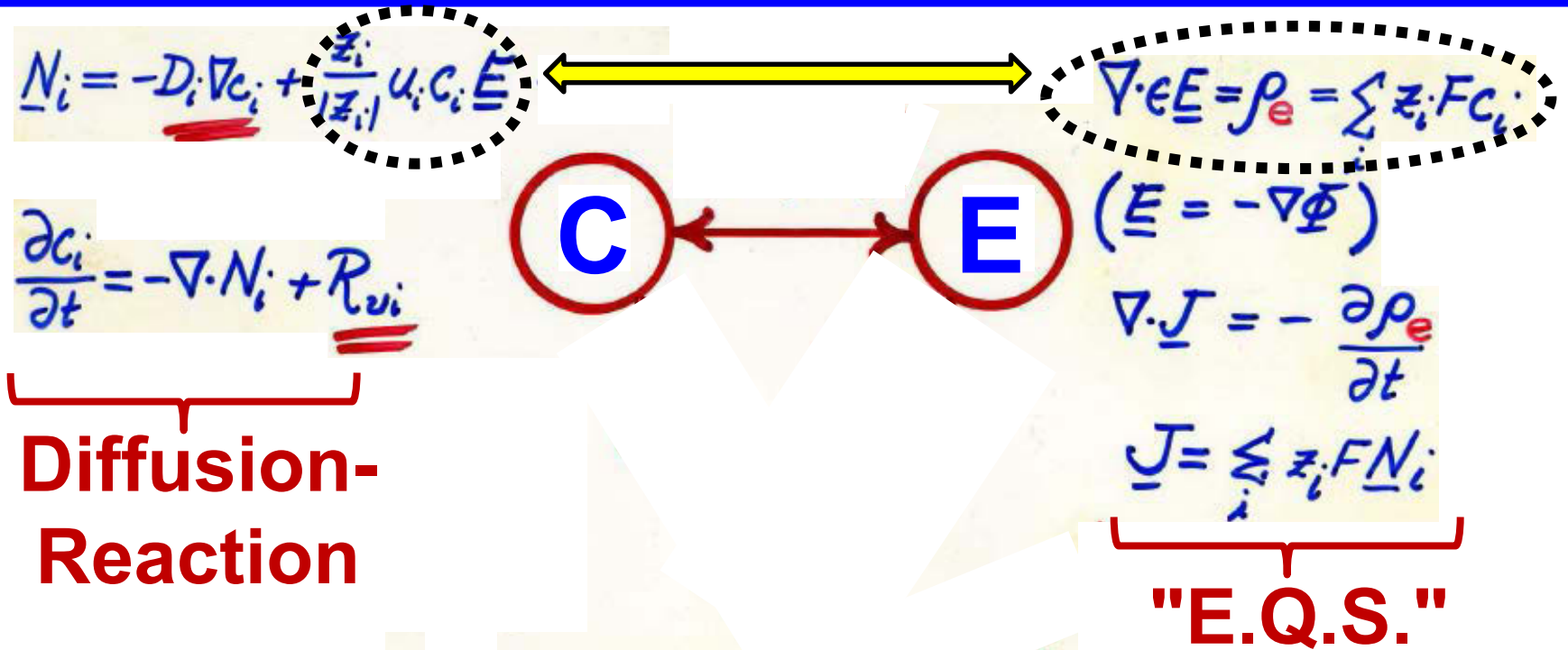
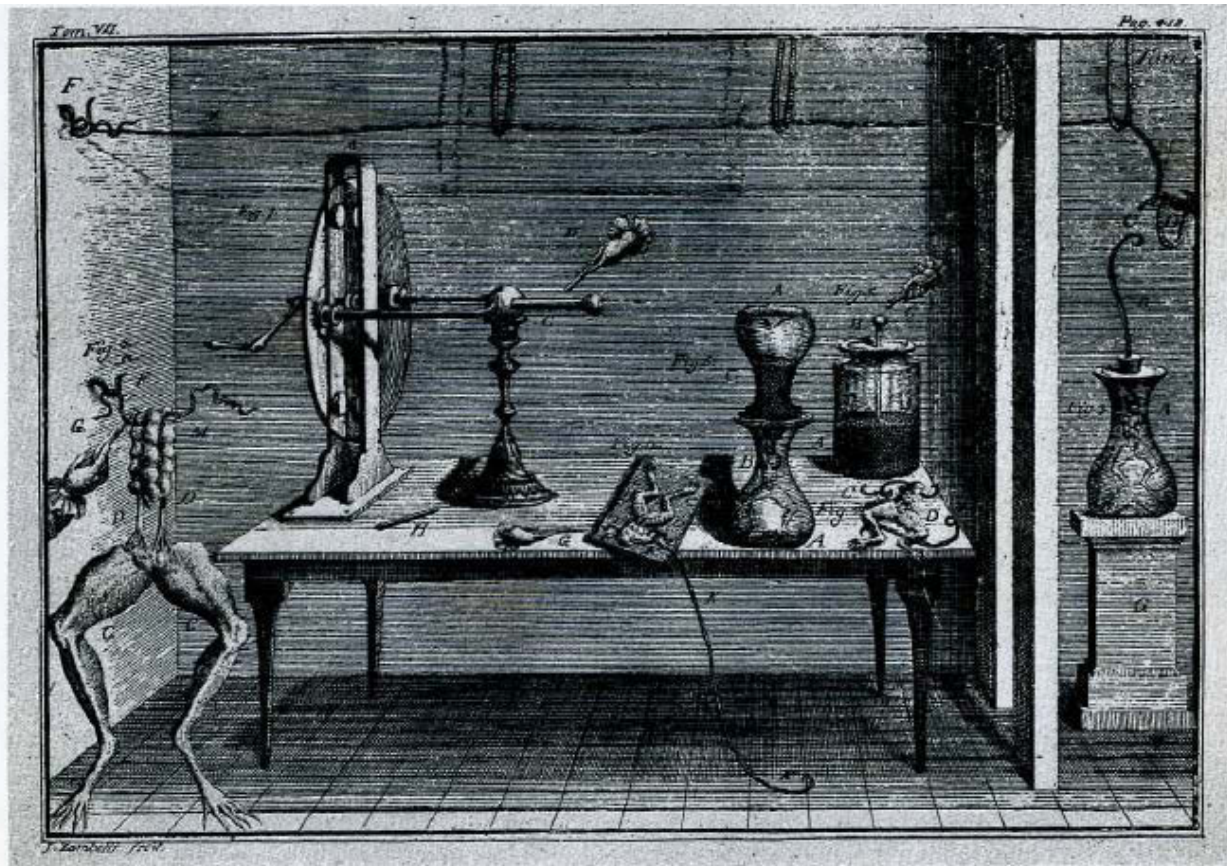


FFF: Complete Description of Coupled Transport and Biomolecular Interactions



Start with Maxwell's Equations



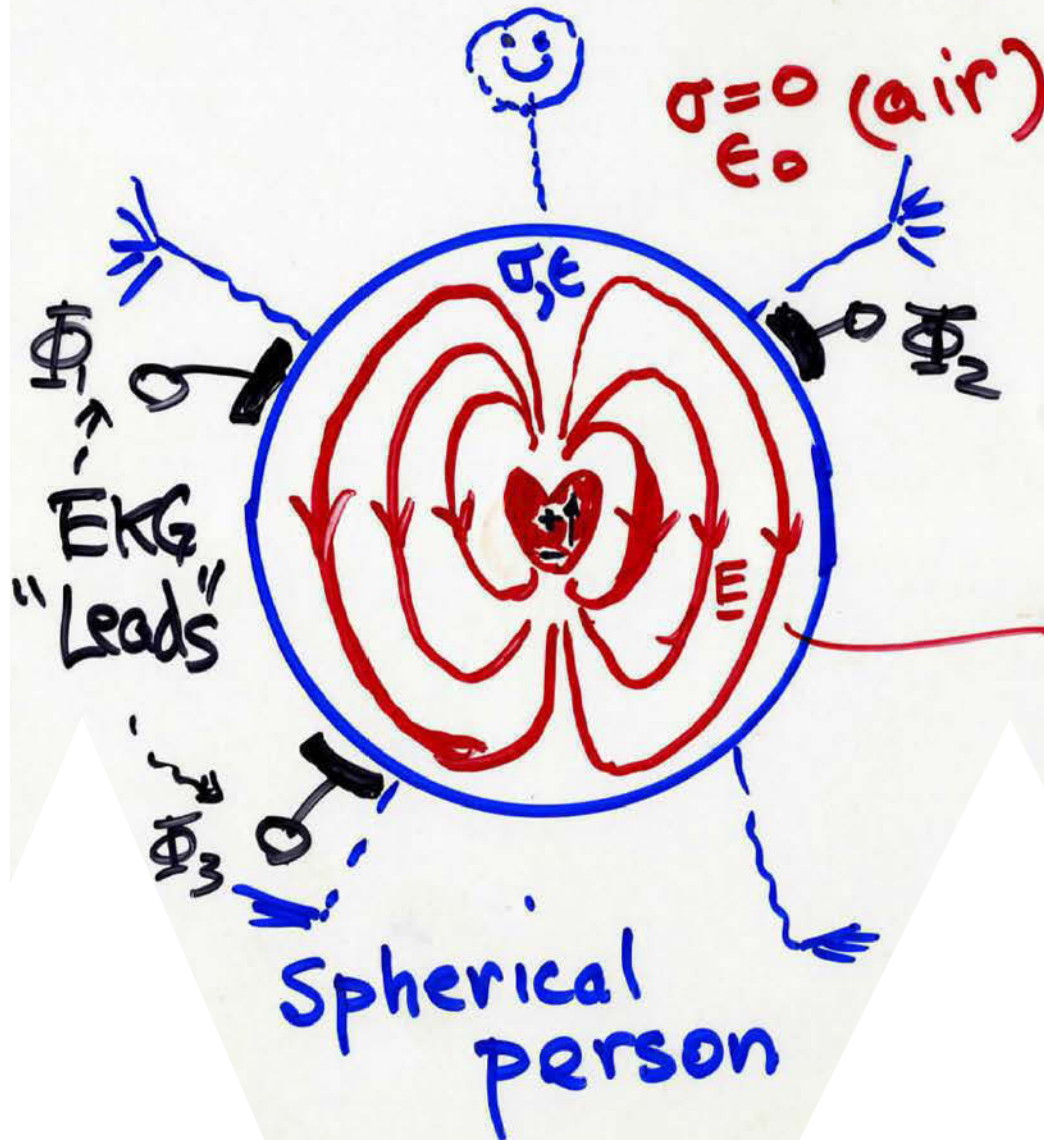
The first of the four engravings that illustrated Galvani's text in the original publication in 1791. In Fig. 2, the prepared frog's legs CC hang from the spinal stub by the crural nerves DD. When the electrostatic machine in Fig. 1 revolved, or the Leyden jar, Fig. 5, was discharged, Galvani observed that the legs jerked when a scalpel touched the nerve.

