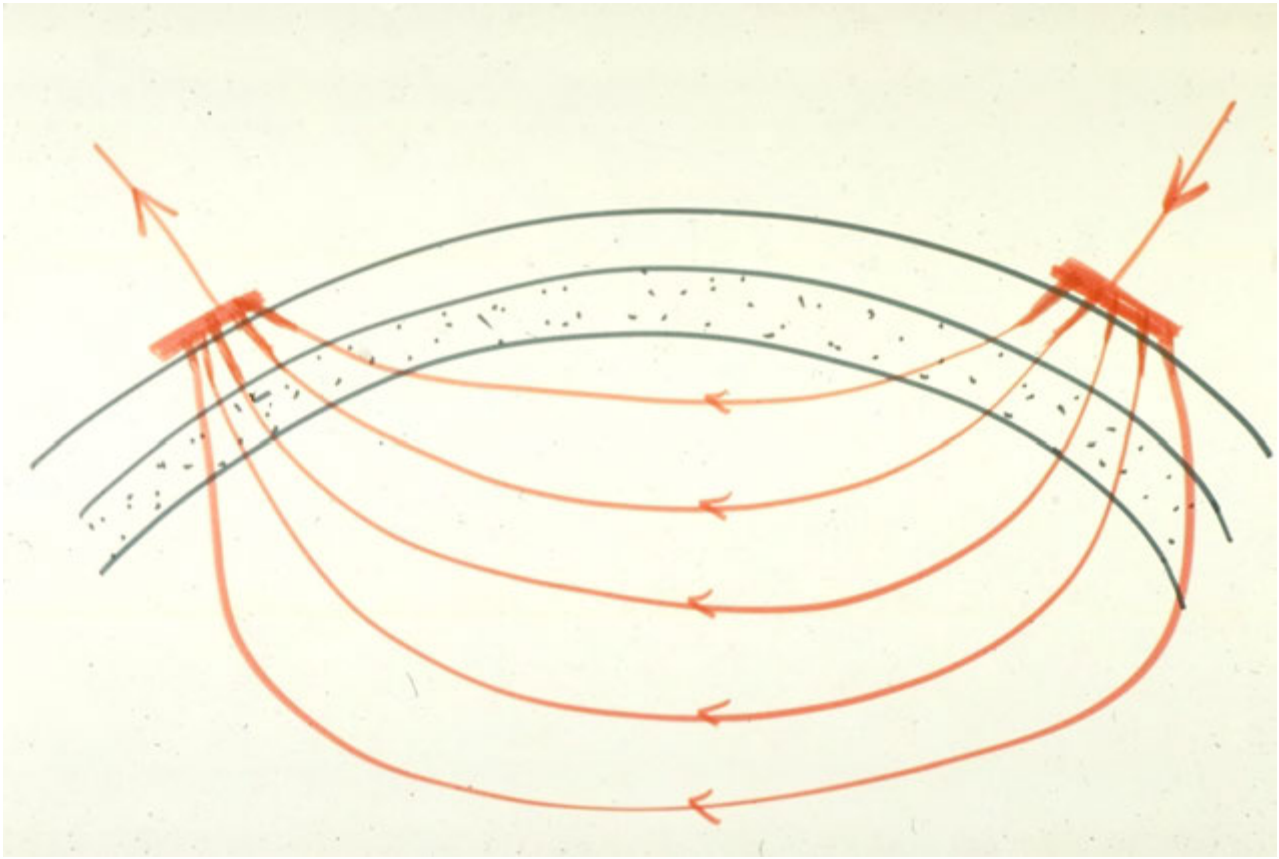
TMS PHYSICS

David Cohen

MGH/MIT/HMS Athinoula A. Martinos Center
for Biomedical Imaging
at Massachusetts General Hospital ;
also Magnet Lab at Mass. Institute of Technology



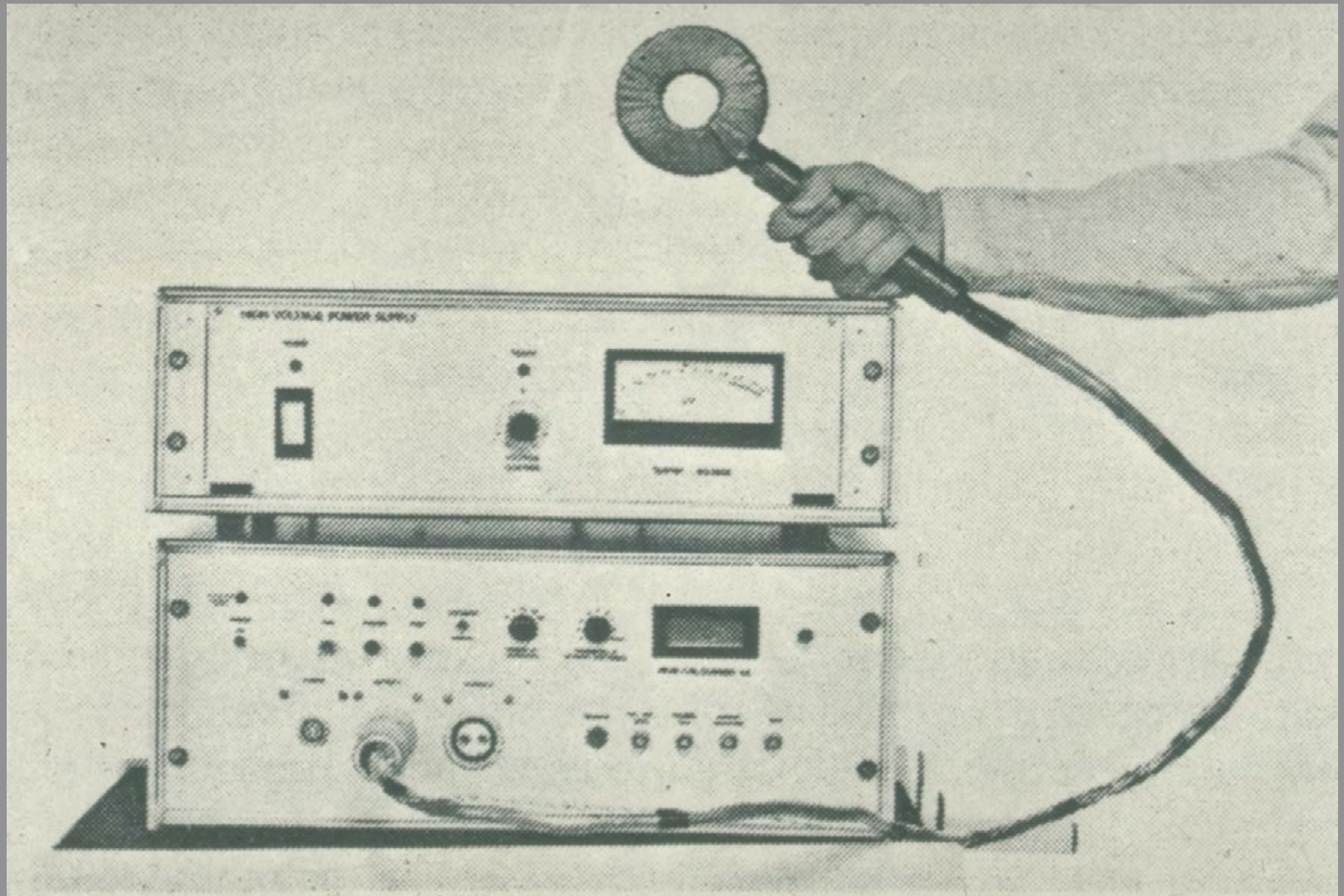


Fig 1—Magnetic stimulator and coil.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

FRANCIS BITTER NATIONAL MAGNET LABORATORY

FEASIBILITY OF A MAGNETIC STIMULATOR FOR THE BRAIN

A Research Proposal Submitted

to

The Office of Naval Research

Proposed starting date: April 1, 1983

Proposed duration: Three years

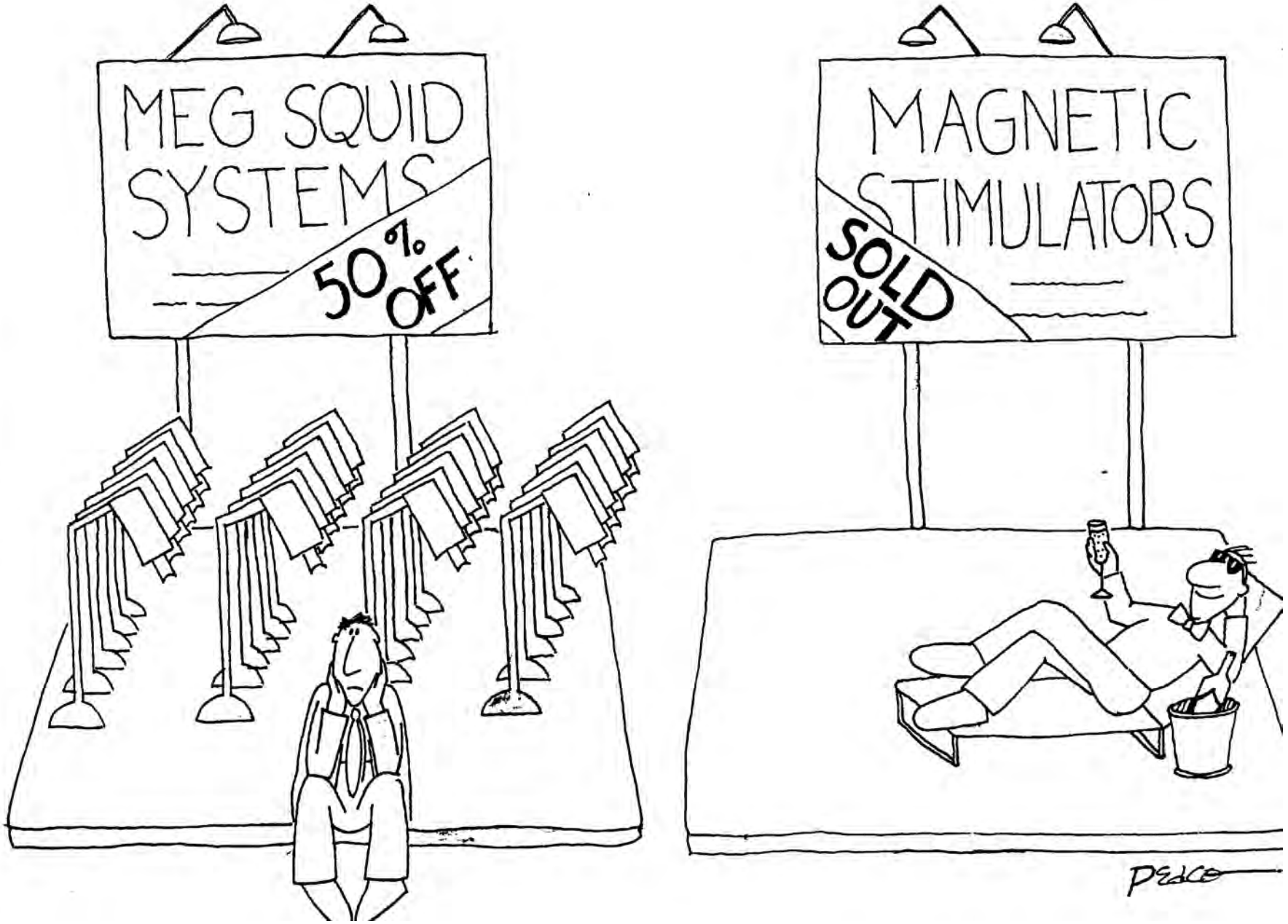
Amount requested: $369,960 (including indirect costs)

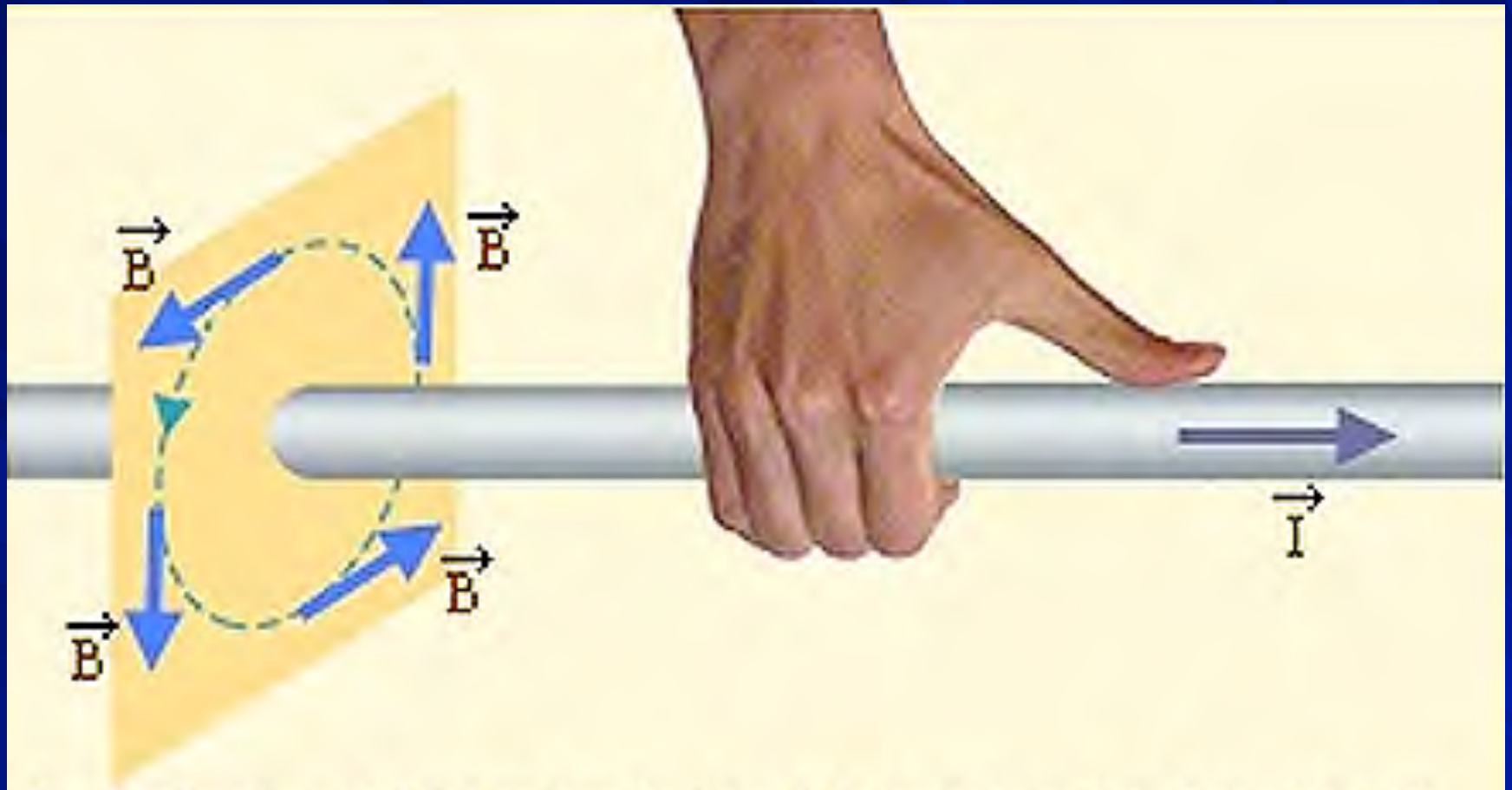
Principal Investigator:

David Cohen

David Cohen, Senior Scientist
Francis Bitter National Magnet Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139
Tel. (617) 253-5544

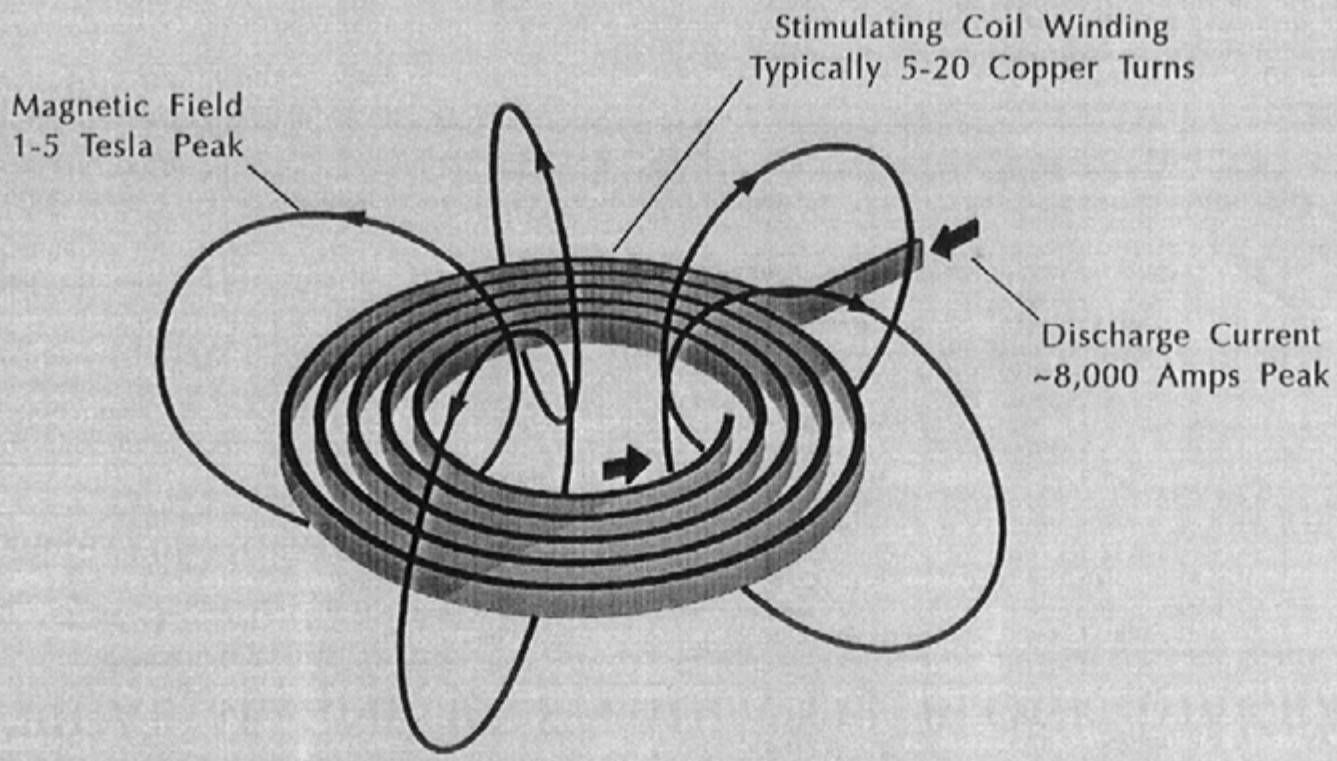
George H. Dummer, Director
Office of Sponsored Programs
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139
Tel. (617) 253-2492

