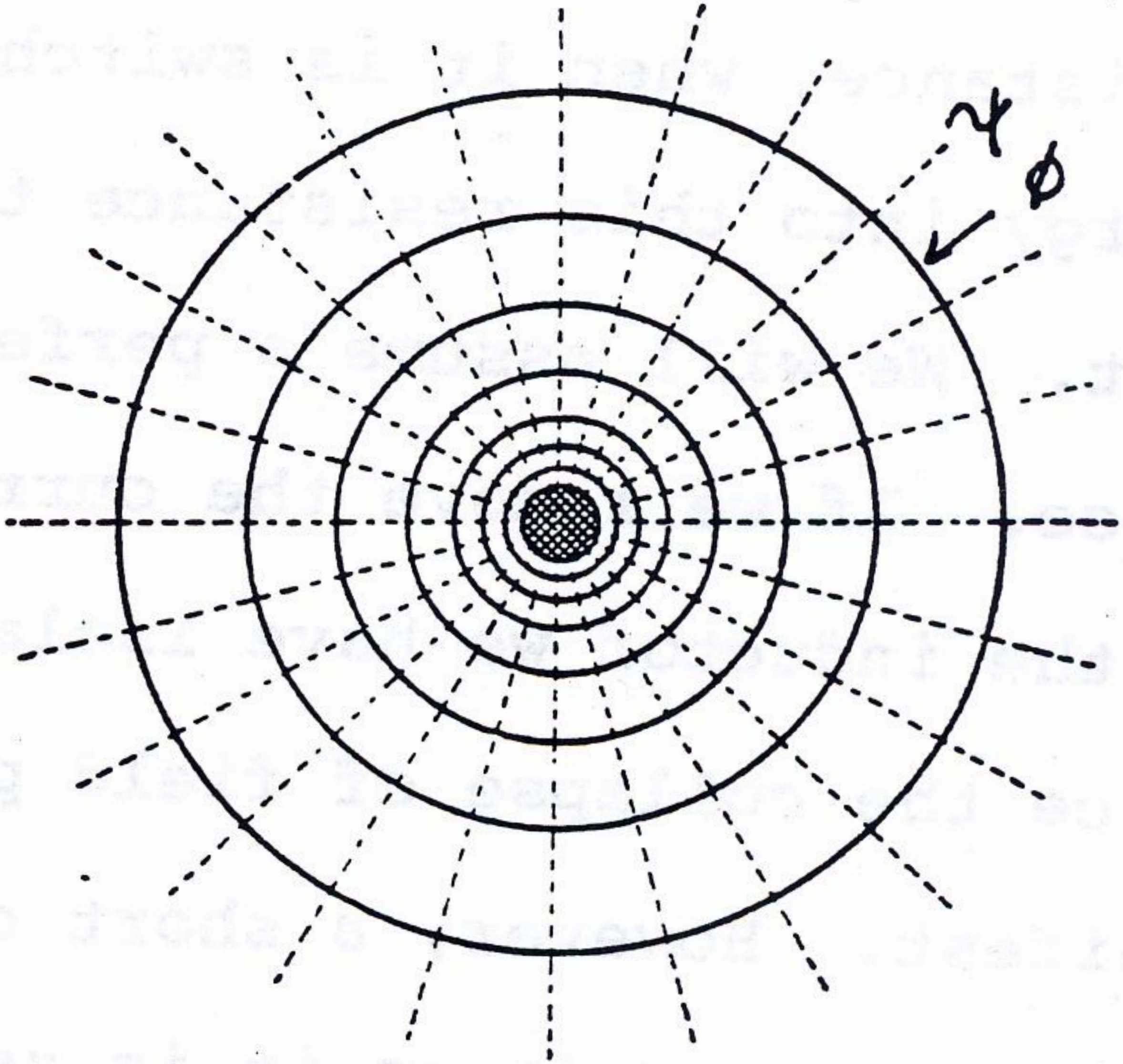


Fig. 25 — Electric Field of Conductor.

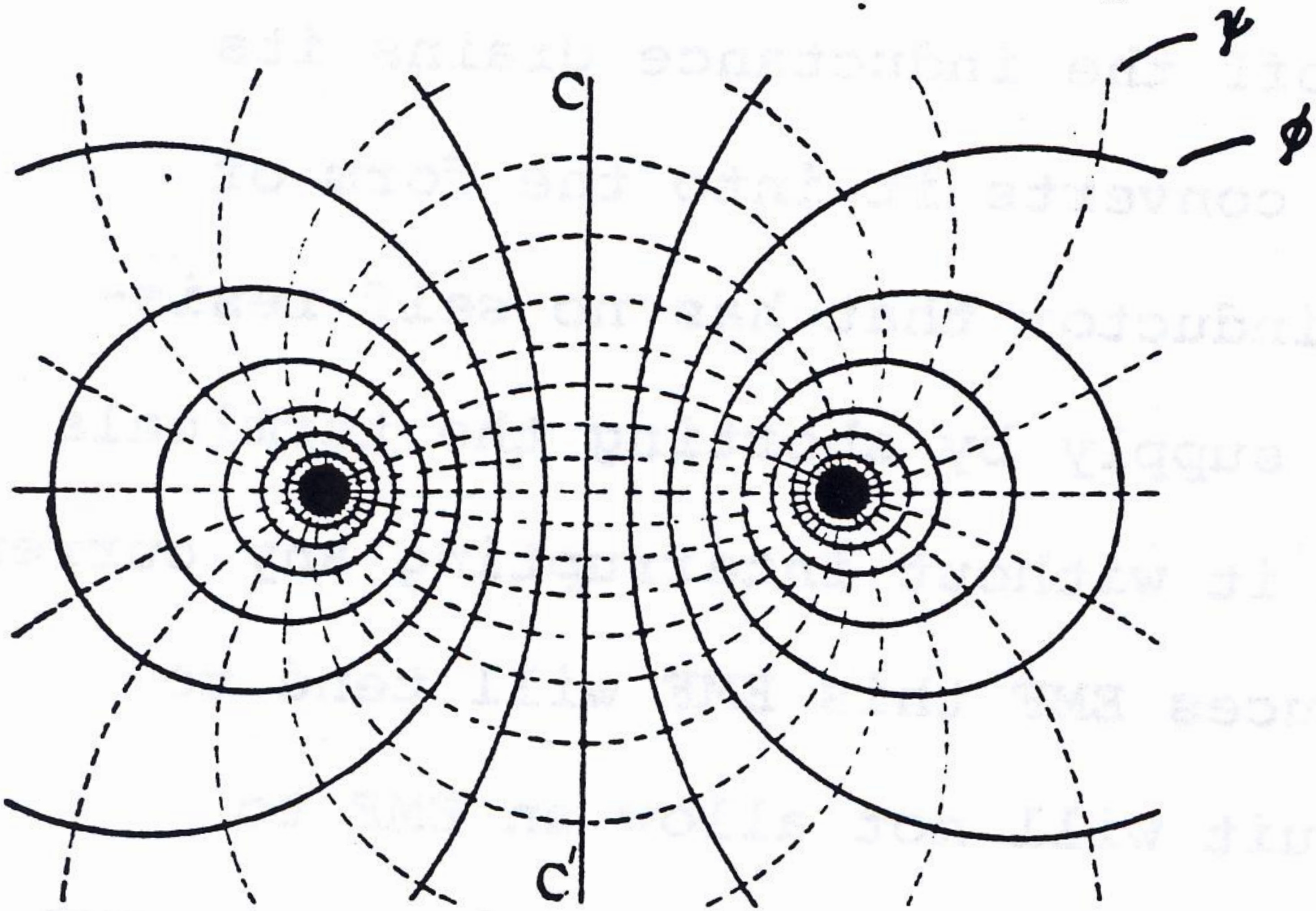
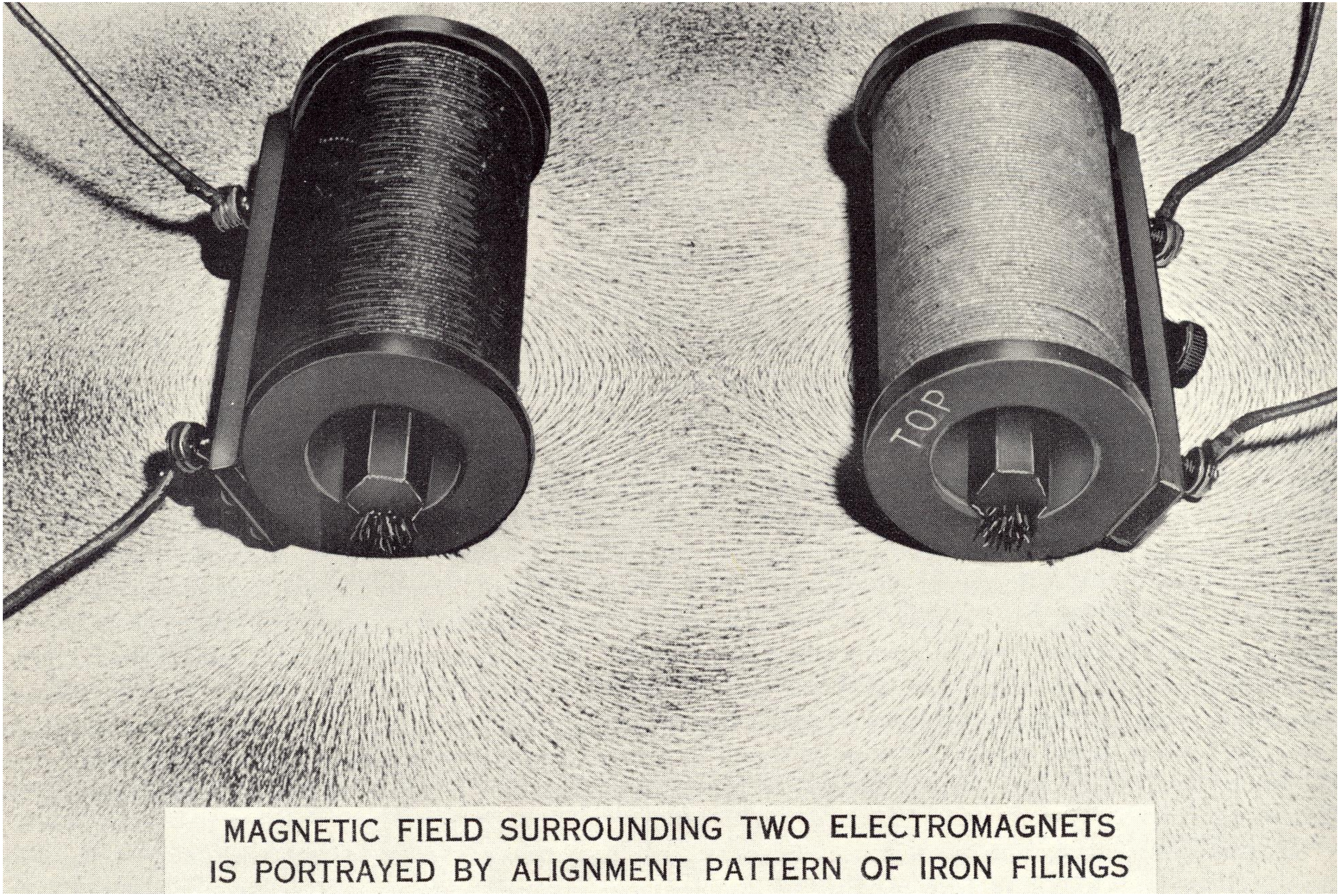


Fig. 1a — Electric Field of Circuit.



MAGNETIC FIELD SURROUNDING TWO ELECTROMAGNETS
IS PORTRAYED BY ALIGNMENT PATTERN OF IRON FILINGS

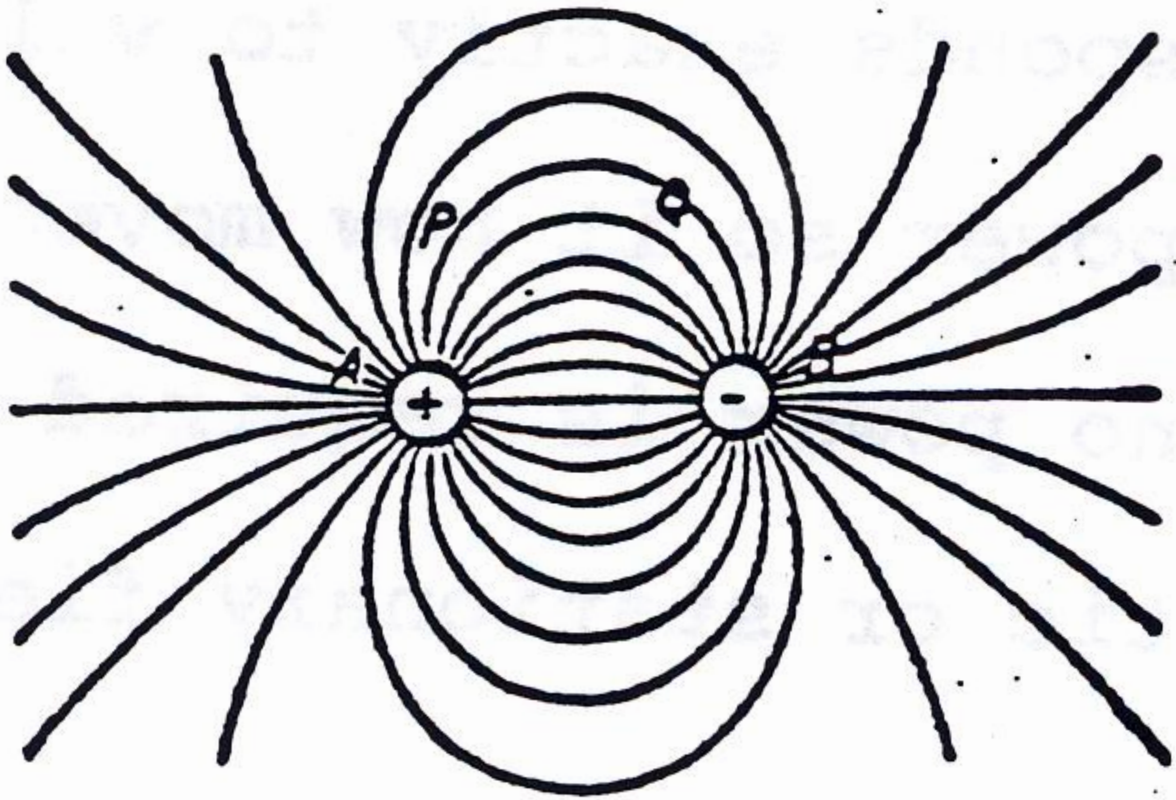


FIG. 2.

