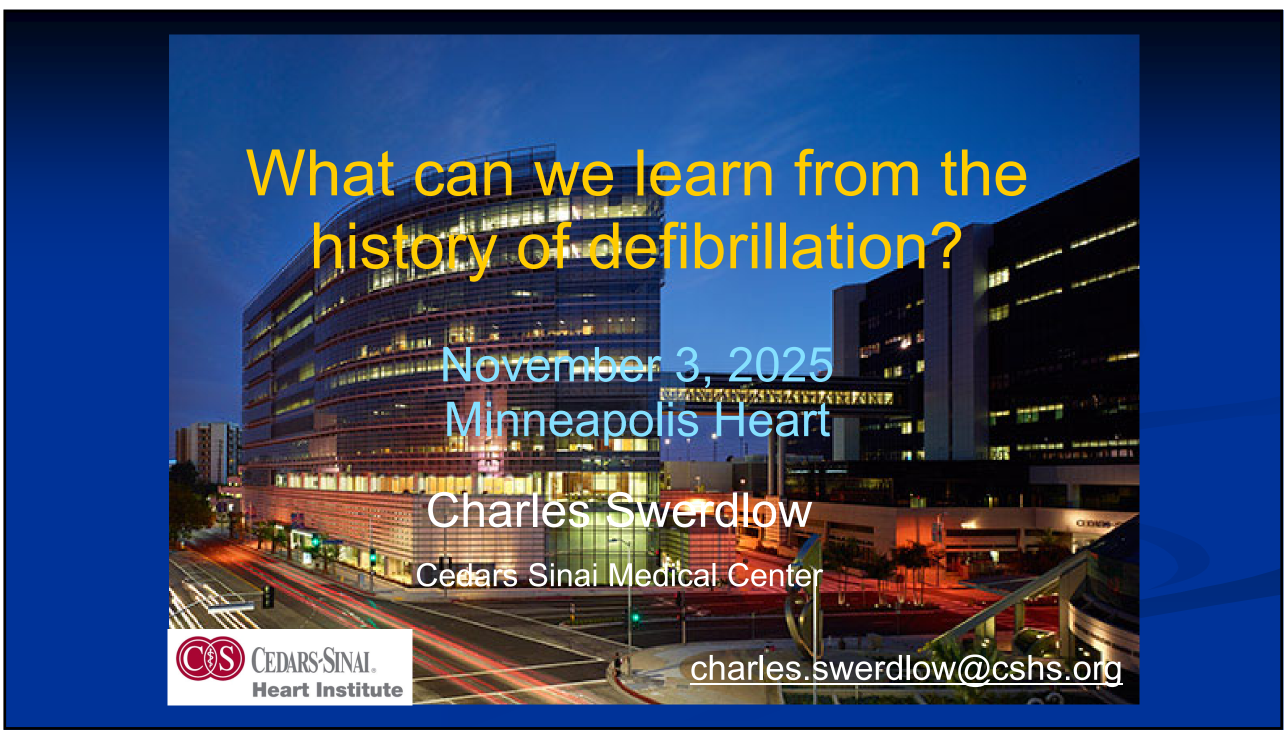

Minneapolis Heart Institute Foundation
GRAND ROUNDS

1


What can we learn from the history of defibrillation?
November 3, 2025
Minneapolis Heart
Charles Swerdlow
Cedars Sinai Medical Center
CEDARS-SINAI
Heart Institute
charles.swerdlow@cshs.org

2

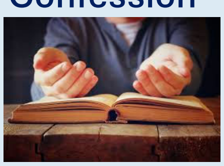
A lecture on “The History of…”

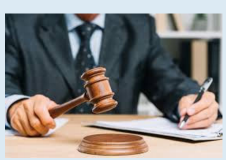
3

A Talk on What We Can Learn About

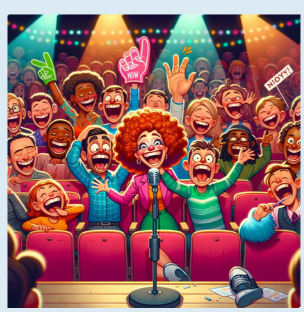
- How to approach engineering/scientific challenges
- How the history of defibrillation relates to broader trends in science, technology, and society

Confession





Total Newbie



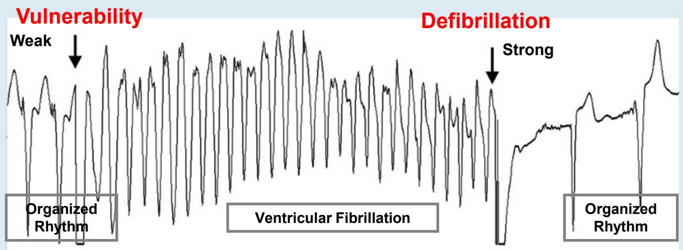
Audience Participation

4

DC Shocks both induce and defibrillate VF
(Prevost & Battelli 1899)

J.-L. Prevost and F. Battelli, La Mort Par Les Déscharges Électriques, Journ. de Physiol., 1: 1085-1100, 1899

- Electrodes in mouth & rectum of small intestine of animals.
- Induced and defibrillated VF with capacitor-discharge waveforms [induced 20-40 V, defibrillated 2000-6000 V, x 1-2 s].

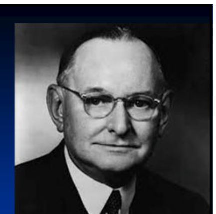


Identified all 3 conditions for clinical defibrillation

- Stop VF (reentrant wavefronts): Strong shocks
- Prevent reinitiation of VF: Stronger shocks
- Clinical resuscitation: After defibrillation, animals died of post-shock “respiratory paralysis” (PEA).

5

Prevost and Battelli’s claims were met by disbelief in the West.



In 1940, Carl Wiggers chose not to reinvestigate.

“The idea seemed so fantastic that I read their reports in a biased and unfriendly frame of mind and concluded that their experimental evidence fell short of their claims. I should have considered the possibility that the work might have been presented badly." Reminiscences and adventures. *Circ Research* 1959.

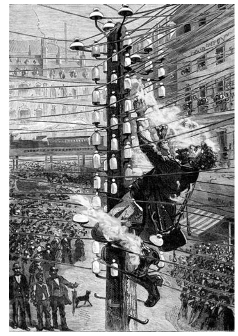
Poorly written papers may report important findings.

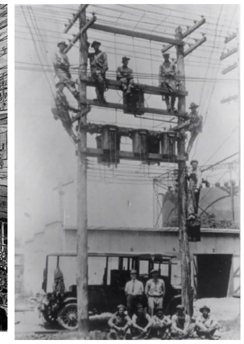
- In USA, AC defibrillation was introduced in 1948. DC defibrillation made no progress until the 1960s.
- But DC defibrillation progressed in the Soviet Union...

