pacific: Dr. Horace B. Baker, of
Philadelphia, Pa., is making an anatomical and syste-
matic study of the Pacific Zonitidae at the Bishop Mu-
seum under the direction of Dr. C. Montague Cook, Jr.
Dr. Ernest Beaglehole, of Wellington, New Zealand, is
making a general ethnographic study at Puca Puca in
the Tuamotu group of islands. In the field of chem-
istry, Dr. Robert O. Bengis, of New Haven, is holder of
the Standard Brands, Inc., fellowship; Dr. Werner Berg-
mann, of New Haven, and Dr. Mearl A. Kise, of Allen-
and Dr. Orval W. Ries, of Marquette, New York,
both in surgery.

SYMPOSIUM IN THEORETICAL PHYSICS AT THE UNIVERSITY OF MICHIGAN

THE Symposium in Theoretical Physics at the Uni-
versity of Michigan will be held between the dates
of June 24 and August 16. Professor Enrico Fermi,
of the Royal University of Rome, will lecture through-
out the session on "Selected Subjects in Quantum
Mechanics." He will place special emphasis upon
applications to nuclear physics and other recent de-
velopments. Professor Felix Bloch, of Stanford Uni-
versity, will present the "Quantum Theory of the
Metallic State." His lectures will extend from July
1 to July 26 and will treat theoretically the various
properties of metals. "The Theory of Atomic Spec-
tra" including interpretations of line spectra, the
many electron problems, hyperfine structure and
nuclear spin, will be offered by Professor S. A.
Goudsmit, University of Michigan. He will lecture
throughout the session. Professor G. E. Uhlenbeck,
of the University of Michigan, will lecture for the
first half of the session on "Advanced Quantum
Mechanics." The Dirac theory of the electron and
positron will receive special attention.

In addition to the formal lecture courses, there will
be a series of informal seminars throughout the ses-

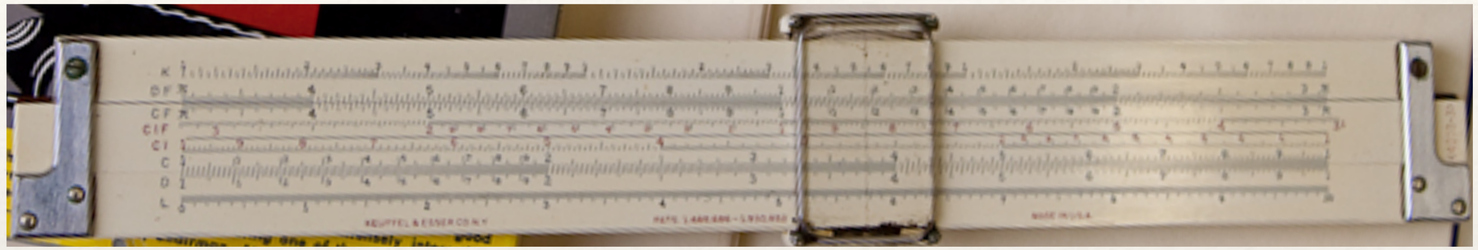
SCIENCE
12 Apr 1935
Vol 81, Issue 2102
pp. 357-358

[1] Alaina G. Levine, University of Michigan APS Historic Site, American Physical Society, 2010.

[2] Anne Duderstadt, *The History of University of Michigan: 1817 - 2017*, http://um2017.org/History_of_Physics.html.

[3] David Krogh (Editor), University of California: In Memoriam, 1989, "Emilio G. Segrè, Physics: Berkeley", University of California, 1989.