Galvani – 1791: Electrophysiology

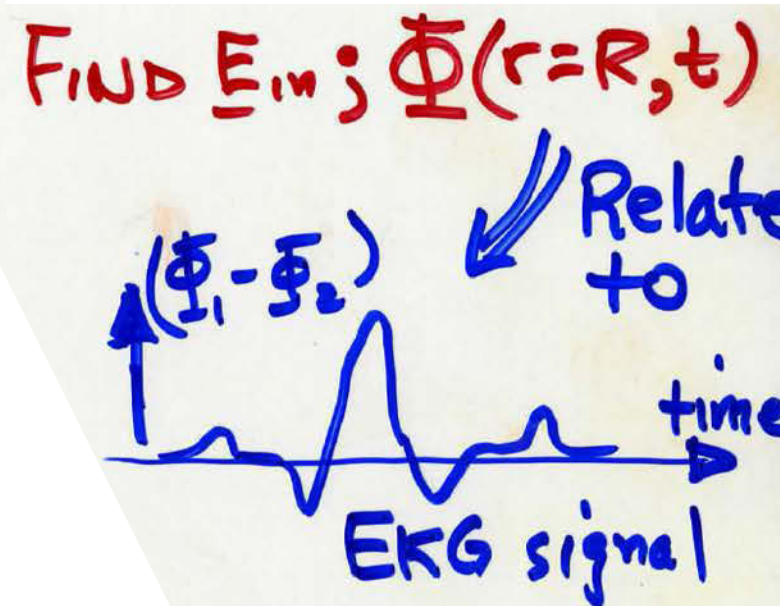
Nerve-muscle action potentials

“animal electricity”

EKG: Centric Dipole Model of the Heart



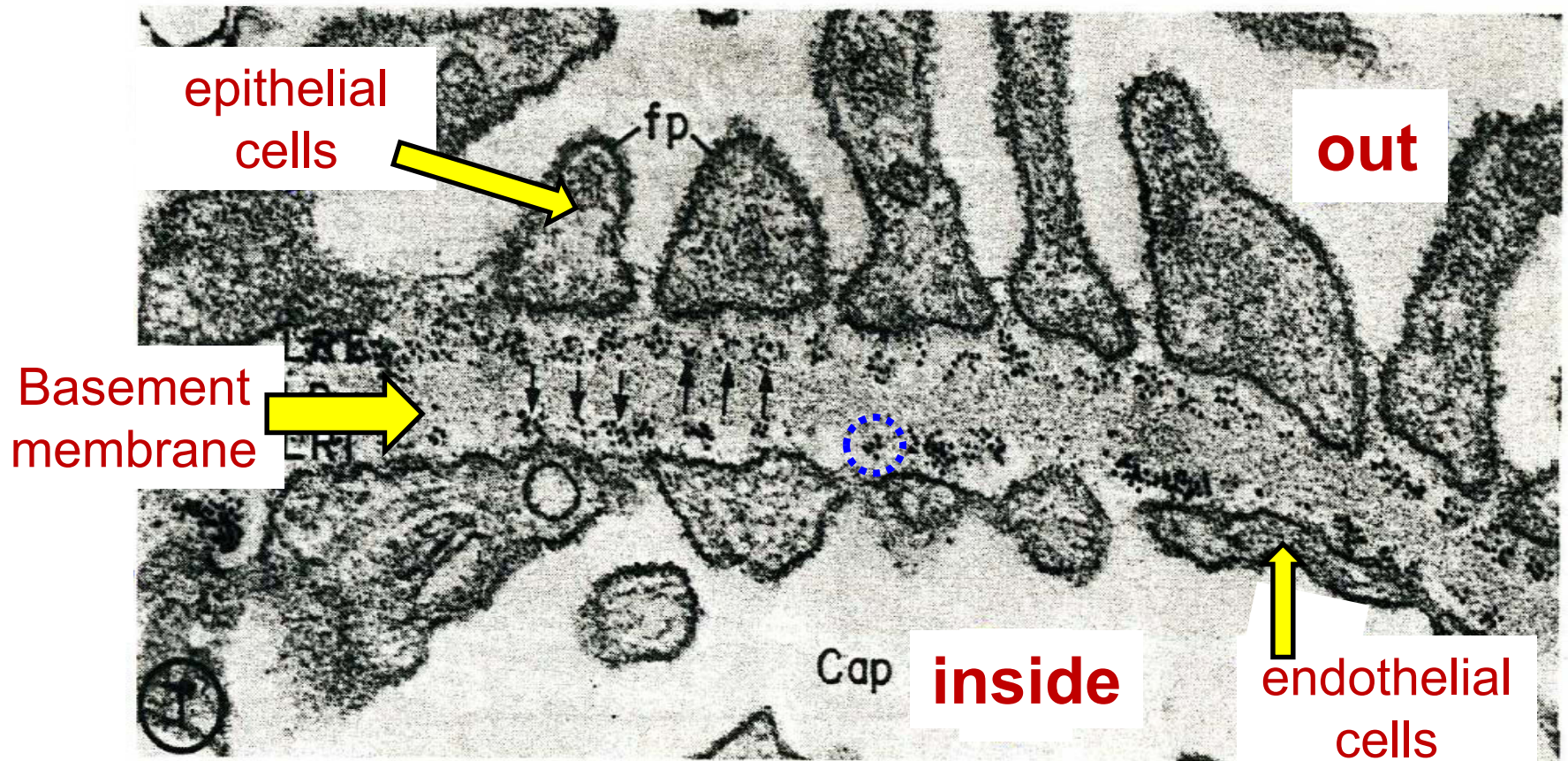
$f \sim 1 \text{ Hz}$
low enough
for EQS!





Courtesy of the U.S. Army; image in the public domain.

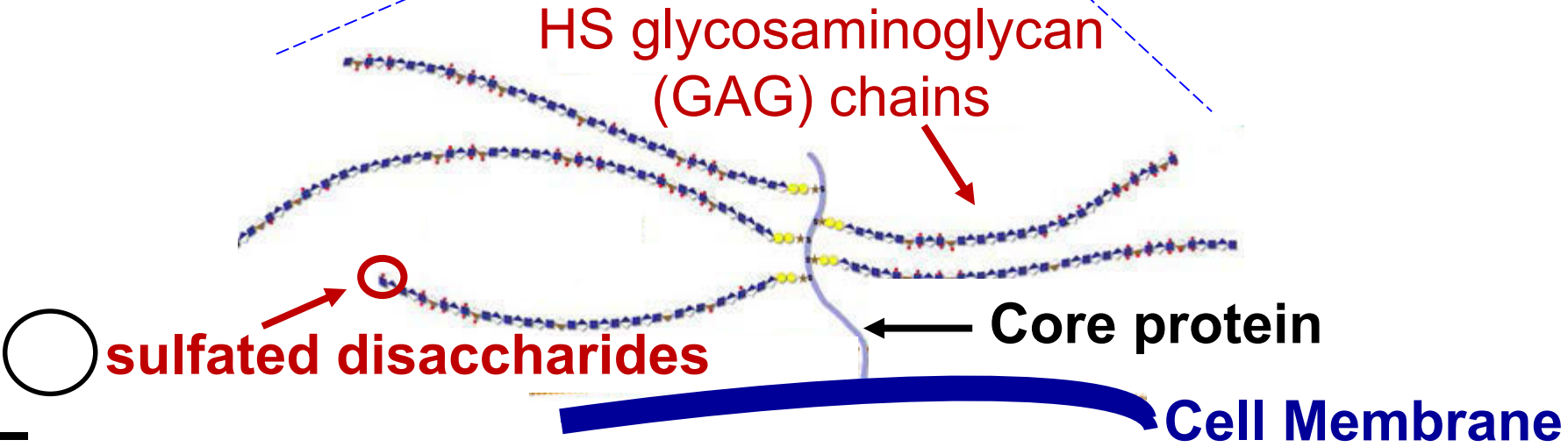
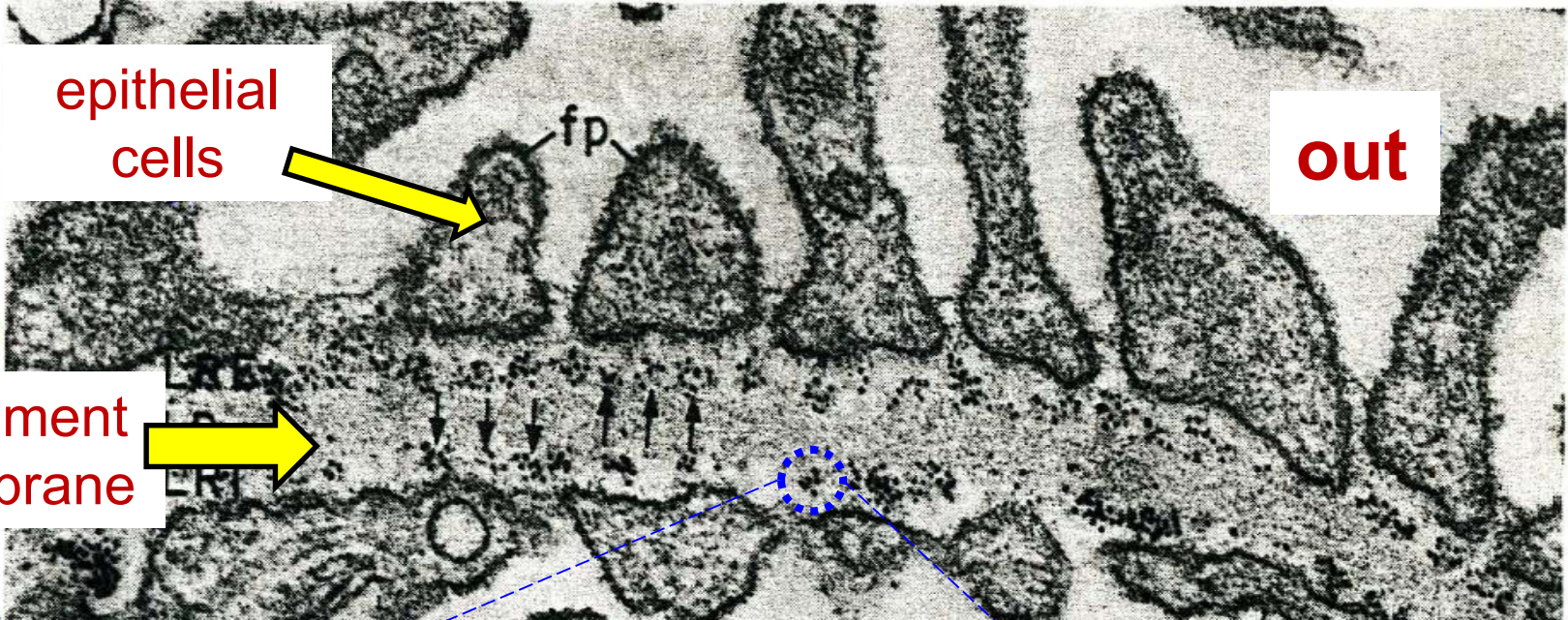
Glomerular Capillary (rat): Transport in Kidney