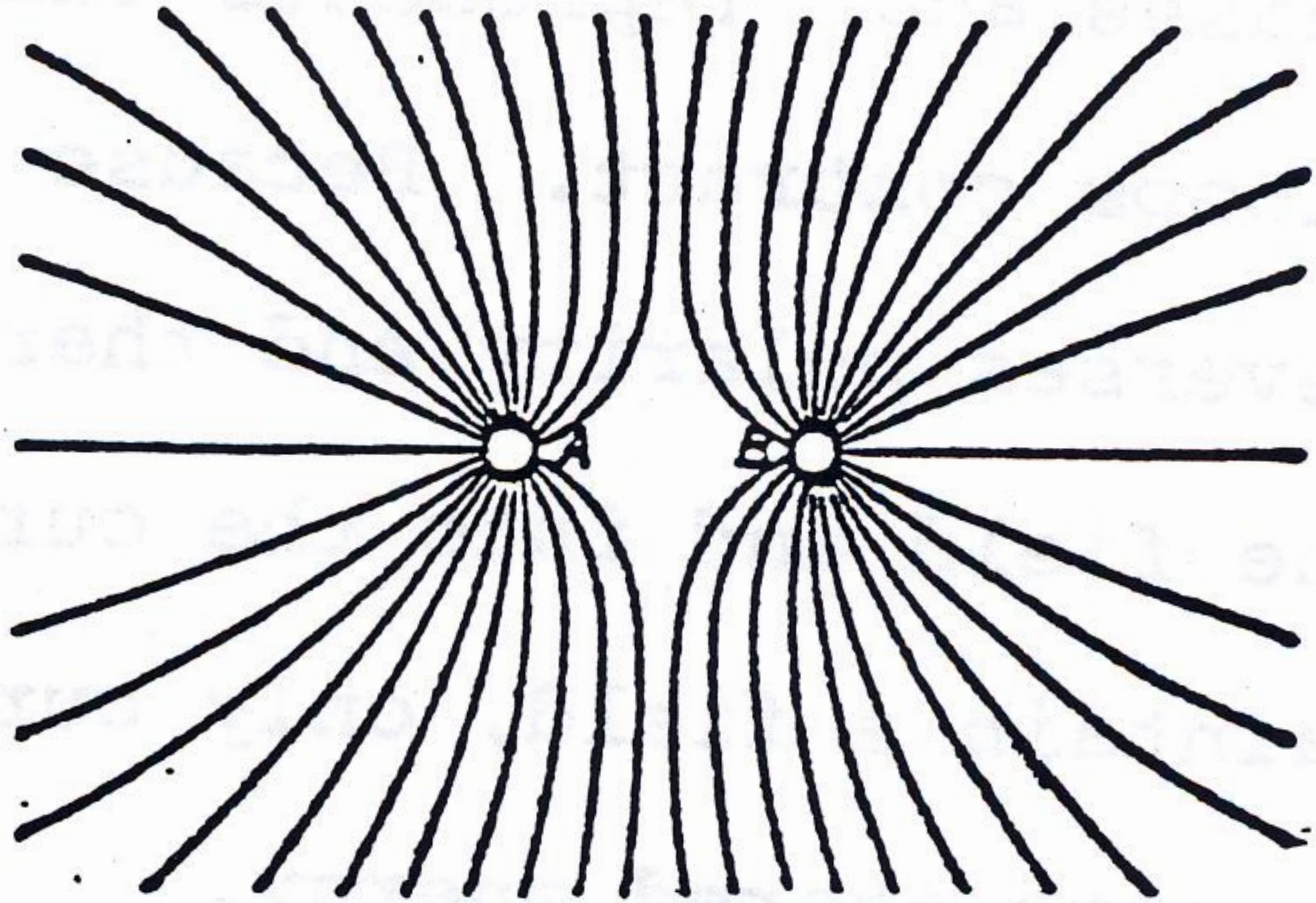


FIG. 3.

THE

LONDON, EDINBURGH AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FOURTH SERIES.]

MARCH 1861.

XXV. *On Physical Lines of Force.* *By* J. C. MAXWELL, *Professor of Natural Philosophy in King's College, London**.

PART I.—*The Theory of Molecular Vortices applied to Magnetic Phenomena.*

IN all phenomena involving attractions or repulsions, or any forces depending on the relative position of bodies, we have to determine the *magnitude* and *direction* of the force which would act on a given body, if placed in a given position.

Fig 1

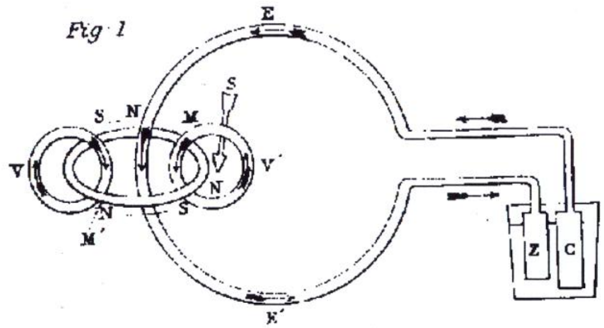


Fig: 2.

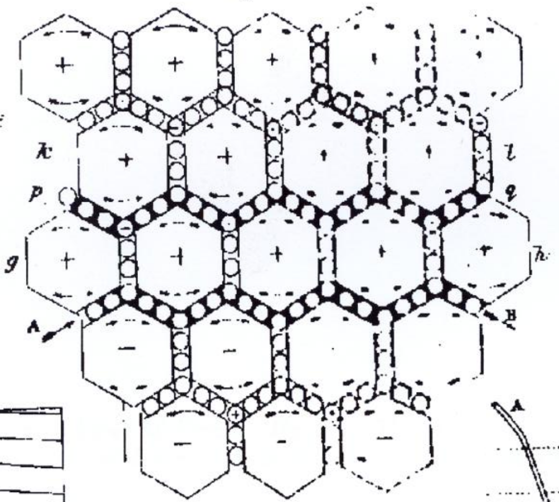


Fig: 3.

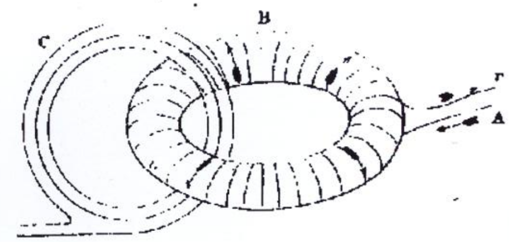


Fig: 4.

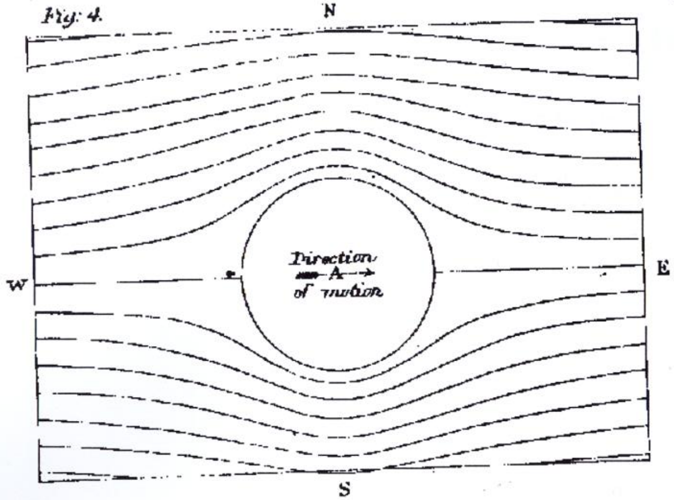


Fig 5.

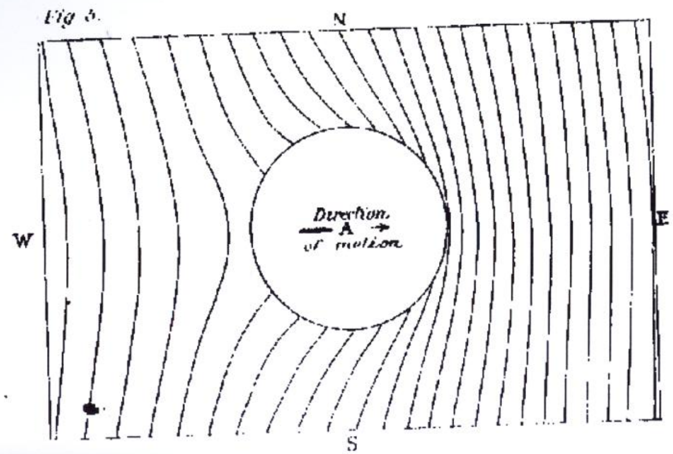


Fig: 6.

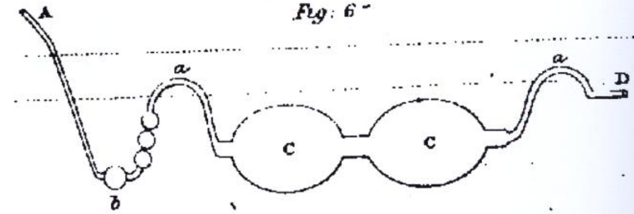


Fig: 7.

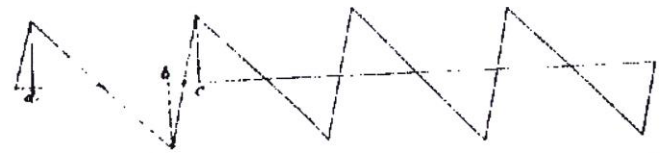


Fig: 8.

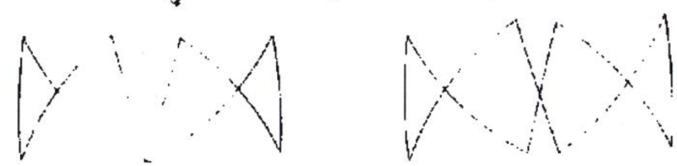


Fig: 9.

Fig: 10.

'I suppose that the "magnetic medium" is divided into small portions or cells, the divisions or cell walls being composed of a single stratum of spherical particles, these particles being "electricity." The substance of the cells I suppose to be highly elastic, both with respect to compression and distortion; and I suppose the connection between the cells and the particles in the cell walls to be such that there is perfect rolling without slipping between them and that they act on each other tangentially.

'I then find that if the cells are set in rotation, the medium exerts a stress equivalent to a hydrostatic pressure combined with a longitudinal tension along the lines of axes of rotation.

'If there be two similar systems, the first a system of magnets, electric currents and bodies capable of magnetic induction, and the second composed of cells and cell walls, the density of the cells everywhere proportional to the capacity for magnetic induction at the corresponding point of the other, and the magnitude and direction of the cells proportional to the magnetic force, then