6

Defibrillation in the USA: Innovation Born From a Crisis in the Electric Power Industry

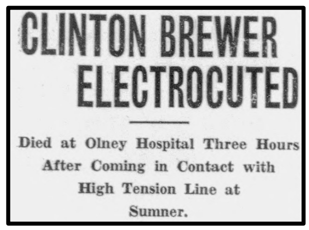
- Electrification → epidemic of [AC] power-line worker electrocutions that drew public attention in 1920s.
- Research into high-voltage AC determined VF as a cause of death.
- Kouwenhoven (1932) showed that AC could not only induce VF, but also terminate it.
- **As a result, the US embarked on 30 years of misguided work on AC defibrillation.**






Man Electrocuted On Power Line

MARTINSVILLE, June 11.—(AP)


CLINTON BREWER ELECTROCUTED

Died at Olney Hospital Three Hours After Coming in Contact with High Tension Line at Sumner.


WORKMAN ELECTROCUTED

TERRIBLE ACCIDENT IN DUNEDIN.

(PRESS ASSOCIATION TELEGRAM.)

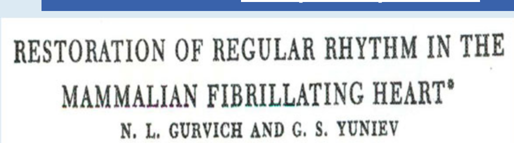
DUNEDIN, May 25.

7

Naum Gurvich: Transthoracic Defibrillation in the Soviet Union

- Lina Stern returned to Moscow as Chair of Physiology. Encouraged student Naum Gurvich to study DC defibrillation.
- 1933-39: **transthoracic** defibrillation experiments to resuscitate ("reanimate") from VF
  - Unwieldy AC: defibrillation dangerous, unreliable, post-shock hypotension/PEA
  - DC: defibrillation: Empirical testing adding inductors of various sizes to capacitive discharge waveforms. Visualized differences in waveforms on oscilloscope
  - 1939: Reliable resuscitation using optimized waveform.
- 1940s: Empirical studies demonstrated superiority of biphasic waveforms.
- 1957: First commercial external DC defibrillator for clinical use.
- 1970: First commercial external DC biphasic defibrillator -> Soviet standard.

Waveform = temporal pattern of shock strength (amplitude) measured by V or I.

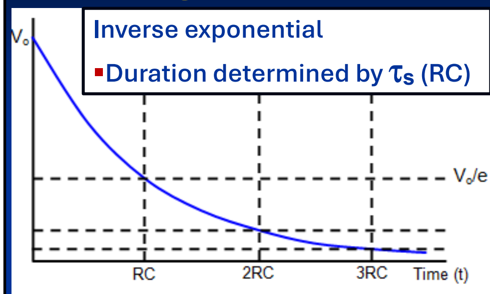

RESTORATION OF REGULAR RHYTHM IN THE MAMMALIAN FIBRILLATING HEART*

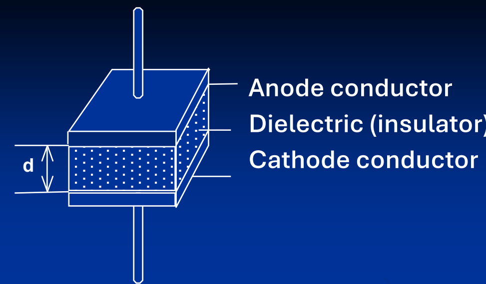
N. L. GURVICH AND G. S. YUNIEV

Bull Experiment Biol Med, 1939; 8 (1): 55–58

8

Defibrillator shocks are capacitor-discharge waveforms

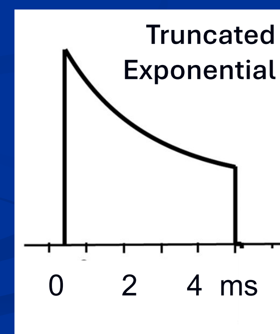




- Store charge & energy at high voltage in electric field C = Q/V
- ($E_s = 1/2\ CV^2$)
- Resist changes in voltage by discharging over time: τ_S = RC.
- Capacitors are implicit clocks

[τ_S = system time constant]

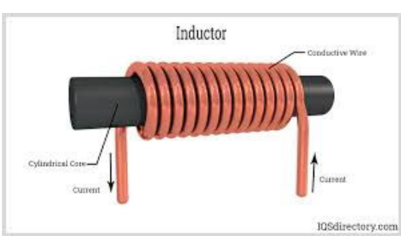
Oil-Filled Paper Capacitor

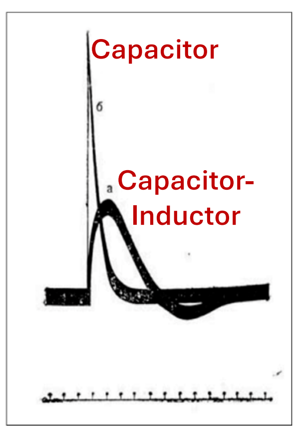


9

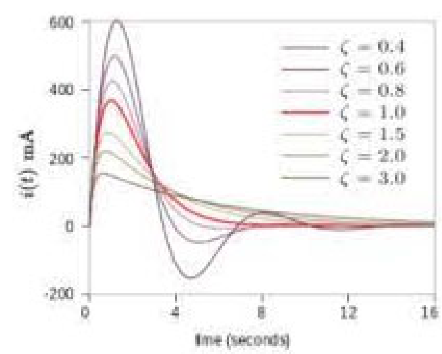
Inductors

- Store energy at high voltage in magnetic field.
- Resist changes in current.





Gurvich NL, Yuniev GS. Restoration of heart rhythm during fibrillation by a condenser discharge. *Am Rev Soviet Med* 1947;4:252–256



Capacitor-Inductor Waveforms

Gurvich. *Am Rev Soviet Med* 1947;4:252–256

10

The Fate of Lina Stern

- During WWII, the Soviet government asked Stern to join a new Anti-Fascist Jewish Association.
- She raised millions of dollars from the American Jews.
- After the war, Stalin accused prominent members of this and other scientific associations of espionage.
- Many were executed. Stern was imprisoned. Others were deported.
- They were replaced by politically correct scientists chosen to promote “socialist” science.
- Western-trained scientists, who were once actively recruited, were banned.
- **As a result of political persecution of foreign-born scientists, Soviet science was crippled for decades (e.g. genetics, computer science…).**
- By association with Stern, Gurvitch lost his position.