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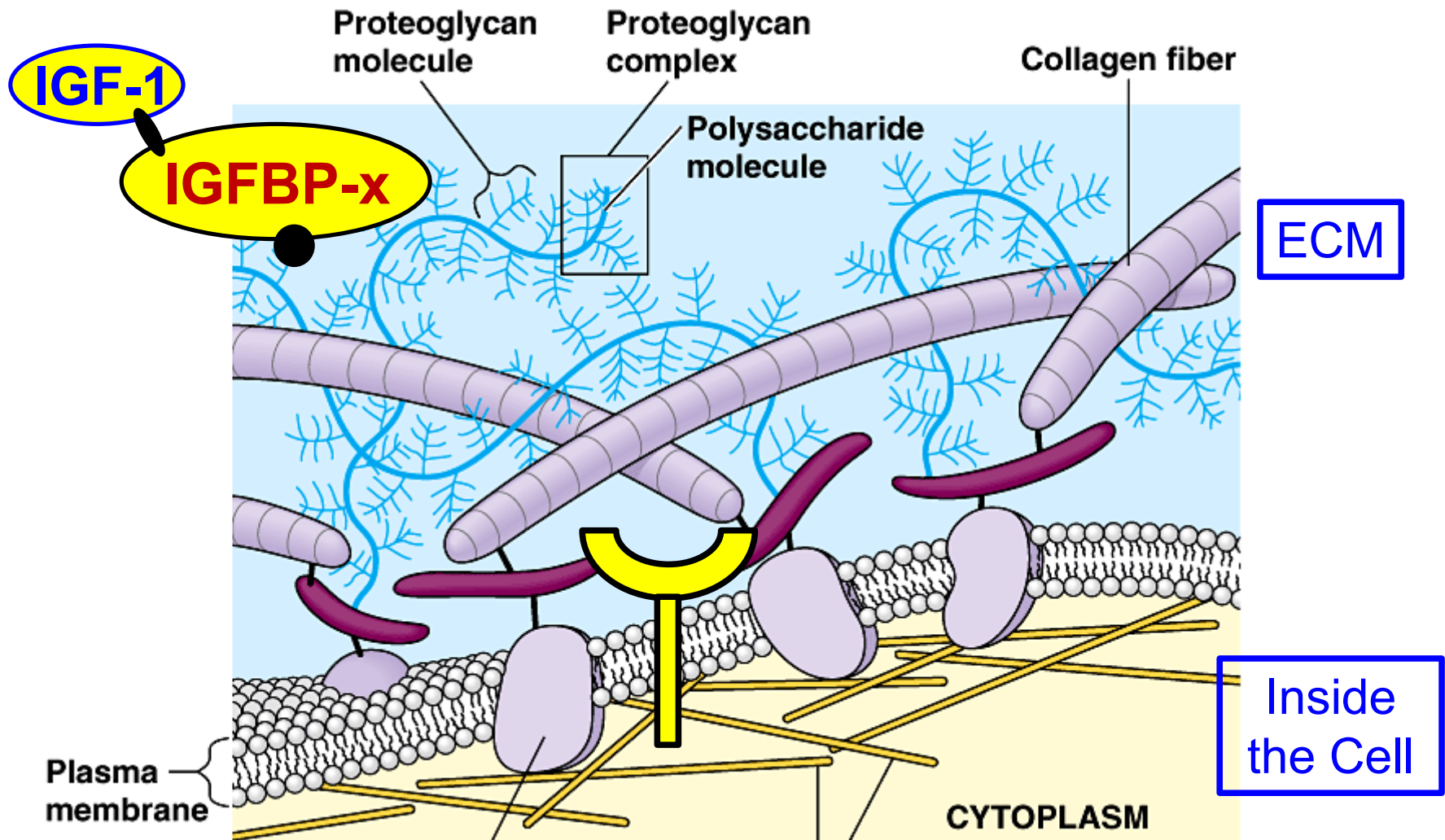
“Black Dots” = stained negatively charged heparan sulfate GAGs (on Heparan Sulfate proteoglycans). Together with Collagen IV, they regulate **transport of charged proteins/solutes in kidney (filtration of blood)**

Glomerular Capillary (rat): Transport in Kidney



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IGFBPs can bind to **ECM macromolecules** and inhibit IGF-1 transport, uptake, & cell signaling



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Implications for Drug Delivery: Dose and Timing

Cellular Actions of the Insulin-Like Growth Factor Binding Proteins

Endocrine Reviews, 2002

SUE M. FIRTH AND ROBERT C. BAXTER

Kolling Institute of Medical Research, University of Sydney, Royal North Shore Hospital, St. Leonards, New South Wales 2065, Australia

- **IGFBP-2, -3, -5, and -6 have basic (\oplus) heparin-binding domains that can bind (\ominus) HS glycosaminoglycans....**

Identification of the Extracellular Matrix Binding Sites for Insulin-like Growth Factor-binding Protein 5*

Alex Parker, Jane Badley Clarke, Walker H. Busby, Jr., and David R. Clemmons‡

From the Department of Medicine, University of North Carolina School of Medicine, Chapel Hill, North Carolina 27599

- **Increasing the salt concentration** in the incubation buffer results in **decreased binding of IGFBP-5 to fibroblast extracellular matrix.**