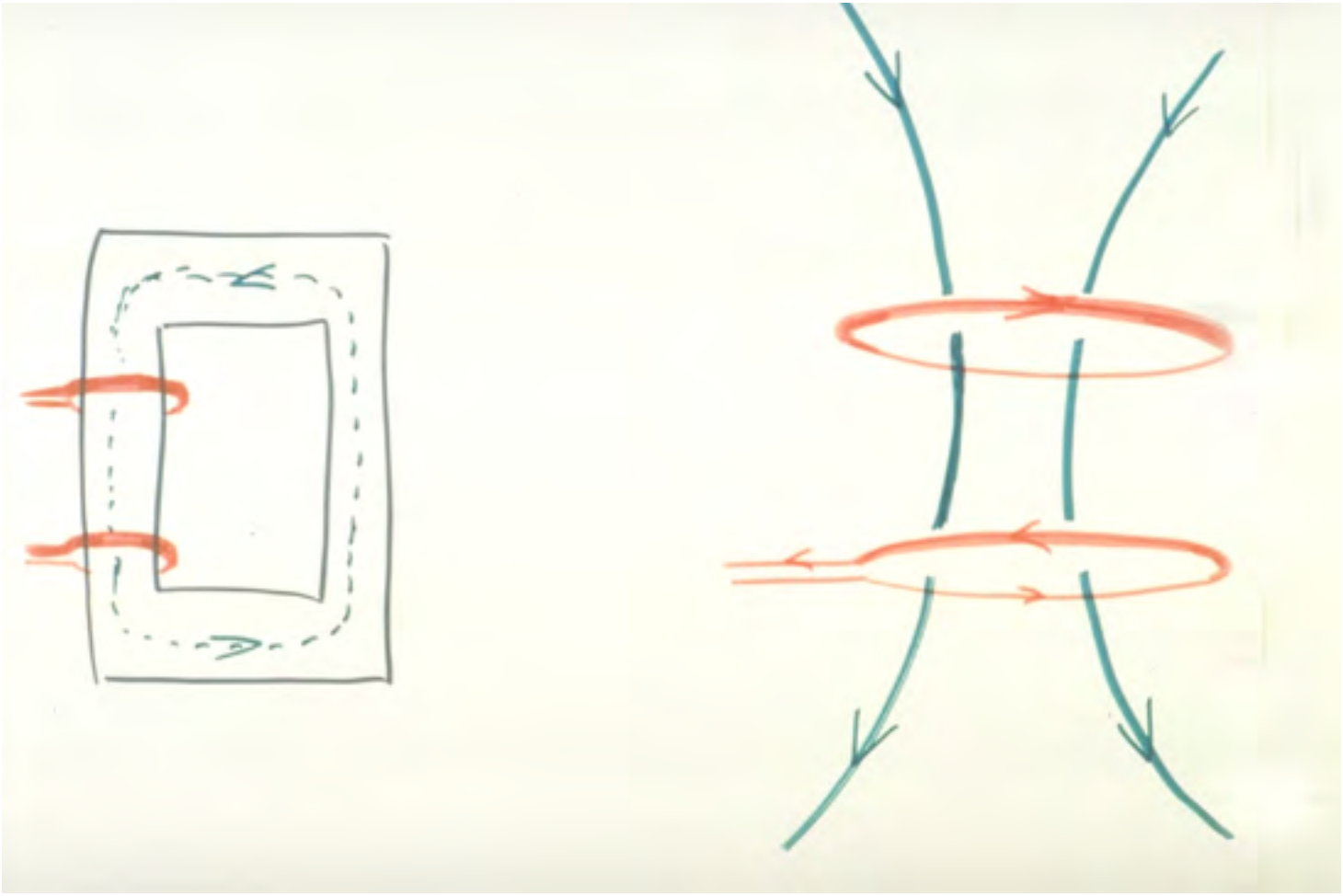

MEG SQUID SYSTEMS
50% OFF
MAGNETIC STIMULATORS
SOLD OUT
PEACE

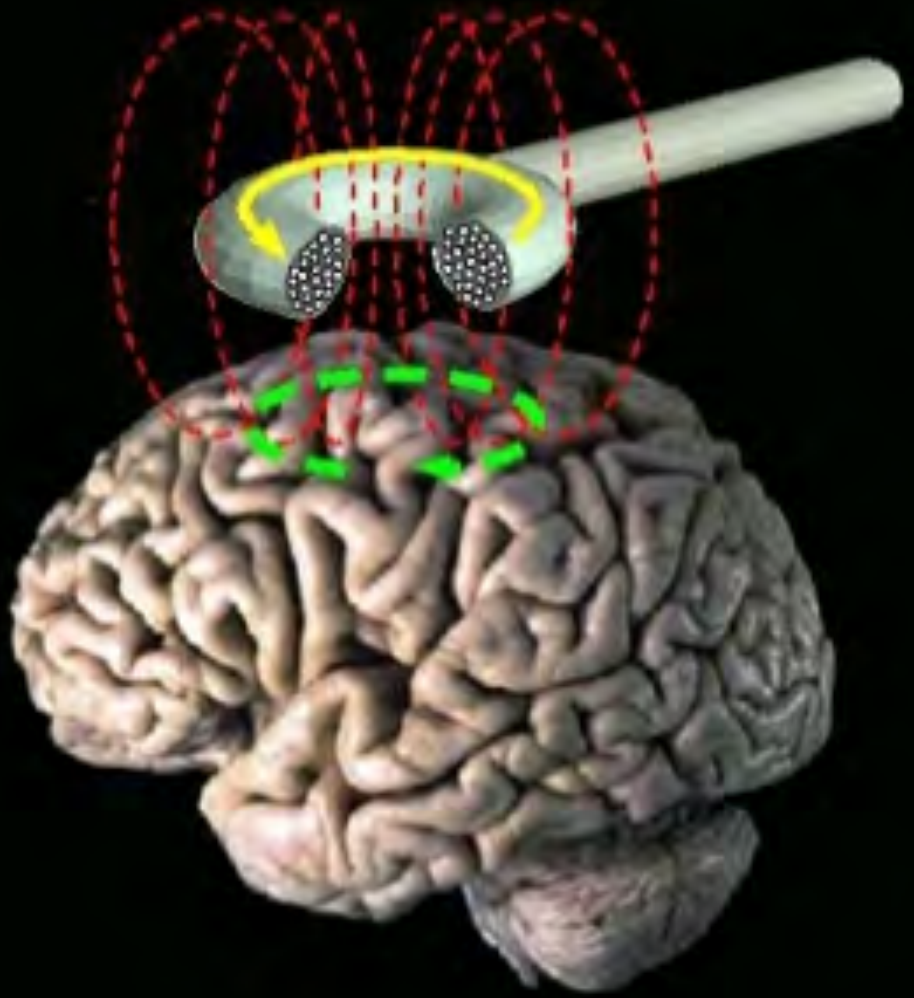


To apply the right-hand rule for determining the direction of the magnetic field produced by a steady current, imagine gripping the wire with your right hand so that your thumb points in the direction of current flow. Your fingers naturally curl in the direction in which the magnetic field circulates.