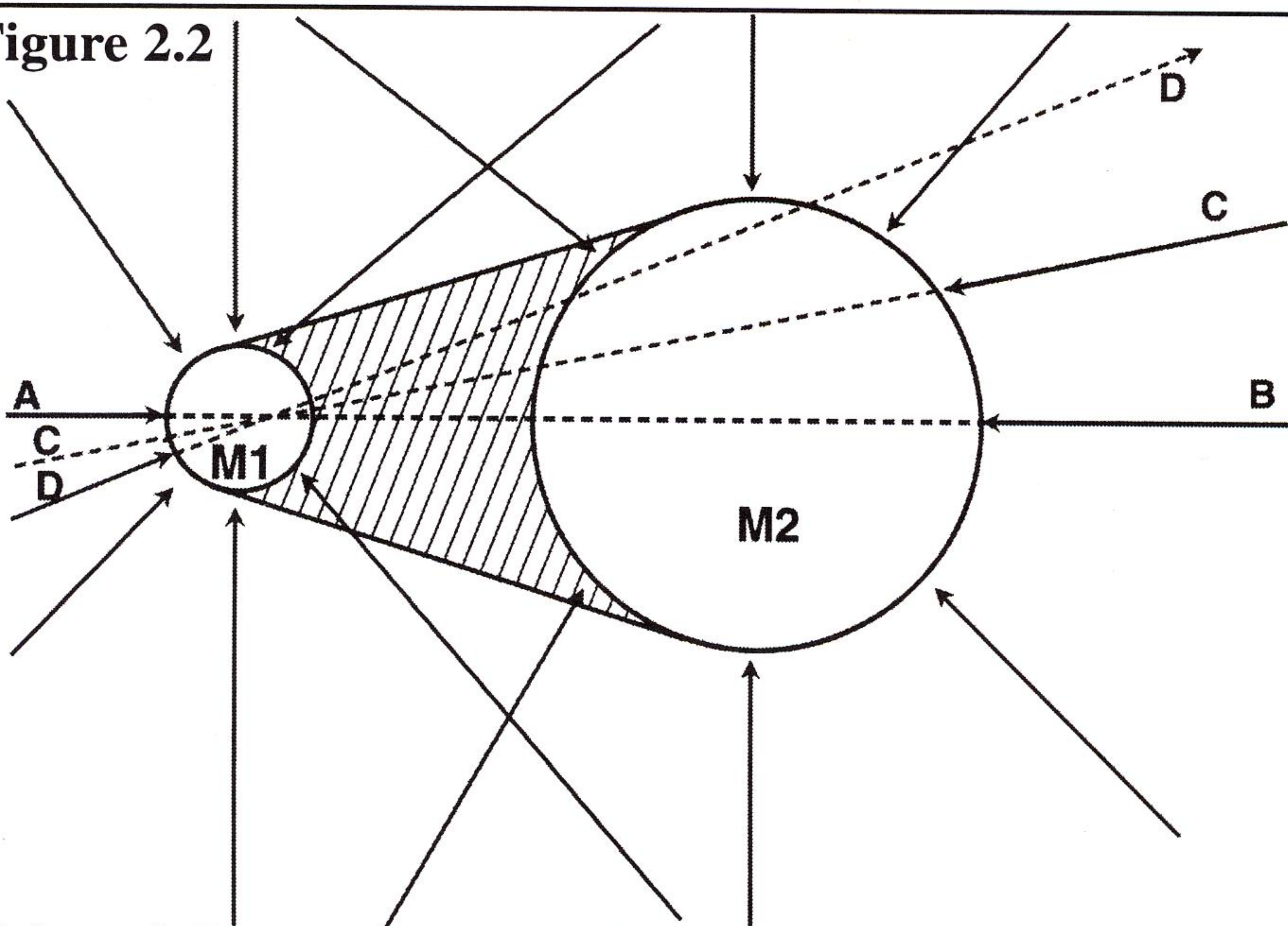
‘1 All the mechanical magnetic forces in the one system will be proportional to forces in the other arising from centrifugal force.

‘2 All the electric currents in the one system will be proportional to currents of the particles forming the cell walls in the other.

‘3 All the electromotive forces in the one system, whether arising from changes of position of magnets or currents, or from motions of conductors, or from changes of intensity of magnets or currents will be proportional to forces urging the particles of the cell walls arising from the tangential action of the rotating cells when their velocity is increasing or diminishing.

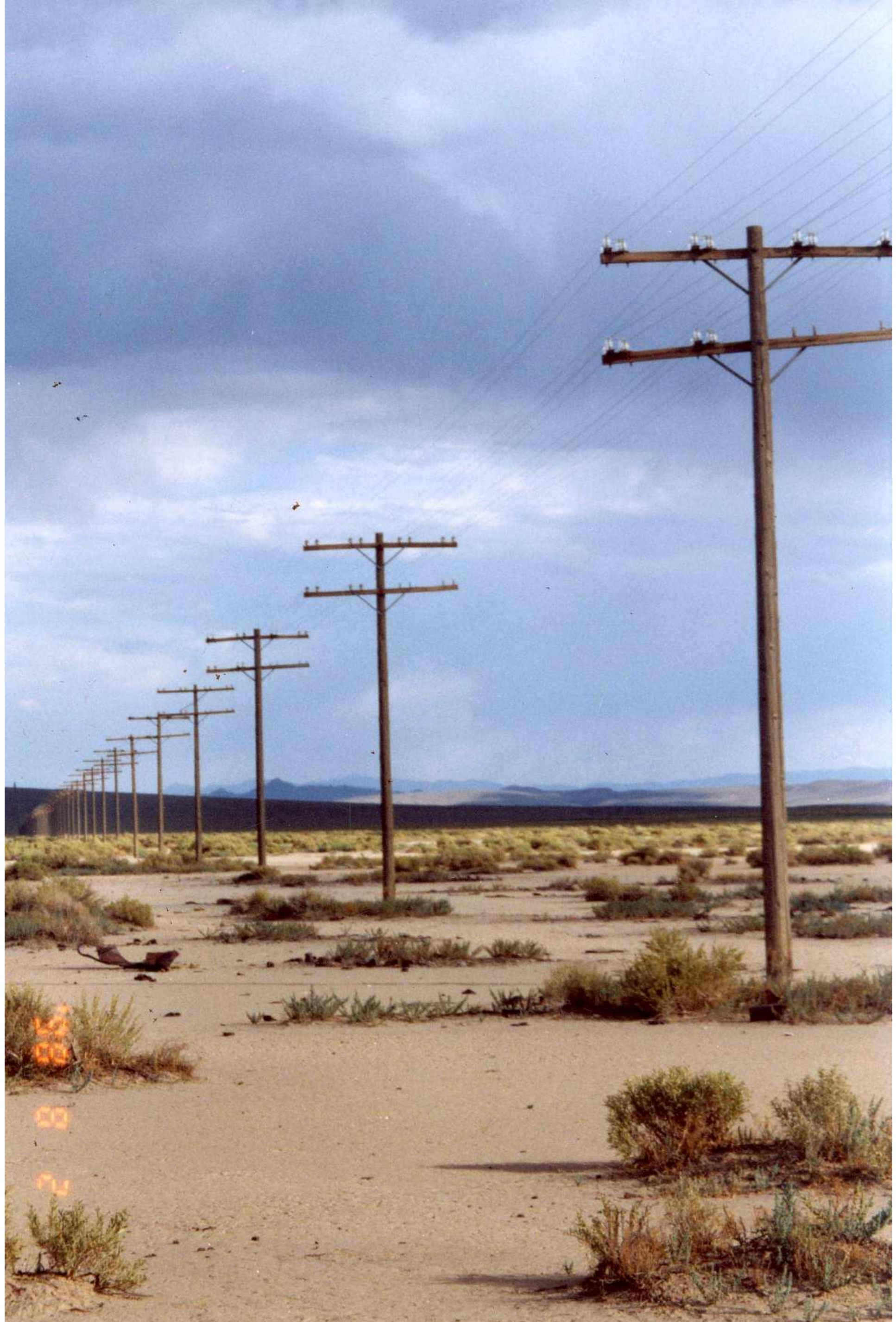
‘4 If in a non-conducting body the mutual pressure of the particles of the cell walls (which corresponds to electric tension) diminishes in a given direction, the particles will be urged in that direction by their mutual pressure, but will be restrained by their connection with the substance of the cells. They will, therefore, produce strain in the cells till the elasticity called forth balances the tendency of the particles to move. Thus there will be a displacement of particles proportional to the electromotive force, and when this force is removed, the particles will recover from displacement.’