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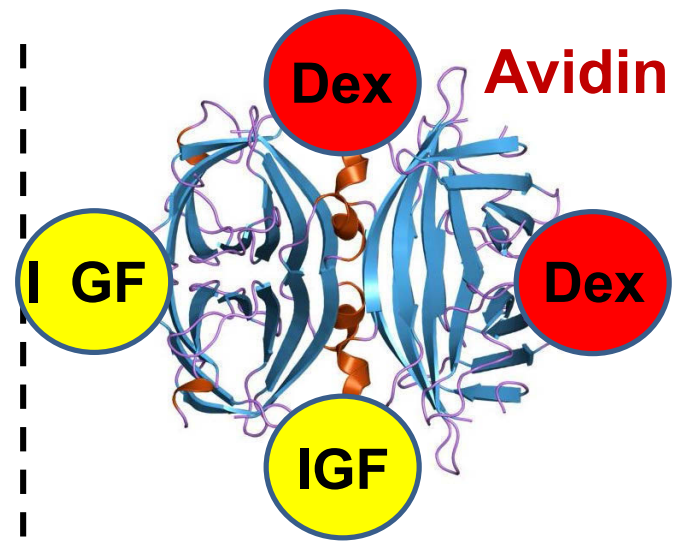
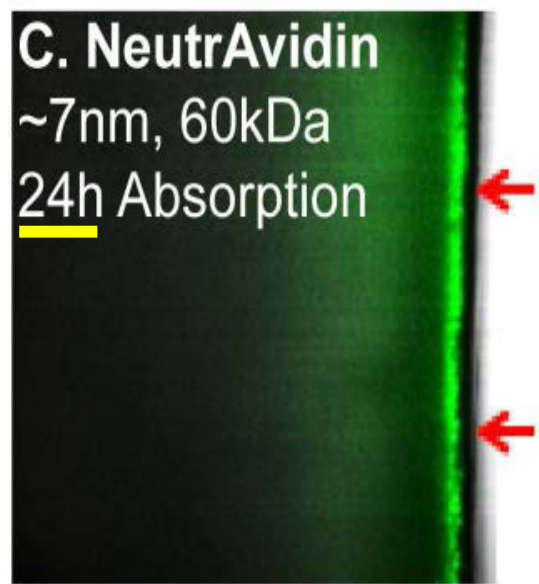
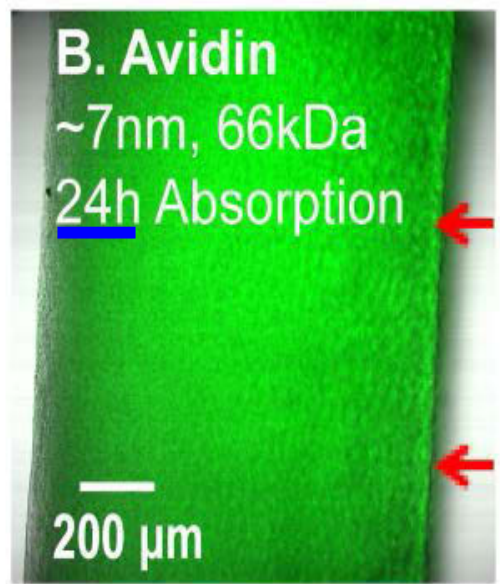
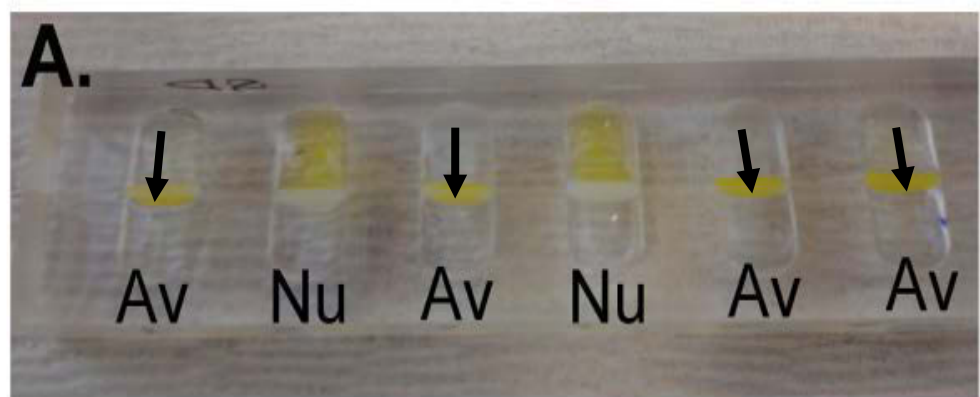
- **Increasing the salt concentration** in the incubation buffer results in **decreased binding of IGFBP-5 to fibroblast extracellular matrix**. This suggests that **binding is ionic (electrostatic)** and not hydrophobic

→ **Charge-Charge interactions!**

- **(But how do you distinguish between real “E-binding” versus “long-range electrostatic attraction” forces (i.e., Boltzmann probability)...need to look case-by-case**

Functionalize drugs to nanoparticles, to target tissues via electrostatic and binding interactions to (—) ECM:

Avidin: highly basic; $R_{\text{uptake}} \sim 200$



9 lysine (+);
8 Arginine (+)
7 Glutamic (-)
5 Aspartic (-)

+5 per chain; 4 chains

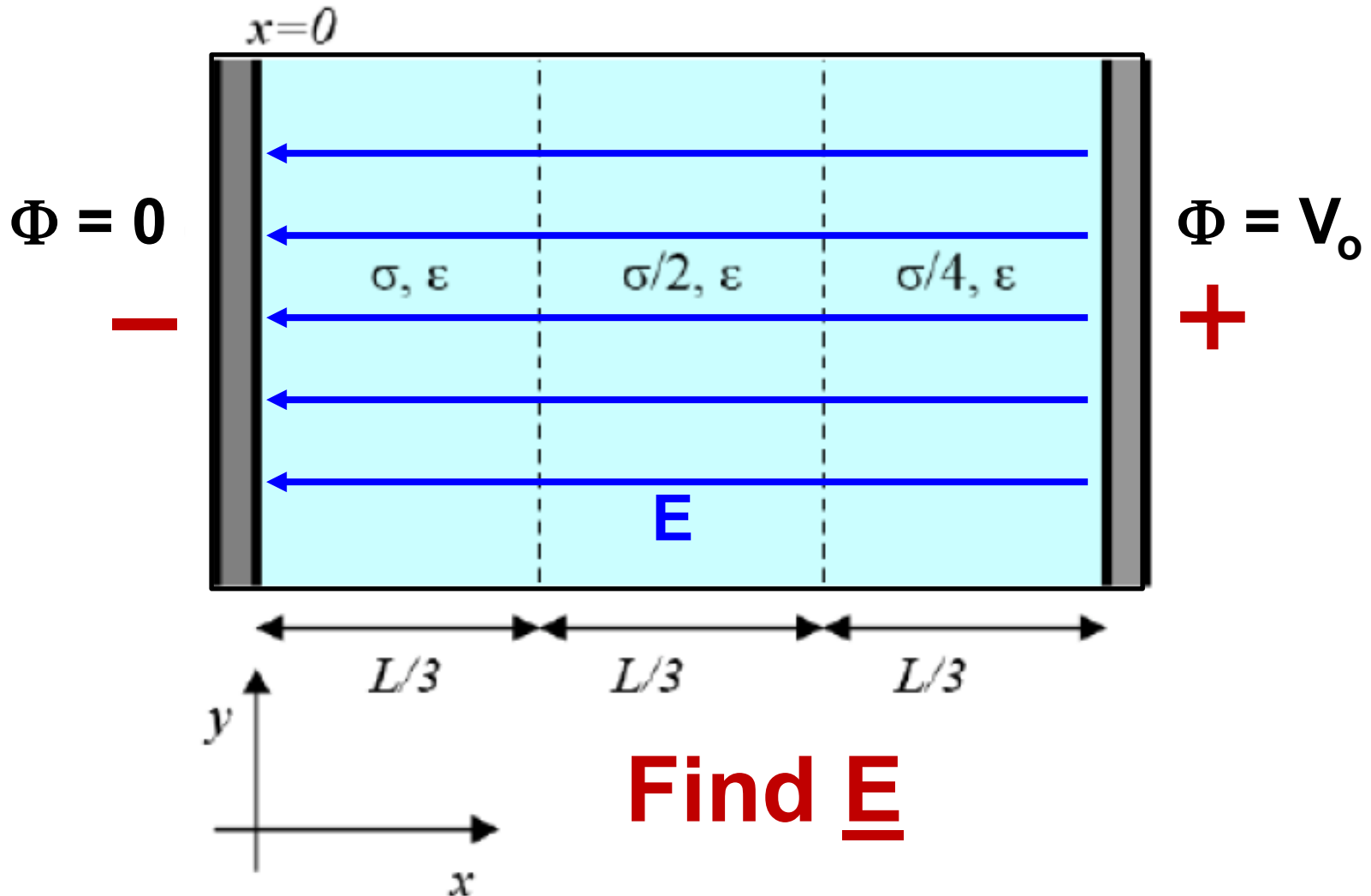
Total Charge +20

Courtesy of Alan Grodzinsky. Used with permission.

Courtesy of Jawahar Swaminathan and MSD staff at the European Bioinformatics Institute; image in the public domain.