11

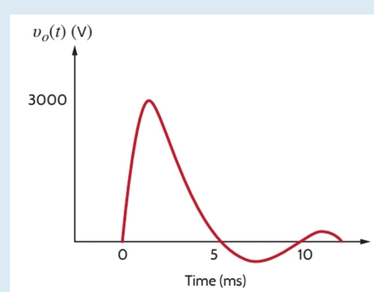
The ”Lown” Defibrillator

- Gurvich’s student Peleska trained engineer Barouh Berkovits.
- 1961: Berkovits builds DC defibrillator based on Gurvich’s design for Bernard Lown.*

Bernard Lown

Barouh Berkovits

New Method for Terminating Cardiac Arrhythmias
Nov 3, 1962
(JAMA 1962;182:548-555)
Use of Synchronized Capacitor Discharge
Bernard Lown, M.D., Raghavan Amarasingham, M.B., B.S., and Jose Neuman, M.D., Boston



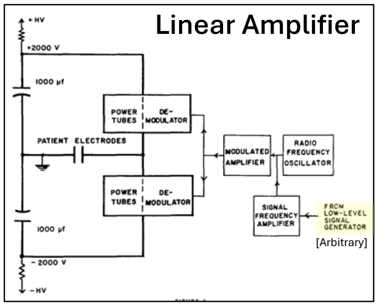
“At the present time there is no physiologic basis for predicting a waveform optimal for defibrillation. Development of an effective instrument, therefore, becomes a tedious trial-and-error procedure…

*Barouch Berkovits BV. Defibrillator. 1966. U.S. Patent No. 3,236,239.

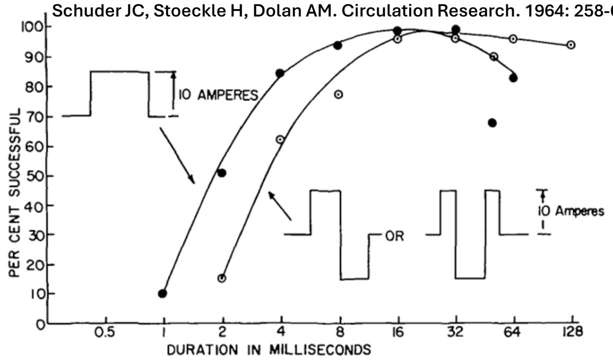
12

Empirical Trials of Defibrillation Waveforms

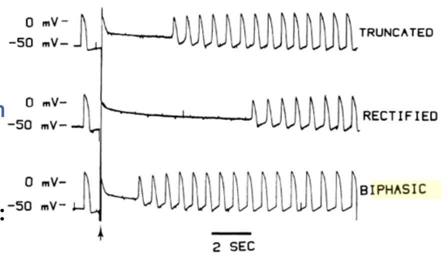
John Schuder 1964-1984



Schuder JC, Stoeckle H, Dolan AM. Circulation Research. 1964: 258-64.



Jones, JL & Jones, RE Improvement in defibrillator waveform safety factor using biphasic waveforms. Medical Instrumentation 1981: 323-323.



"In addition, a review of some of our own early bidirectional rectangular wave transthoracic defibrillation studies in dogs showed that bidirectional wave shocks were effective over a wider range of pulse durations than were unidirectional waveforms."

Schuder JC et al. ASAIO Journal. 1981;27:467-70.

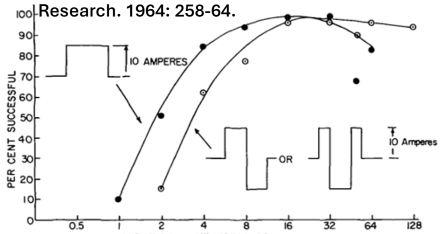
13

Taking a Second Look at Data...

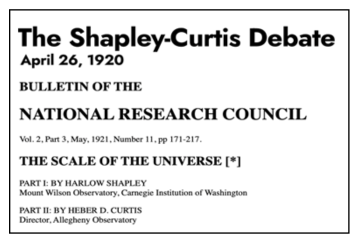
"In addition, a review of some of our own early ...studies showed that bidirectional wave shocks were more effective ...than were unidirectional waveforms."

Schuder JC et al. ASAIO Journal. 1981;27:467-70.

Schuder JC, Stoeckle H, Dolan AM. Circulation Research. 1964: 258-64.



Could Schuder have saved 20 years?


The Shapley-Curtis Debate
April 26, 1920

BULLETIN OF THE

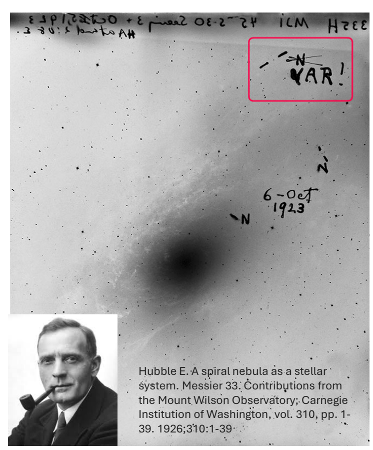
NATIONAL RESEARCH COUNCIL

Vol. 2, Part 3, May, 1921, Number 11, pp 171-217.

THE SCALE OF THE UNIVERSE [*]

PART I: BY HARLOW SHAPLEY
Mount Wilson Observatory, Carnegie Institution of Washington

PART II: BY HEBER D. CURTIS
Director, Allegheny Observatory



Hubble E. A spiral nebula as a stellar system. Messier 33. Contributions from the Mount Wilson Observatory; Carnegie Institution of Washington, vol. 310, pp. 1-39. 1926;310:1-39

14

The Vision of an Implantable Defibrillator

- In 1966, chief of medicine at Tel Hashomer Hospital (Israel) Harry Heller died suddenly at dinner.
- His former assistant Michel Mirowski realized that Heller could have been saved by an implantable defibrillator.
- A few weeks later, American thoracic surgeon Victor Parsonet had lunch with Mirowski, who shared his vision.

> "To understand the complexity of miniaturization... the desktop version derived its power by plugging it into table ... Mirowski wanted to reduce its size 100-fold to be made into an implantable gizmo. It seemed inconceivable ....I visualized the enormity of the undertaking and tried gently to discourage him that day."

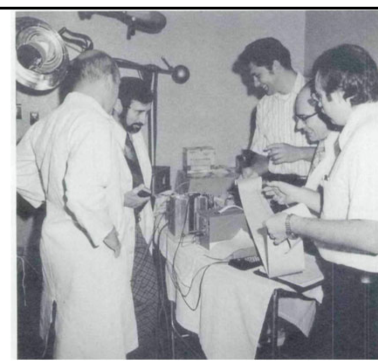
Parsonnet, Victor. "Oops!." *Pacing and Clinical Electrophysiology* 35.10 (2012): 1280-1280.