# Fermi's Golden Slide Rule



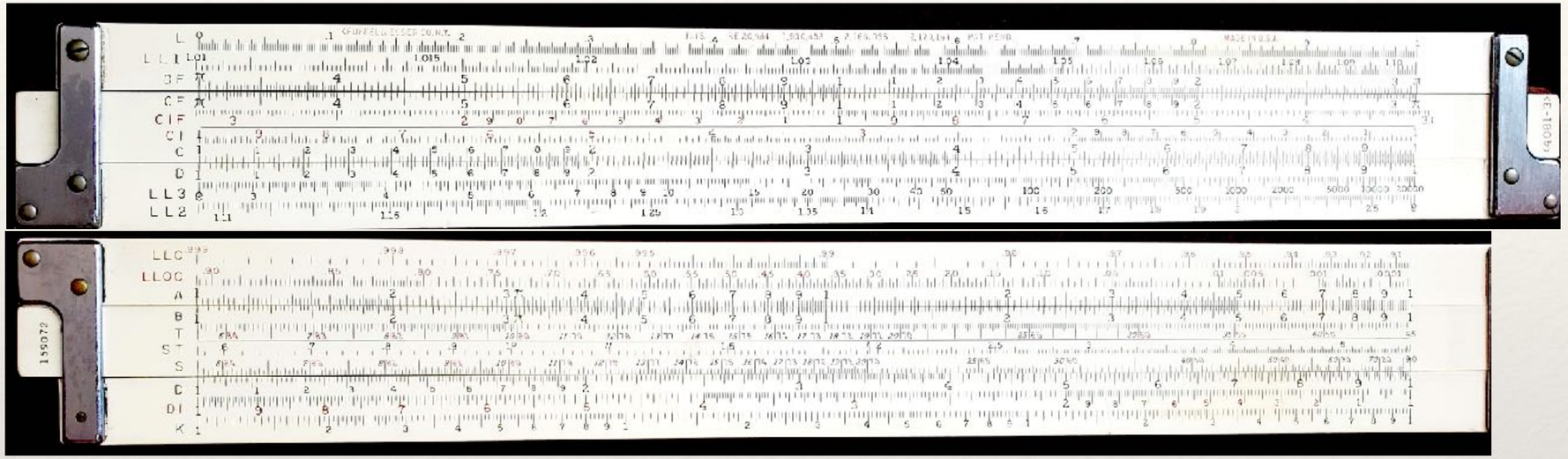
- Fermi visited Ann Arbor and the UM Symposium again in 1936 and 1937, and it is also possible that the slide rule came into his possession after his immigration in 1939 (and his 5th visit to UM), but it is perhaps most likely to have been acquired closer to its manufacturing date.
  - By 1937 K&E had stopped making the 4092-3, as the newer Log-Log slide rule models (e.g., 4080-3, 4081-3, 4083-3) had become more popular.[1]

[1]Kate Matthews, "The Evolution of the 4092", JOS 10:2 (2001).

# Was There Another Fermi Rule?

- During discussions with Olivia Fermi, she recalled the family having another slide rule. After a few family internal discussions (including the recognition that the yellow Pickett rule belonged to their parents, and not to Enrico), the second rule was tracked down.
  - In 1990 Olivia's mother, Nella Fermi Weiner (1931-1995), had loaned this second rule to the Engineering and Science Hall of Fame in Dayton, Ohio, during Enrico's induction to the Hall. Olivia's brother, Paul Weiner, was there to present the rule.
  - The Hall of Fame still had the slide rule in their archives and sent Olivia and Paul photos of the rule…