Gradient Gels for Protein Separation

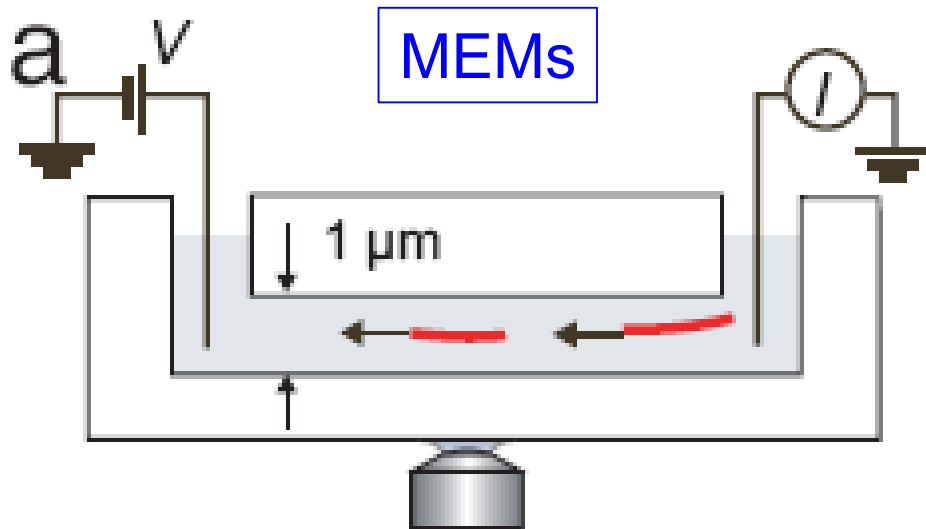
("Steady Conduction")...sec 2.7



Electrophoresis of individual microtubules in microchannels

PNAS 2007

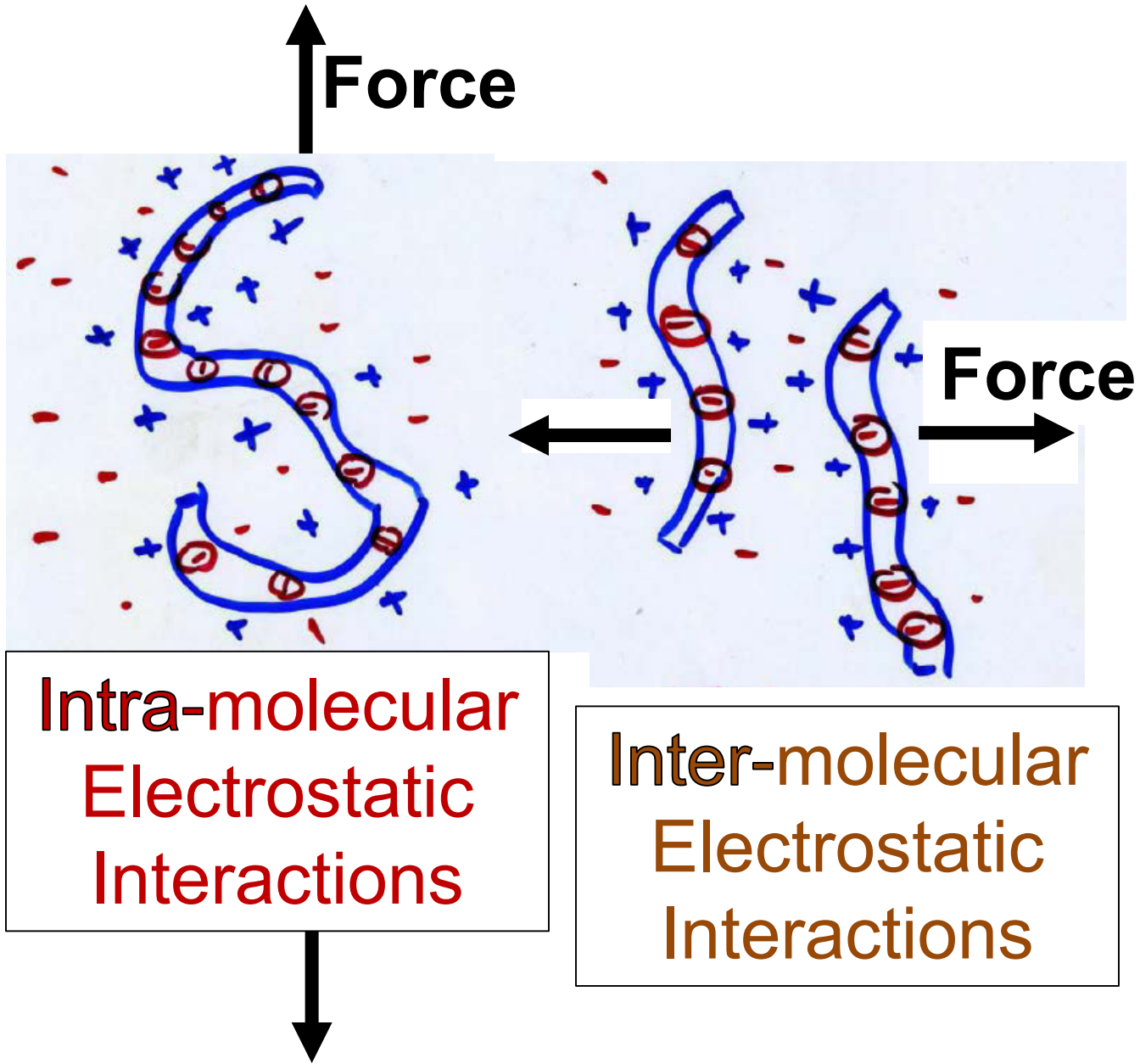
M. G. L. van den Heuvel, M. P. de Graaff, S. G. Lemay, and C. Dekker*



**“Electrokinetics”
in action**

Courtesy of National Academy of Sciences. Used with permission.
Source: Van den Heuvel, M. G. L. et al. "Electrophoresis of individual microtubules in microchannels." Proceedings of the National Academy of Sciences 104, no. 19 (2007): 7770-7775.

Microfabricated slit-like fluidic channels form an excellent system to confine and observe the electrophoretic motion of individual fluorescently labeled biomolecules, such as microtubules, actin filaments, or virus particles.



Intra-molecular
Electrostatic
Interactions

Inter-molecular
Electrostatic
Interactions



KARL FRIEDRICH GAUSS

1777-1855

Astronomer and
mathematician;

Discovered Gauss'
Theorem in the
mathematics of
electricity;

With Weber (right),
he constructed an
electric telegraph
and extended data
on terrestrial
magnetism



ANDRÉ MARIE AMPIÈRE
(Mathématicien et Physicien),

Membre de l'Académie des Sciences,
Professeur au Collège royal de France et à

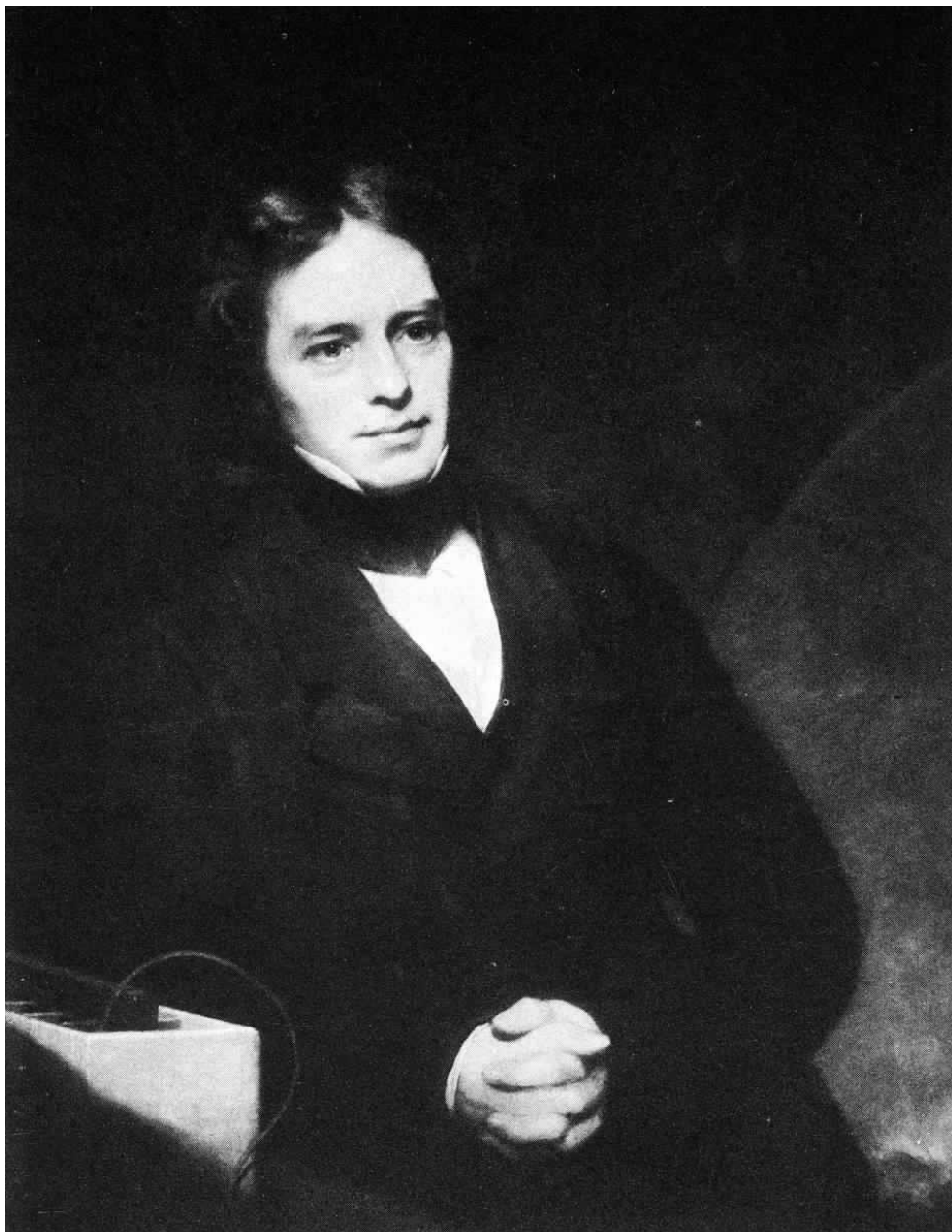
l'École polytechnique, des sociétés d'Edimbourg,
de Cambridge, de Genève, Helvétique, etc.

Né à Lyon (Dép. du Rhône) le 20 Janvier 1775.

1775-1836

Mathematician and
Physicist

Established
mathematical theory
of electricity via
experiments on
adjacent current-
carrying conductors



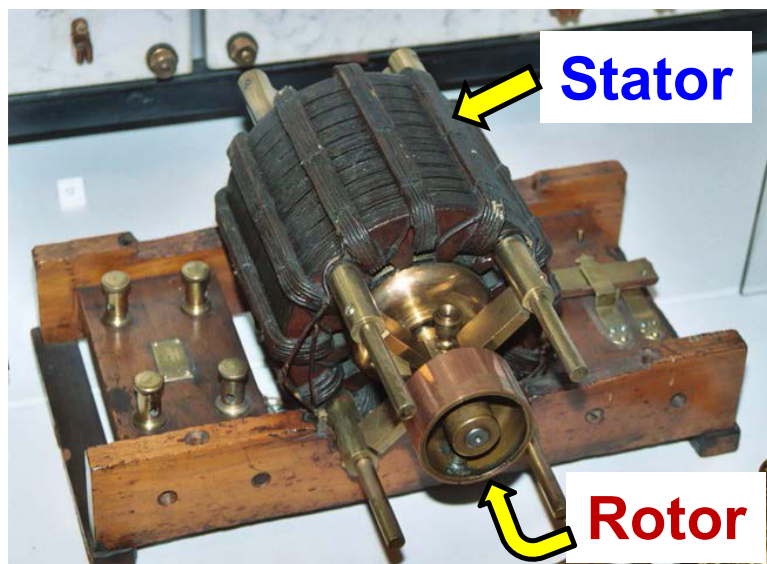
MICHAEL FARADAY

1791-1867

English Chemist &
electrical experimenter;

**Discovered
Electromagnetic
Induction**, laws of
electrolytic action and
magnetic rotation;

Discoveries led to
motors, generators,
transformers, large-
scale **distribution of
electric power** for
homes & industry