15

Michel Mirowski

A Man on a Mission

- Had no understanding of
  - Bioelectricity
  - Effects of shocks on contractility
  - Electronic circuitry
- But he had grit.
  - He had skin in the game that drove his vision.
  - He had overcome longer, existential life odds.

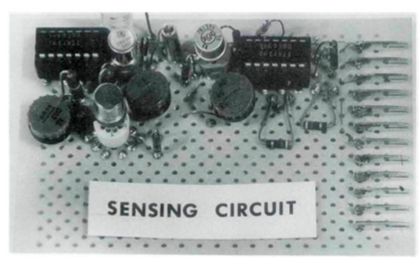


Not Implantable

Standby Automatic Defibrillator
An Approach to Prevention of Sudden Coronary Death

M. Mirowski, MD; Morton M. Mower, MD; William S. Staewen; et al

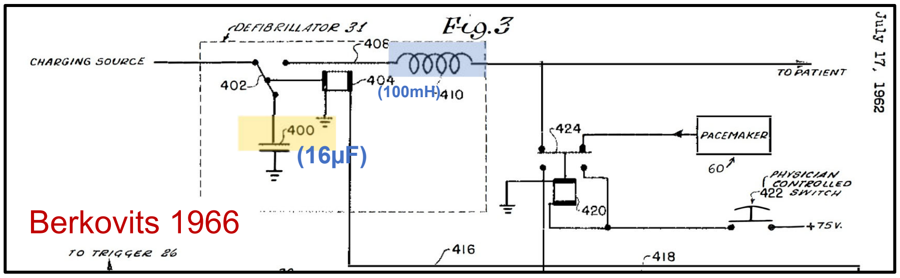
Archives of Internal Medicine 126:1 (1970): 158-161.

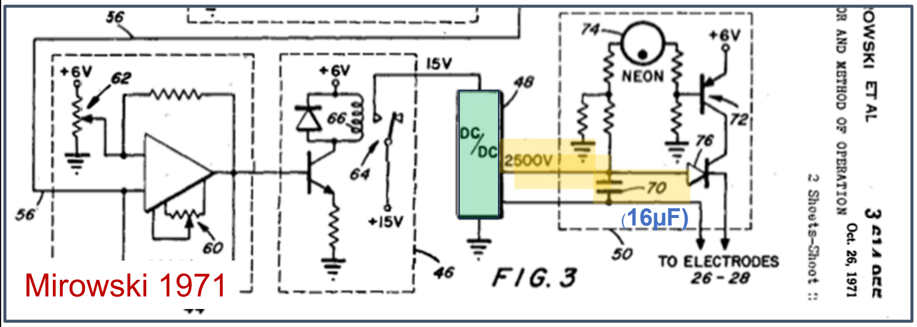


Off-the-Shelf Technology

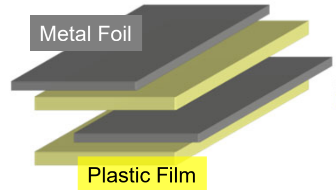
16

ICD: Mirowski's Original Design from Berkovits

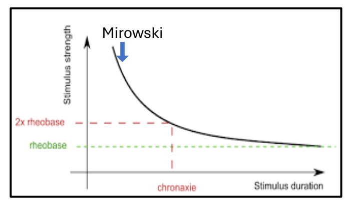




Film Capacitor

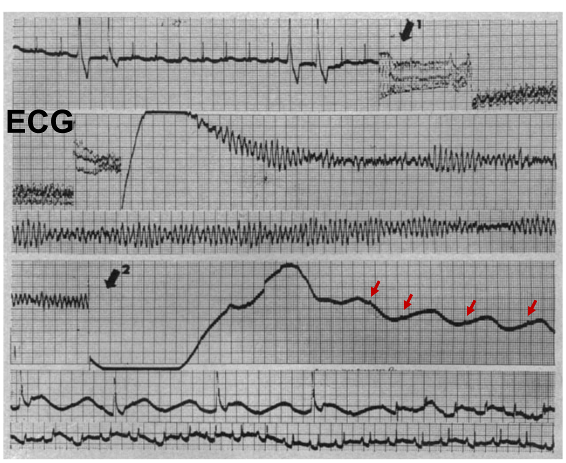


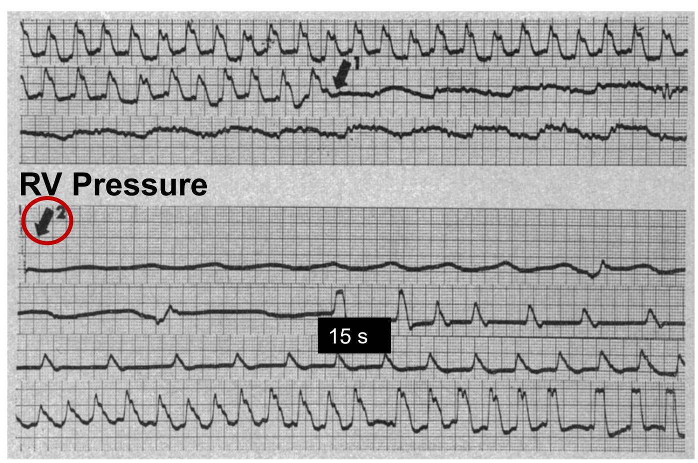
- > High Voltage
- Low capacitance
- Short inefficient waveform for internal defibrillation (τ_s = RC)



First Recorded Internal Defibrillation

(50 J @2500 V) Normal Dog





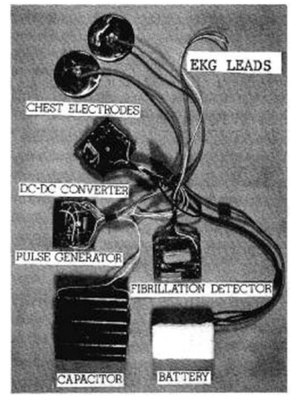
Mirowski et al. Archives of Internal Medicine 126:1 (1970): 158-161.

Imagine myopathic human heart.