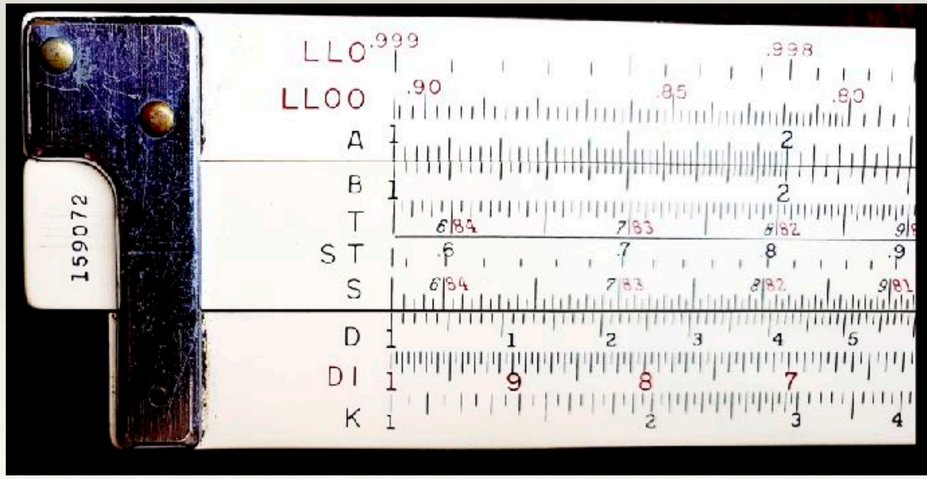
# Rule No. 2

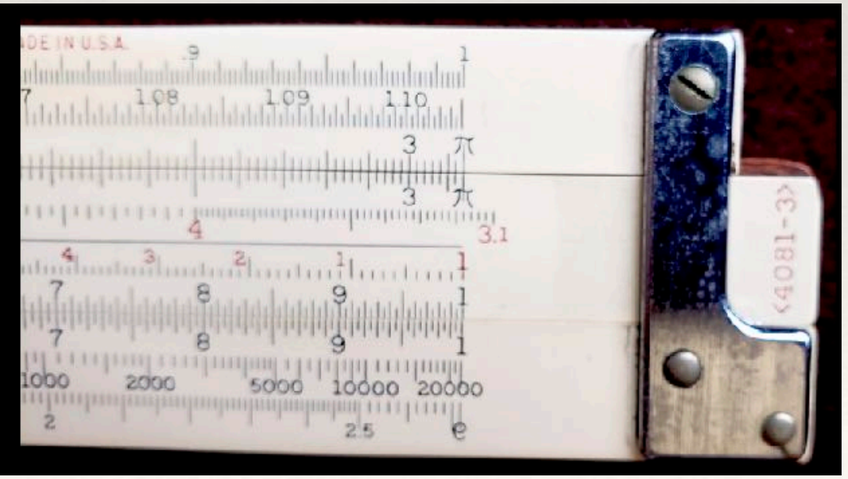



K&E 4081-3
1939-1947 scale set

Serial Number:
**159072**

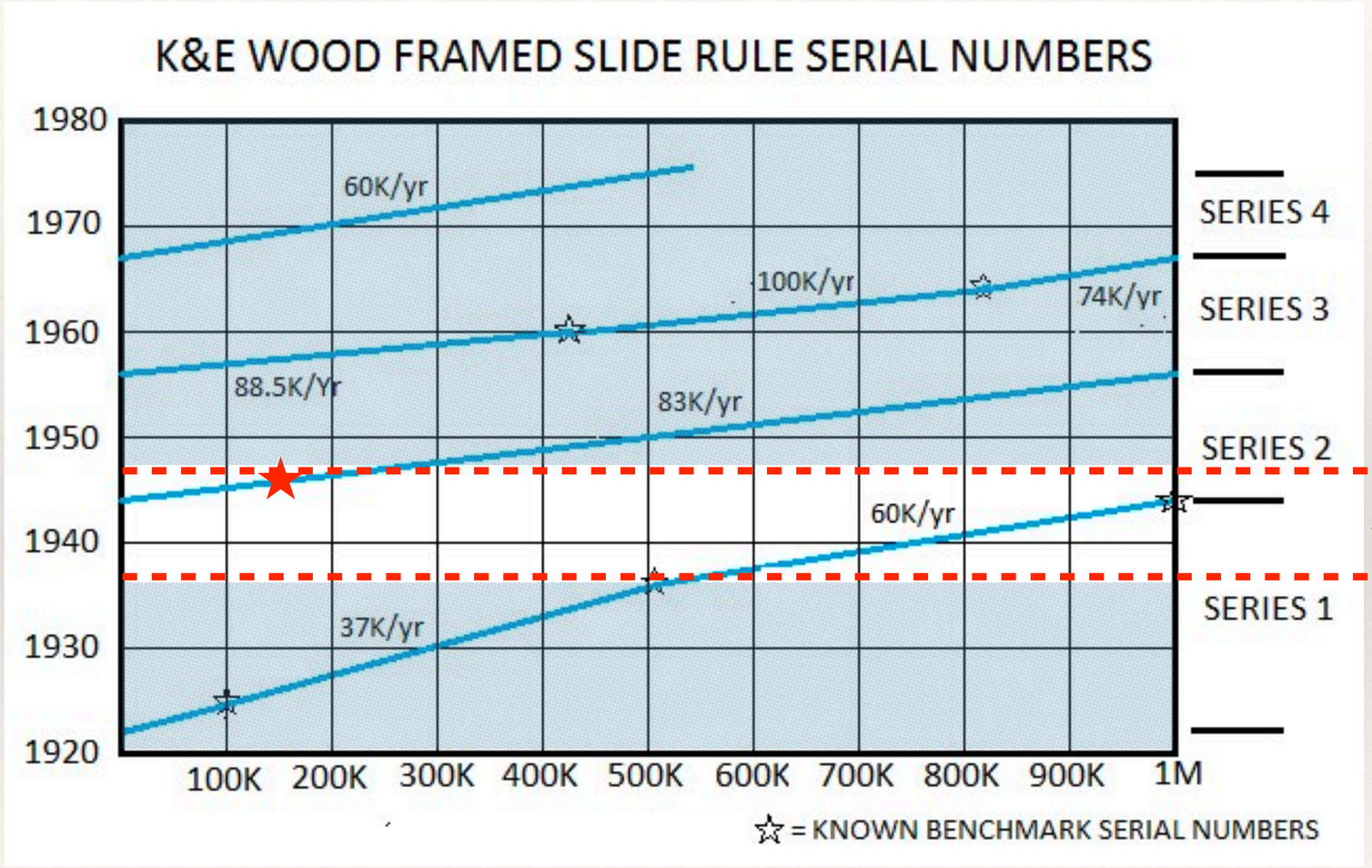
*Photos courtesy of James Mattice, President, Engineering and Science Hall of Fame, Dayton, Ohio.*



# Rule No. 2

dates to early 1946, likely less than 1 year after the end of WWII




*4081-3 window*

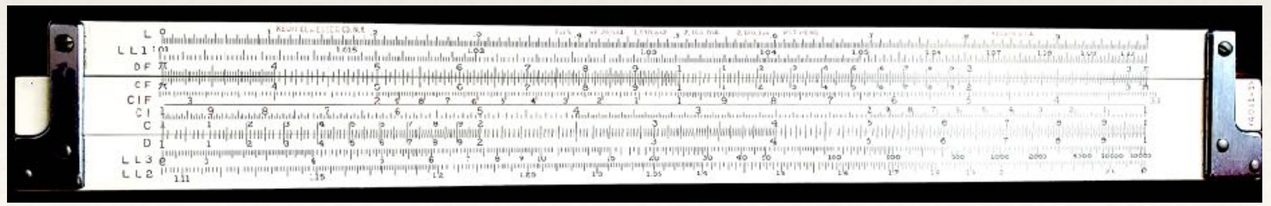
See https://www.lib.uchicago.edu/e/scrc/findingaids/view.php?eadid=ICU.SPCL.FERMI.

# Rule No. 2

- By 1938 the 4092 models were being phased out in favor of newer Log-Log Trig, Decitrig and Vector slide rules being sold by K&E. It is not surprising that Enrico Fermi would have wanted to own a newer Log-Log Duplex Decitrig Model 4081-3!
  - "[Enrico] never lost interest in gadgets, and, although parsimonious by nature and education, he was always ready to buy one more… "
    - - Laura Fermi, *Atoms in the Family*, p. 149 (1954).