COIL CURRENT AND MAGNETIC FIELD

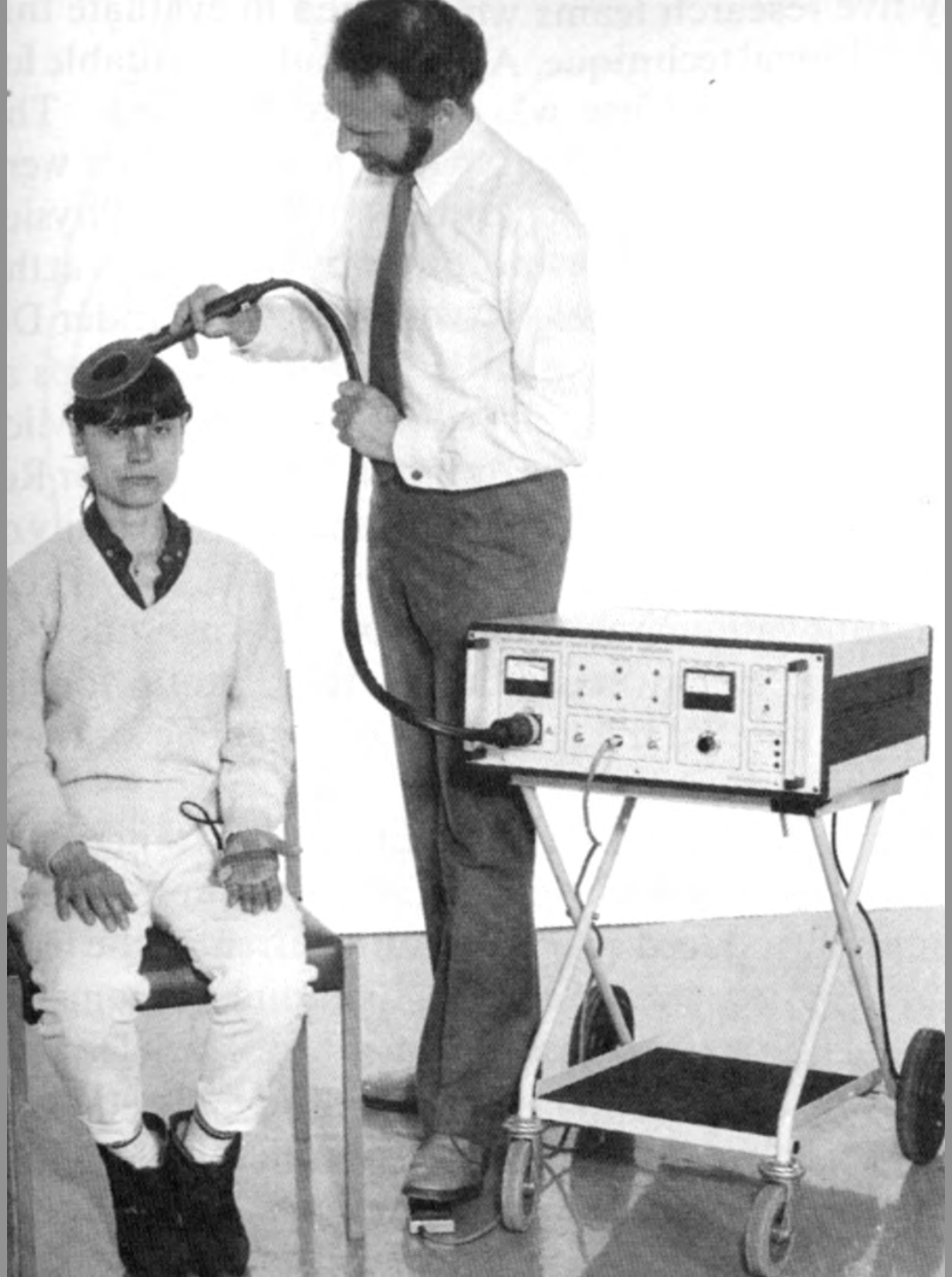


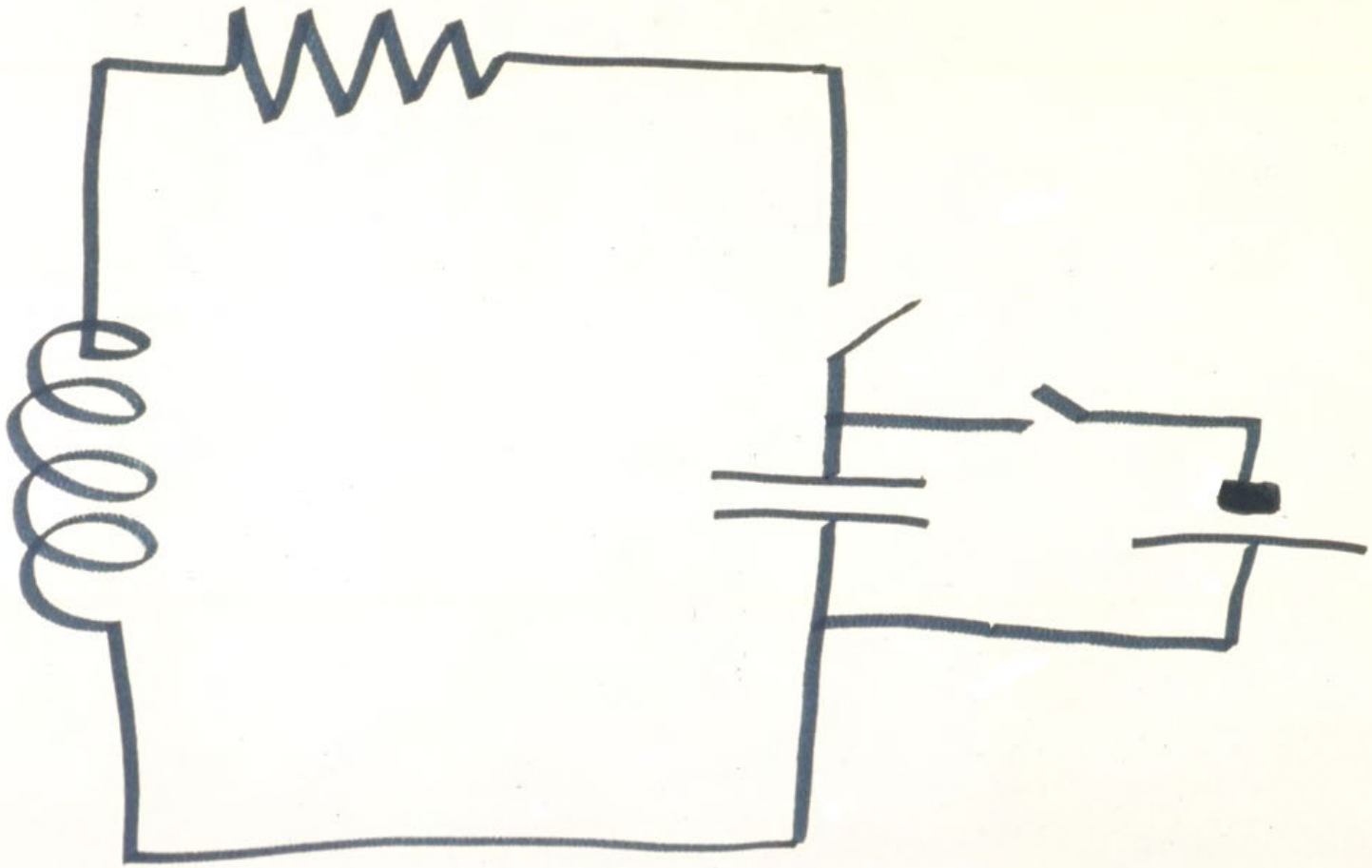


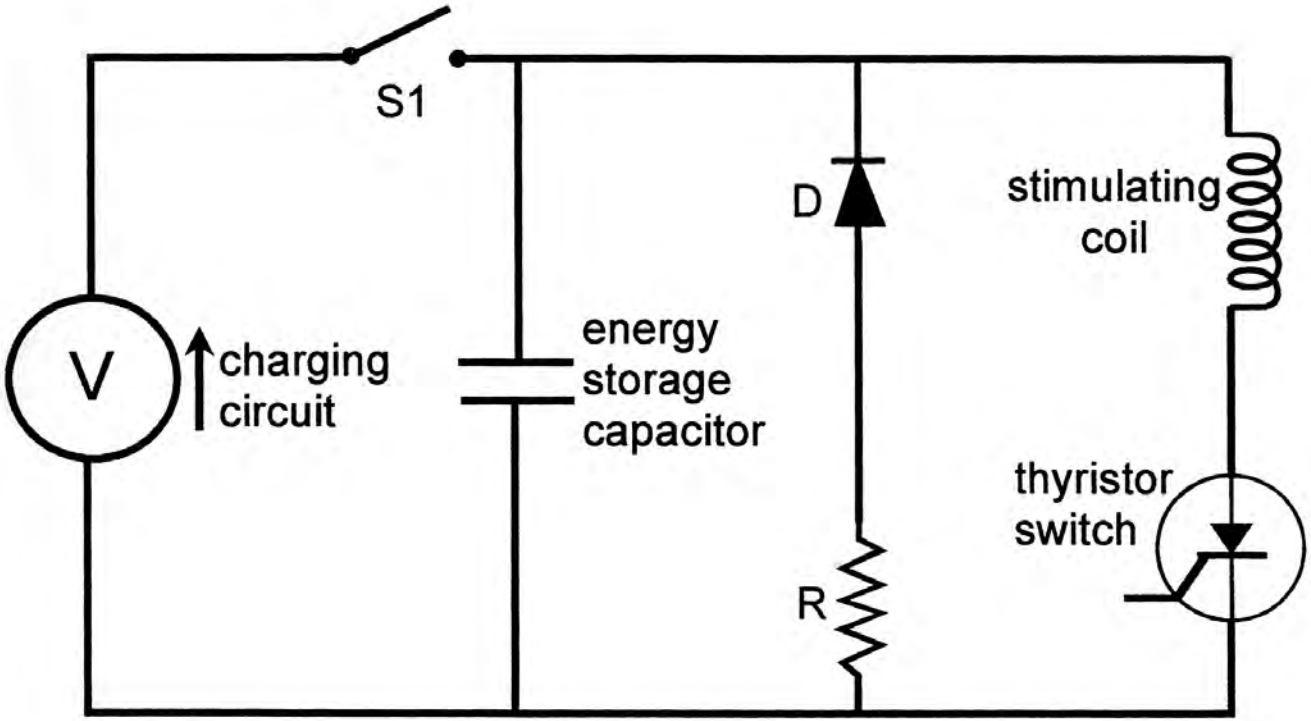


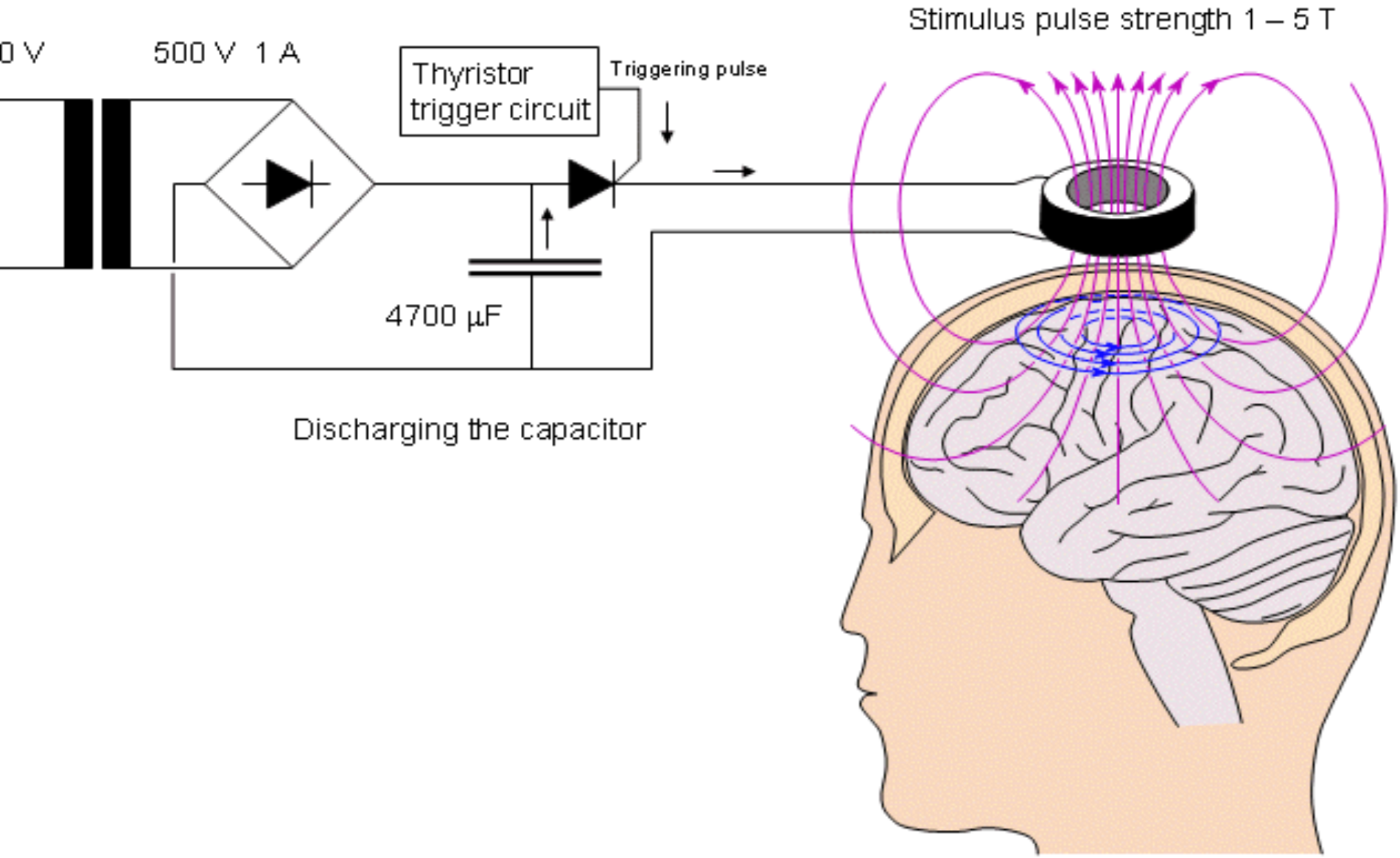
The Basic Law of Magstim:

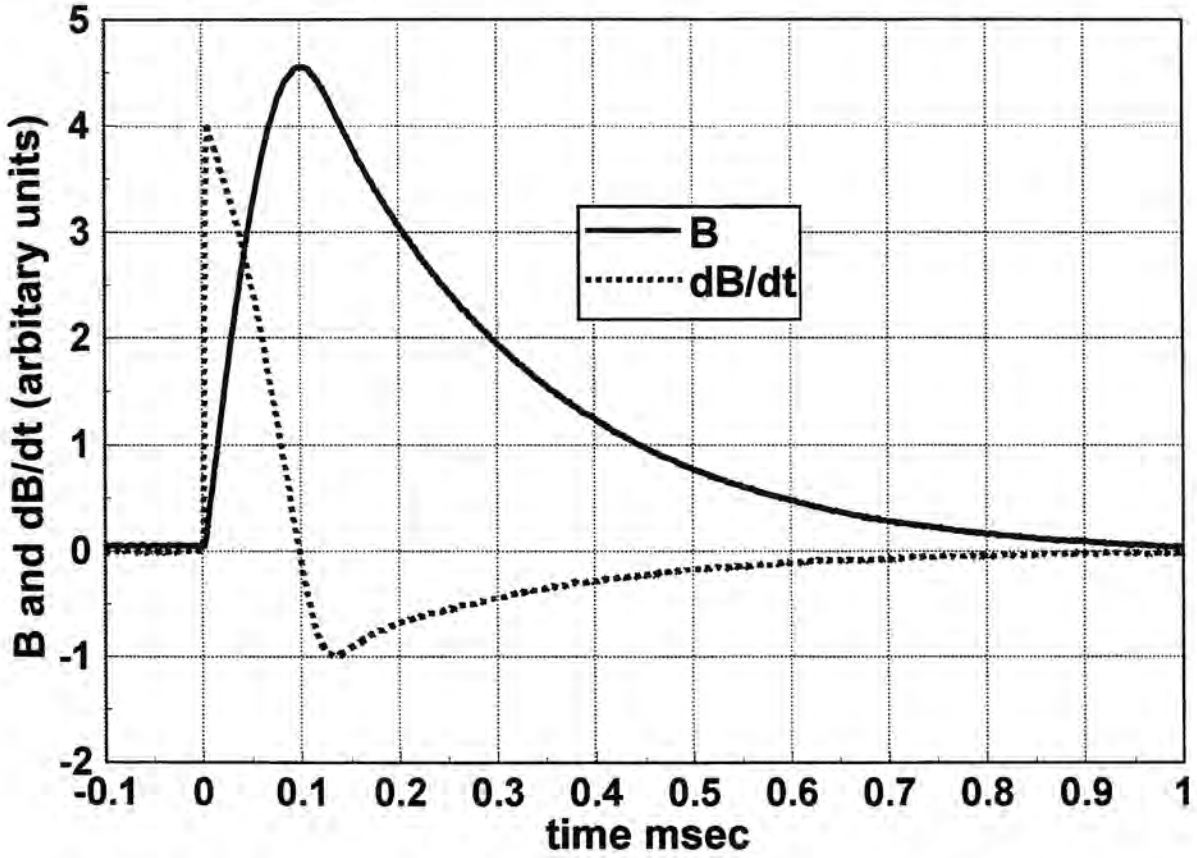
Faradays Law of Induction. When a magnetic field through a conductor changes, an electric field (hence a current) is induced in the conductor.



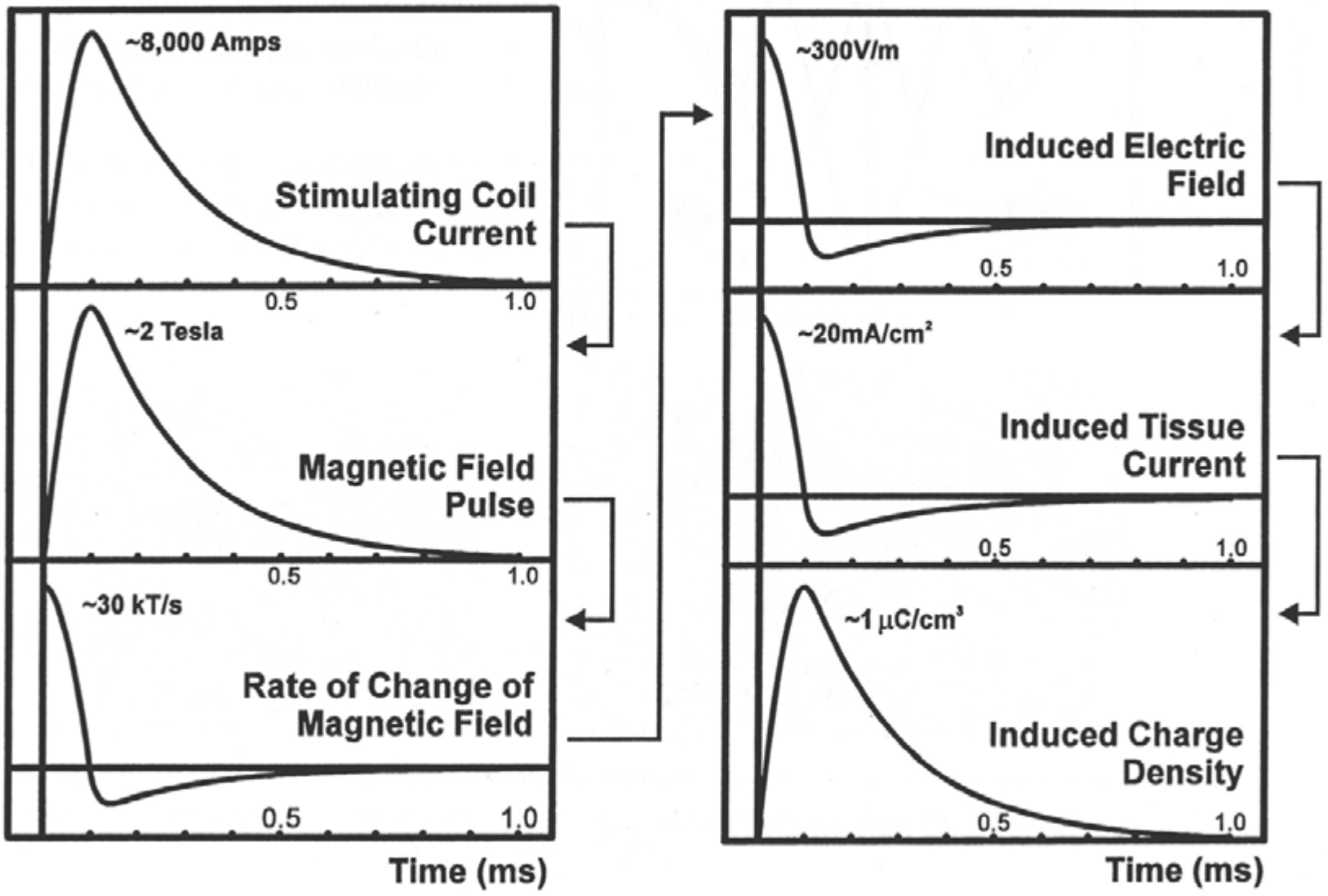



S1
D
stimulating
coil
V
charging
circuit
energy
storage
capacitor
thyristor
switch
R


Stimulus pulse strength 1 – 5 T
0 V
500 V 1 A
Thyristor
trigger circuit
Triggering pulse
4700 µF
Discharging the capacitor


B and dB/dt (arbitary units)
time msec
B
dB/dt
5
4
3
2
1
0
-1
-2
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

FROM COIL CURRENT TO INDUCED CHARGE



TMS SEQUENCE

-- Changing magnetic field induces an electric field everywhere (as a time derivative)

-- In a conductor, the electric field generates a current (according to ohm's law E=IR)

-- The current stimulates the axons (according to its rate-of-change along the axon)

Journal of Clinical Neurophysiology
8(1):102–111, Raven Press, Ltd., New York
© 1991 American Electroencephalographic Society

Developing a More Focal Magnetic Stimulator. Part I: Some Basic Principles

David Cohen and B. Neil Cuffin

Francis Bitter National Magnet Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, U.S.A.

Summary: Some general properties of currents induced by magnetic stimulators in volume conductors of any shape are first reviewed. Then, the property of focality (concentration at some internal point) of the current induced in a spherical model of the head is discussed, due to coils of various orientations and configurations. It is shown that one important property for focality is the complete absence of the radial component of current, regardless of the coil used. The theoretically computed current distributions in the sphere produced by three different coils are illustrated. These are (1) a circular coil parallel to the head (very nonfocal), (2) a circular coil erect on the head (more focal), and (3) a figure-eight coil parallel to the head (most focal). A computational search for yet more focal coil configurations shows that the figure-eight focality can only be altered

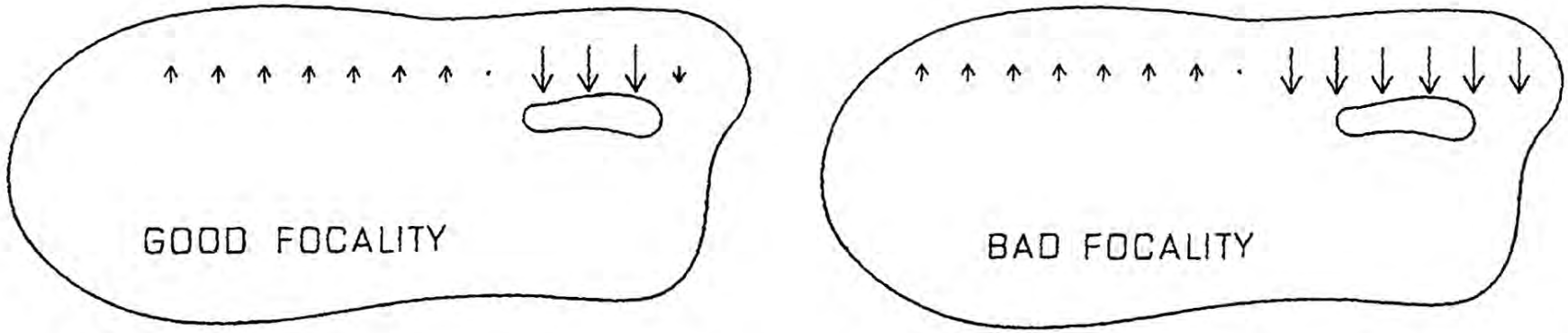


Fig. 2. Two different ways to pass current through a target area shown as the enclosed area at the upper right. The conductor here is again of arbitrary shape. In this arrow display, the arrows are equally spaced and, for illustration purposes, are only shown along one line instead of in the entire plane.