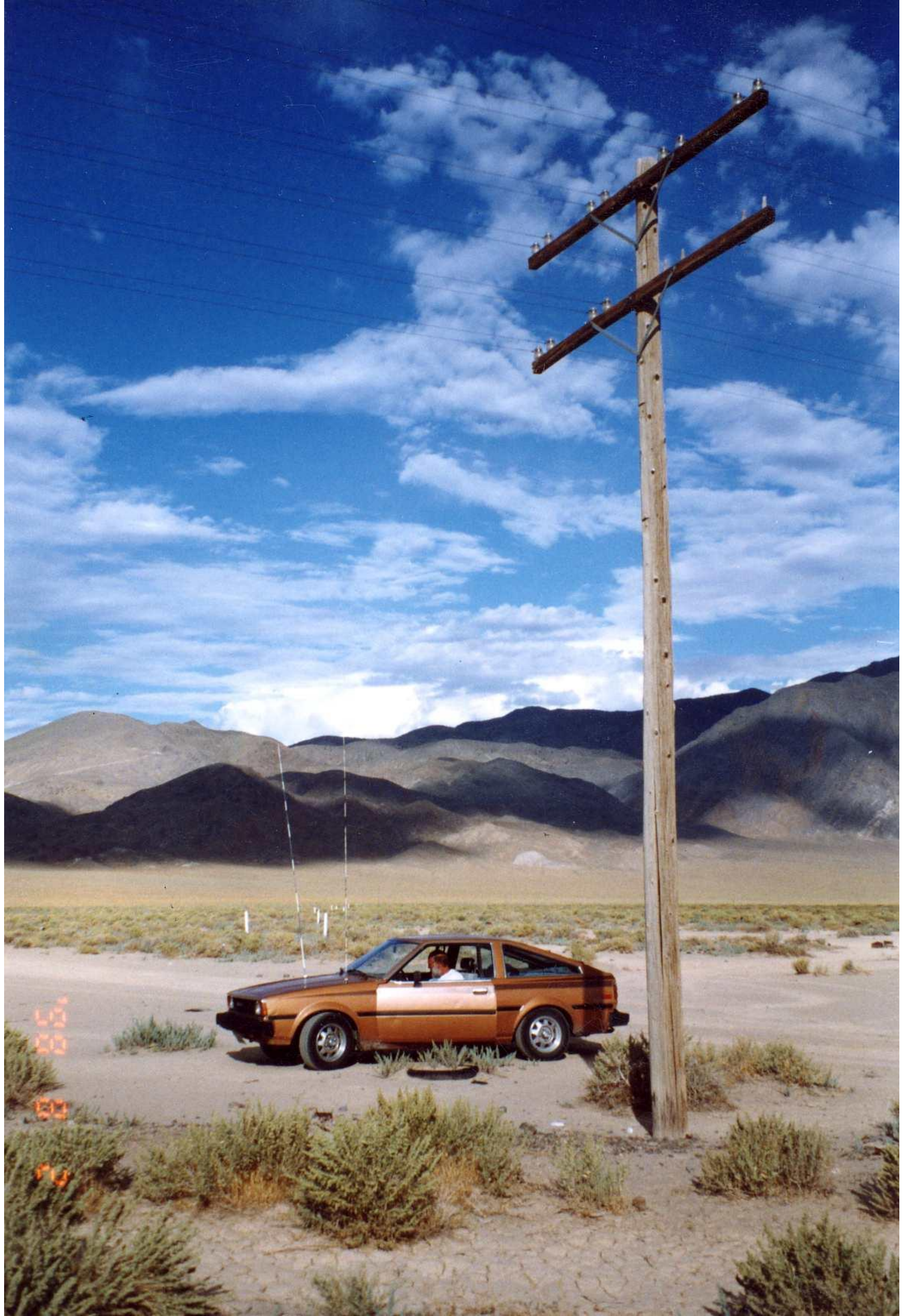
Figure 2.2

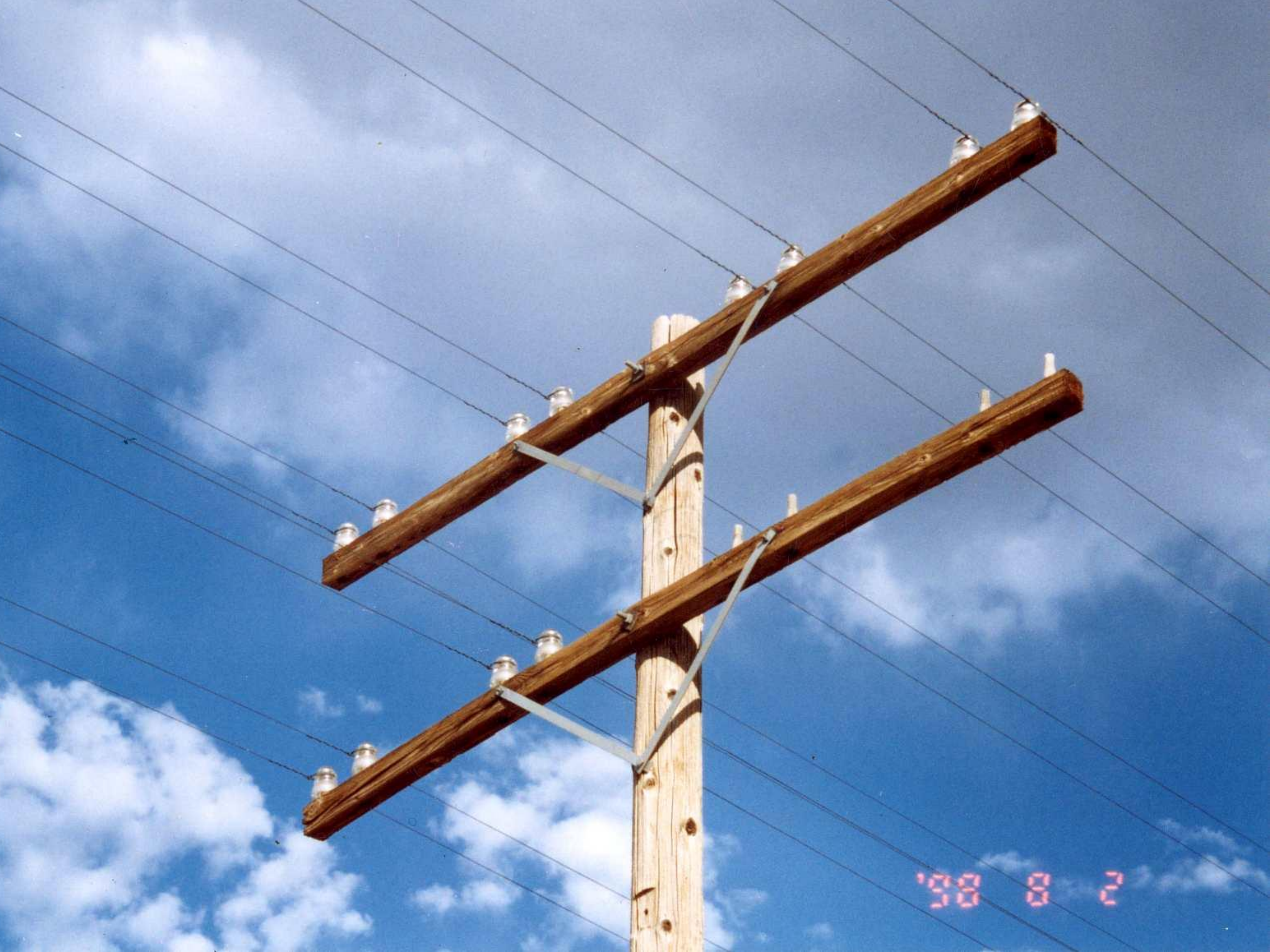


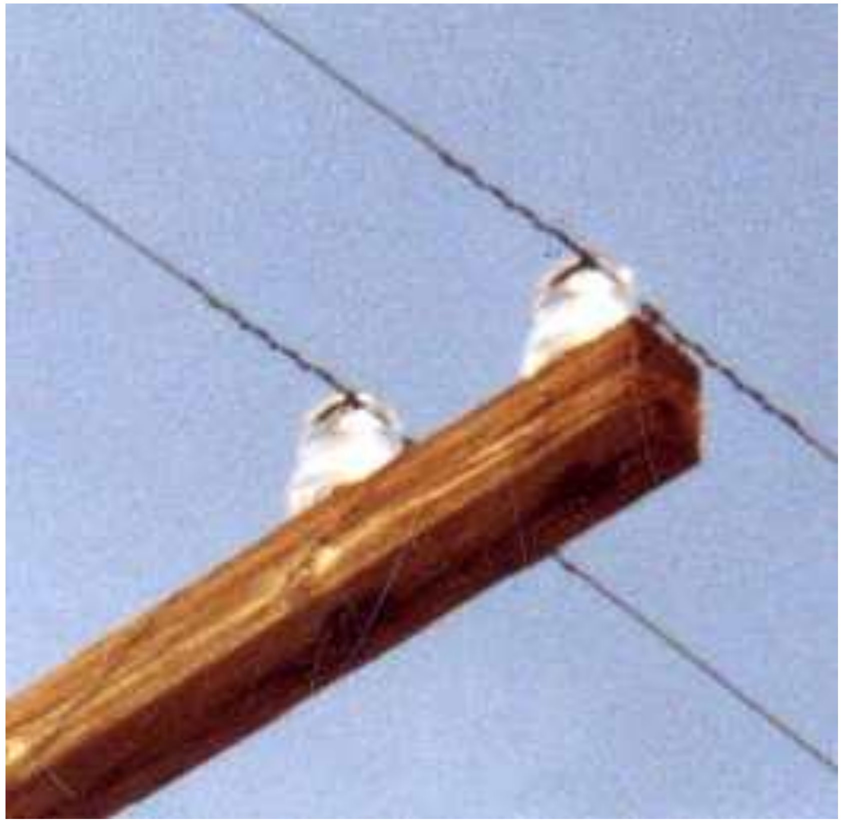
Universal Pressure creates a low pressure area which causes Gravity. The shaded area is the Low Pressure zone.

Artist: Billy Baty






'98 8 2



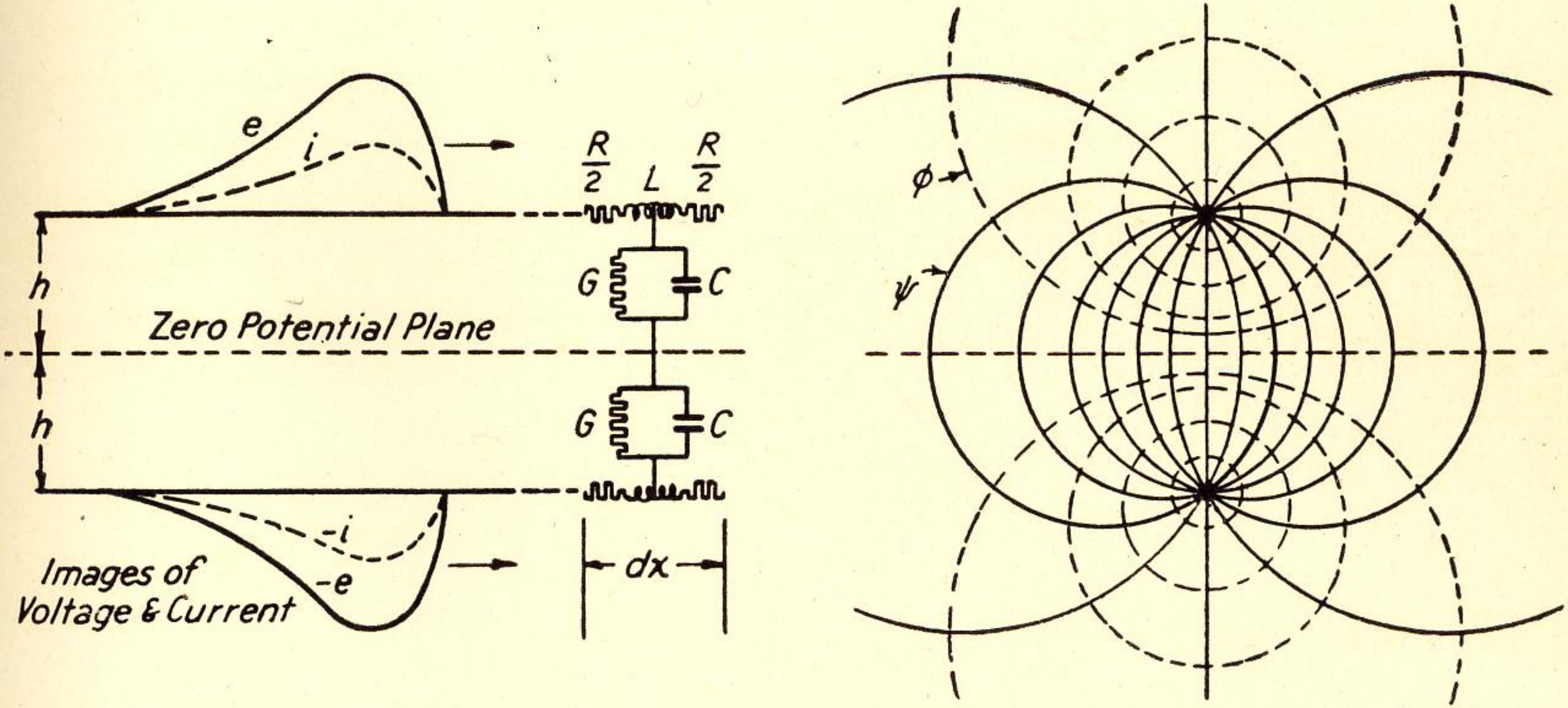
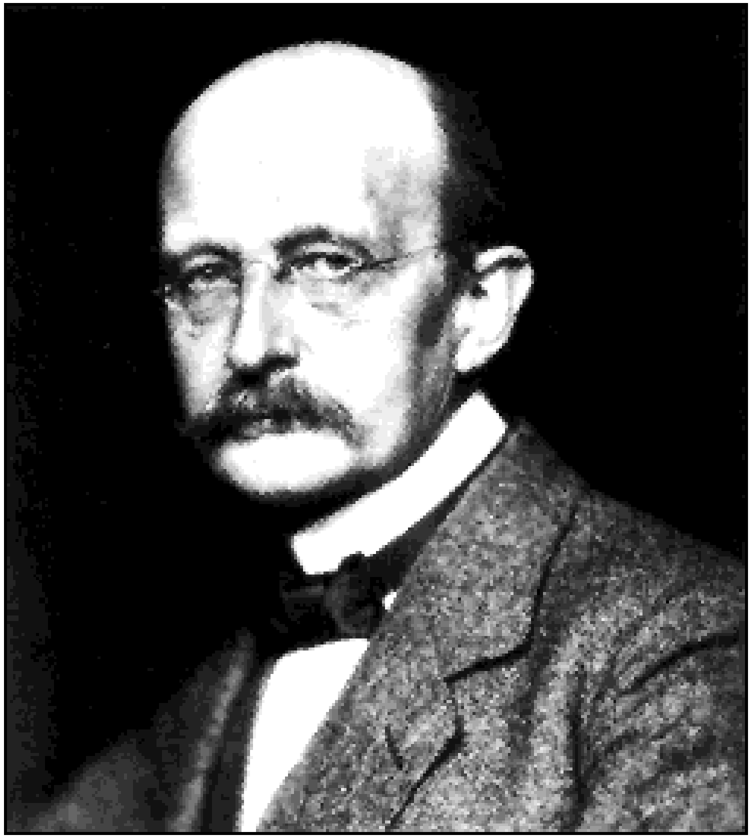