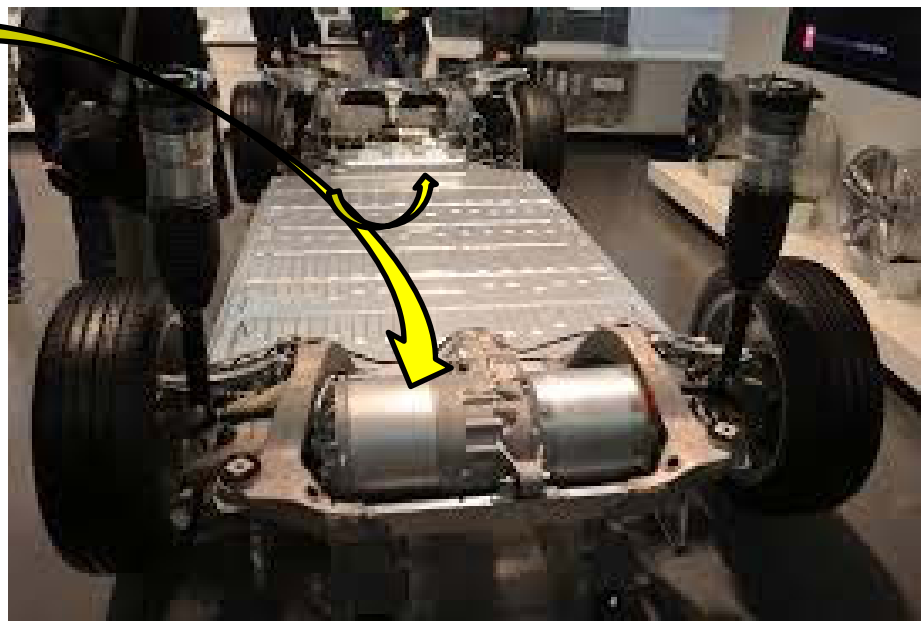
- Nikola Tesla's original **Induction Motor** patented **1888**, on display in British Science Museum, London
- **Currents in Stator** windings → **rotating $H(t)$** → induces (current in &) **rotation of Rotor**

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Induction Motor
used in the **2015**
Tesla Model S Sedan



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“The **Tesla Model S** sedan is widely regarded as not just the best electric car, *but best car of any type on the mass market*”



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Faraday's Law in action!!

$$\text{vel} = \text{accel} \times \text{time}$$

$$\underline{61 \text{ mph}} \leftarrow \underbrace{(9.8 \text{ m/s}^2)}_{1 \text{ g} \text{ 😊}} \times (2.8 \text{ sec})$$

Tesla Model S (P90D) is the fastest car Consumer Reports has ever tested: **762 horsepower, 0 to 60 mph in 2.8 sec**, “as fast as falling!”
(No Gears; No Transmission; Range-single battery charge: ~275 mile)

“The **Tesla Model S** sedan demolishes 2015 Consumer Reports’ rating system: **...the best car (of any type) ever.**” “...scored 103 in Consumer Reports’ system, which by definition doesn’t go past 100”



1777-1855

Astronomer and
mathematician;

Discovered Gauss'
Theorem in the
mathematics of
electricity;

With Weber (right),
he constructed an
electric telegraph
and extended data
on terrestrial
magnetism

PHYS. REV. LETT. 48:1378, 1982

First Results from a Superconductive Detector for Moving Magnetic Monopoles

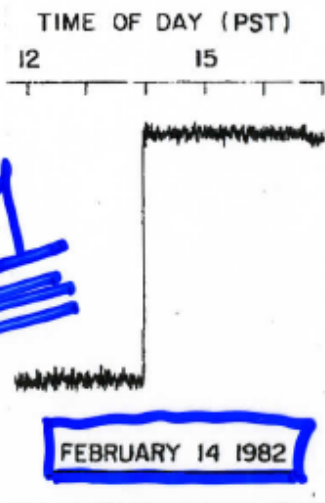
Blas Cabrera

Physics Department, Stanford University, Stanford, California 94305

(Received 5 April 1982)

A velocity- and mass-independent search for moving magnetic monopoles is being performed by continuously monitoring the current in a 20-cm²-area superconducting loop. A single candidate event, consistent with one Dirac unit of magnetic charge, has been detected during five runs totaling 151 days. These data set an upper limit of 6.1×10^{-10} cm⁻² sec⁻¹ sr⁻¹ for magnetically charged particles moving through the earth's surface.

one "event" in 151 days



the candidate monopole event

The following statements about spurious detector response can be made:

(a) Line voltage fluctuations caused by two power outages and their accompanying transients.....

(f) Mechanically induced offsets have been intentionally generated and are probably caused by shifts of the four-turn loop-wire geometry which produce inductance changes. Sharp raps with a screwdriver handle against the detector assembly cause such offsets.

(g) No seismic disturbance occurred on 14 February 1982.

p. 1379

positive control



VALENTINE'S DAY

MONOPOLE



VALENTINE'S DAY

MONOPOLE

Poem written by Stephen Weinberg (*Physics Nobel Laureate, 1979*) to the author* on Valentine's day a year later (Feb 14, 1983):

Roses are red,
Violets are blue,
It's time for monopole
Number *TWO!*

.....but it never arrived.....

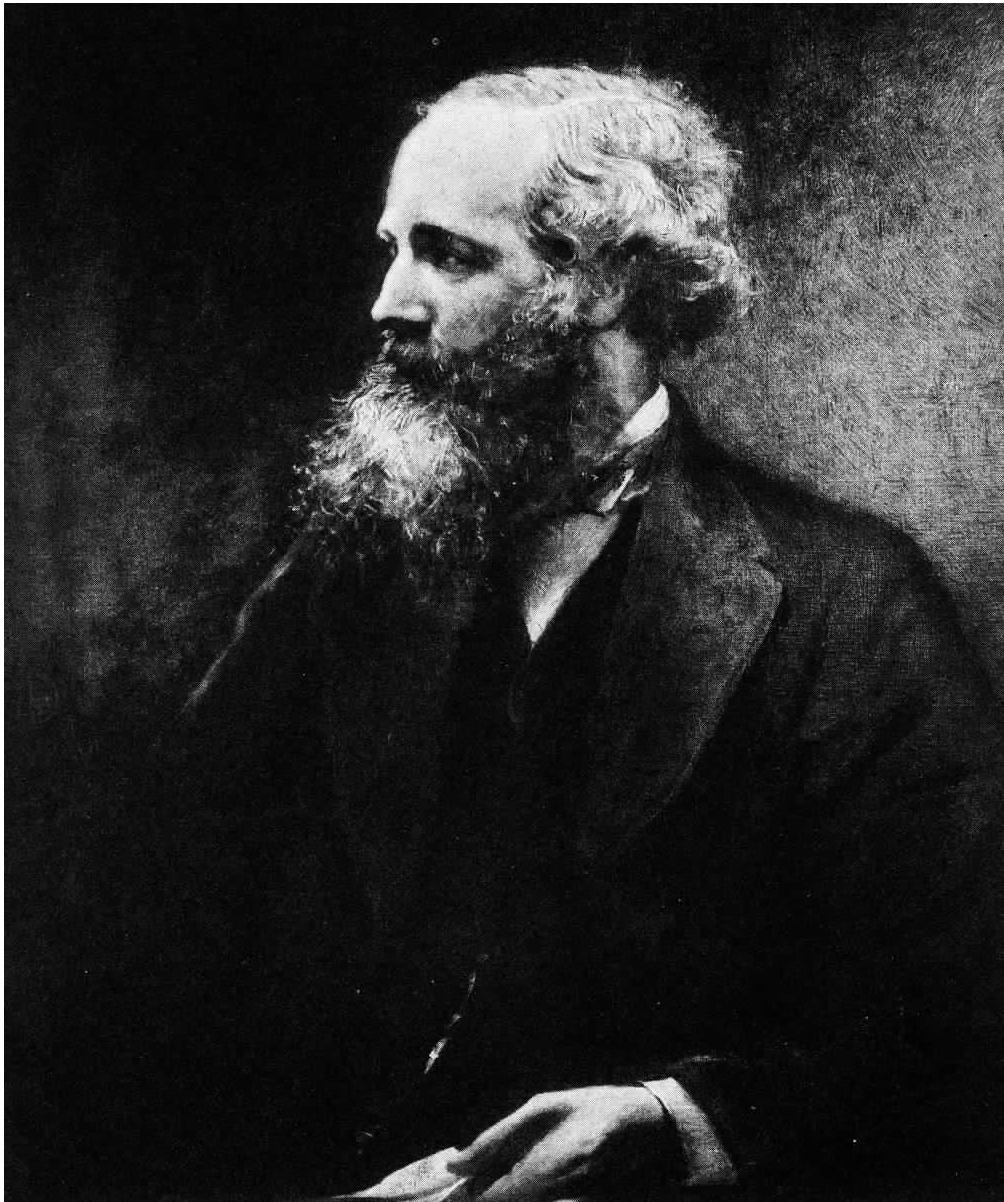
(*Blas Cabrera, *the Stanley G. Wojcicki Professor at Stanford, head of cryogenic dark matter experiment*)

Quest for magnetic monopoles

Henry J. Frisch,

High Energy Physics, Enrico Fermi Institute, Chicago

- “The experiment (Feb 14, 1982) created a flurry of excitement when it recorded a single candidate event.....The experiment would have seen 2,000 events by now *if that one event had been real.*”
- “Those in the field joke that it may have been the only monopole in the Universe, but having traversed California, it’s not coming back soon.”