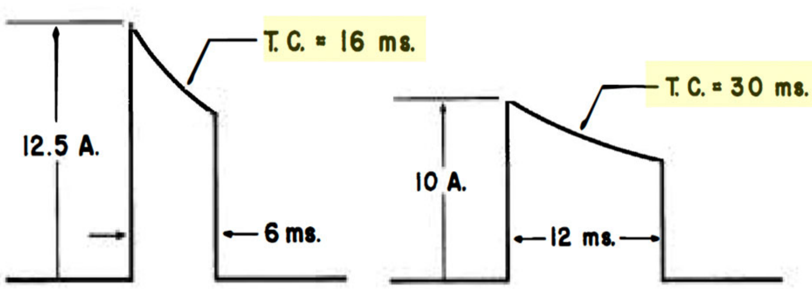
EXPERIMENTAL VENTRICULAR DEFIBRILLATION WITH AN AUTOMATIC AND COMPLETELY IMPLANTED SYSTEM

John C. Schuder, Harry Stoeckle, Jerry H. Gold, Joe A. West, and Prabhaker Y. Keskar

ASAIO Journal 16.1 (1970): 207-212

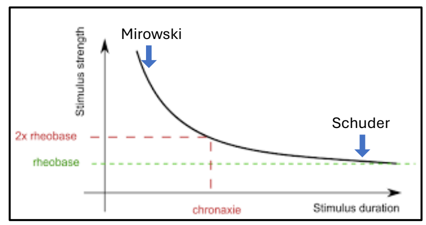


- Aluminum-foil electrolytic capacitors offered higher capacitance but were unreliable at high voltages.
- Lower voltage: No PEA, but inefficient waveforms (τ_s = RC).
- If pacemaker manufacturers had committed to an AID in 1970, they would almost certainly have chosen Schuder's design.



400 μF capacitor

600 μF capacitor



19

What did Key Opinion Leaders say?

"There is serious question whether an indication can be spelled out for the use of an implanted standby defibrillator.... In fact, the system represents an imperfect solution in search of a plausible and practical application."

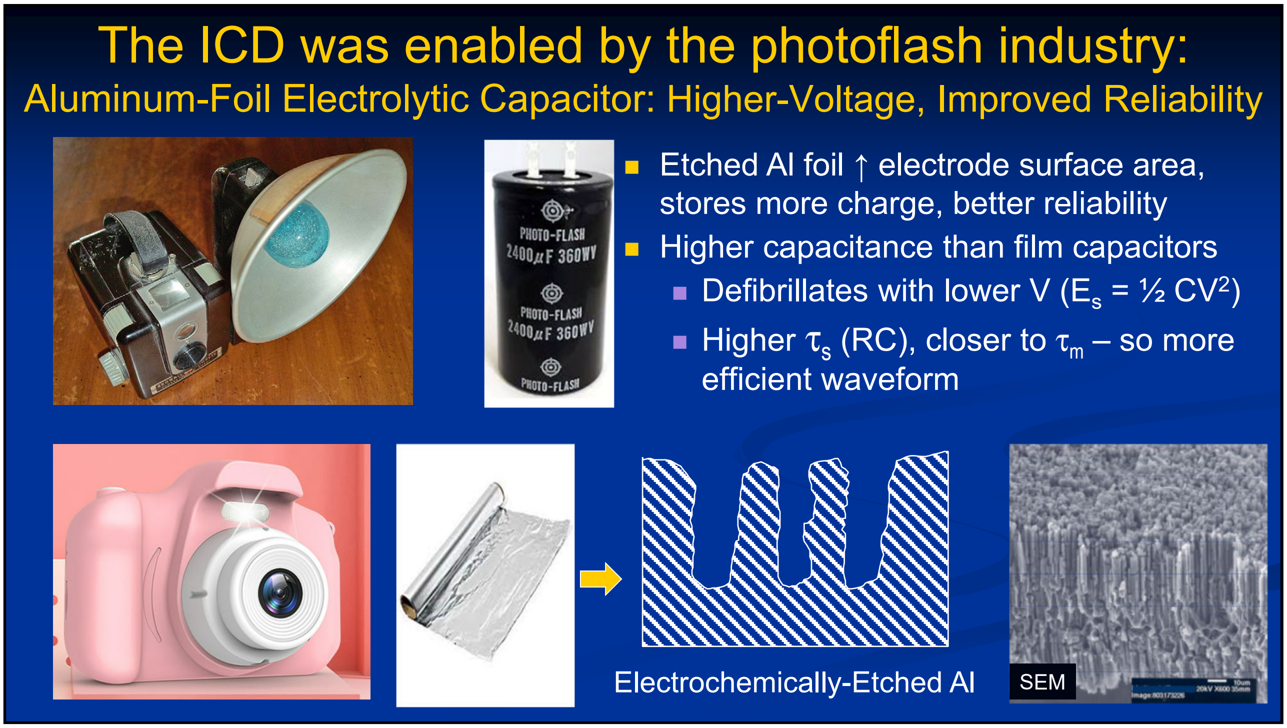
Lown, Bernard and Paul Axelrod. "Implanted standby defibrillators." Circulation 46.4 (1972): 637-639.

"Medtronic and Cordis ....concurred with my conclusion that Mirowski's idea was impractical and that he was an unrealistic dreamer. And so, his appeals to them were spurned...

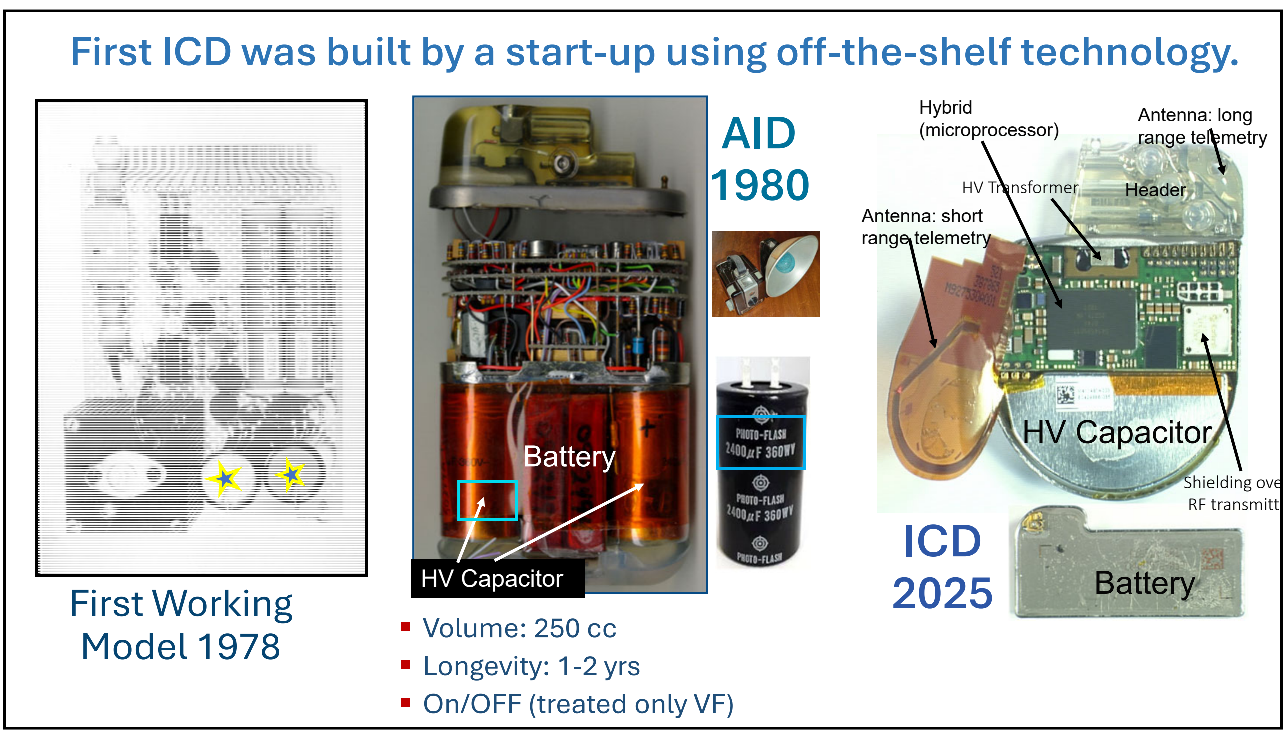
Parsonnet, Victor. "Oops!" Pacing and Clinical Electrophysiology 35.10 (2012): 1280-1280.