- The 4081-3 slide rule is presently in the process of being transferred to the the Enrico Fermi permanent collection at the University of Chicago Library.

- But, where is its cursor?? …



# But Where Is Its Cursor?

Still exists!  In pieces — the all-too-common KERCS disease!  The museum in Dayton still had all the parts!


*Photo courtesy of James Mattice*

# Have we see this before?

- KERCS?  Obviously, YES!
  - No, I mean, have we seen this 4081-3 before?

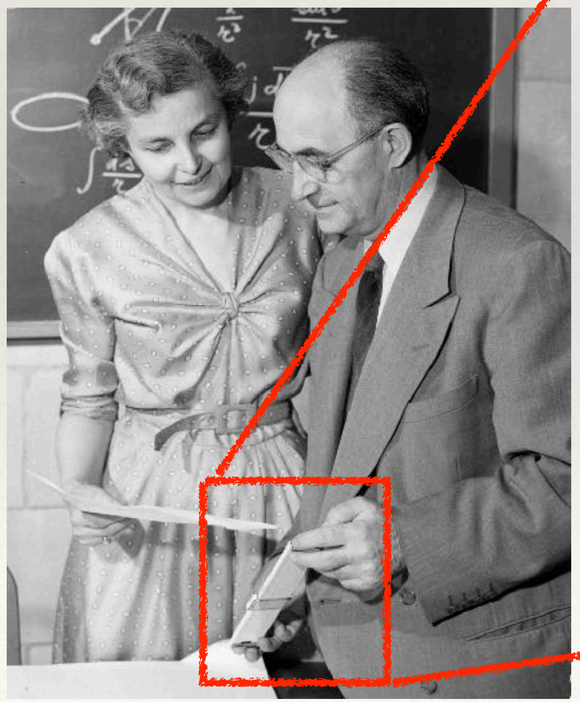
# 1954 Los Alamos Photos

- There was a second photo (at least) that day…

# 1954 Los Alamos Photos

- There was a second photo (at least) that day, easily found on the internet…