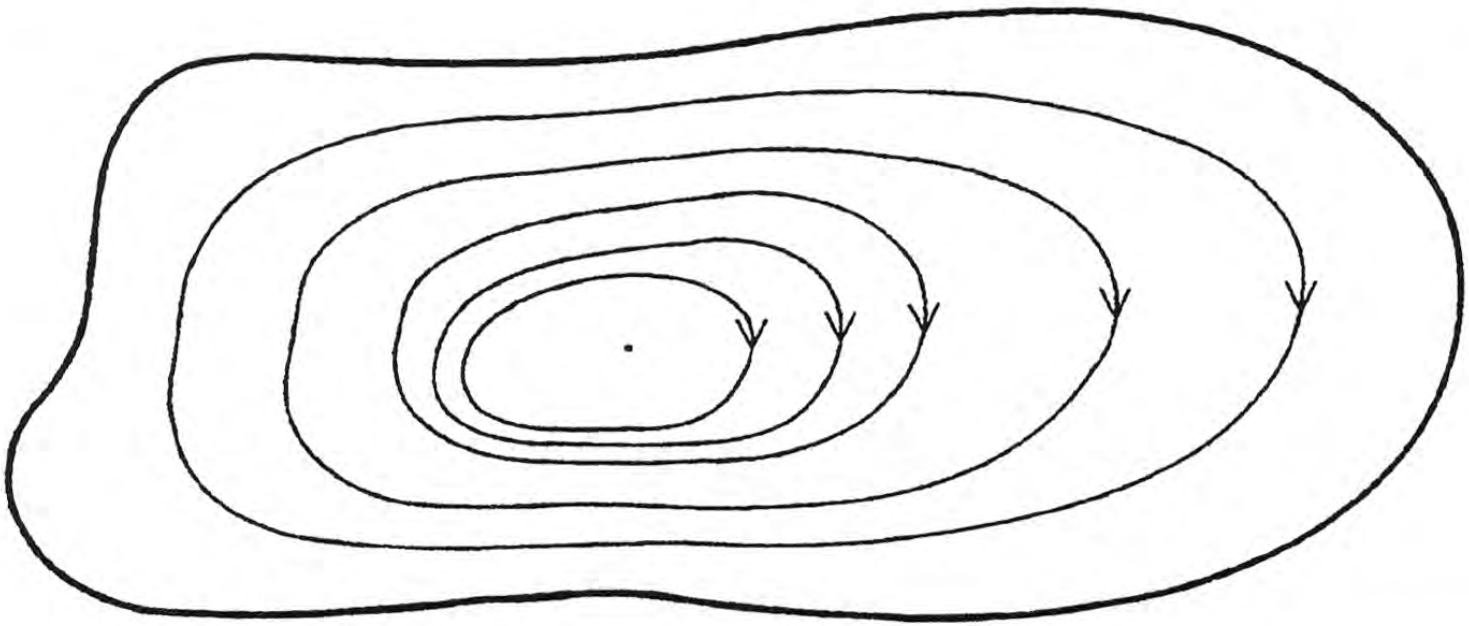
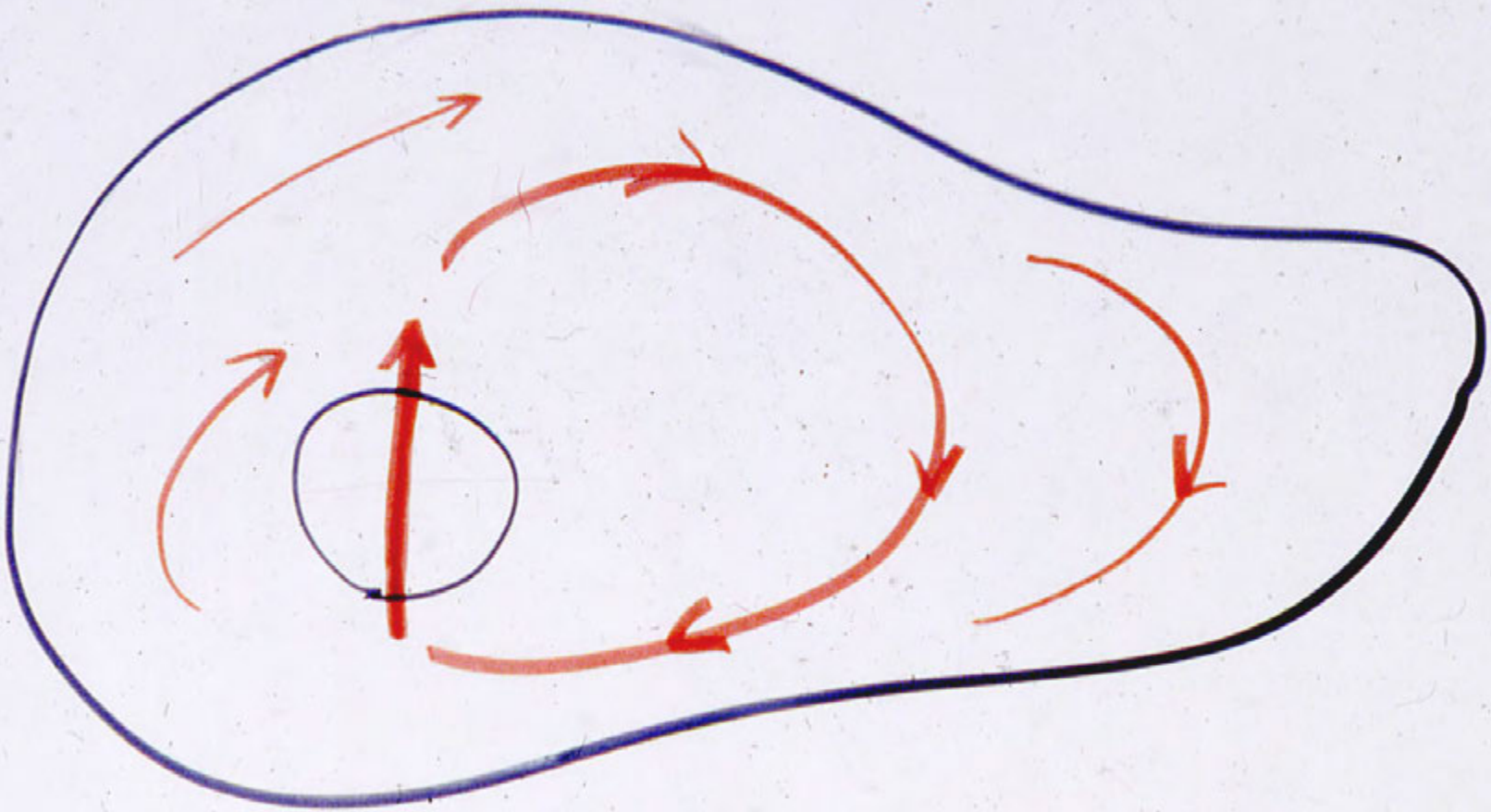
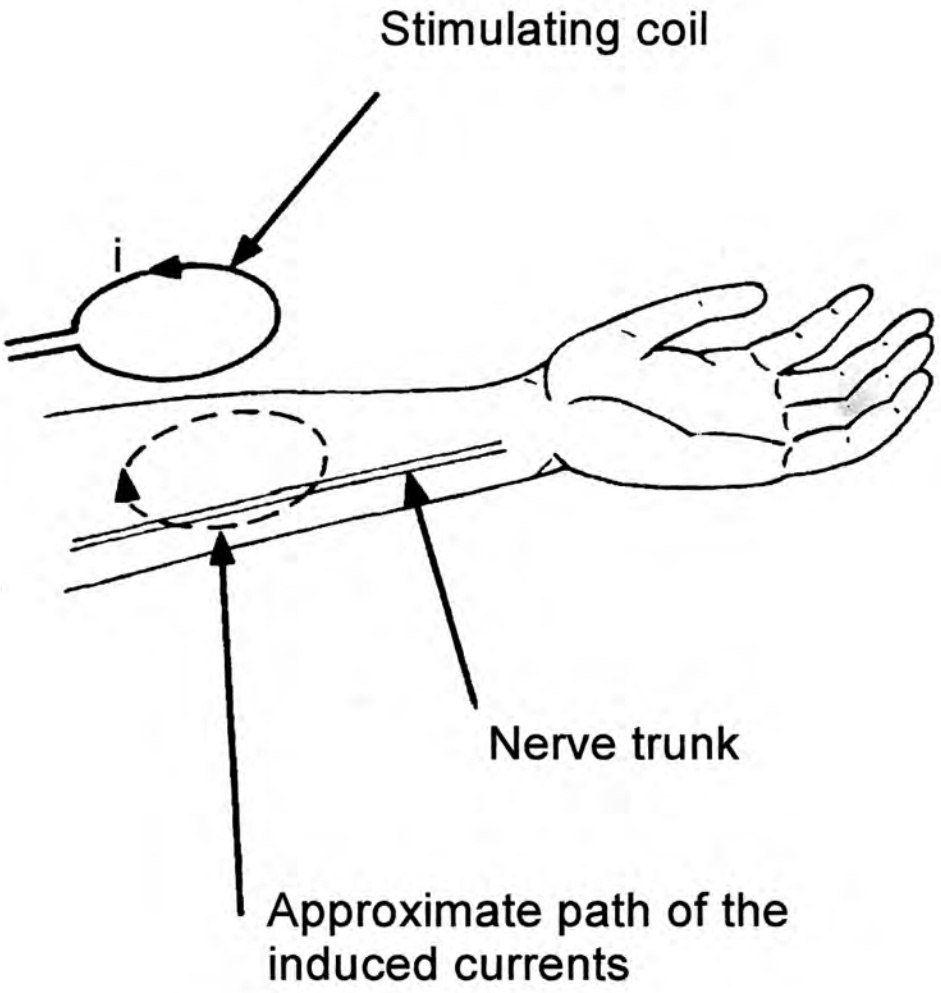
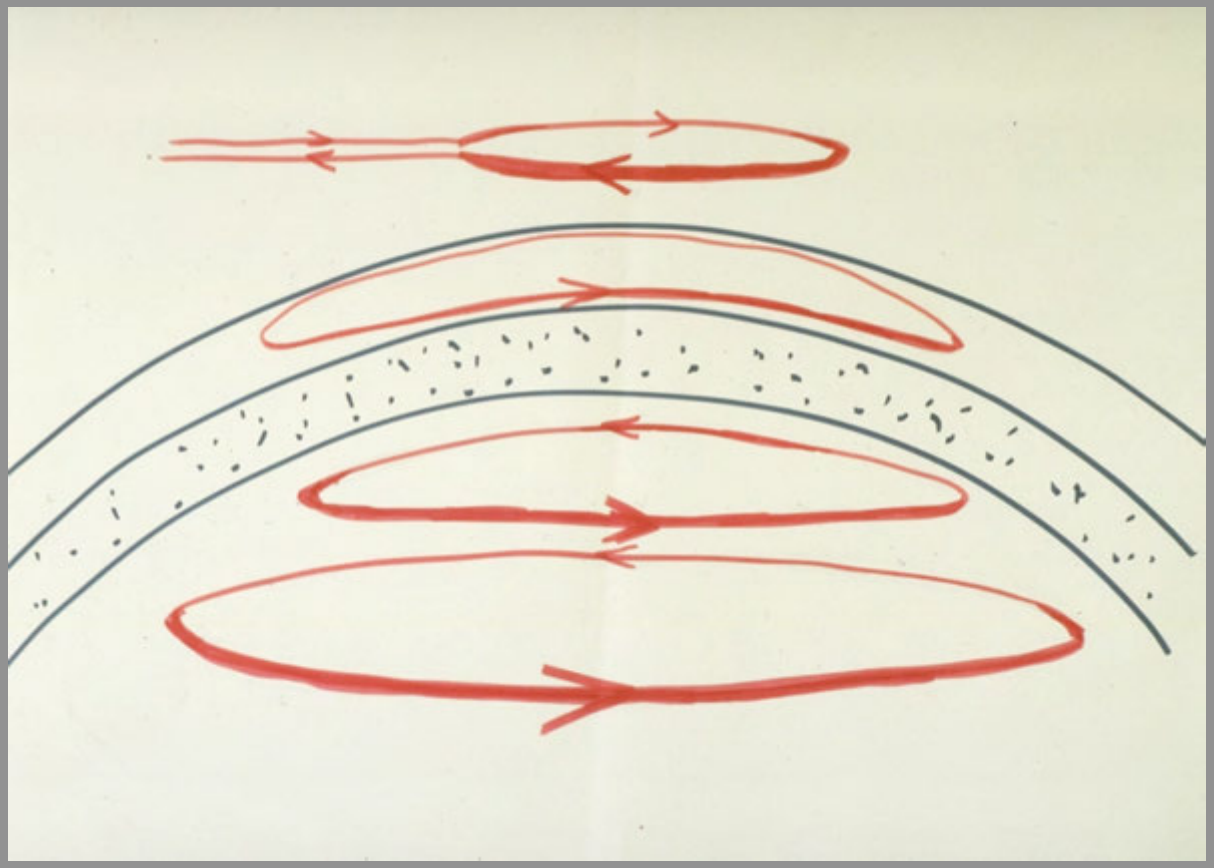
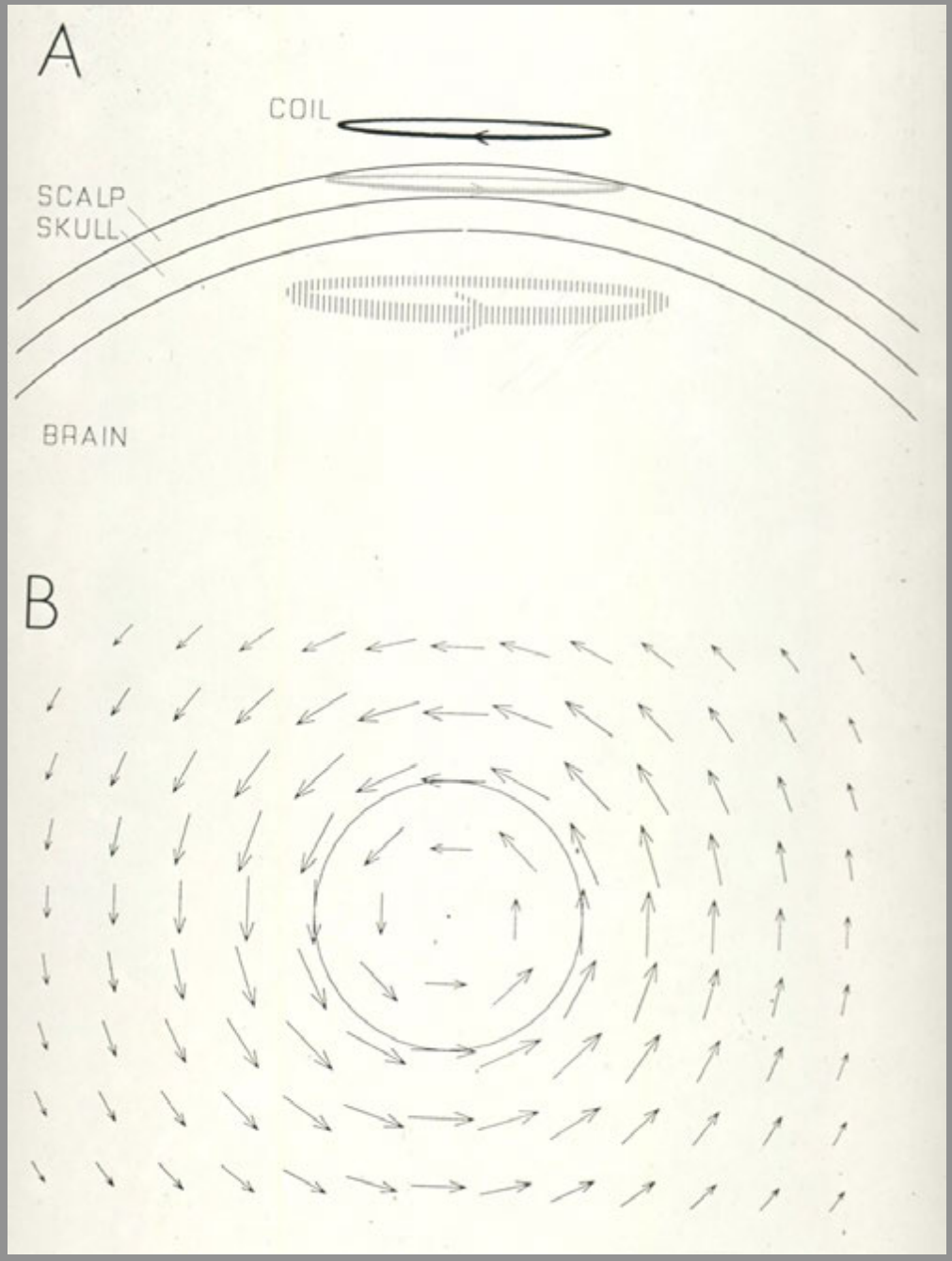