This was lucky for Mirowski

20


The ICD was enabled by the photoflash industry:
Aluminum-Foil Electrolytic Capacitor: Higher-Voltage, Improved Reliability
PHOTO-FLASH 2400µF 360WV
Etched Al foil ↑ electrode surface area, stores more charge, better reliability
Higher capacitance than film capacitors
Defibrillates with lower V ($E_s = ½ CV^2$)
Higher τ_s (RC), closer to τ_m – so more efficient waveform
Electrochemically-Etched Al
SEM

21

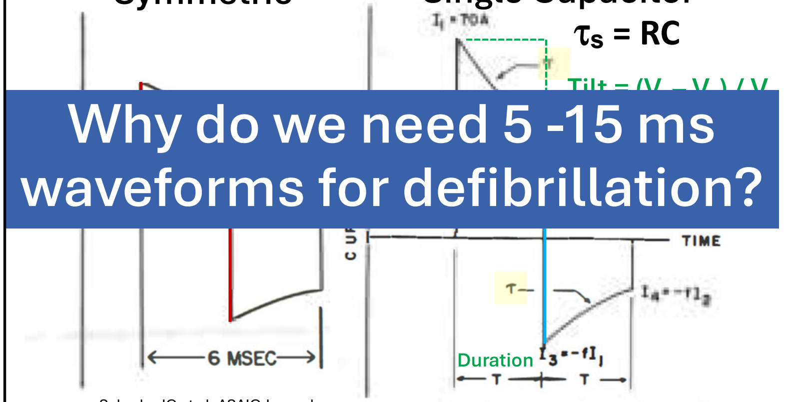

First ICD was built by a start-up using off-the-shelf technology.
First Working Model 1978
AID 1980
Battery
HV Capacitor
PHOTO-FLASH 2400µF 360WV
Volume: 250 cc
Longevity: 1-2 yrs
On/OFF (treated only VF)
Hybrid (microprocessor)
Antenna: long range telemetry
HV Transformer
Header
Antenna: short range telemetry
HV Capacitor
Shielding ove
RF transmitt
ICD 2025
Battery

22

The Biphasic Waveform

Symmetric → Single Capacitor

$\tau_s = RC$



Schuder JC et al. ASAIO Journal. 1981;27:467-70.

Schuder JC et al. ASAIO Journal. 1984;30:520-5.

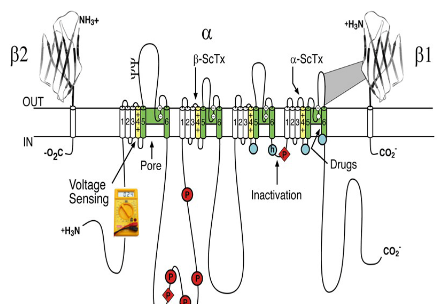
Why do we need 5 -15 ms waveforms for defibrillation?

Galileo's Clock

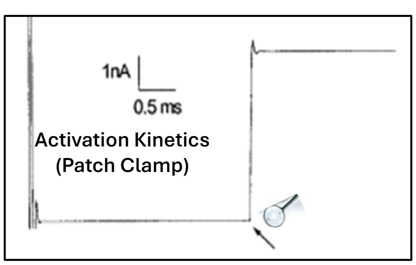
- No low-power accurate clock to truncate phase 1/2 for AID.
- Schuder knew waveforms had τ_s.
- He chose "tilt" to overcame the limits of existing clock technology.
- He chose to truncate at τ_s.
- But he could only calibrate his dial to ±5%.
- So he set tilt = 65%.

23

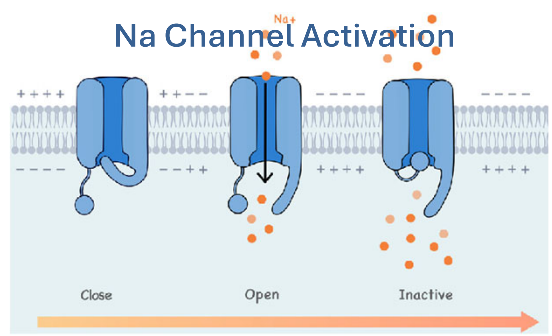
Why do we need a 0.5 ms waveform for transvenous pacing?



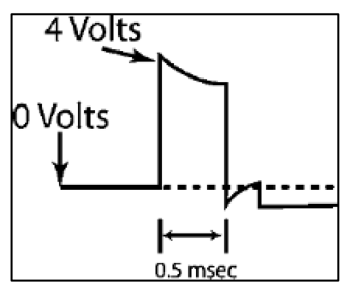
Speed of molecules 10^{-15} s



Na Channel Activation



Pacemaker Waveform



24

Modeling Defibrillation Waveforms

Mark Kroll 1993-4

Kroll MW. A minimal model of the monophasic defibrillation pulse. PACE. 1993;16:769–77.

Kroll MW. A minimal model of the single capacitor biphasic defibrillation waveform. PACE. 1994;17:1782–1792.

Optimal waveform defibrillates with the lowest stored energy.

Kroll's Assumptions

Defibrillation can be modeled as discharging a high-voltage defibrillator capacitor into the heart to

- *Charge the cell membrane capacitor [Phase 1]*
- *Discharge the cell-membrane capacitor [phase 2]*

Optimal Phase 1: charges cell membrane to maximum voltage at truncation.