FIG. 1.—Traveling Waves and Associated Electromagnetic Fields

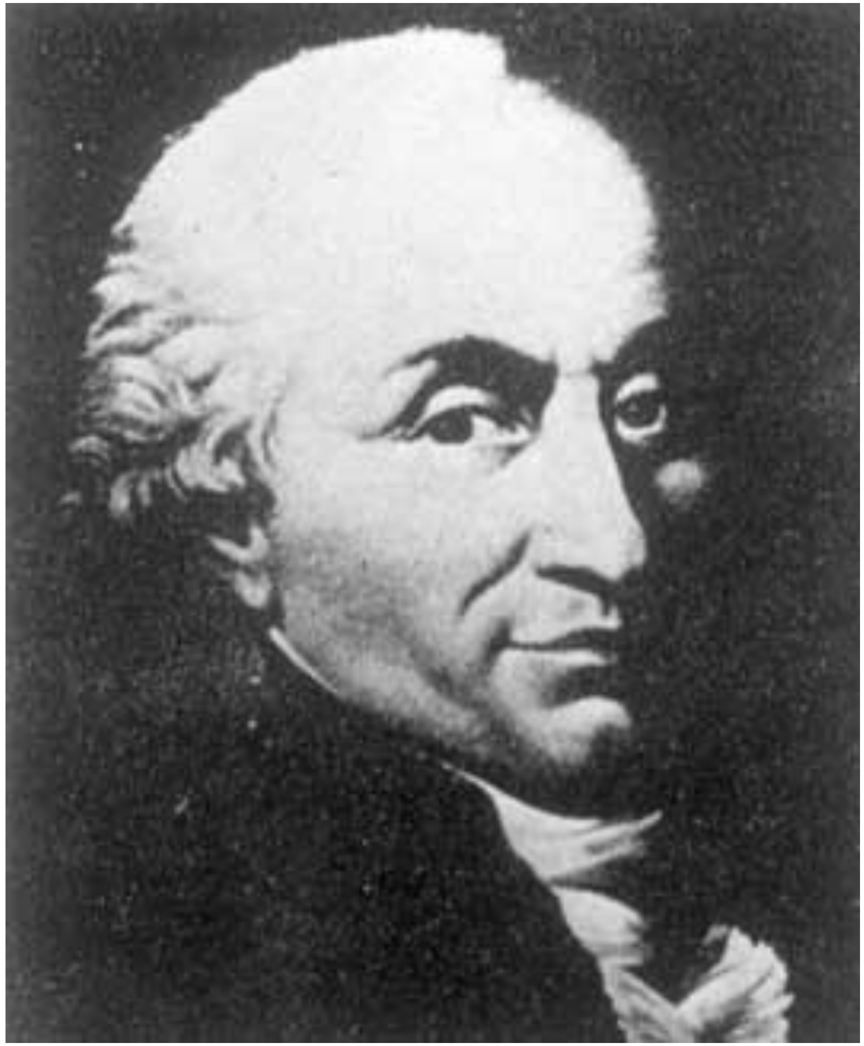
I QUANTITY IN UNDIVIDED FORM

(1)	ϕ	TOTAL ELECTRIFCATION	PLANK
(2)	Φ	TOTAL MAGNETIZATION	WEBER
(3)	Ψ	TOTAL DIELECTRIFICATION	COULOMB



Max Planck

Wilhelm Eduard Weber



Charles-Augustin de Coulomb

II

BASIC RELATIONS

(4) $$\frac{\varphi}{\Psi} = \Phi$$ MAGNETIC INDUCTION — WEBER

(5) $$\Phi \times \Psi = \varphi$$ PLANK

(6) $$\frac{\varphi}{\Phi} = \Psi$$ DIELECTRIC INDUCTION — COULOMB

(IV) DERIVATIVES OF QUANTITY BY SPACE A

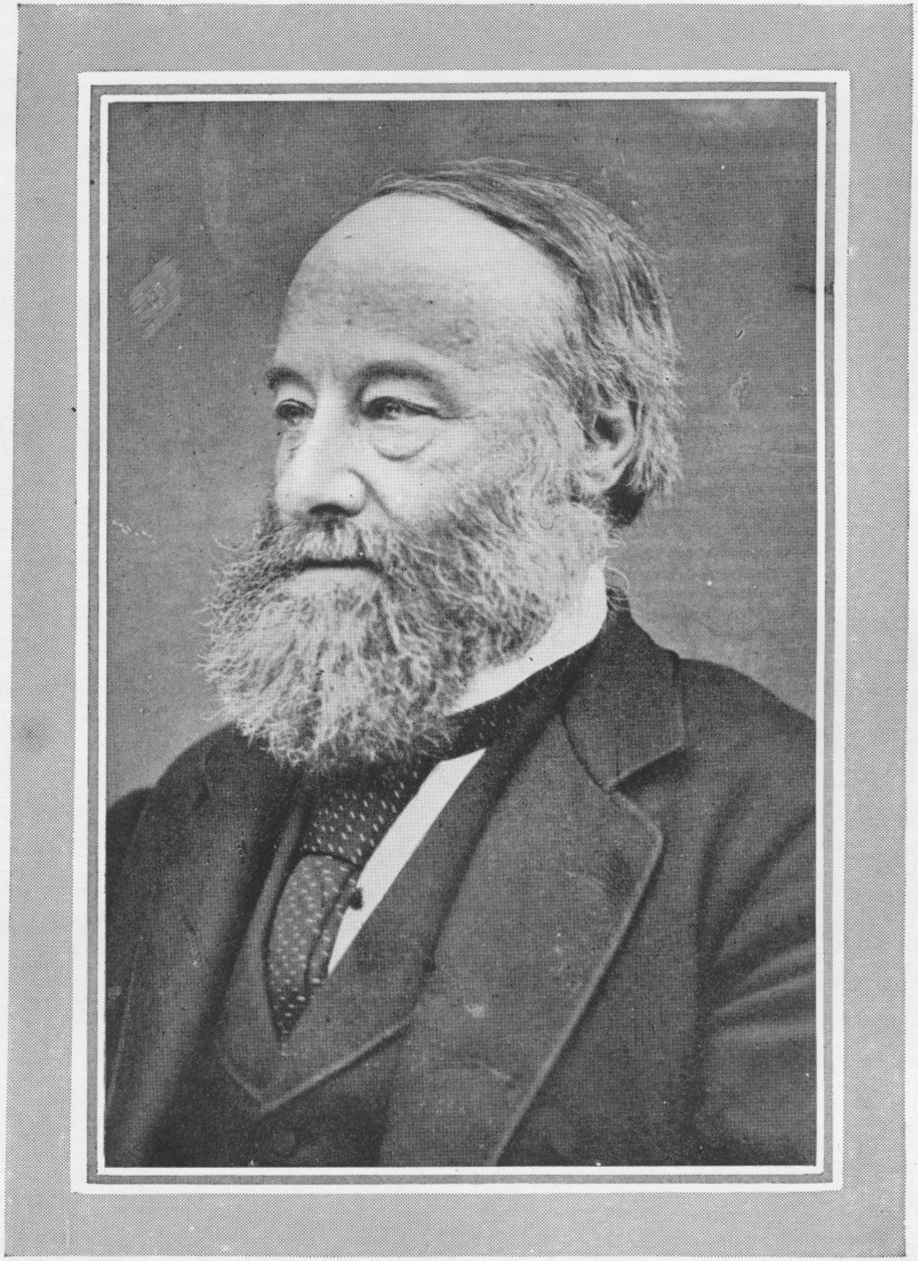
$$\frac{\Phi}{A} = \text{DENSITY OF MAGNETIC INDUCTION} \quad \text{PER } cm^2$$

$$\frac{\Psi}{A} = \text{DENSITY OF DIELECTRIC INDUCTION} \quad \text{PER } cm^2$$

$$\frac{\varphi}{A^2} = \text{DENSITY OF ELECTRIFICATION} \quad \text{PER } cm^4$$

(III) DERIVATIVES OF QUANTITY BY TIME T

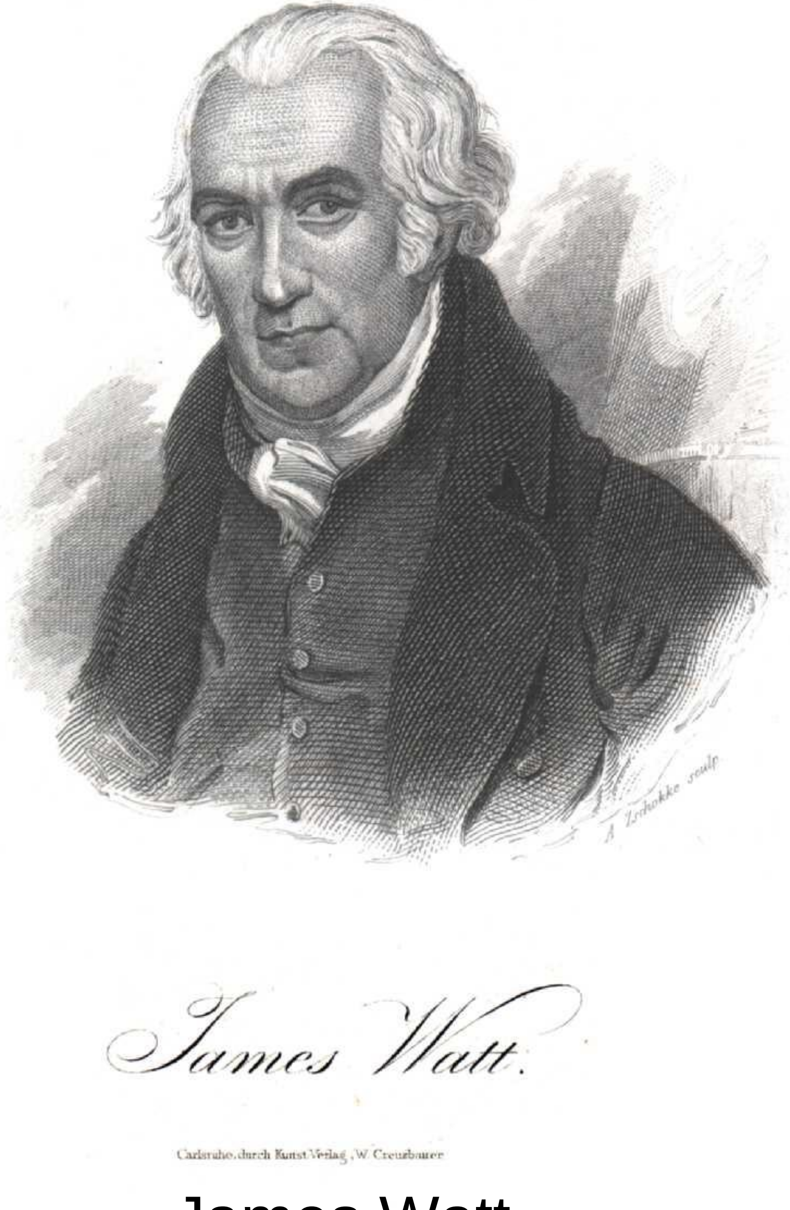
$\dfrac{\Phi}{T} = W$	, WORK, OR ENERGY	JOULE
$\dfrac{\Phi}{T} = E$	, ELECTROMOTIVE FORCE	VOLT
$\dfrac{\Psi}{T} = I$	, MAGNETOMOTIVE FORCE	AMPERE
$\dfrac{\Phi}{T^2} = P$	, POWER, OR ACTIVITY	WATT



James Prescott Joule

Alessandro Volta

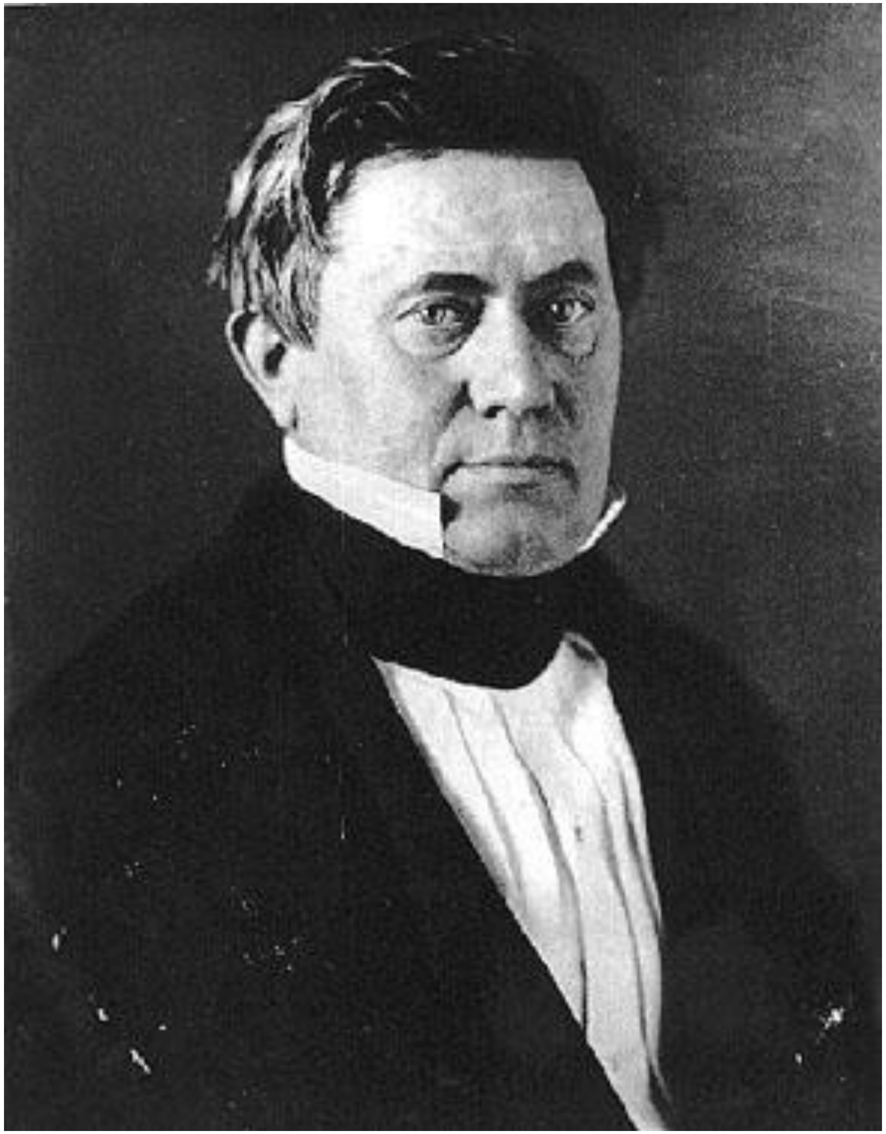
André-Marie Ampère


A. Zschokke sculp
James Watt.
Carlsruhe, durch Kunst Verlag, W. Creuzbauer

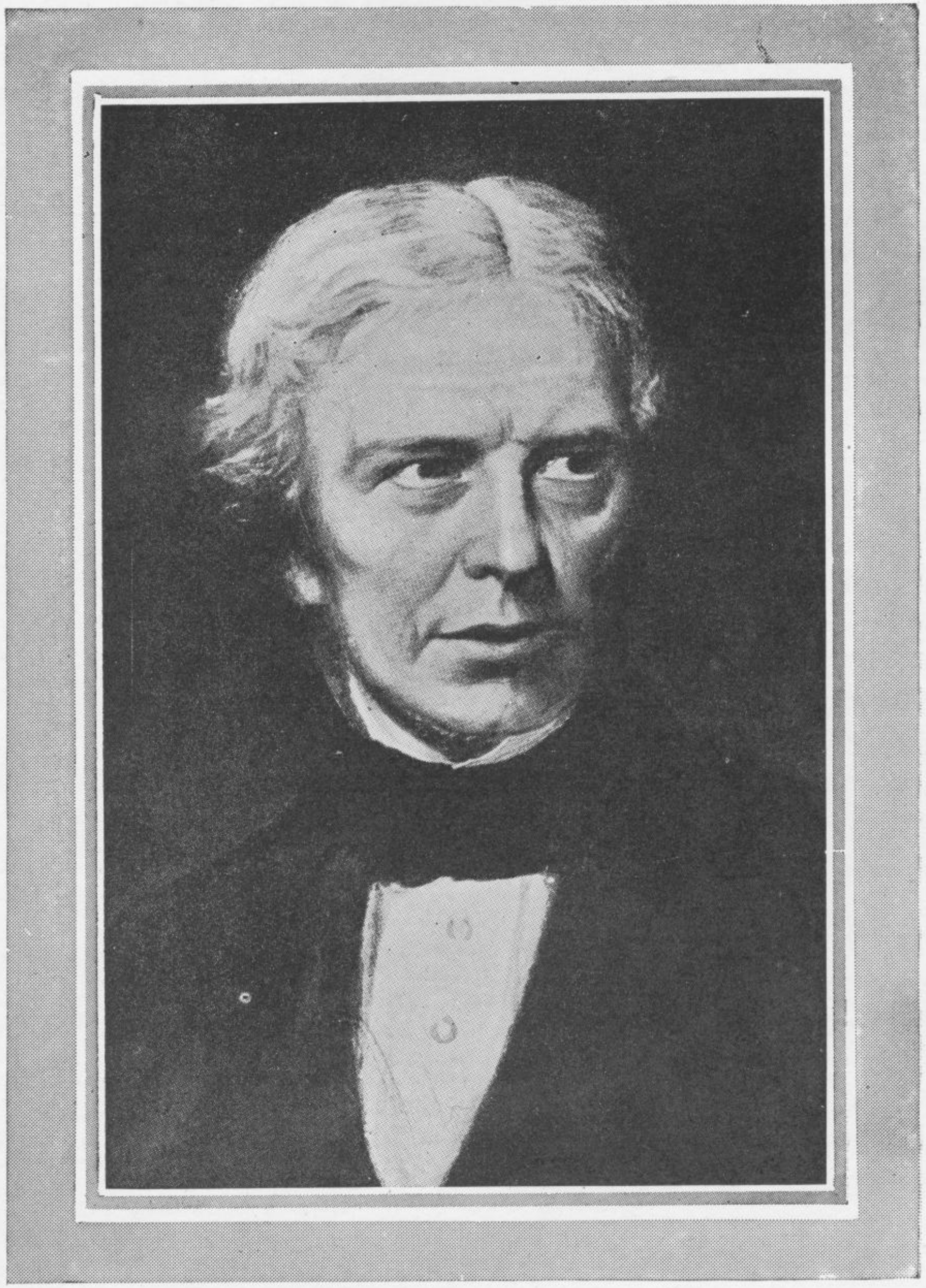
James Watt

(V) PROPORTIONALITY

$\dfrac{\Phi}{I} = L$,	MAGNETIC INDUCTANCE	HENRY
$\dfrac{\Psi}{E} = C$,	DIELECTRIC CAPACITY	FARAD
$\dfrac{E}{I} = Z$,	IMPEADANCE	OHM
$\dfrac{I}{E} = Y$,	ADMITTANCE	SIEMENS



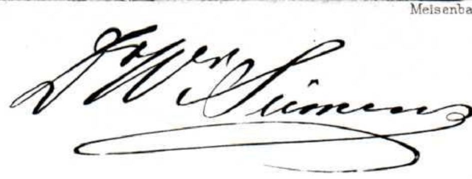
Joseph Henry



Michael Faraday

George Simon Ohm

G. Brogi Florenz, phot. Meisenbach, Riffarth & Co. Berlin, grav.



Verlag von Julius Springer in Berlin, N.