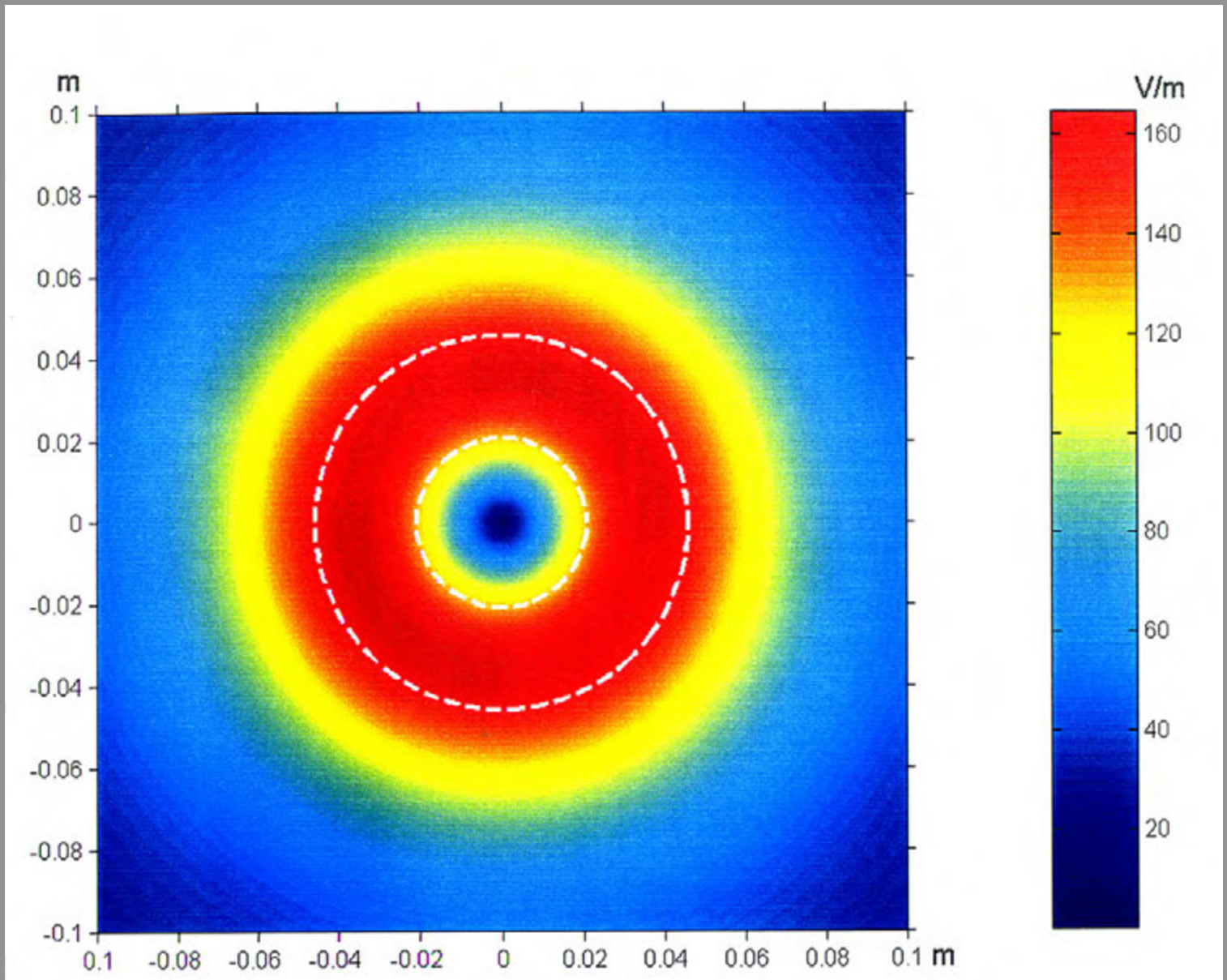
Fig. 1. Current induced by a magnetic stimulator in a volume conductor of arbitrary shape or a "blob", where the boundary is the dark outer line. The current density is indicated by the density of inner lines, and the null point by a dot near the center.