1831-1879

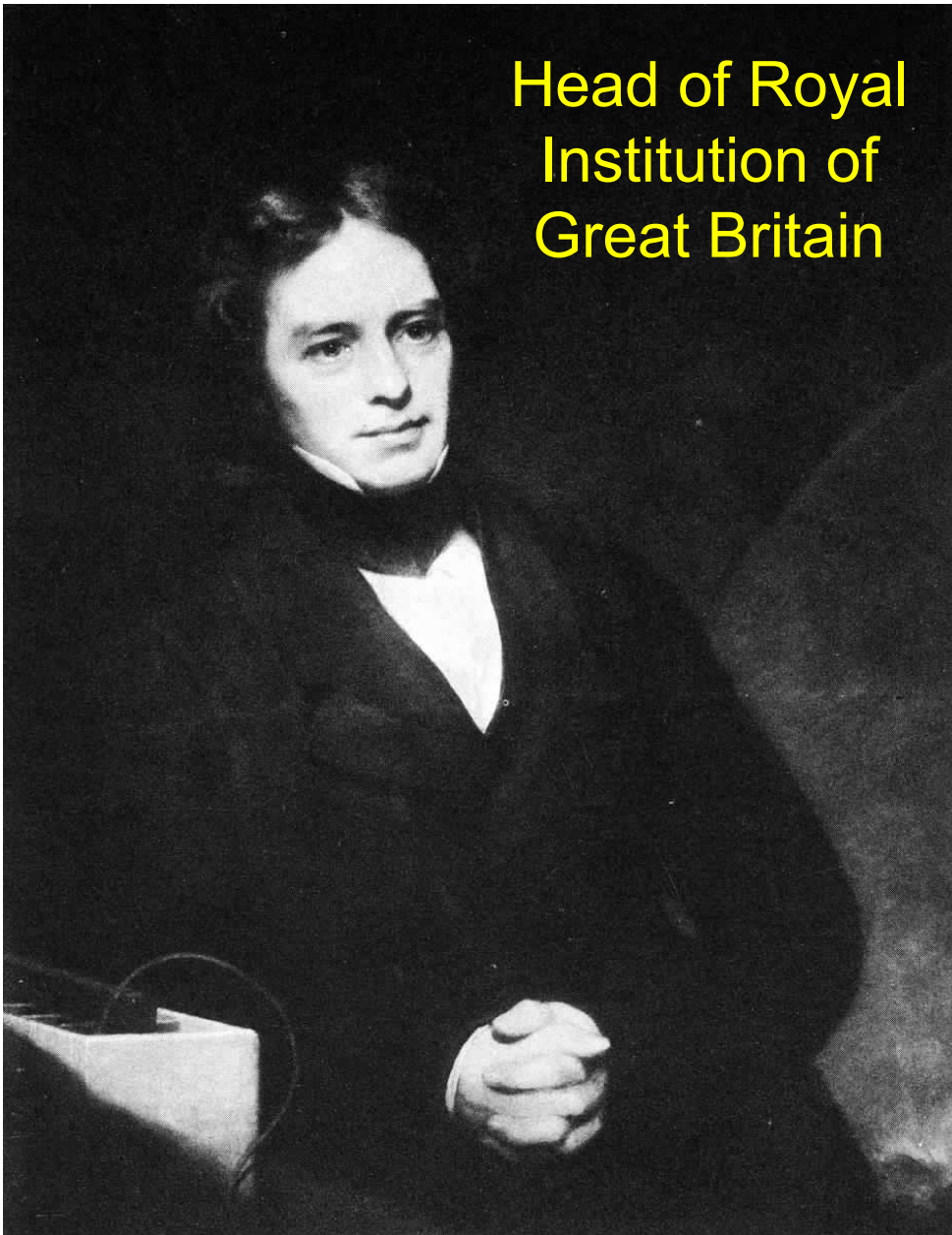
Physicist & electrical
experimenter;

Developed
mathematical theory
for electromagnetic
fields;

Led to the discovery
of electromagnetic
waves and the
relation to the
nature of light

JAMES CLERK MAXWELL

Head of Royal
Institution of
Great Britain



MICHAEL FARADAY

1791-1867

English Chemist &
electrical experimenter;

Discovered

**Electromagnetic
Induction**, laws of
electrolytic action and
magnetic rotation;

Discoveries led to
motors, generators,
transformers, large-
scale distribution of
electric power for
homes & industry

Faraday's contributions to Physical Science

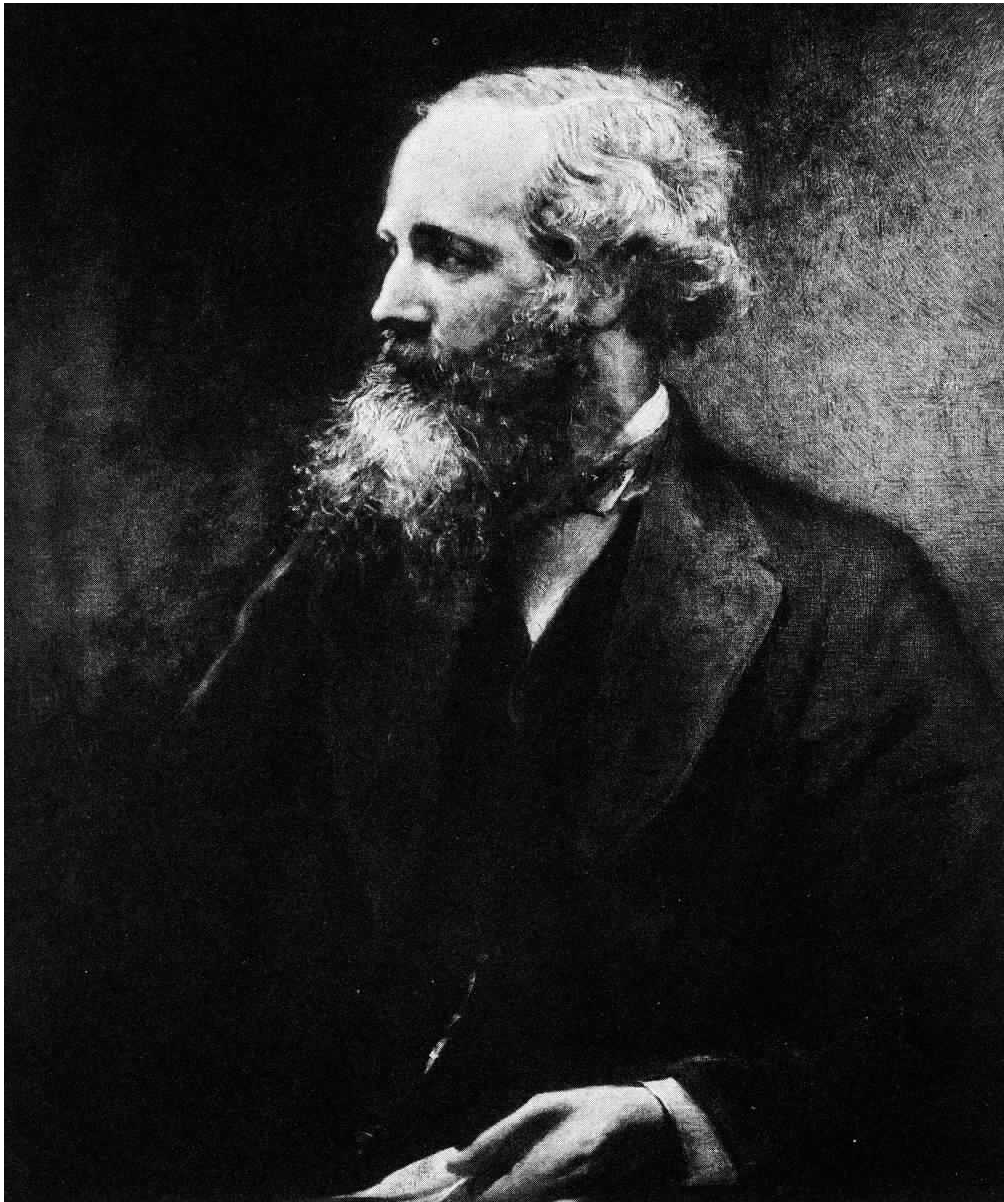
- | | |
|--------|--|
| 1821 | Electromagnetic rotations. |
| 1831 * | Electromagnetic induction. |
| | Acoustic vibrations. |
| 1832 | Identity of electricities from various sources. |
| 1833 * | Electrolytic decompositions. |
| 1835 * | Discharge of electricity through evacuated gases.
(Plasma physics and chemistry.) |
| 1836 * | Electrostatics. Faraday cage. |
| 1845 | Relationship between light, electricity and magnetism; diamagnetism; paramagnetism. |
| 1846 | 'Thoughts on ray vibrations.' |
| 1849 | Gravity and electricity. |
| 1857 | Time and magnetism. |
| 1862 | Influence of a magnetic field on the spectral lines of sodium. |

Motors &
Generators
→ Electric
Power
Distribution

! **Lines of force and the concept of a field.** The energy of a magnet lies outside its perimeter. The notion that light and magnetism and electricity were interconnected.