Ernst Werner von Siemens

(VI) GROWTH & DECAY

$$\frac{L}{T} = R$$

RESISTANCE,
HENRY PER SECOND

OHM

$$\frac{C}{T} = G$$

CONDUCTANCE
FARAD PER SECOND

SIEMENS

$$L \times C = T^2 \qquad \sqrt[2]{LC} = T = F^{-1}$$

HERTZ^{-1}

TIME^2 SECOND SQUARED

THE DIMENSION OF TIME, T SECONDS	THE DIMENSION OF SPACE, l c.m.
FOWARD TIME	OUTER SPACE
$+1T$	l^{+1}
REVERSE TIME	INNER SPACE
$-1T$	l^{-1}
ADDITIVE	MULTIPLICITIVE

$$x^2 = -1$$

$$x^2 = x + 1$$

1. CAPACITANCE

The phenomena of capacitance is a type of electrical energy storage in the form of a field in an enclosed space. This space is typically bounded by two parallel metallic plates or two metallic foils on an interviening insulator or dielectric. A nearly infinite variety of more complex structures can exhibit capacity, as long as a difference in electric potential exists between various areas of the structure. The oscillating coil represents one possibility as to a capacitor of more complex form, and will be presented here.

2. CAPACITANCE INADEQUATELY EXPLAINED

The perception of capacitance as used today is wholly inadequate for the proper understanding of this effect. Steinmetz mentions this in his introductory book "Electirc Discharges, Waves and Impulses". To quote, "Unfortunately, to a large extent in dealing with dielectric fields the prehistoric conception of the electrostatic charge (electron) on the conductor still exists, and by its use destroys the analogy between the two components of the electric field, the magnetic and the dielectric, and makes the consideration of dielectric fields unnecessarily complicated."

3. LINES OF FORCE AS REPRESENTATION OF DIELECTRICITY

Steinmetz continues, "There is obviously no more sense in thinking of the capacity current as current which charges the conductor with a quantity of electricity, than there is of speaking of the inductance voltage as charging the conductor with a quantity of magnetism. But the latter conception, together with the notion of a quantity of magnetism, etc., has vanished since Faraday's representation of the magnetic field by lines of force."

4. THE LAWS OF LINES OF FORCE

All the lines of magnetic force are closed upon themselves, all dielectric lines of force terminate on conductors, but may form closed loops in electromagnetic radiation.

These represent the basic laws of lines of force. It can be seen from these laws that any line of force cannot just end in space.

5. FARADAY AND LINES OF FORCE THEORY

Farady felt strongly that action at a distance is not possible thru empty space, or in other words, "matter cannot act where it is not." He considered space pervaided with lines of force. Almost everyone is familiar with the patterns formed by iron filings around a magnet. These filings act as numerous tiny compasses and orientate themselves along the lines of force existing around the poles of the magnet. Experiment has indicated that a magnetic field does possess a fiberous construct. By passing a coil of wire thru a strong magnetic field and listening to the coil output in headphones, the experimenter will notice a scraping noise. J. J. Thompson performed further experiments involving the ionization of gases that indicate the field is not continuous but fiberous (electricity and matter, 1906).

6. PHYSICAL CHARACTERISTICS OF LINES OF FORCE

Consider the space between poles of a magnet or capacitor as full of lines of electric force. See Fig. 1. These lines of force act as a quantity of stretched and mutually repellent springs. Anyone who has pushed together the like poles of two magnets has felt this springy mass. Observe Fig. 2. Notice the lines of force are more dense along $\overline{A\ B}$ in between poles, and that more lines on A are facing B than are projecting outwards to infinity. Consider the effect of the lines of force on A. These lines are in a state of tension and pull on A. Because more are pulling on A towards B than those pulling on A away from B, we have the phenomena of physical attraction. Now observe Fig. 3. Notice now that the poles are like rather than unlike, more or all lines pull A away from B; the phenomena of physical repulsion.

7. MASS ASSOCIATED WITH LINES OF FORCE IN MOTION

The line of force can be more clearly understood by representing it as a tube of force or a long thin cylinder. Maxwell presented the idea that the tension of a tube of force is representative of electric force (volts/inch), and in addition to this tension, there is a medium through which these tubes pass. There exists a hydrostatic pressure against this media or ether. The value of this pressure is one half the product of dielectric and magnetic density. Then there is a pressure at right angles to an electric tube of force. If through the growth of a field the tubes of force spread sideways or in width, the broadside drag through the medium represents the magnetic reaction to growth in intensity of an electric current. However, if a tube of force is caused to move endwise, it will glide through the medium with little or no drag as little surface is offered. This possibly explains why no magnetic field is associated with certain experiments performed by Tesla involving the movement of energy with no accompanying magnetic field.

8. INDUCTANCE AS AN ANALOGY TO CAPACITY

Much of the mystery surrounding the workings of capacity can be cleared by close examination of inductance and how it can give rise to dielectric phenomena. Inductance represents energy storage in space as a magnetic field. The lines of force orientate themselves in closed loops surrounding the axis of current flow that has given rise to them. The larger the space between this current and its images or reflections, the more energy that can be stored in the resulting field.

9. MECHANISM OF STORING ENERGY MAGNETICALLY

The process of pushing these lines or loops outward, causing them to stretch, represents storing energy as in a rubber band. A given current strength will hold a loop of force at a given distance from conductor passing current hence no energy movement. If the flow of current increases, energy is absorbed by the field as the loops are then pushed outward at a corresponding velocity. Because energy is in motion an E.M.F. must accompany the current flow in order for it to represent power. The magnitude of this EMF exactly corresponds to the velocity of the field. Then if the current ceases changing in magnitude thereby becoming constant, no EMF accompanys it, as no power is being absorbed. However, if the current decreases and represents then a negative velocity of field as the loops contract. Because the EMF corresponds exactly to velocity it reverses polarity and thereby reverses power so it now moves out of the field and into the current. Since no power is required to maintain a field, only current, the static or stationary field, represents stored energy.

10. THE LIMITS OF ZERO AND INFINITY

Many interesting features of inductance manifest themselves in the two limiting cases of trapping the energy or releasing it instantly. Since the power supply driving the current has resistance, when it is switched off the inductance drains its energy into this resistance that converts it into the form of heat. We will assume a perfect inductor that has no self resistance. If we remove the current supply by shorting the terminals of the inductor we have isolated it without interrupting any current. Since the collapse of field produces EMF this EMF will tend to manifest. However, a short circuit will not allow an EMF to develop across it as it is zero resistance by definition. No EMF can combine with current to form power, therefore, the energy will remain in the field. Any attempt to collapse forces increased current which pushes it right back out. This is one form of storage of energy.

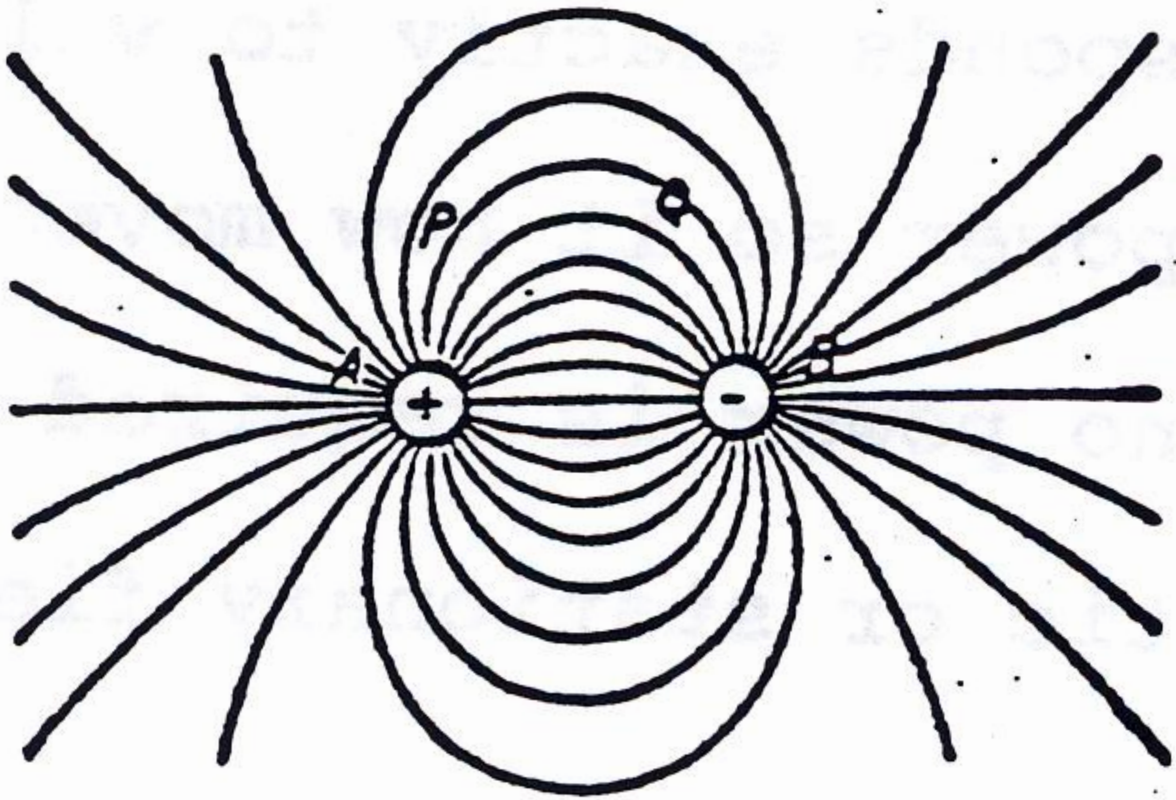


FIG. 2.

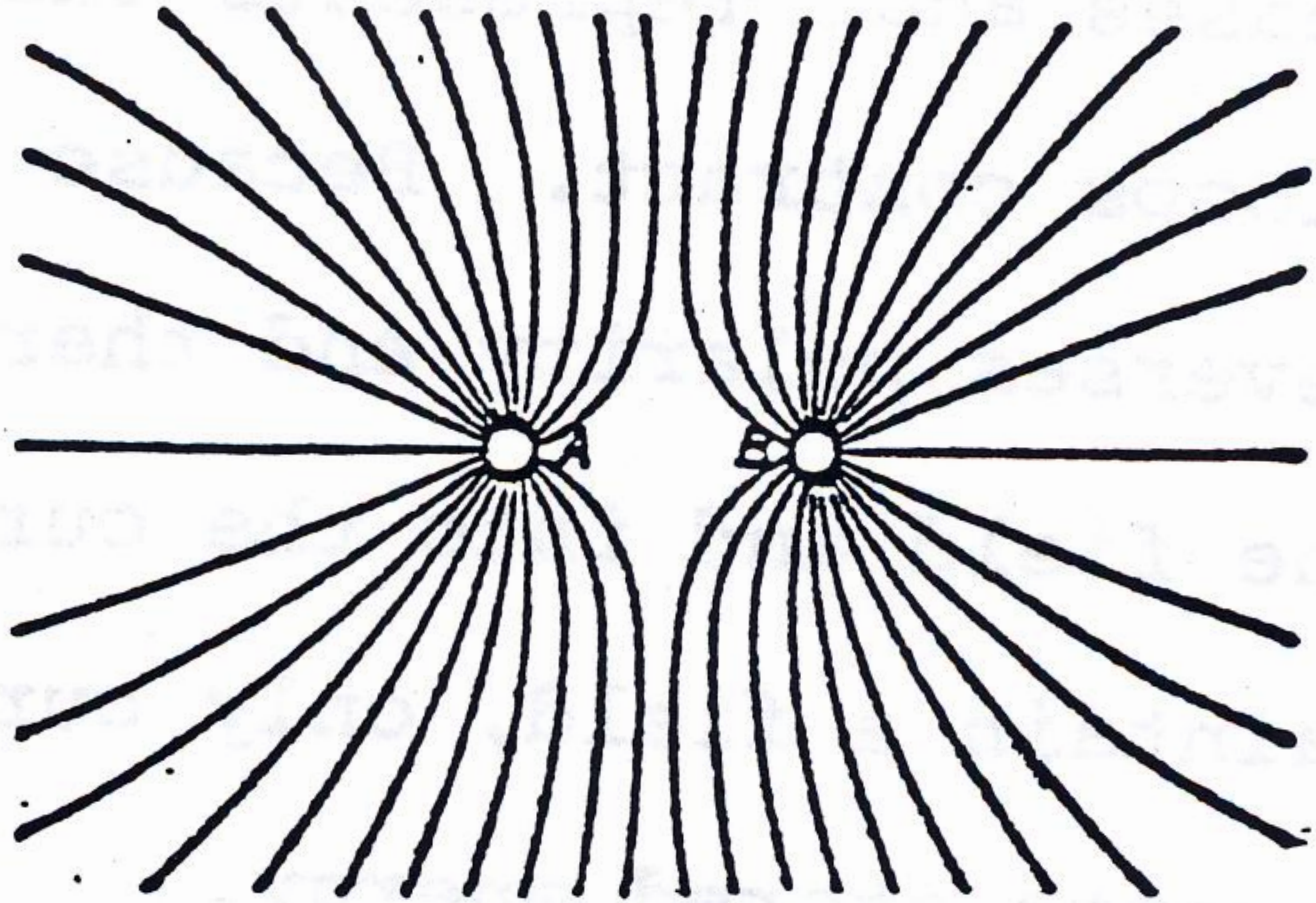


FIG. 3.

