GULABCHAND PRASAD AGARWAL COLLEGE, SADMA

NILAMBER PITAMBER UNIVERSITY
MEDININAGAR (PALAMU)

A PROJECT ON

ELECROMAGNETIC FIELD AND ITS EFFECTS

SUBMITTED BY :

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I wish to express my deep sense of gratitude to my guide prof. Rani Srivastava . Under Graduate department of Physics for the valuable and inspiring guidance throughout the course of project .

I am grateful to the chairman and members of a project evaluation committee for providing the opportunity to present the project on this topic .

CERTIFICATE

This is to certify that Vicky KOMAR PAdel of B.Sc physics UG Department of Physics NPU Medininagar has completed his project work successfully and satisfactory on the topic .

" Electromagnetic field and it's effects "

During the period of 28 Jan 2022 to 5 Feb 2022 under my guidance .

Wish him success in all their future endeavours .

Prof.Rani Srivastava

CONTENTS :

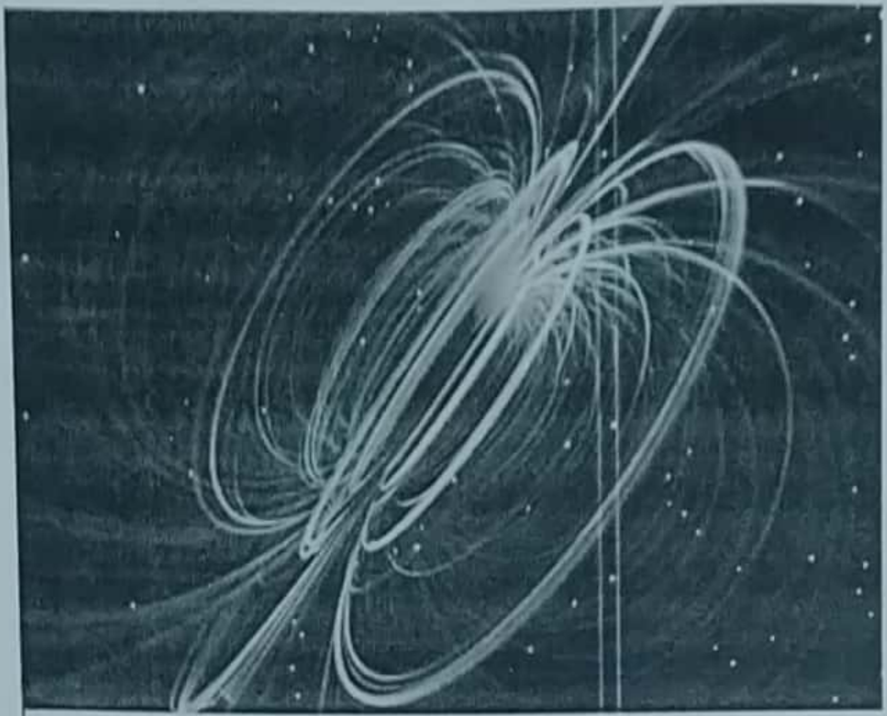
INTRUDUCTION

Electromagnetic field

*An **electromagnetic field** (also **EM field** or **EMF**) is a classical (i.e. non-quantum) field produced by accelerating electric charges.[1] It is the field described by classical electrodynamics and is the classical counterpart to the quantized electromagnetic field tensor in quantum electrodynamics. The electromagnetic field propagates at the speed of light (in fact, this field can be identified as light) and interacts with charges and currents. Its quantum counterpart is one of the four fundamental forces of nature (the others are gravitation, weak interaction and strong interaction.)*

The field can be viewed as the combination of an electric field and a magnetic field. The electric field is produced by stationary charges, and the magnetic field by moving charges (currents); these two are often described as the sources of the field. The way in which charges and currents interact with the electromagnetic field is described by Maxwell's equations and the Lorentz force law. The force created by the electric field is much stronger than the force created by the magnetic field.