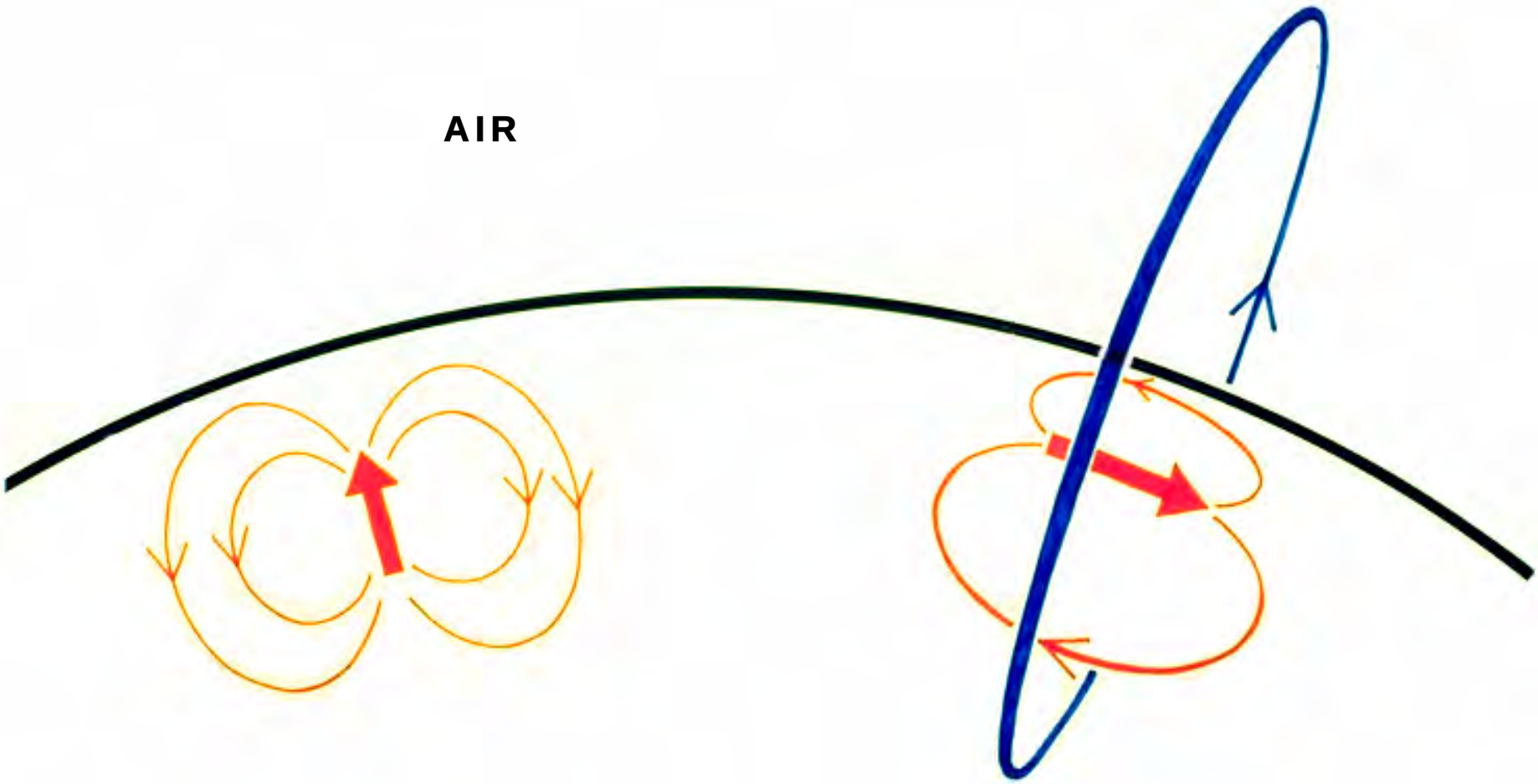


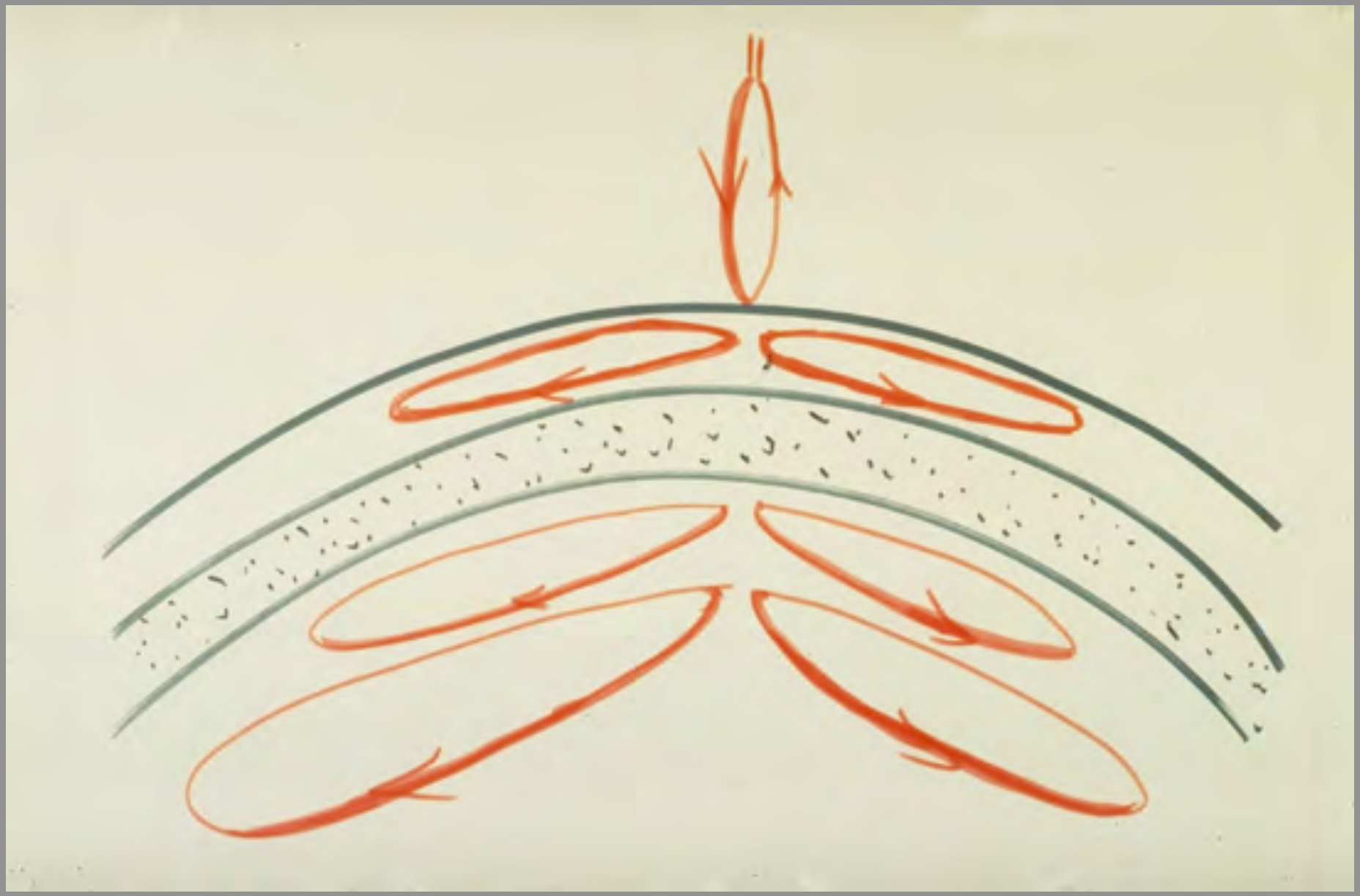

Stimulating coil
i
Nerve trunk
Approximate path of the
induced currents

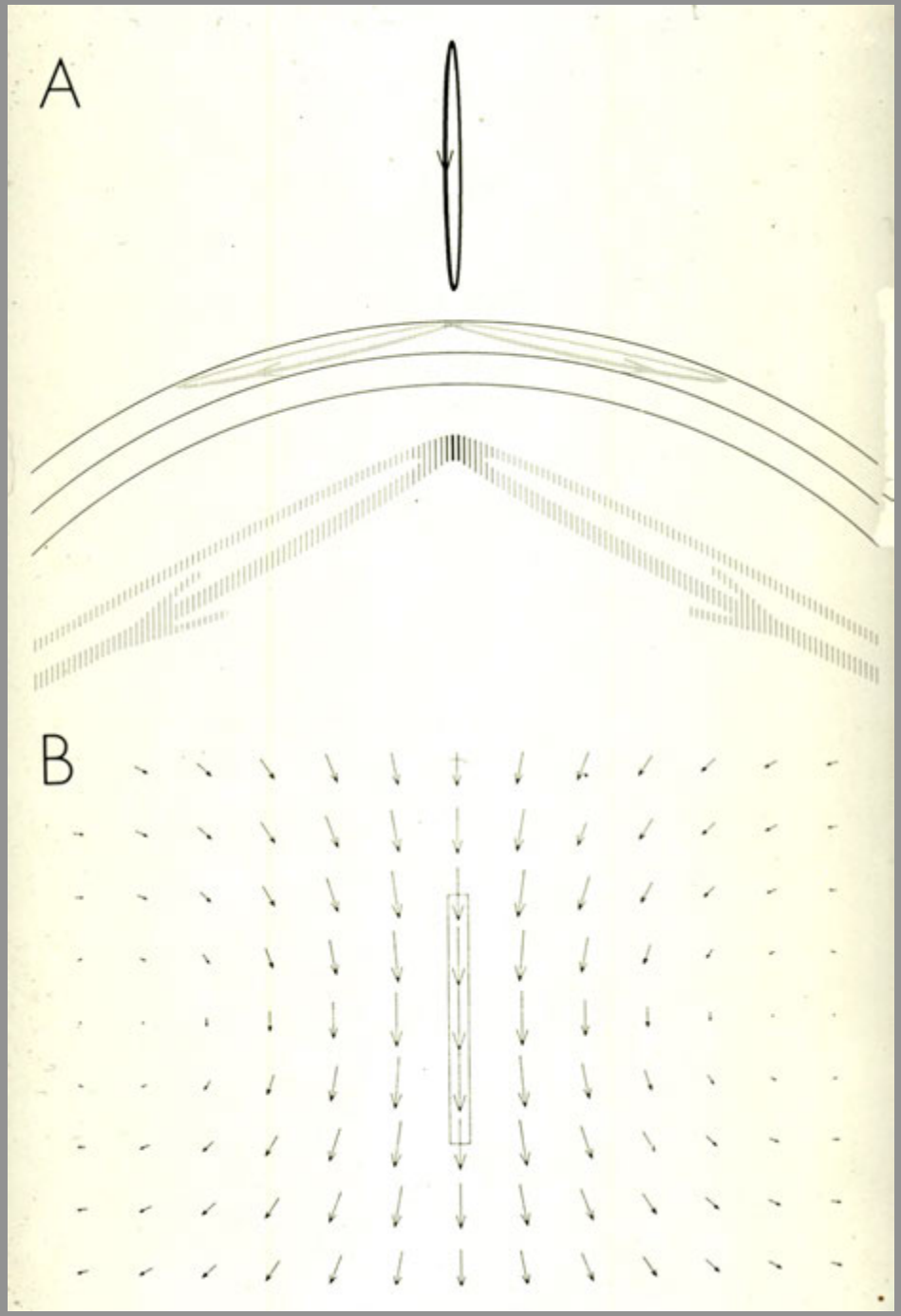


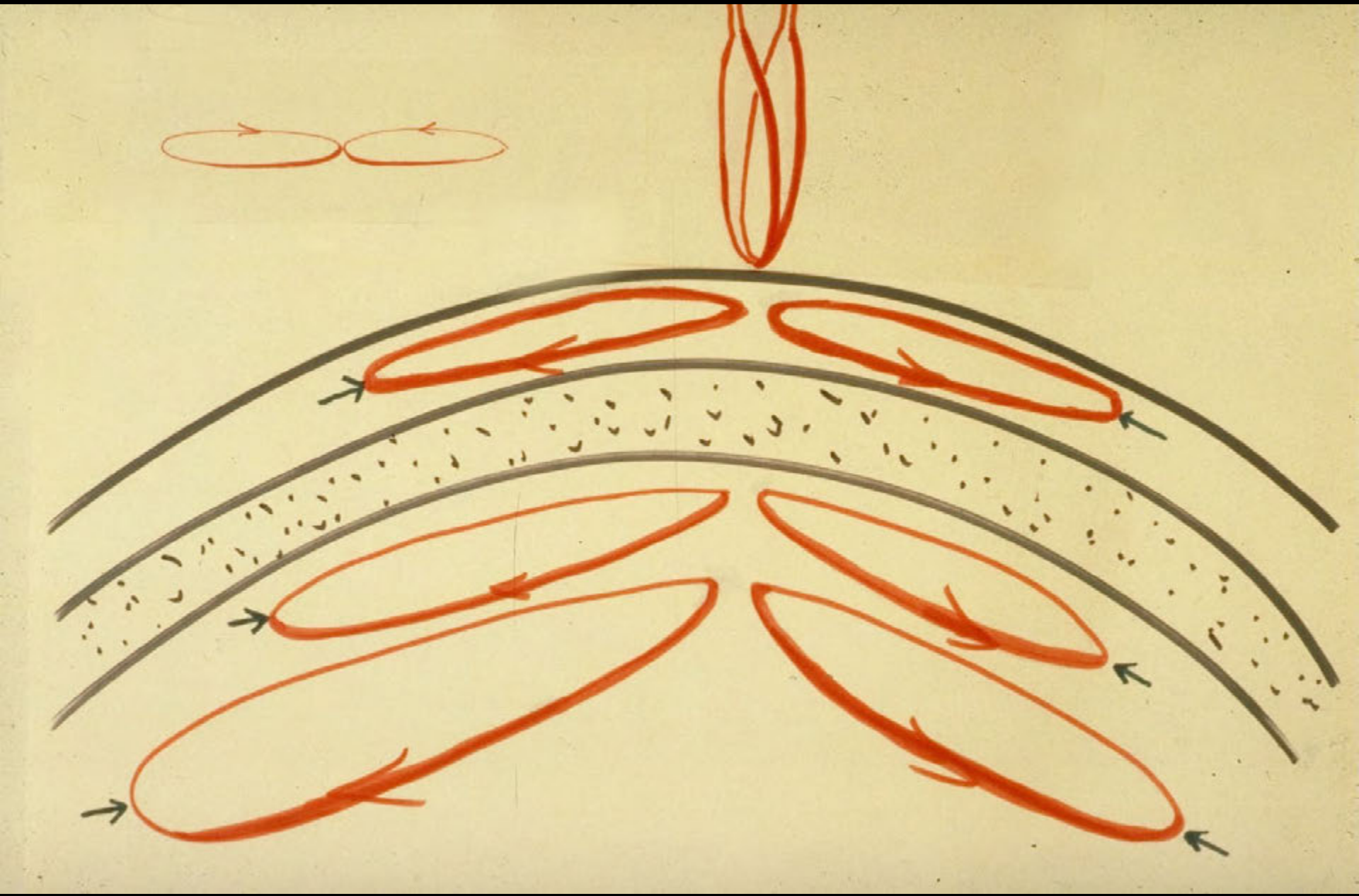

A
COIL
SCALP
SKULL
BRAIN
B

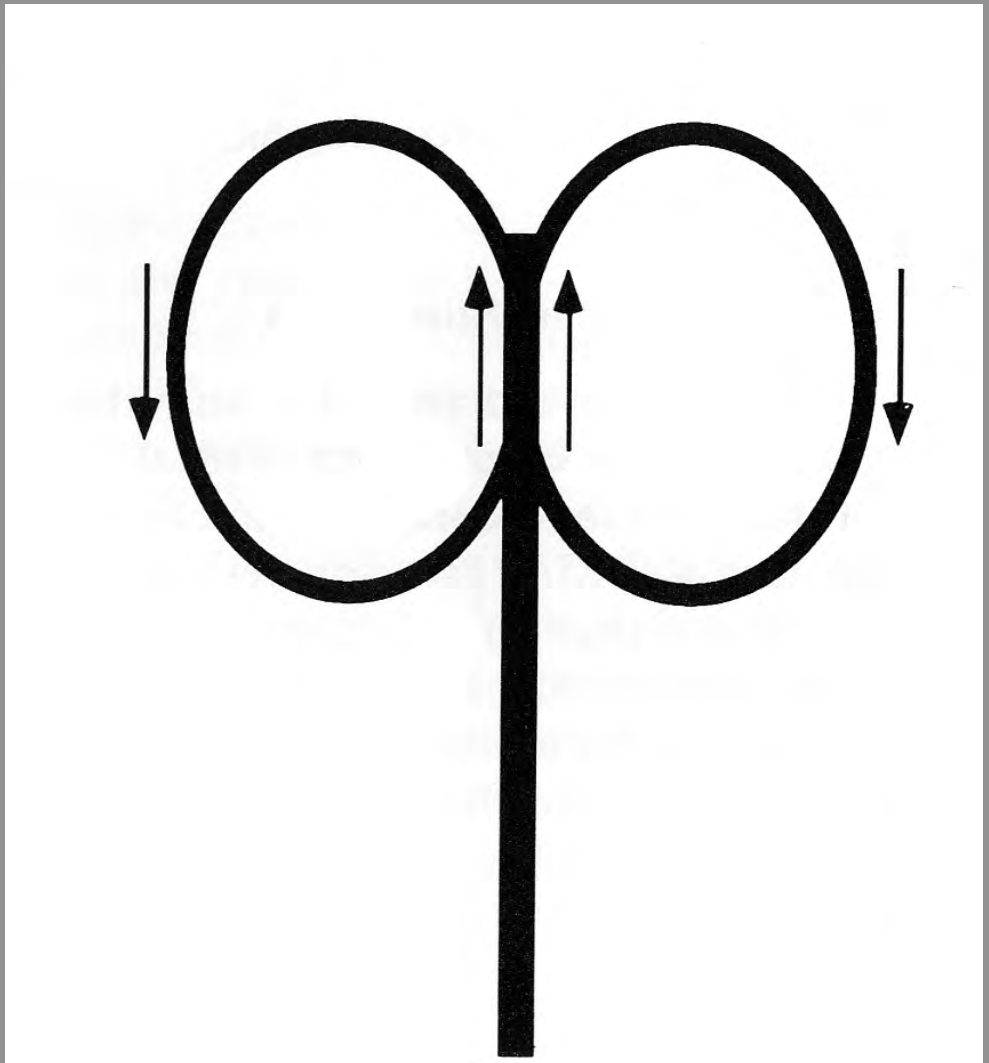

m
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1
m
V/m
160
140
120
100
80
60
40
20