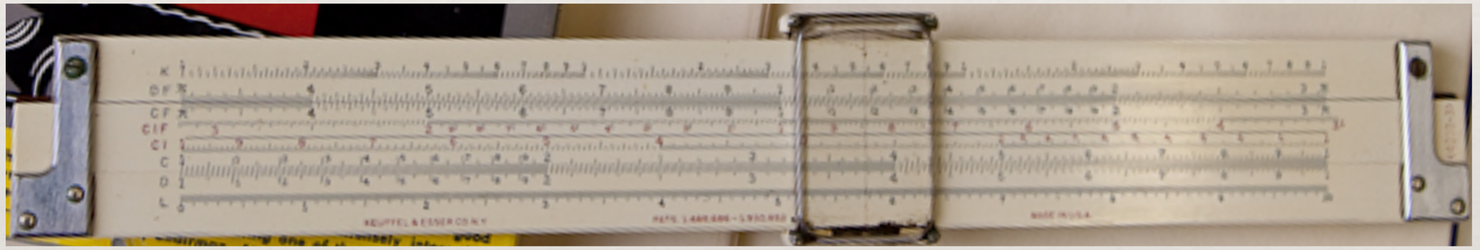
*Thanks to Jim Bready!*



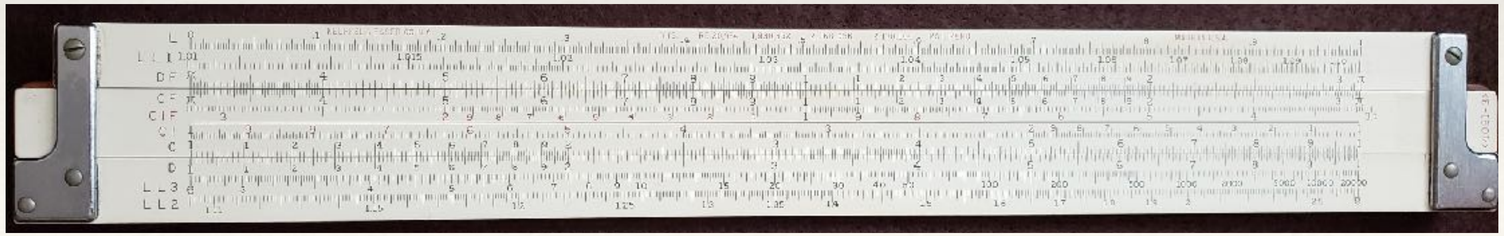
the 4081-3?

# Fermi Rules

- So, TWO RULES exist that were *definitely* Enrico Fermi's and that can be ID'd uniquely by their serial number and other characteristics:
  - Rule No. 1 — **K&E 4092-3**, serial number **481252**

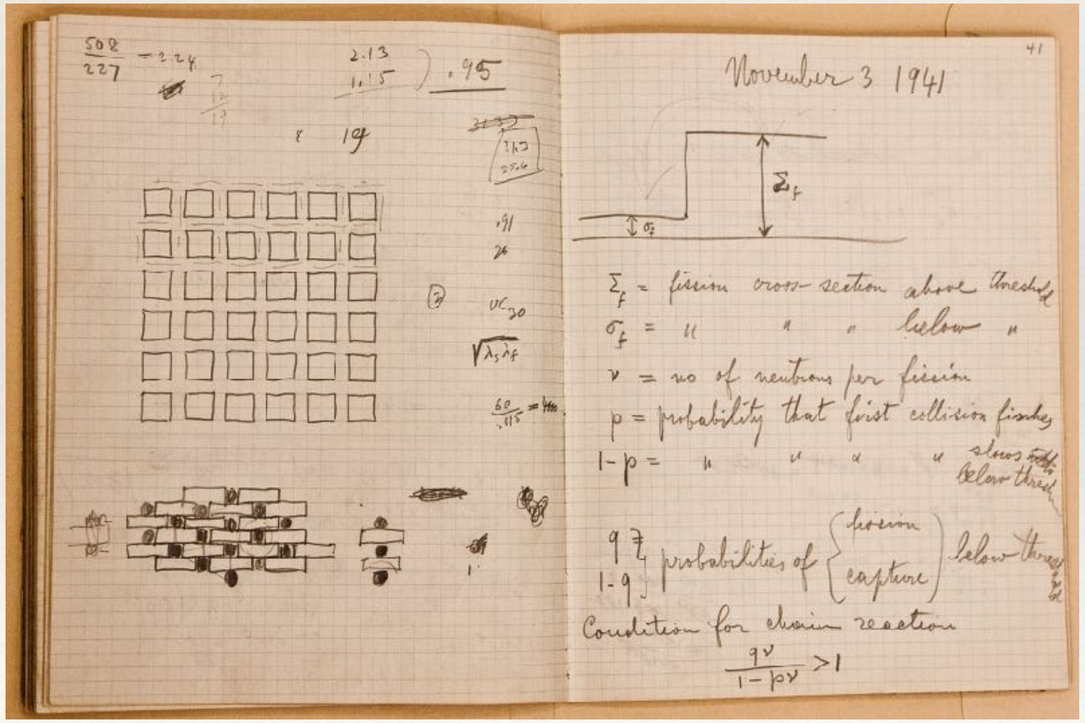


  - Rule No. 2 — **K&E 4081-3**, serial number **159072**



# Special Thanks to Olivia Fermi!

For graciously sharing her grandfather's history with me and for her support and encouragement through the unfolding of this story.