Optimal Phase 2: returns cell membrane voltage to baseline at truncation.

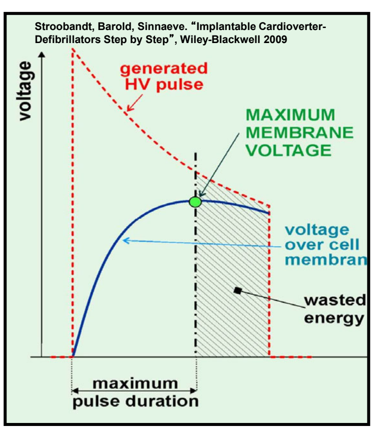
Solved for

- Optimal waveform for arbitrary capacitance
- Optimal capacitance for an ICD

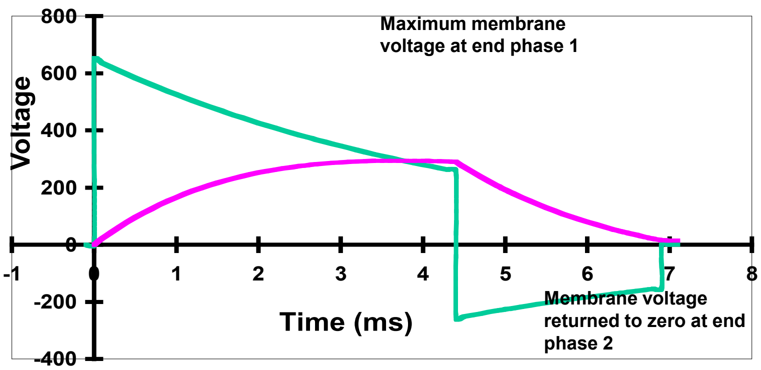
25

Efficient defibrillation waveforms have an electronic time constant (τ_s) tuned to the cardiac cell membrane's biological time constant (τ_m).

- Ion channels in cell membranes also have time constants (τ_m).
- Membranes reach maximum voltage at a time that depends only on τ_m.
- Shorter/longer pulses are inefficient.



Kroll, PACE. 1993;16:769–77.

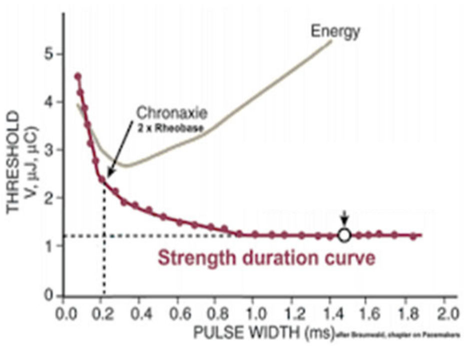


Kroll. PACE 17:1782-92;1994

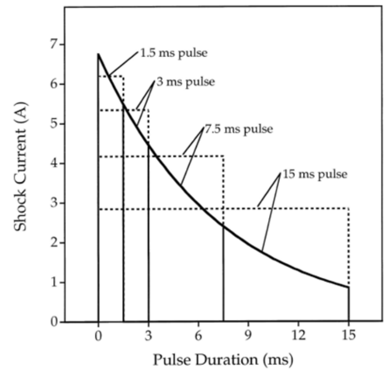
26

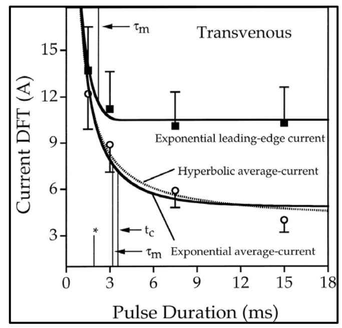
How do we find τ_m?

From the strength-duration curve



Weiss G. Arch Italienn Biol **1901**; 35:413–464
Lapicque L. J Physiol Pathol Générale **1907**; 9:567–578
Blair HA. Journal of General Physiology. **1932**;15:709-29.





Swerdlow, et al. "Application of models of defibrillation to human defibrillation data: implications for optimizing implantable defibrillator capacitance." Circulation 1997;96: 2813-2822.

Shorofsky et al. Effect of waveform tilt on defibrillation thresholds in humans. JCE. 1997;8:496–501.

27

The Role of Mathematical Models

" It can scarcely be denied that the supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience. "

~ *Albert Einstein* — June 10, 1933

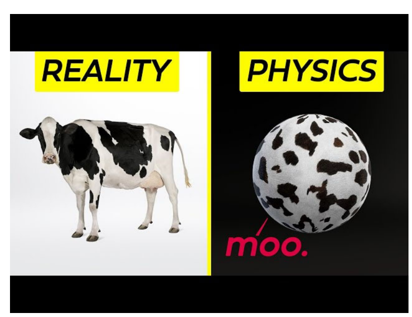
The Unreasonable Effectiveness of Mathematics in the Natural Sciences

E. P. Wigner

Symmetries and Reflections.
Indiana University Press, Bloomington, Indiana, 1967, pp. 222–237

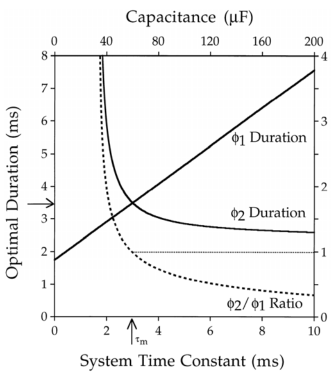
Assume a Spherical Cow

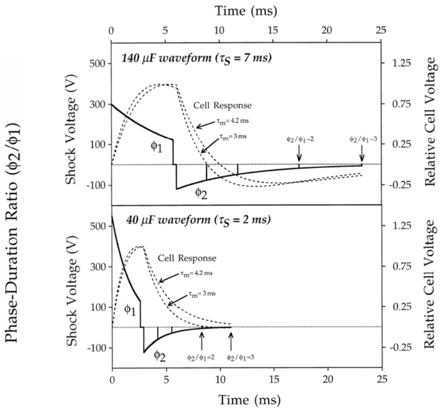
Is Kroll's model unreasonably effective in predicting optimal waveforms or a spherical cow?