From a classical perspective in the history of electromagnetism, the electromagnetic field can be regarded as a smooth, continuous field, propagated in a wavelike manner. By contrast, from the perspective of quantum field theory, this field is seen as quantized; meaning that the free quantum field (i.e. non-interacting field) can be expressed as the Fourier sum of creation and annihilation operators in energy-momentum space while the effects of the interacting quantum field may be analyzed in perturbation theory via the S-matrix with the aid of a whole host of mathematical technologies such as the Dyson series, Wick's theorem, correlation functions, time-evolution operators, Feynman diagrams etc. Note that the quantized field is still spatially continuous; its energy states however are discrete (the field's energy states must not be confused with its energy values, which are continuous; the quantum field's creation operators create multiple discrete states of energy called photons.)



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STRUCTURE

The electromagnetic field may be viewed in two distinct ways: a continuous structure or a discrete structure.

Continuous structure

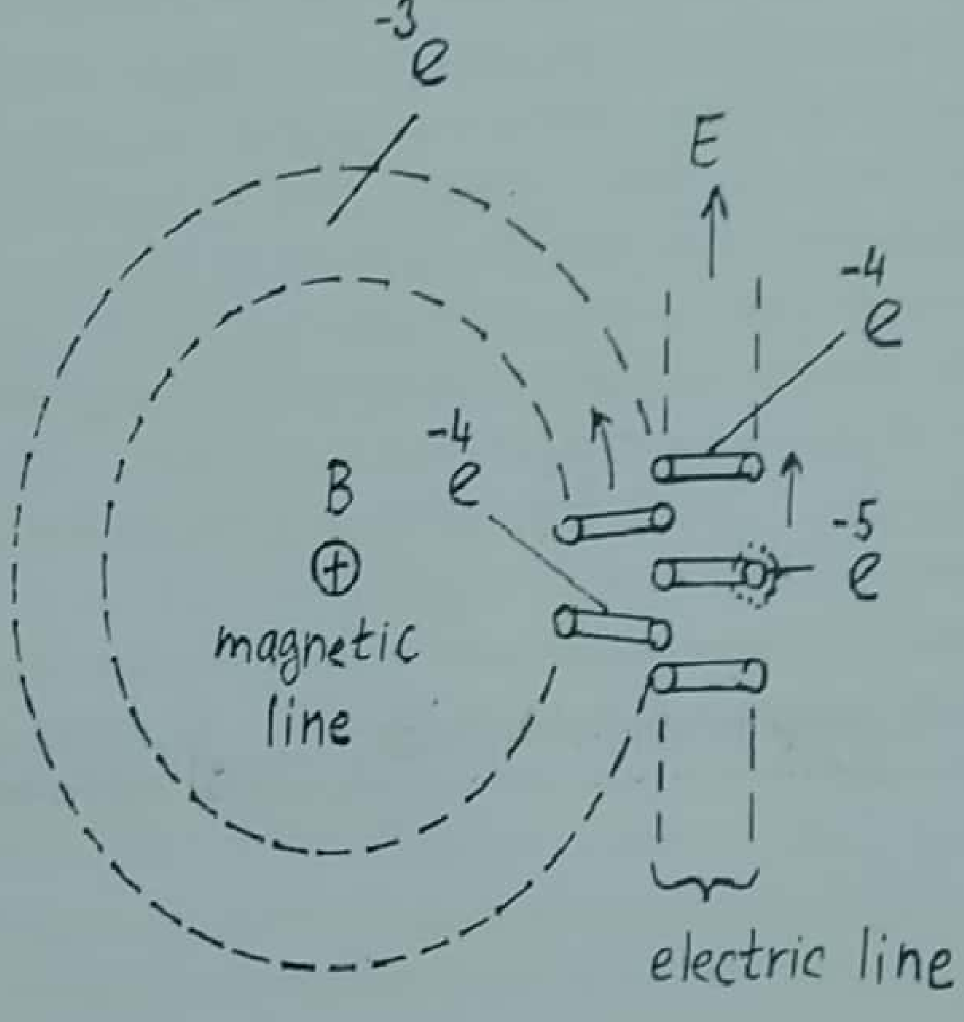
Classically, electric and magnetic fields are thought of as being produced by smooth motions of charged objects. For example, oscillating charges produce variations in electric and magnetic fields that may be viewed in a 'smooth', continuous, wavelike fashion. In this case, energy is viewed as being transferred continuously through the electromagnetic field between any two locations. For instance, the metal atoms in a radio transmitter appear to transfer energy continuously. This view is useful to a certain extent (radiation of low frequency), however, problems are found at high frequencies (see ultraviolet catastrophe).