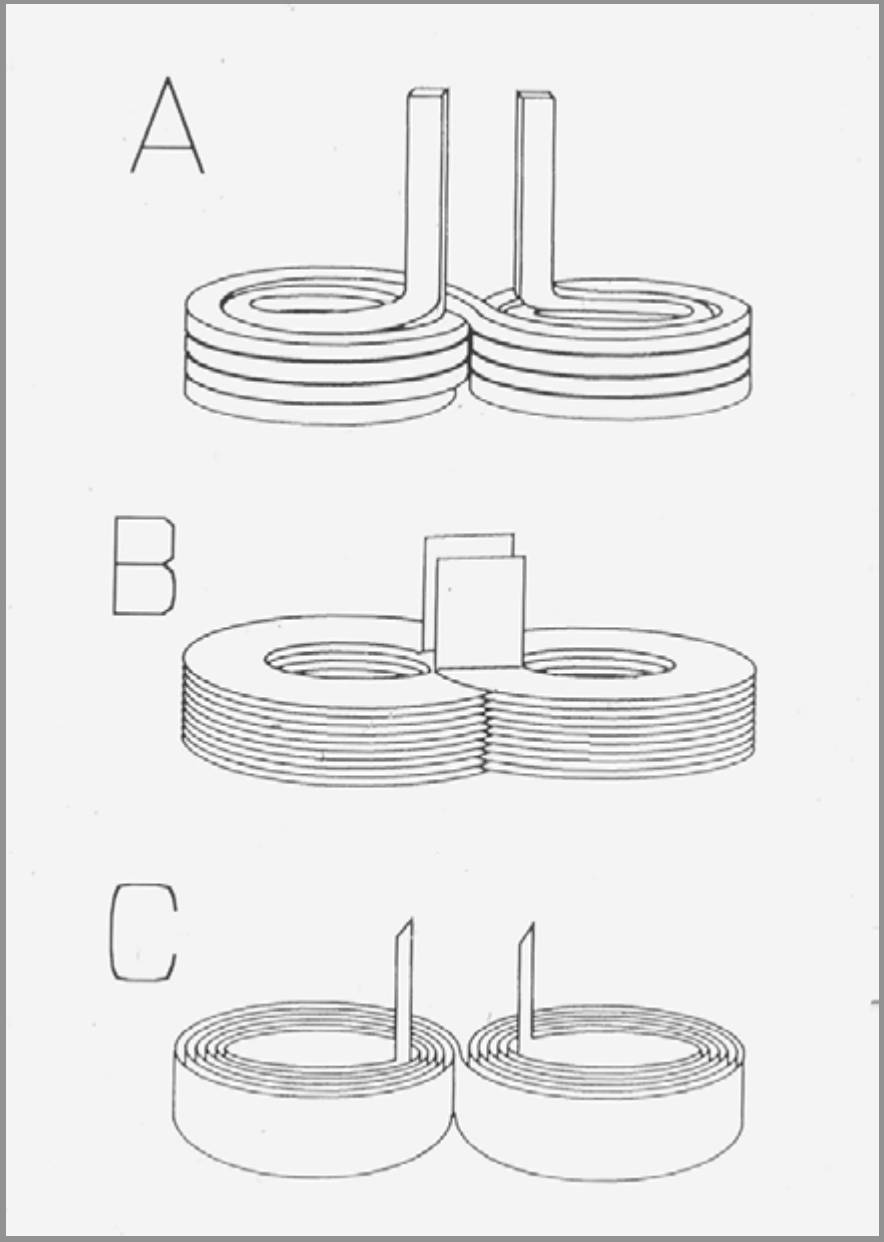

AIR
SALT WATER

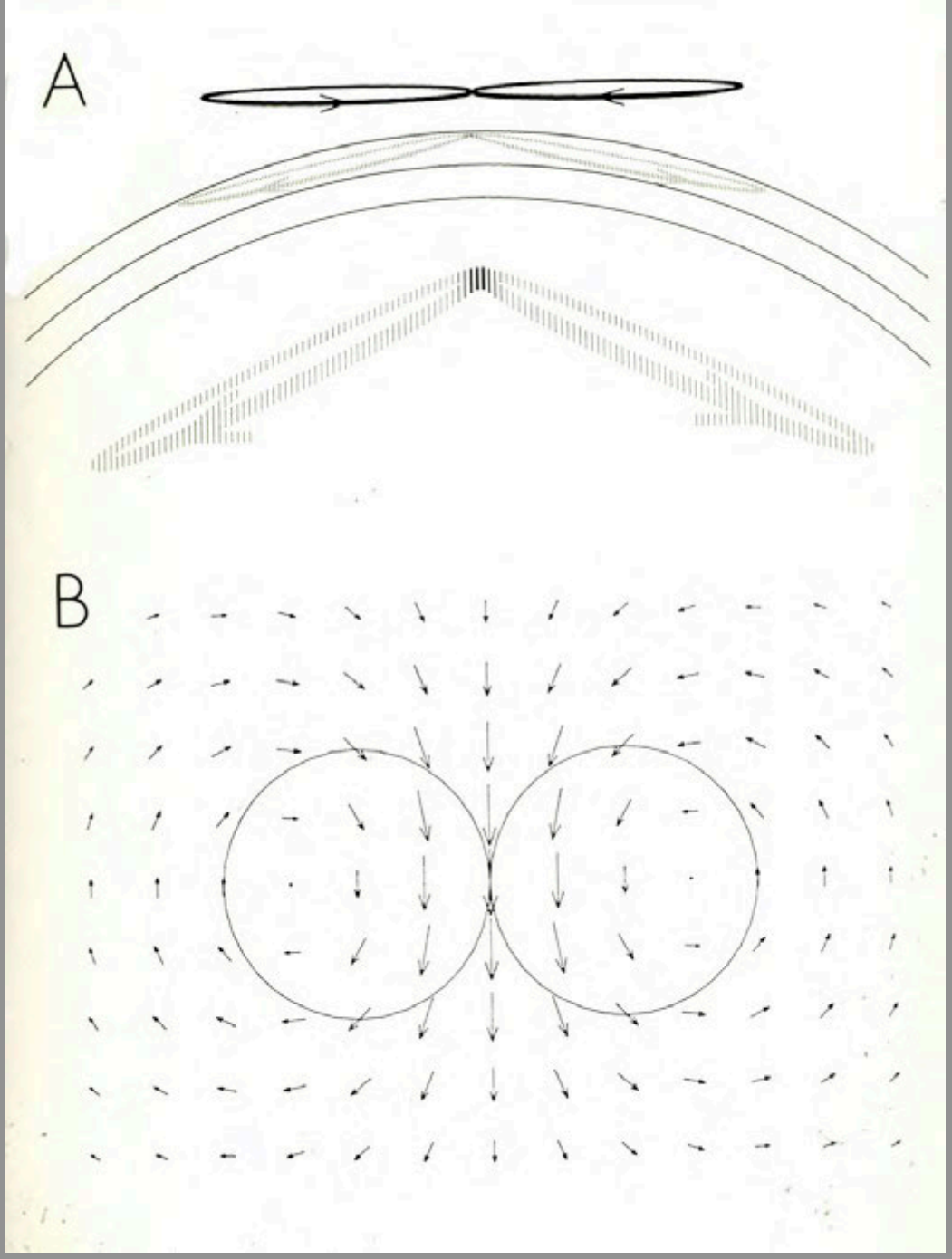


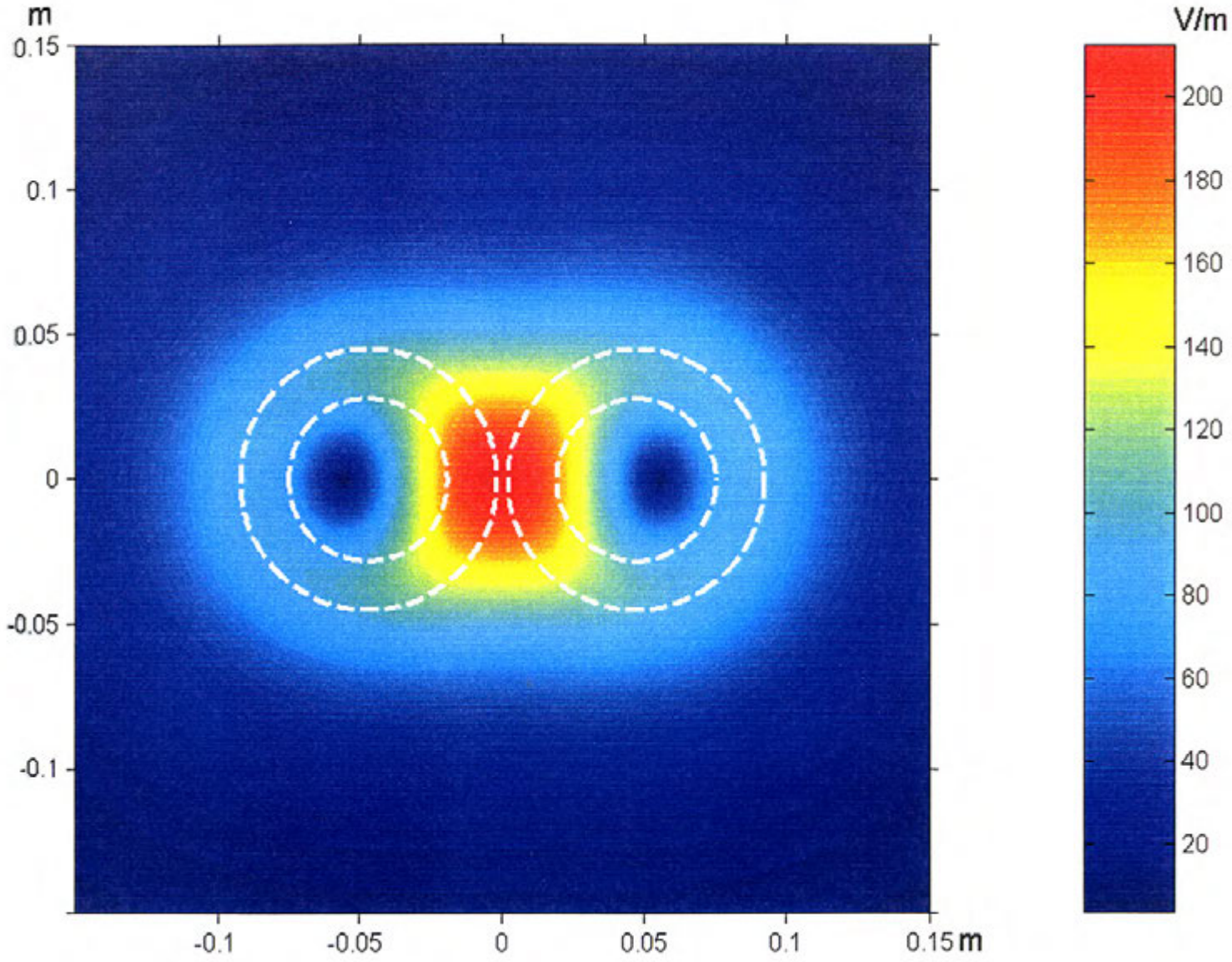

A
B

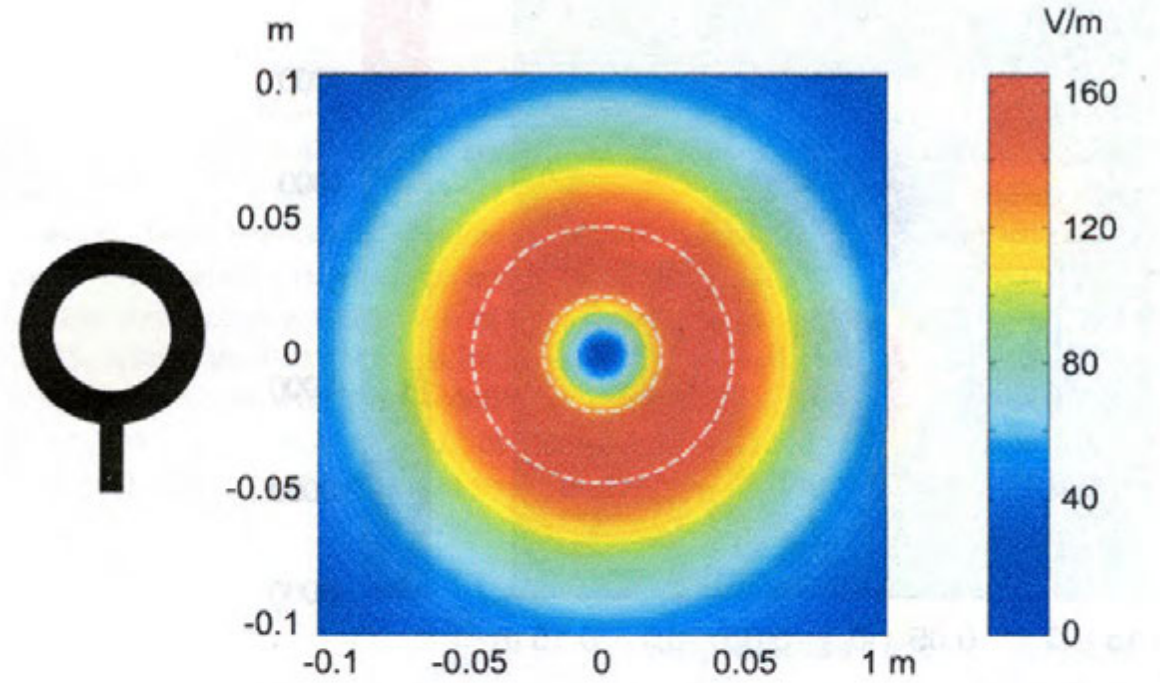


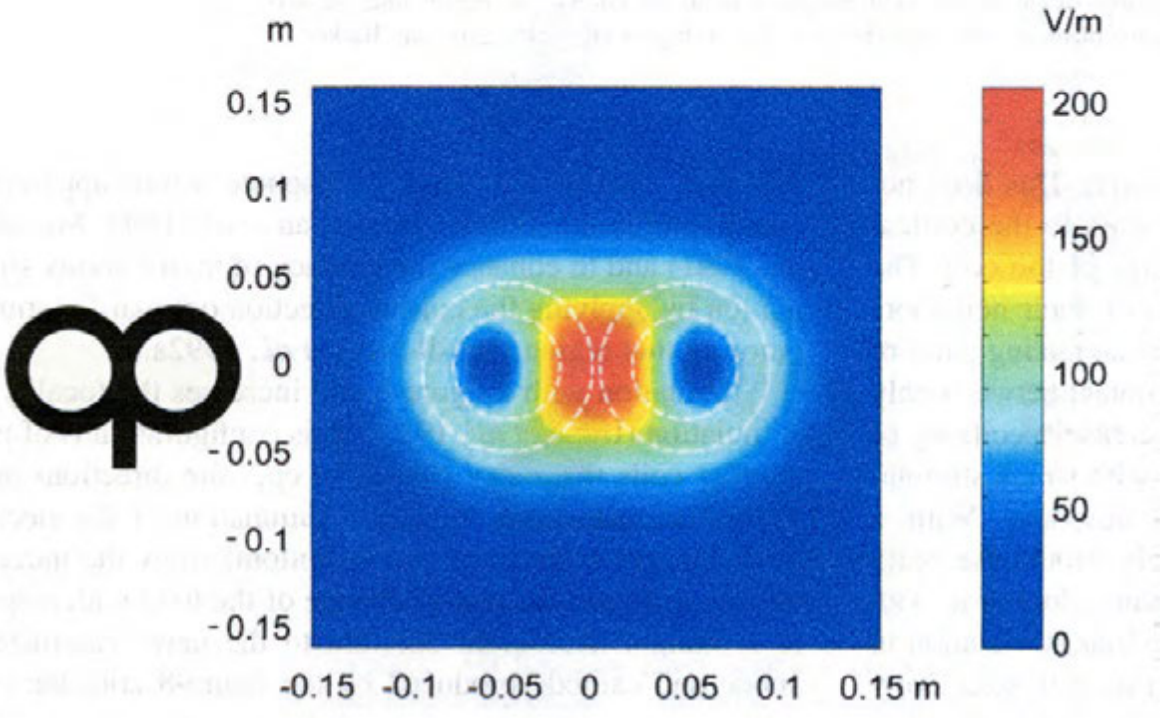


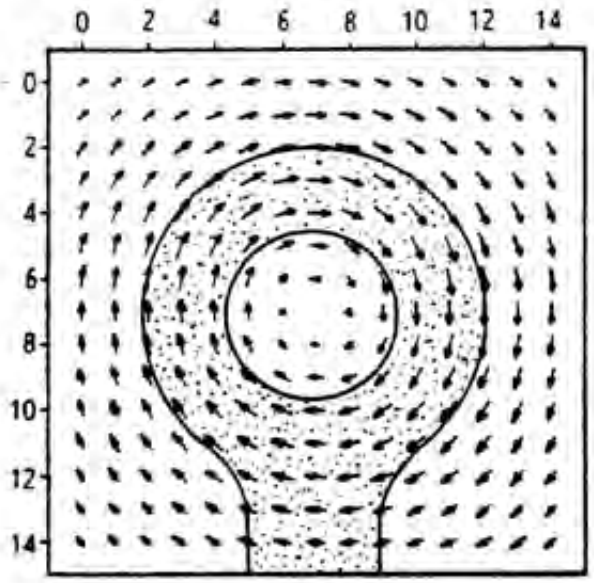

A
B
C

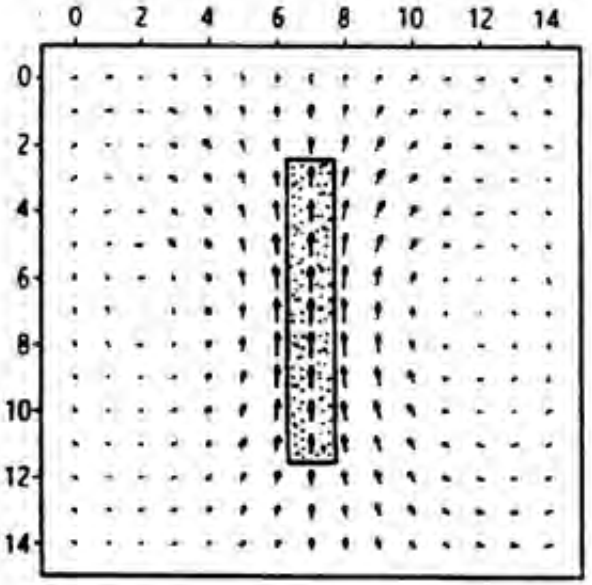

A
B


m
0.15
0.1
0.05
0
-0.05
-0.1
-0.1
-0.05
0
0.05
0.1
0.15
m
V/m
200
180
160
140
120
100
80
60
40
20


m
V/m
0.1
0.05
0
-0.05
-0.1
-0.1
-0.05
0
0.05
1 m
160
120
80
40
0


m
V/m
0.15
0.1
0.05
0
- 0.05
- 0.1
- 0.15
-0.15
-0.1
-0.05
0
0.05
0.1
0.15 m
200
150
100
50
0


0 2 4 6 8 10 12 14
0
2
4
6
8
10
12
14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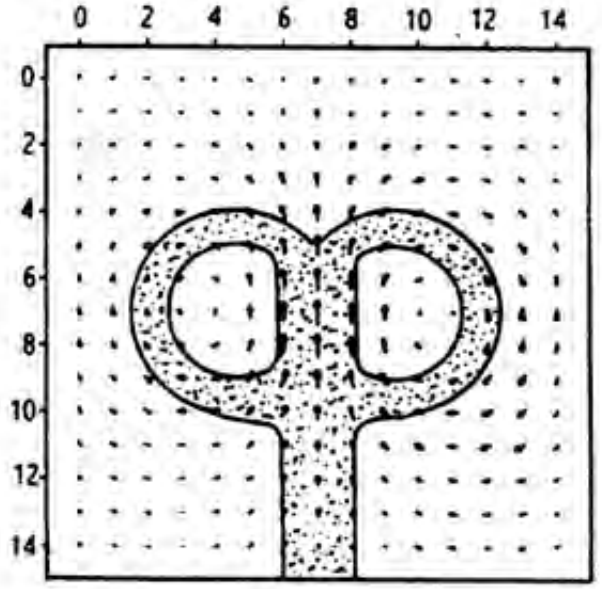
0
2
4
6
8
10
12
14


0 2 4 6 8 10 12 14
0
2
4
6
8
10
12
14

Coil type and induced currents

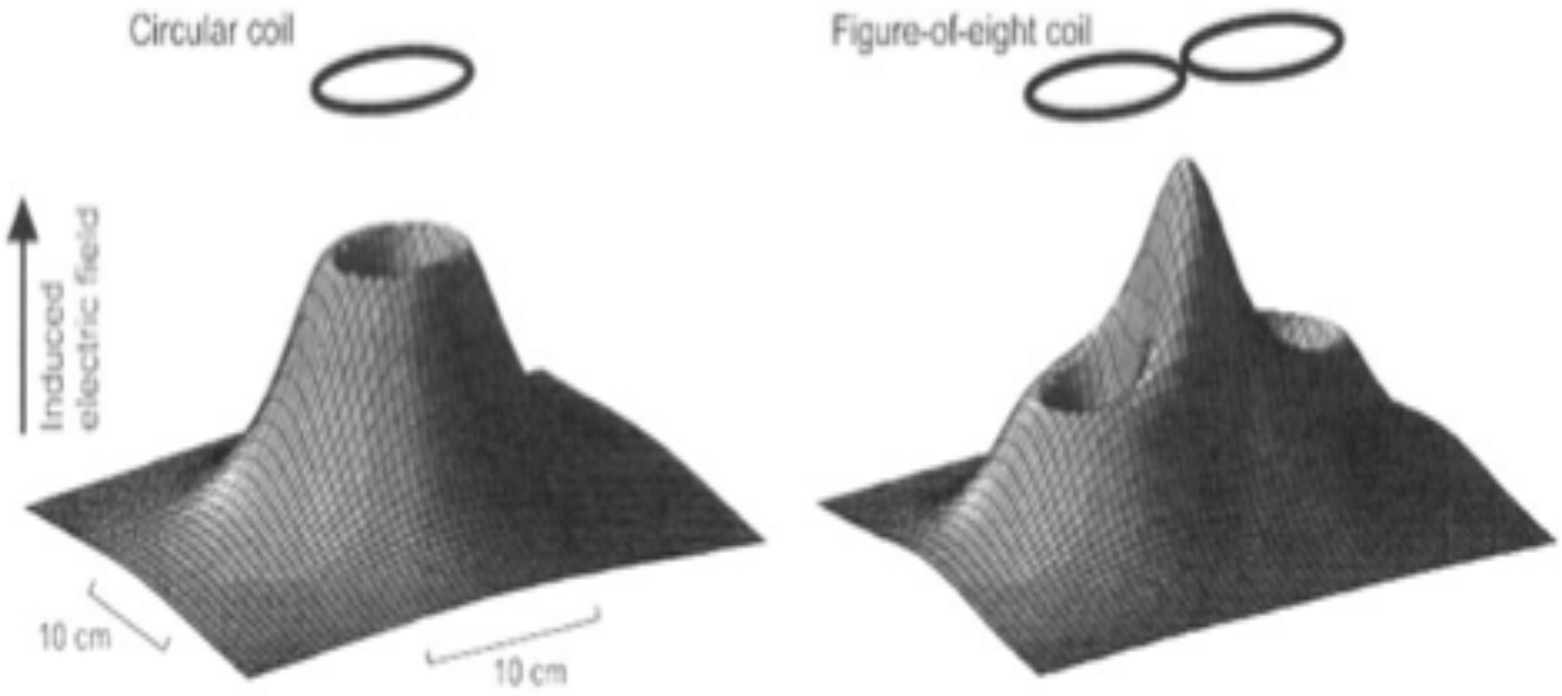


Fig. 2. The strength of the electric field induced in a spherical volume conductor below a circular (*left*) and a figure-of-eight coil (*right*). Reprinted from (Ilmoniemi *et al.*, 1999), with permission of Begell House, Inc.

Cohen & Cuffin (1991) J Clin Neurophysiol 8:102-11

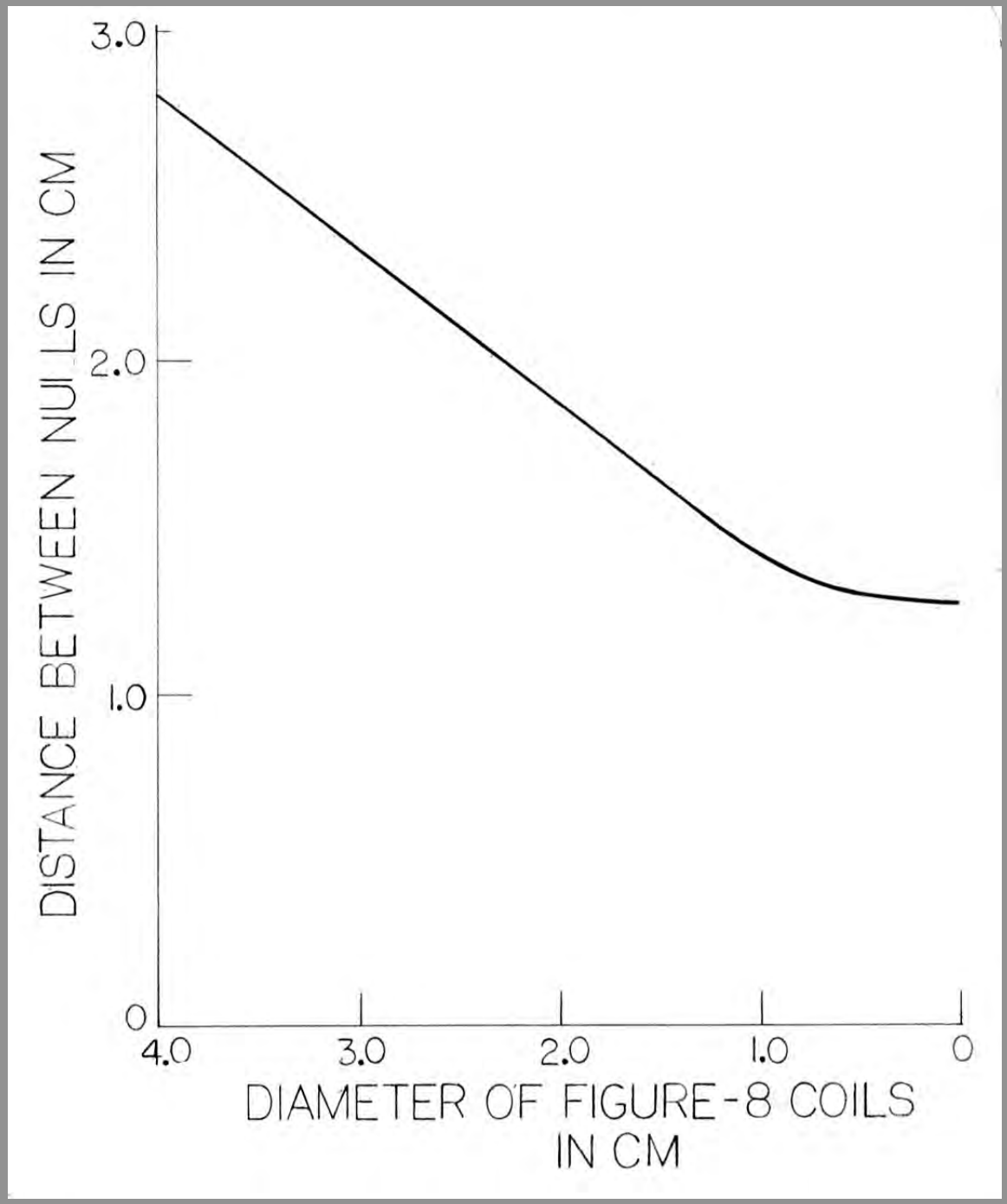
Ilmoniemi et al. (1999) Crit Rev Biomed Eng 27:241-8