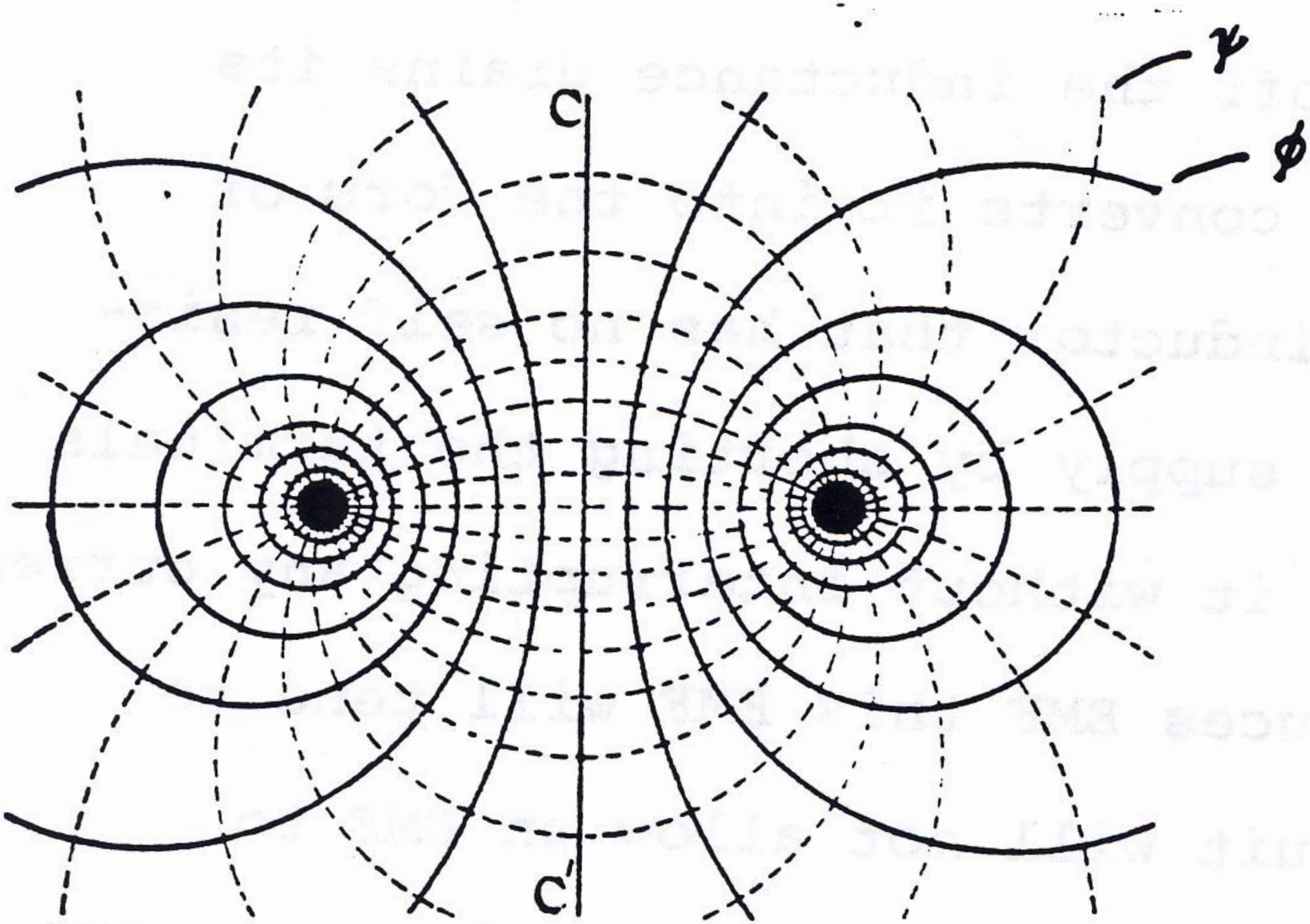


Fig. 1a — Electric Field of Circuit.

11. INSTANT ENERGY RELEASE AS INFINITY

Very interesting (and dangerous) phenoma manifest themselves when the current path is interrupted, thereby causing infinite resistance to appear. In this case resistance is best represented by its inverse, conductance. The conductance is then zero. Because the current vanished instantly the field collapses at a velocity approaching that of light. As EMF is directly releated to velocity of flux, it tends towards infinity. Very powerful effects are produced because the field is attempting to maintain current by producing whatever EMF required. If a considerable amount of energy exists, say several kilowatt hours* (250 KWH for lightning stroke), the ensuing discharge can produce most profound effects and can completely destroy inadequately protected apparatus.

* The energy utilized by an average household in the course of one day.

12. ANOTHER FORM OF ENERGY APPEARS

Through the rapid discharge of inductance a new force field appears that reduces the rate of inductive EMF formation. This field is also represented by lines of force but these are of a different nature than those of magnetism. These lines of force are not a manifestation of current flow but of an electric compression or tension. This tension is termed voltage or potential difference.

13. DIELECTRIC ENERGY STORAGE SPATIALLY DIFFERENT THAN MAGNETIC ENERGY STORAGE

Unlike magnetism the energy is forced or compressed inwards rather than outwards. Dielectric lines of force push inward into internal space and along axis, rather than pushed outward broadside to axis as in the magnetic field. Because the lines are mutually repellent certain amounts of broadside or transverse motion can be expected but the phenomena is basically longitudinal. This gives rise to an interesting paradox that will be noticed with capacity. This is that the smaller the space bounded by the conducting structure the more energy that can be stored. This is the exact opposite of magnetism. With magnetism, the units volumes of energy can be thought of as working in parallel but the unit volumes of energy in association with dielectricity can be thought of as working in series.

14. <u>VOLTAGE IS TO DIELECTRICITY AS CURRENT IS TO MAGNETISM</u>.

With inductance the reaction to change of field is the production of voltage. The current is proportionate to the field strength only and not velocity of field. With capacity the field is produced not by current but voltage. This voltage must be accompanied by current in order for power to exist. The reaction of capacitance to change of applied force is the production of current. The current is directly proportional to the velocity of field strength. When voltage increases a reaction current flows into capacitance and thereby energy accumulates. If voltage does not change no current flows and the capacitance stores the energy which produced the field. If the voltage decreases then the reaction current reverses and energy flows out of the dielectric field.

As the voltage is withdrawn the compression within the bounded space is relieved. When the energy is fully dissipated the lines of force vanish.

15. AGAIN THE LIMITS ZERO AND INFINITY

Because the power supply which provides charging voltage has internal conductance, after it is switched off the current leaking through conductancedrains the dielectric energy and converts it to heat. We will assume a perfect capacitance having no leak conductance. If we completely disconnect the voltage supply by open circuiting the terminals of the capacitor, no path for current flow exists by definition of an open circuit. If the field tends to expand it will tend towards the production of current. However, an open circuit will not allow the flow of current as it has zero conductance. Then any attempt towards field expansion raises the voltage which pushes the field back inwards. Therefore, energy will remain stored in the field. This energy can be drawn for use at any time. This is another form of energy storage.

16. INSTANT ENERGY RELEASE AS INFINITY

Phenomena of enormous magnitude manifest themselves when the criteria for voltage or potential difference is instantly disrupted, as with a short circuit. The effect is analogous with the open circuit of inductive current. Because the forcing voltage is instantly withdrawn the field explodes against the bounding conductors with a velocity that may exceed light. Because the current is directly related to the velocity of field it jumps to infinity in its attempt to produce finite voltage across zero resistance. If considerable energy had resided in the dielectric force field, again let us say several K.W.H. the resulting explosion has almost inconceivable violence and can vaporize a conductor of substantial thickness instantly. Dielectric discharges of great speed and energy represent one of the most unpleasant experiences the electrical engineer encounters in practice.

$$+1^{\frac{1}{4}} = \begin{bmatrix} +1 & +j \\ -1 & -j \end{bmatrix} = \sqrt[4]{+1}$$

THE FOUR REAL ELEMENTS

$$-1^{\frac{1}{4}} = \begin{bmatrix} +h & +k \\ -h & -k \end{bmatrix} = \sqrt[4]{-1}$$

THE FOUR IMAGE ELEMENTS

17. ENERGY RETURNS TO MAGNETIC FORM

The powerful currents produced by the sudden expansion of a dielectric field naturally give rise to magnetic energy. The inertia of the magnetic field limits the rise of current to a realistic value. The capacitance dumps all its energy back into the magnetic field and the whole process starts over again. The inverse of the product of magnetic storage capacity and dielectric storage capacity represents the frequency or pitch at which this energy interchange occurs. This pitch may or may not contain overtones depending on the extent of conductors bounding the energies.

18. CHARACTERISTIC IMPEDANCE AS REPRESENTATION OF PULSATION OF ENERGY FIELD

The ratio of magnetic storage ability to that of the dielectric is called the characteristic impedance. This gives the ratio of maximum voltage to maximum current in the oscillitory structure. However, as the magnetic energy storage is outward and the dielectric storage is inward the total or double energy field pulsates in shape or size. The axis of this pulsation of force is the impedance of the system displaying oscillations and pulsation occurs at the frequency of oscillation.

19. ENERGY INTO MATTER

As the voltage or impedance is increased the emphasis is on the inward flux. If the impedance is high and rate of change is fast enough (perfect overtone series), it would seem possible the compression of the energy would transform it into matter and the reconversion of this matter into energy may or may not synchronize with the cycle of oscillation. This is what may be considered supercapacitance, that is, stable longterm conversion into matter.

20. <u>MISCONCEPTIONS OF PRESENT THEORY OF CAPACITANCE</u>

The misconception that capacitance is the result of accumulating electrons has seriously distorted our view of dielectric phenomena. Also the theory of the velocity of light as a limit of energy flow, while adequate for magnetic force and material velocity, limits our ability to visualize or understand certain possibilities in electric phenomena. The true workings of free space capacitance can be best illustrated by the following example. It has been previously stated that dielectric lines of force must terminate on conductors. No line of force can end in space. If we take any conductor and remove it to the most remote portion of the universe, no lines of force can extend from this electrode to other conductors. It can have no free space capacity, regardless of the size of the electrode, therefore it can store no energy. This indicates that the free space capacitance of an object is the sum mutual capacity of it to all the conducting objects of the universe.

21. FREE SPACE INDUCTANCE IS INFINITE

Steinmetiz in his book on the general or unified behavior of electricity "The Theory and Calculation of Transient Electric Phenomena and Oscillation," points out that the inductance of any unit length of an isolated filimentary conductor must be infinite. Because no image currents exist to contain the magnetic field it can grow to infinite size. This large quantity of energy cannot be quickly retrieved due to the finite velocity of propagation of the magnetic field. This gives a non reactive or energy component to the inductance which is called electromagnetic radiation.

22. WORK OF TESLA, STEINMETZ AND FARADAY

In the aforementioned books of Steinmetz he develops some rather unique equations for capacity. Tesla devoted an enormous portion of his efforts to dielectric phenomena and made numerous remarkable discoveries in this area. Much of this work is yet to be fully uncovered. It is my contention that the phenomena of dielectricity is wide open for profound discovery. It is ironic that we have abandoned the lines of force concept associated with a phenomena measured in the units called farads after Farady, whose insight into forces and fields has led to the possibility of visualization of the electrical phenomena.

23. QUESTION AS TO THE VELOCITY OF DIELECTRIC FLUX

It has been stated that all magnetic lines of force must be closed upon themselves, and that all dielectric lines of force must terminate upon a conducting surface. It can be infered from these two basic laws that no line of force can terminate in free space. This creates an interesting question as to the state of dielectric flux lines before the field has had time to propagate to the neutral conductor. During this time it would seem that the lines of force, not having reached the distant neutral conductor would end in space at their advancing wave front. It could be concluded that either the lines of force propagate instantly or always exist and are modified by the electric force, or voltage. It is possible that additional or conjugate space exists within the same boundaries as ordinary space. The properties of lines of force within this conjugate space may not obey the laws of normally conceived space.

IMPORTANT REFERENCE MATERIAL

1. "Electricity and Matter," J. J. Thompson New York, 1906, Scribner's Sons, and 1904, Yale University

2. "Elementary Lectures on Electric Discharges, Waves, and Impulses and other Transients." C. P. Steinmetz, second edition, 1914, McGraw-Hill

3. "Theory and Calculation of Transient Electric Phenomena and Oscillations," C. P.Steinmetz, third edition, 1920, McGraw-Hill. Section III Transients in Space, Chapter VIII, Velocity of Propagation of Electric Field.

TABLE I.