Faraday's contributions to Chemical Science

- 1816: (With Davy) Evolution of Miners' Safety Lamp.
- 1818-24 Preparation and properties of alloy steels (study of Indian Wootz). **Metallography.**
- 1812-30 **Analytical chemistry.**
Determination of purity and composition of: clays, native lime, water, gunpowder, rust, dried fish, various gases, liquids and solids.
- 1820-26 **Organic chemistry.**
Discovery of: benzene, iso-butene, tetrachloro-ethene, hexachlorobenzene, isomers of alkenes and of naphthalene sulphonic acids (α and β), **vulcanization** of rubber. ***Photochemical** preparations.
- 1825-31 Improvements in the production of optical grade glass.
- 1823, 1845 **Liquefaction** of gases (H_2S , SO_2 and six other gases).
Recognized existence of **critical temperature** and established reality of **continuity of state.**
- 1833-36 Electrochemistry and the electrical properties of matter.
- * **Laws of electrolysis.** *
- * **Equivalence** of voltaic, static, thermal and animal electricity.
First example of **thermistor** action.
Fused salt electrolytes; **superionic** conductors.
- 1834 **Heterogeneous catalysis:**
Poisoning and inhibition of surface reactions.
Selective adsorption; wettability of solids.
- 1835 'Plasma' chemistry (discharge of electricity through gases).
- * 1836 **Dielectric constant, permittivity.**
- 1845-50 **Magneto-chemistry** and the magnetic properties of matter. * **Magneto-optics.** Faraday effect.
Diamagnetism. Paramagnetism. Anisotropy.
- 1857 **Colloidal metals.** Scattering of light. Sols and **hydrogels.**



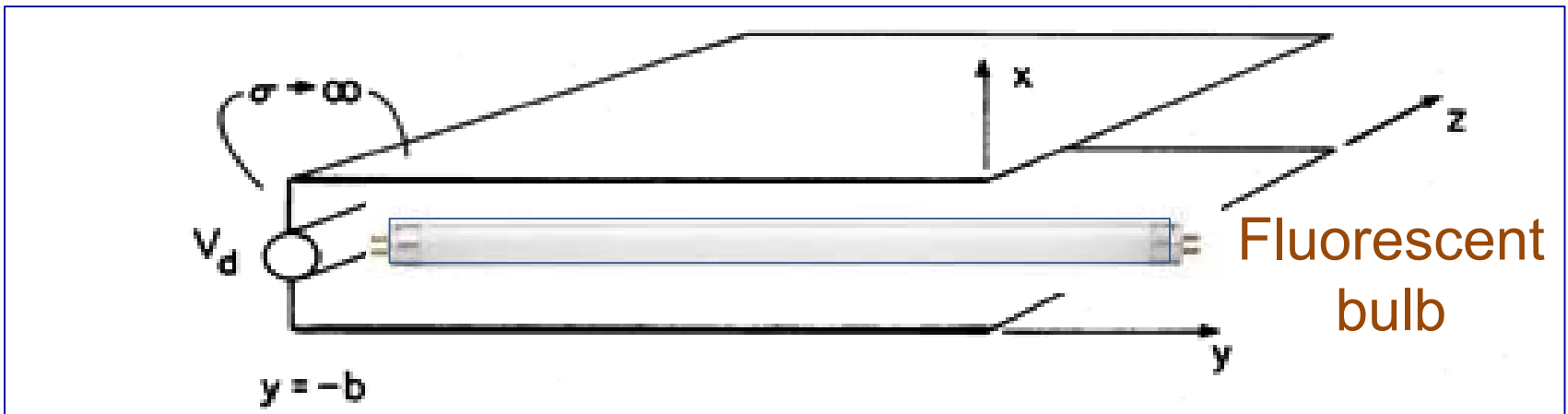
JAMES CLERK MAXWELL

1831-1879

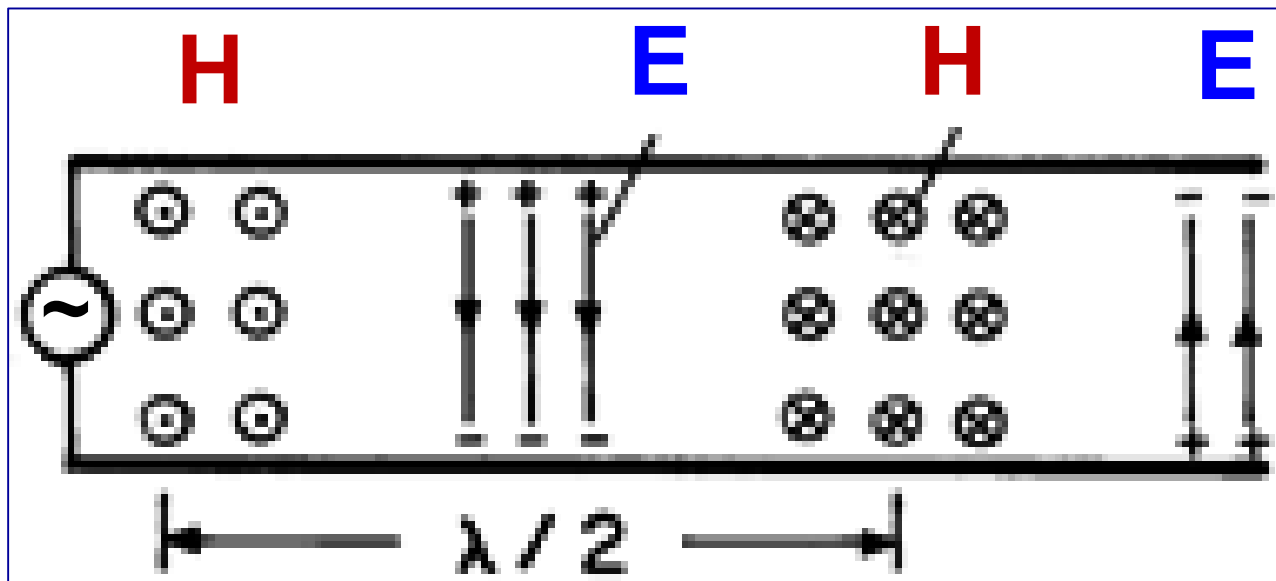
Scottish

Physicist & electrical
experimenter;

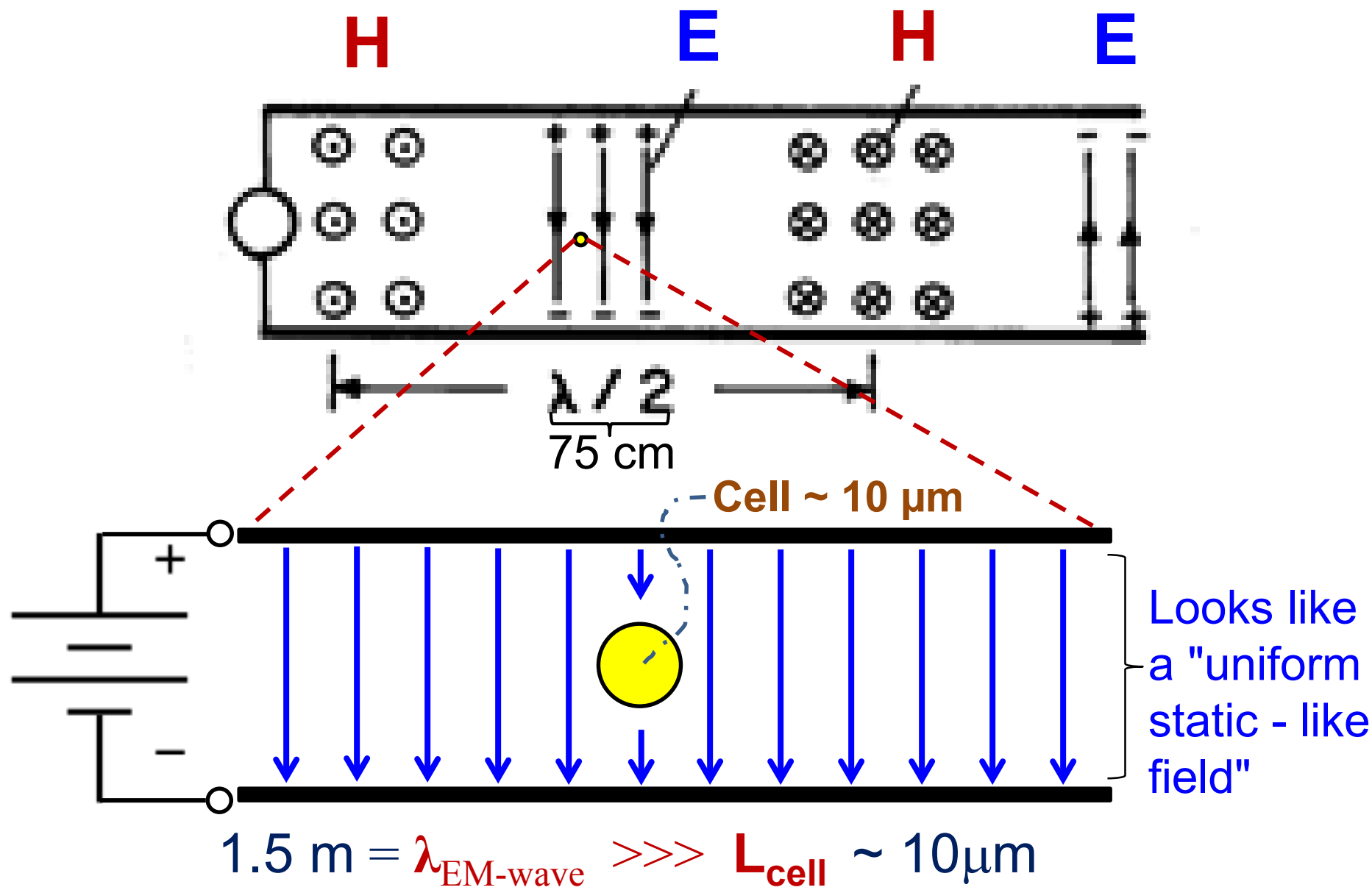
...Publicly credited his
theoretical insights to
the fundamental
experimental studies
of Faraday (English)



DEMO: Standing Electromagnetic Wave



$$f = \underbrace{200 \text{ MHz}}_{2 \times 10^8 \text{ Hz}}; \quad (f\lambda = c = 3 \times 10^8 \text{ m/s}) \Rightarrow \underline{\lambda = 1.5 \text{ m}}$$



low freq = long $\lambda \Rightarrow$ Look at Electro Quasi Static Limit

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20.430J / 2.795J / 6.561J / 10.539J Fields, Forces, and Flows in Biological Systems
Fall 2015

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