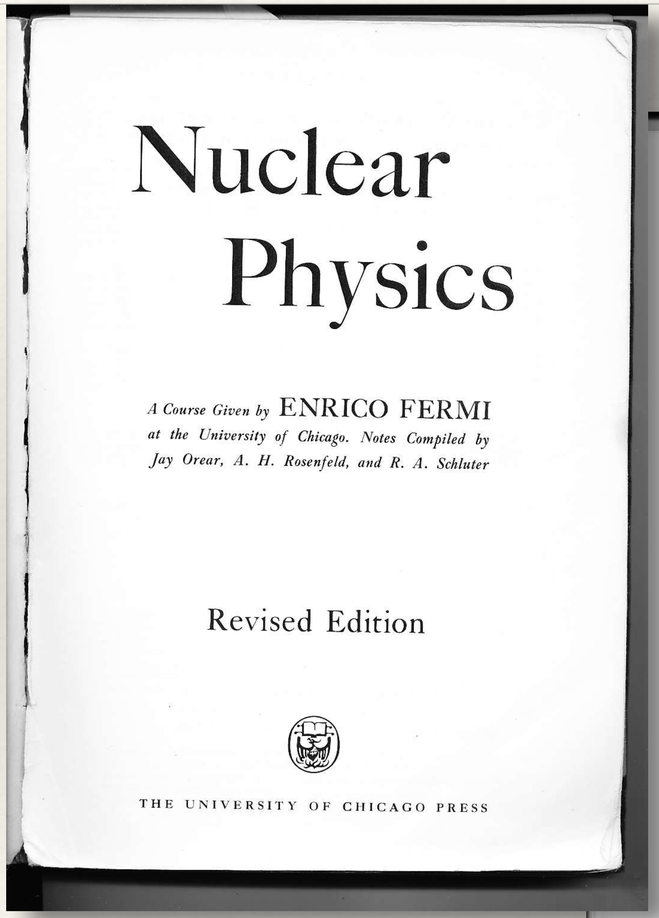


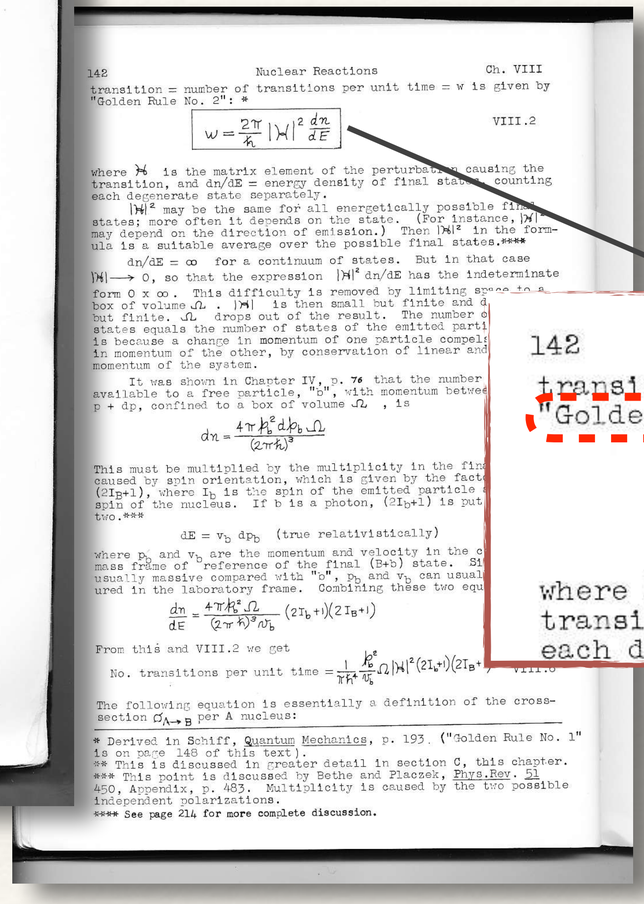

Pages from Fermi's 1941 lab notebook at U. Chicago


Fermi's "clicker" for counting events from radioactive decay; with his office room number!