Magnetic Field.	Dielectric Field.
Magnetic flux: $\Phi = Li\,10^8$ lines of magnetic force.	Dielectric flux: $\Psi = Ce$ lines of dielectric force, or coulombs.
Inductance voltage: $e' = n\frac{d\Phi}{dt}10^{-8} = L\frac{di}{dt}$ volts.	Capacity current: $i' = \frac{d\psi}{dt} = C\frac{de}{dt}$ amperes.
Magnetic energy: $w = \frac{Li^2}{2}$ joules.	Dielectric energy: $w = \frac{Ce^2}{2}$ joules.
Magnetomotive force: $F = ni$ ampere turns.	Electromotive force: e = volts.
Magnetizing force: $f = \frac{F}{l}$ ampere turns per cm.	Electrifying force or voltage gradient: $G = \frac{e}{l}$ volts per cm.
Magnetic-field intensity: $\mathcal{H} = 4\pi f\,10^{-1}$ lines of magnetic force per cm^2.	Dielectric-field intensity: $K = \frac{G}{4\pi v^2}10^9$ lines of dielectric force per cm^2, or coulombs per cm^2.
Magnetic density: $\mathcal{B} = \mu\mathcal{H}$ lines of magnetic force per cm^2.	Dielectric density: $D = \kappa K$ lines of dielectric force per cm^2, or coulombs per cm^2.
Permeability: μ	Permittivity or specific capacity: κ
Magnetic flux: $\Phi = A\mathcal{B}$ lines of magnetic force.	Dielectric flux: $\Psi = AD$ lines of dielectric force, or coulombs.

$v = 3 \times 10^{10}$ = velocity of light.

TABLE II.

Magnetic Circuit.	Dielectric Circuit.	Electric Circuit.
Magnetic flux (magnetic current): Φ = lines of magnetic force.	Dielectric flux (dielectric current): Ψ = lines of dielectric force.	Electric current: i = electric current.
Magnetomotive force: $F = ni$ ampere turns.	Electromotive force: e = volts.	Voltage: e = volts.
Permeance: $M = \frac{\Phi}{.4\pi F}$. Inductance: $L = \frac{n^2\Phi}{F}10^{-8} = \frac{n\Phi}{i}10^{-8}$ henry.	Permittance or capacity: $C = \frac{\Psi}{e}$ farads.	Conductance: $g = \frac{i}{e}$ mhos.
Reluctance: $R = \frac{F}{\Phi}$.	(Elastance): $\frac{1}{C} = \frac{e}{\Psi}$.	Resistance: $r = \frac{e}{i}$ ohms.
Magnetic energy: $w = \frac{Li^2}{2} = \frac{F\Phi}{2}10^{-8}$ joules.	Dielectric energy: $w = \frac{Ce^2}{2} = \frac{e\Psi}{2}$ joules.	Electric power: $p = ri^2 = ge^2 = ei$ watts.
Magnetic density: $\mathcal{B} = \frac{\Phi}{A} = \mu\mathcal{H}$ lines per cm².	Dielectric density: $D = \frac{\Psi}{A} = \kappa K$ lines per cm².	Electric-current density: $I = \frac{i}{A} = \gamma G$ amperes per cm².
Magnetizing force: $f = \frac{F}{l}$ ampere turns per cm.	Dielectric gradient: $G = \frac{e}{l}$ volts per cm.	Electric gradient: $G = \frac{e}{l}$ volts per cm.
Magnetic-field intensity: $\mathcal{H} = .4\pi f$.	Dielectric-field intensity: $K = \frac{G}{4\pi v^2}10^9$.	
Permeability: $\mu = \frac{\mathcal{B}}{\mathcal{H}}$.	Permittivity or specific capacity: $\kappa = \frac{D}{K}$.	Conductivity: $\gamma = \frac{I}{G}$ mho-cm.
Reluctivity: $\rho = \frac{f}{\mathcal{B}}$.	(Elastivity ?): $\frac{1}{\kappa} = \frac{K}{D}$.	Resistivity: $\rho = \frac{1}{\gamma} = \frac{G}{I}$ ohm-cm.
Specific magnetic energy: $w_0 = \frac{.4\pi\mu f^2}{2} = \frac{f\mathcal{B}}{2}10^{-8} = \frac{\mathcal{H}\mathcal{B}}{8\pi}10^{-7}$ joules per cm³.	Specific dielectric energy: $w_0 = \frac{\kappa G^2}{4\pi v^2}10^9 = \frac{GD}{2}10^9 = 2\pi v^2 KD$ joules per cm³.	Specific power: $p_0 = \rho I^2 = G^2 = GI$ watts per cm³.

APPENDIX I

Table of Units, Symbols, and Dimensions

	Quantity	Symbol	mks Unit Rationalized	Defining Equation	Dimensional Formula Exponents of L	M	T	Q	cgs emu	No. of emu / No. of mks	cgs esu	No. of esu / No. of mks	No. of esu / No. of emu
1	Length	L	m		1	0	0	0	cm	10^2	cm	10^2	1
2	Area	A	m^2	$A = L^2$	2	0	0	0	cm^2	10^4	cm^2	10^4	1
3	Volume	v	m^3	$v = L^3$	3	0	0	0	cm^3	10^6	cm^3	10^6	1
4	Mass	M, m	kilogram		0	1	0	0	gram	10^3	gram	10^3	1
5	Time	T, t	second		0	0	1	0	second	1	second	1	1
6	Velocity	v	m/sec	$v = L/T$	1	0	−1	0	cm/sec	10^2	cm/sec	10^2	1
7	Acceleration	a	m/sec^2	$a = L/T^2$	1	0	−2	0	cm/sec^2	10^2	cm/sec^2	10^2	1
8	Force	F	newton	$F = Ma$	1	1	−2	0	dyne	10^5	dyne	10^5	1
9	Energy	W	joule	$W = FL$	2	1	−2	0	erg	10^7	erg	10^7	1
10	Power	P	watt	$P = W/T$	2	1	−3	0	erg/sec	10^7	erg/sec	10^7	1
11	Charge	Q, q	coulomb	$F = Q^2/(4\pi\epsilon_0 L^2)$	0	0	0	1	abcoulomb	10^{-1}	statcoulomb	$10c$	$100c$
12	Dielectric constant of free space	ϵ_0	farad/m	$\epsilon_0 = 1/(\mu_0 c^2)$	−3	−1	2	2			1	$4\pi c^2/10^7$	
13	Dielectric constant	ϵ	farad/m		−3	−1	2	2					
14	relative	ϵ_r	numeric	$\epsilon_r = \epsilon/\epsilon_0$	0	0	0	0				1	
	Charge density												
15	volume	ρ	coulomb/m^3	$\rho = Q/v$	−3	0	0	1	abcoulomb/cm^3	10^{-7}	statcoulomb/cm^3	$c/10^5$	$100c$
16	surface	ρ_s	coulomb/m^2	$\rho_s = Q/A$	−2	0	0	1	abcoulomb/cm^2	10^{-5}	statcoulomb/cm^2	$c/10^3$	$100c$
17	line	ρ_l	coulomb/m	$\rho_l = Q/L$	−1	0	0	1	abcoulomb/cm	10^{-3}	statcoulomb/cm	$c/10$	$100c$
18	Electric intensity	E	volt/m	$E = F/Q = -V/L$	1	1	−2	−1	abvolt/cm	10^6	statvolt/cm	$10^6/c$	$1/(100c)$
19	Electric flux density	D	coulomb/m^2	$D = \epsilon E = \psi/A$	−2	0	0	1		$4\pi/10^5$		$4\pi c/10^3$	$100c$
20	Electric flux	ψ	coulomb	$\psi = DA$	0	0	0	1		$4\pi/10$		$4\pi 10c$	$100c$
21	Electric potential	V	volt	$V = -EL$	2	1	−2	−1	abvolt	10^8	statvolt	$10^8/c$	$1/(100c)$
22	EMF	V_g	volt	$V_g = -d\phi/dt$	2	1	−2	−1	abvolt	10^8	statvolt	$10^8/c$	$1/(100c)$
23	Capacitance	C	farad	$C = Q/V$	−2	−1	2	2	abfarad	10^{-9}	statfarad	$c^2/10^5$	$(100c)^2$
24	Current	I, i	ampere	$I = Q/T$	0	0	−1	1	abampere	10^{-1}	statampere	$10c$	$100c$
25	Current density	J	ampere/m^2	$J = I/A$	−2	0	−1	1	abampere/cm^2	10^{-5}	statampere/cm^2	$c/10^3$	$100c$
26	Resistance	R	ohm	$R = V/I$	2	1	−1	−2	abohm	10^9	statohm	$10^5/c^2$	$1/(100c)^2$
27	Resistivity	ρ	ohm-m	$\rho = RA/L$	3	1	−1	−2	abohm-cm	10^{11}	statohm-cm	$10^7/c^2$	$1/(100c)^2$
28	Conductance	G	mho	$G = 1/R$	−2	−1	1	2	abmho	10^{-9}	statmho	$c^2/10^5$	$(100c)^2$
29	Conductivity	σ	mho/m	$\sigma = 1/\rho = J/E$	−3	−1	1	2	abmho/cm	10^{-11}	statmho/cm	$c^2/10^7$	$(100c)^2$
30	Electric polarization	P	coulomb/m^2	$P = D - \epsilon_0 E = \rho L$	−2	0	0	1	abcoulomb/cm^2	10^{-5}	statcoulomb/cm^2	$c/10^3$	$100c$
31	Electric susceptibility	χ_e	farad/m	$\chi_e = P/E = \epsilon_0(\epsilon_r - 1)$	−3	−1	2	2			1	$4\pi c^2/10^7$	
32	Electric dipole moment	m_e	coulomb-m	$m_e = QL$	1	0	0	1			statcoulomb-cm	10^3c	
33	Electric energy density	ω_e	joule/m^3	$\omega_e = DE/2$	−1	1	−2	0	erg/cm^3	1	erg/cm^3	10	1

Table of Units, Symbols, and Dimensions

	Quantity	Symbol	mks Unit Rationalized	Defining Equation	Dimensional Formula Exponents of L	M	T	Q	cgs emu	No. of emu / No. of mks	cgs esu	No. of esu / No. of mks	No. of esu / No. of emu
34	Permeability of free space	μ_0	henry/m	$\mu_0 = 4\pi/10^7$	1	1	0	−2		$10^7/4\pi$			
35	Permeability	μ	henry/m	$\mu = B/H$	1	1	0	−2					
36	relative	μ_r	numeric	$\mu_r = \mu/\mu_0$	0	0	0	0		1			
37	Magnetic pole	p	weber	$p = A(B - B_0)$	2	1	−1	−1	pole = maxwell/4π	$10^8/4\pi$			
38	Magnetic moment	m	weber-m	$m = pL$	3	1	−1	−1	pole-cm	$10^{10}/4\pi$			
39	Magnetic intensity	H	ampere/m or newton/weber	$H = U/L$ or F/p	−1	0	−1	1	oersted or gilbert/cm	$4\pi/10^3$			
40	Magnetic flux density	B	weber/m²	$B = \mu H = \phi/A$	0	1	−1	−1	gauss or maxwell/cm²	10^4			
41	Magnetic flux	ϕ	weber	$\phi = BA = V_eT$	2	1	−1	−1	maxwell	10^8			
42	Magnetic potential	U	ampere	$U = \mathfrak{F} = HL$	0	0	−1	1	gilbert	$4\pi/10$			
43	MMF	$\mathfrak{F}$	ampere	$\mathfrak{F} = I$	0	0	−1	1	gilbert	$4\pi/10$			
44	Intensity of magnetization	M	weber/m²	$M = B - B_0 = m/L^3$	0	1	−1	−1	pole/cm² or gauss/4π	$10^4/4\pi$			
	Inductance												
45	self	L	henry	$L = \phi/I$	2	1	0	−2	abhenry	10^9		$10^9/c^2$	$1/(100c)^2$
46	mutual	M	henry	$M = \phi/I = W/I^2$	2	1	0	−2	abhenry	10^9		$10^9/c^2$	$1/(100c)^2$
47	Reluctance	$\mathfrak{R}$	ampere/weber	$\mathfrak{R} = \mathfrak{F}/\phi$	−2	−1	0	2					
48	Reluctivity	ν	meter/henry	$\nu = 1/\mu$	−1	−1	0	2					
49	Permeance	$\mathcal{P}$	weber/amp	$\mathcal{P} = 1/\mathfrak{R}$	2	1	0	−2					
50	Permittivity	μ	henry/meter	$\mu = 1/\nu$	1	1	0	−2					
51	EMF	V_e	volt	$V_e = -d\phi/dt$	2	1	−2	−1	abvolt	10^8	statvolt	$10^8/c$	$1/(100c)$
52	Poynting's vector	$\mathcal{P}$	watts/m²	$\mathcal{P} = EH$	0	1	−3	0	abwatt/cm²	10^3	statwatt/cm²	10^3	1
53	Magnetic energy density	w_m	joule/m³	$w_m = HB/2$	−1	1	−2	0	erg/cm³	10	erg/cm³	10	1
54	Magnetic susceptibility	χ_m	henry/m	$\chi_m = M/H = \mu_0(\mu_r - 1)$	1	1	0	−2	henry/m	$10^7/4\pi$			

$\mu_0 = 4\pi/10^7$ henrys/meter. For $c = 2.998 \times 10^8$ meters/sec, $\epsilon_0 = 1/\mu_0c^2 = 10^7/(4\pi c^2) = 8.854 \times 10^{-12}$ farad/meter
For $c \cong 3 \times 10^8$ meters/sec, $\epsilon_0 \cong 1/(36\pi 10^9)$ farad/meter
$c^2 = 8.988 \times 10^{16} \cong 9 \times 10^{16}$