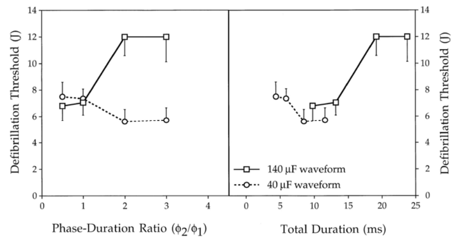
28

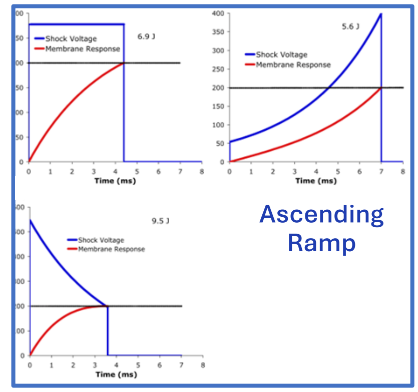
Kroll Model: Validation of Novel Predictions





Swerdlow CD, Fan W, Brewer JE. **Charge-burping theory correctly predicts optimal ratios of phase duration for biphasic defibrillation waveforms.** Circulation. 1996;94:2278-84.





Shorofsky SR, Rashba E, Havel W, et al. **Improved defibrillation efficacy with an ascending ramp waveform in humans.** Heart Rhythm. 2005;2:388–94.

Huang J, Ruse RB, Walcott GP, Litovsky S, Bohanan SJ, Gong DW, Kroll MW. **Ascending defibrillation waveform significantly reduces myocardial morphological damage and injury current.** JACC: EP. 2019;5:854-62.

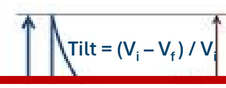
29

Do Waveforms Matter in 2025?

The Problem of Gradually-Rising Shock Z in Gore Coated Leads

Methods of Waveform Truncation

Swerdlow CD et al. Impedance in the Diagnosis of Lead Malfunction. Circ AE.



Boston Scientific

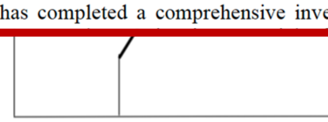
Important Medical Device Information

Rhythm Management
4100 Hamline Avenue North
St. Paul, MN 55112-5798
www.bostonscientific.com

July 2025

Subject: Management of gradually rising daily subthreshold, low-voltage shock impedance (LVSI) pattern associated with calcification of expanded polytetrafluoroethylene (ePTFE) coated single coil (SC) and dual coil (DC) RELIANCE™ defibrillation leads manufactured by Boston Scientific Corporation (BSC) from 2002 to 2021 that are no longer available for distribution. See Appendix B for a list of affected lead models.

Description: The association of calcified defibrillation lead coil(s) with a pattern of gradually rising LVSI measurements has been reported to BSC and described in several publications[1,2,3,4,5,6]. This calcification phenomenon can biologically encapsulate and electrically insulate the defibrillation lead coil(s). BSC has completed a comprehensive investigation of ePTFE RELIANCE lead



30

Consider…

Kroll's Background

- In defibrillation: NOI
- Sources

Weiss G. Arch Italienn Biol **1901**; 35:413–464
Lapicque L. J Physiol Pathol Générale **1907**; 9:567–578
Blair HA. Journal of General Physiology. **1932**;15:709-29.

Kroll's insights could have been made as early as the 1960s.

31

What can we learn from progress in defibrillation?

- it was hindered by lack of fundamental understanding at every step.
- It depended on advances in enabling technology.
- In the west, it was delayed by academic misogyny, KOLs.
- In the USSR, it was delayed by xenophobia and antisemitism.
- It did not occur in dominant medical device companies.
- It highlights the importance of clear scientific writing and reading poorly written papers with an open mind.
- IT COULD HAVE OCCURRED YEARS EARLIER.

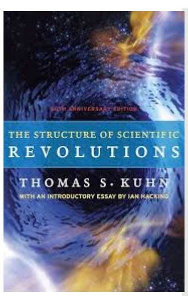
32

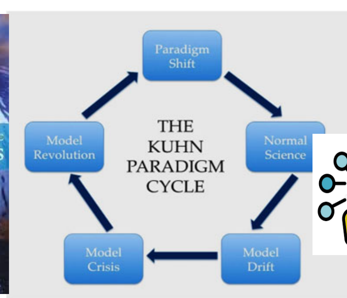
Delays in Defibrillation Technology

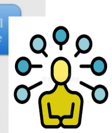
Delay	Possible Reasons
Adding an inductor to the DC circuit	▪ ? [lack of basic understanding of circuits]
Adopting DC defibrillation in the USA	▪ Focus on cause of AC electrocution ▪ KOL reinforce “acceptable research”
The biphasic waveform	▪ No mathematical/conceptual model of defibrillation
Waveform research guided by mathematical models	▪ Modeling not in investigator’s conceptual framework.
Commercializeing the AID after “proof of concept"	▪ KOL; limited access to suitable HV capacitor

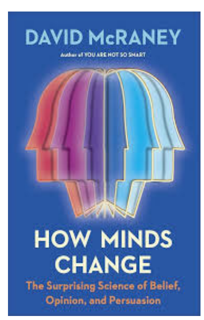
33

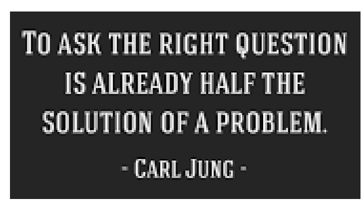
Conceptual framework guides what questions are asked and how results are interpreted.

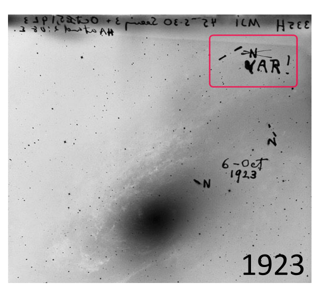






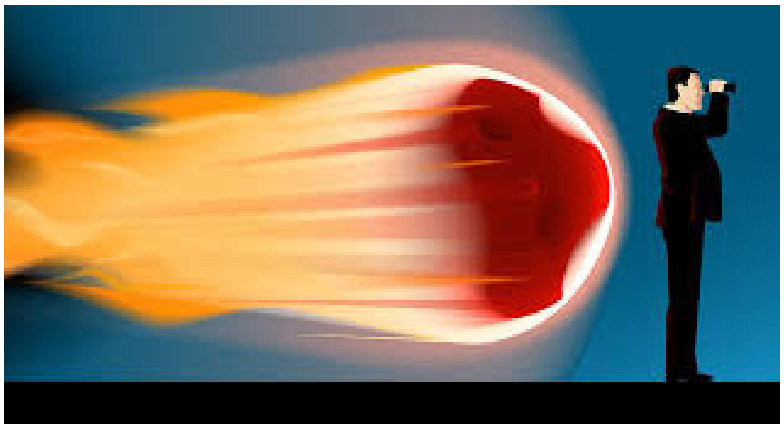






34

What conceptual insights are we missing now?



35

Thank you

36