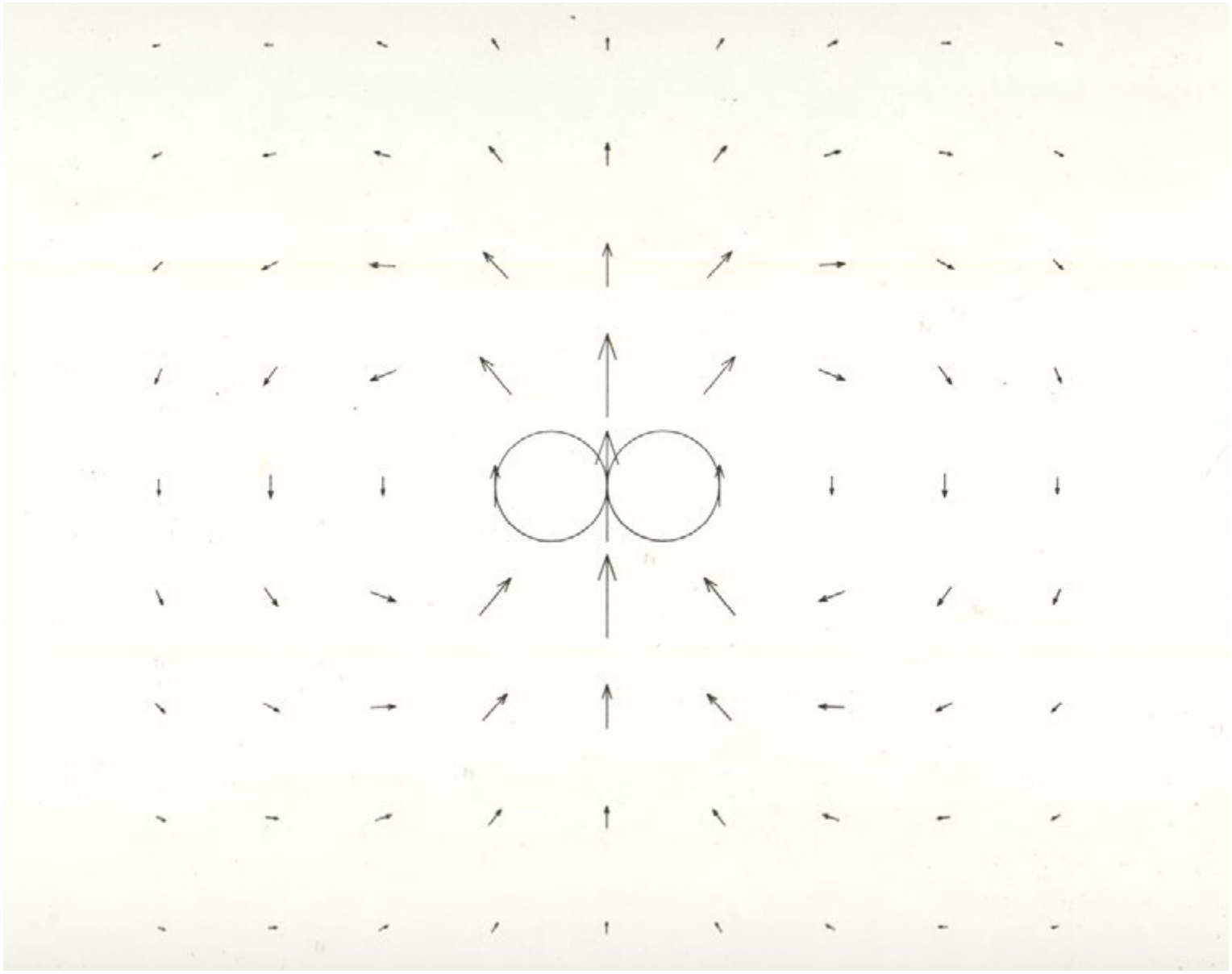
Coil types

- Circular

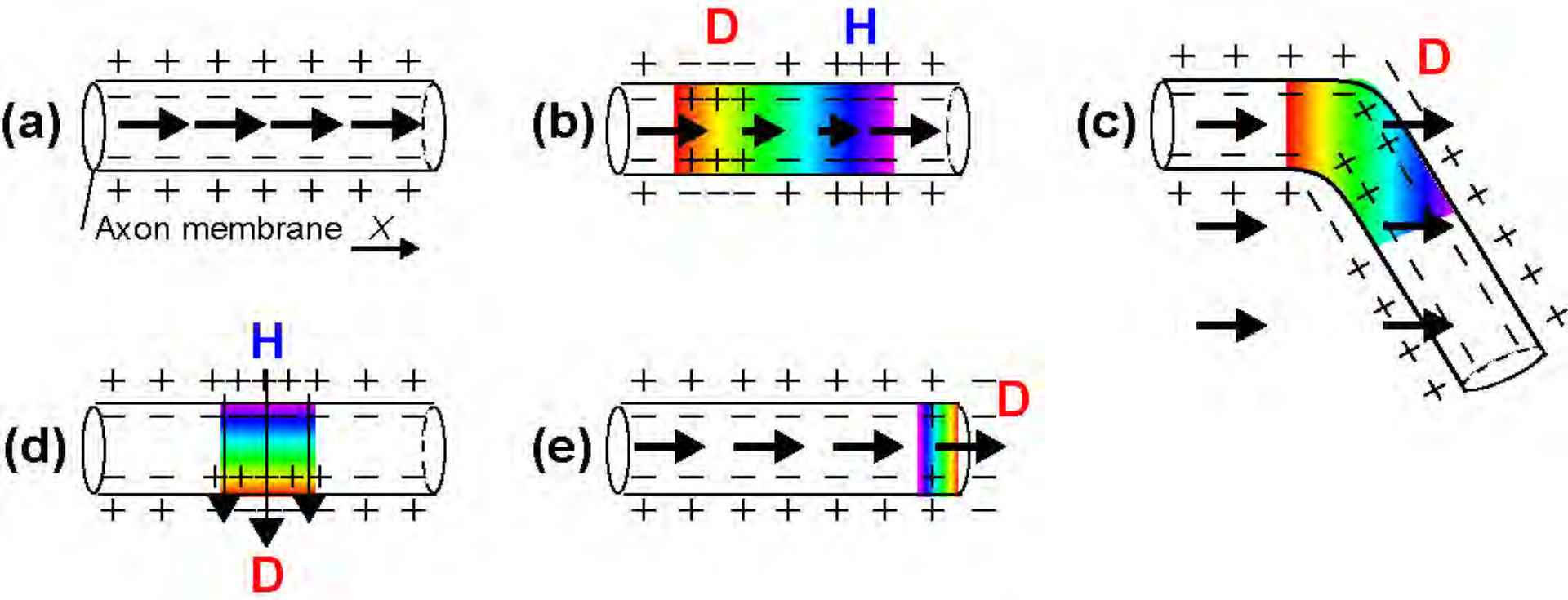
- Figure-of-eight

- H-coil (not shown)

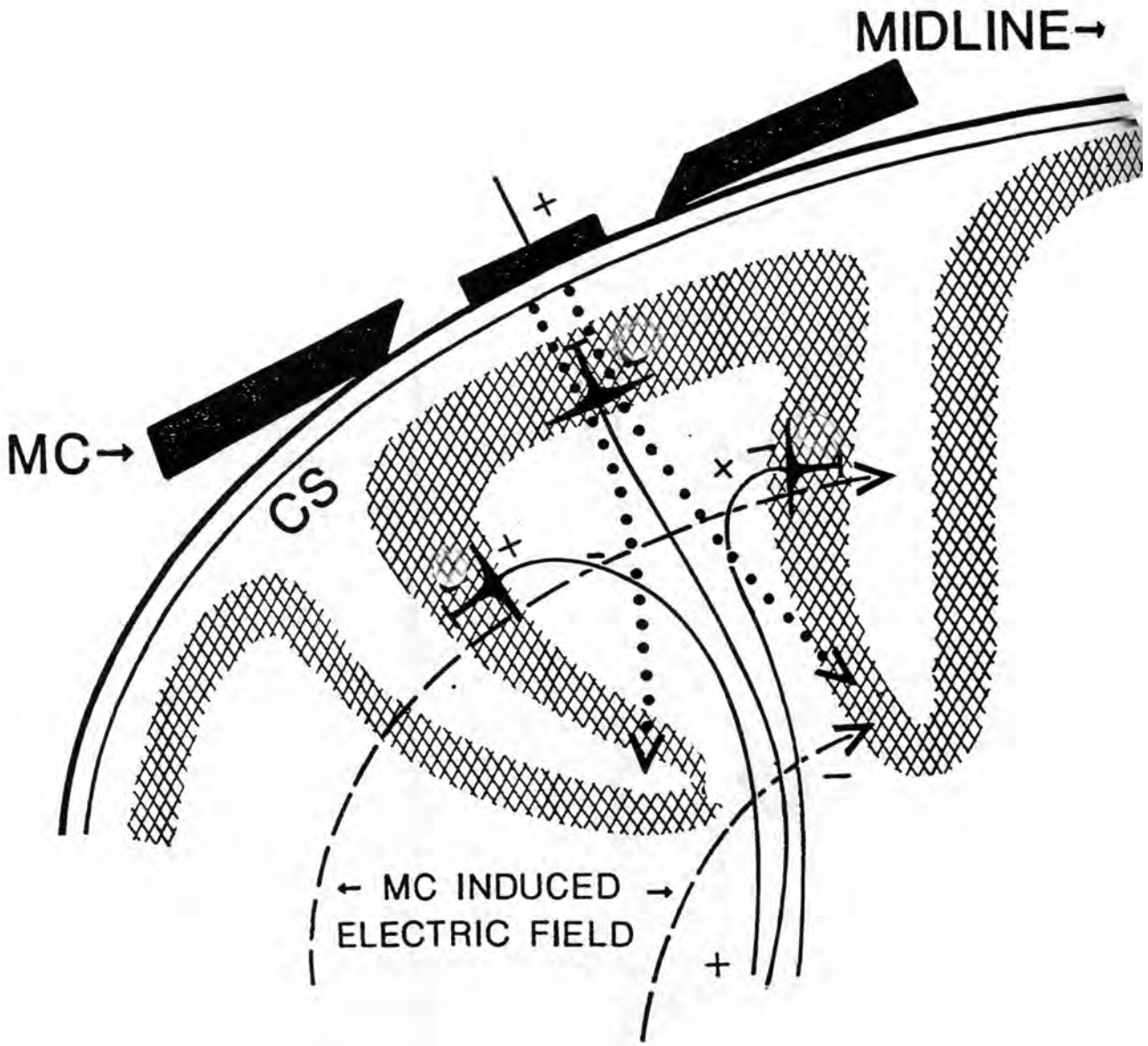

3.0
2.0
1.0
0
DISTANCE BETWEEN NULLS IN CM
4.0
3.0
2.0
1.0
0
DIAMETER OF FIGURE-8 COILS IN CM

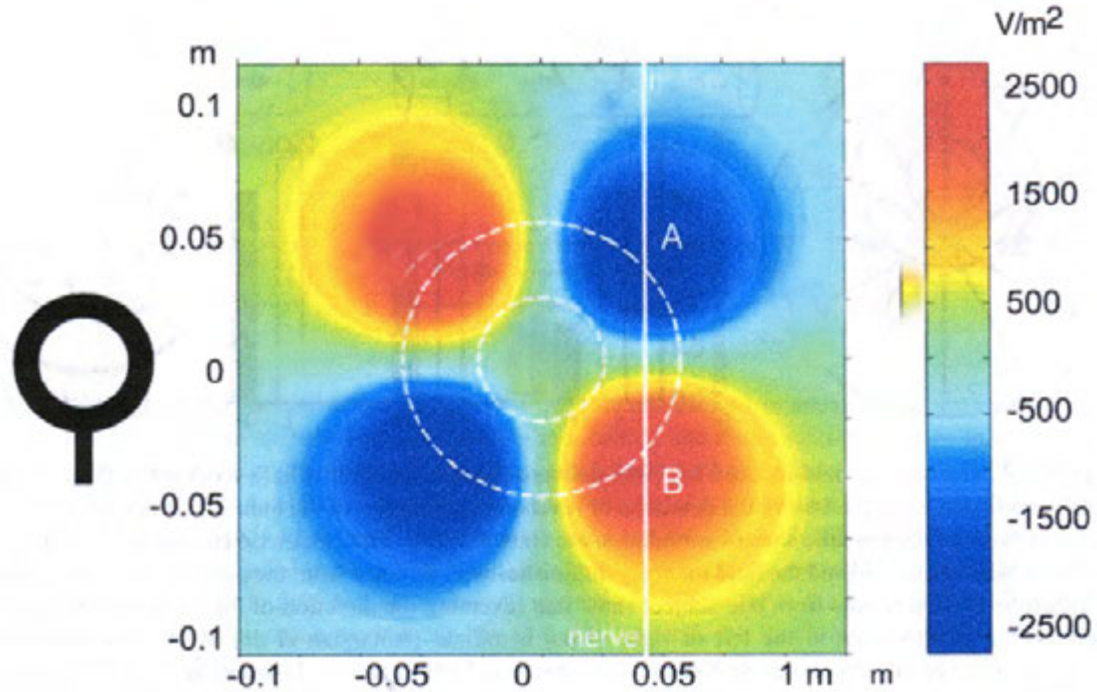


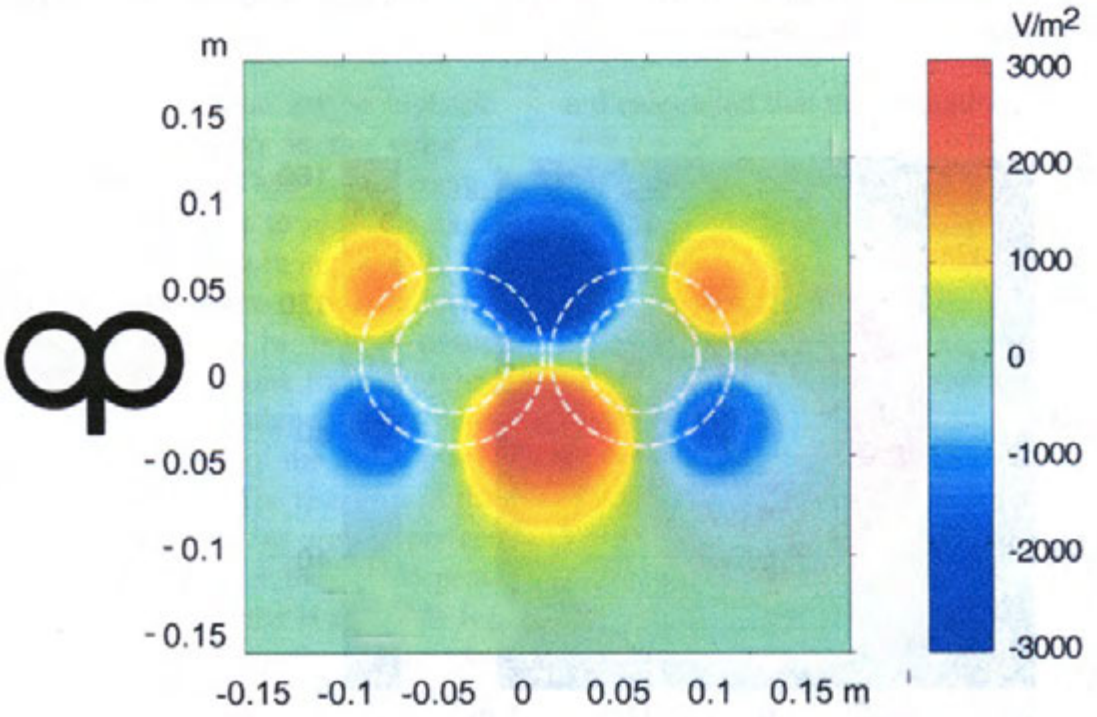
Axon orientation and TMS



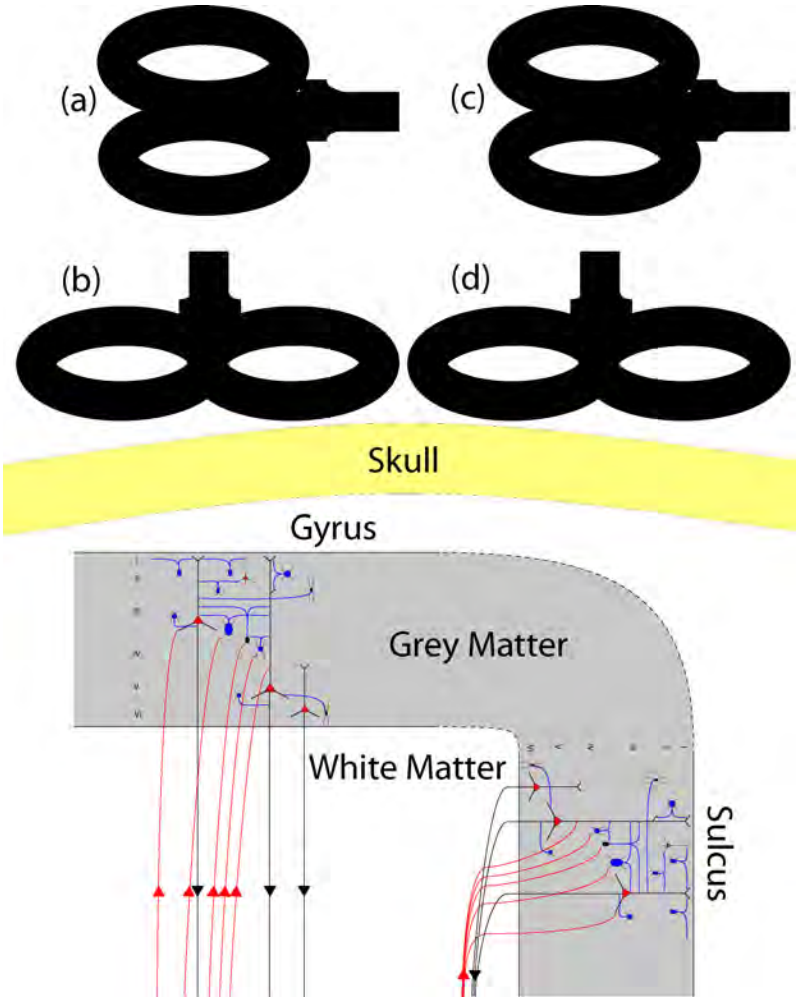
Ilmoniemi et al. (1999) Crit Rev Biomed Eng 27:241-84


MIDLINE→
MC→
CS
+
+
+
−
−
−
+
← MC INDUCED →
ELECTRIC FIELD


V/m2
m
0.1
0.05
0
-0.05
-0.1
A
B
nerve
-0.1
-0.05
0
0.05
1 m
m
2500
1500
500
-500
-1500
-2500


V/m2
m
0.15
0.1
0.05
0
- 0.05
- 0.1
- 0.15
-0.15
-0.1
-0.05
0
0.05
0.1
0.15 m
3000
2000
1000
0
-1000
-2000
-3000

Coil orientation + macroanatomy



Raij et al. (2010) In Preparation

Thank you for listening

I hope