*Photos by Olivia Fermi*

# Fermi's *Actual* Golden Rule



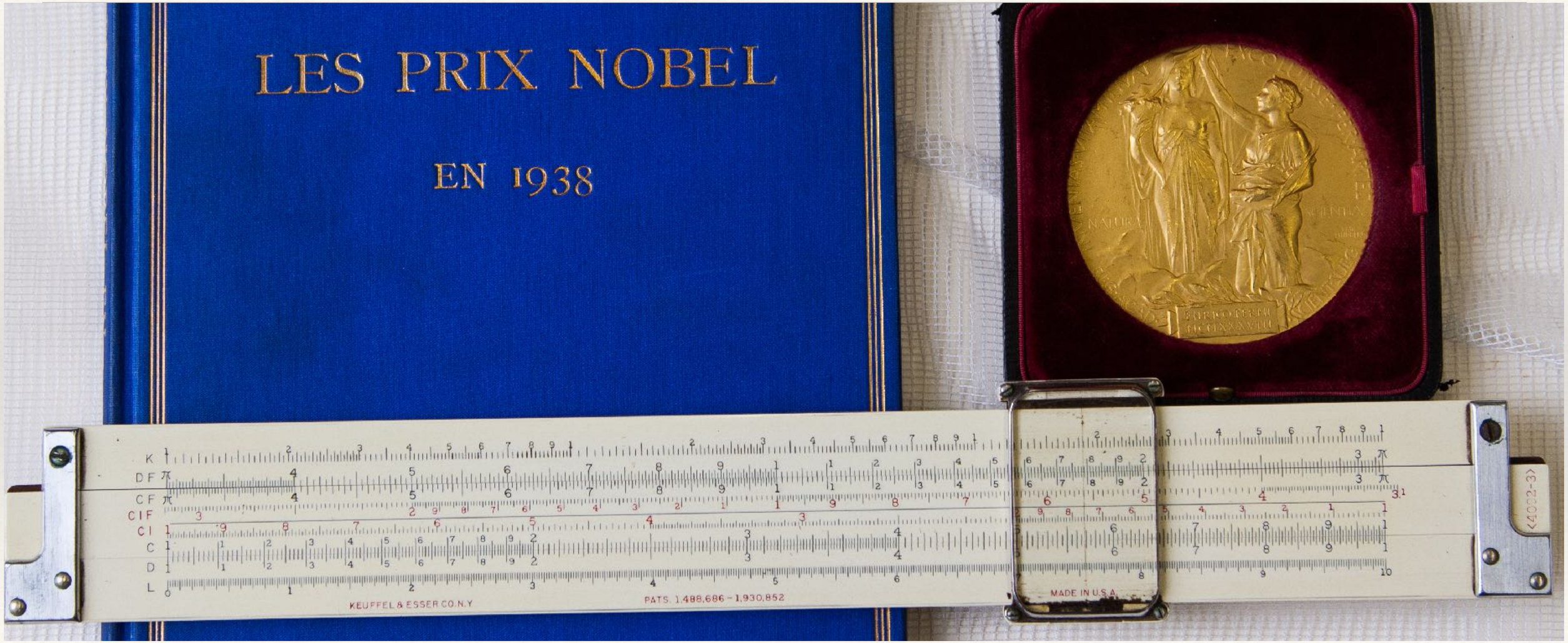

- Enrico Fermi had another rule, though. Graduate physics students learn about Fermi's *Golden Rule* when studying quantum mechanics.
- It's even in Wikipedia, so how hard can it be?

Fermi, Enrico, *Nuclear Physics*, University of Chicago Press, Chicago, 1950.

Note: *Golden Rule No. 1* was an equation written by H. Schiff, *Quantum Mechanics*, McGraw-Hill (1949), p. 193.

# Thanks!

Fermi's ***truly*** Golden (Slide) Rule!




*Enrico Fermi's 1935 K&E 4092-3 with his 1938 Nobel Prize medal. Photo by Olivia Fermi.*