Discrete structure

The electromagnetic field may be thought of in a more 'coarse' way. Experiments reveal that in some circumstances electromagnetic energy transfer is better described as being carried in the form of packets called quanta with a *fixed frequency. Planck's relation links the photon energy E of a photon to its frequency f through the equation:*

where h is Planck's constant, and f is the frequency of the photon. Although modern quantum optics tells us that there also is a semi-classical explanation of the photoelectric effect—the emission of electrons from metallic surfaces subjected to electromagnetic radiation—the photon was historically (although not strictly necessarily) used to explain certain observations. It is found that increasing the intensity of the incident radiation (so long as one remains in the linear regime) increases only the number of electrons ejected, and has almost no effect on the energy distribution of their ejection. Only the frequency of the radiation is relevant to the energy of the ejected electrons.

This quantum picture of the electromagnetic field (which treats it as analogous to harmonic oscillators) has proven very successful, giving rise to quantum electrodynamics, a quantum field theory describing the interaction of electromagnetic radiation with charged matter. It also gives rise to quantum optics, which is different from quantum electrodynamics in that *the matter itself is modelled using quantum mechanics rather than quantum field theory.*



DYNAMICS

In the past, electrically charged objects were thought to produce two different, unrelated types of field associated with their charge property. An electric field is produced when the charge is stationary with respect to an observer measuring the properties of the charge, and a magnetic field as well as an electric field is produced when the charge moves, creating an electric current with respect to this observer. Over time, it was realized that the electric and magnetic fields are better thought of as two parts of a greater whole—the electromagnetic field. Until 1820, when the Danish physicist H. C. Ørsted showed the effect of electric current on a compass needle, electricity and magnetism had been viewed as unrelated phenomena. In 1831, Michael Faraday made the seminal observation that time-varying magnetic fields could induce electric currents and then, in 1864, James Clerk Maxwell published his famous paper "A Dynamical Theory of the Electromagnetic Field".

Once this electromagnetic field has been produced from a given charge distribution, other charged or magnetised objects in this field may experience a force. If these other charges and currents are comparable in size to the sources producing the above electromagnetic field, then a new net electromagnetic field will be produced. Thus, the electromagnetic field may be viewed as a dynamic entity that causes other charges and currents to move, and which is also affected by them. These interactions are described by Maxwell's equations and the Lorentz force law. This discussion ignores the radiation reaction force.

Feedback loop

The behavior of the electromagnetic field can be divided into four different parts of a loop:

- the electric and magnetic fields are generated by moving electric charges,

the electric and magnetic fields interact with each other,

the electric and magnetic fields produce forces on *electric charges.*

the electric charges move in space.

A common misunderstanding is that (a) the quanta of the fields act in the same manner as (b) the charged particles, such as electrons, that generate the fields. In our everyday world, electrons travel slowly through conductors with a drift velocity of a fraction of a centimeter per second and through a vacuum tube at speeds of around 1 thousand km/s, but fields propagate at the speed of light, approximately 300 thousand kilometers (or 186 thousand miles) a second. The speed ratio between charged particles in a conductor and field quanta is on the order of one to a million. Maxwell's equations relate (a) the presence and movement of charged particles with (b) the generation of fields. Those fields can then affect the force on, and can then move other slowly moving charged particles. Charged particles can move at relativistic speeds nearing field propagation speeds, but, as Albert Einstein showed this requires enormous field energies, which are not present in our everyday experiences with electricity, magnetism, matter, and time and space.

The feedback loop can be summarized in a list, including phenomena belonging to each part of the loop:

- charged particles generate electric and magnetic fields
- the fields interact with each other
  - changing electric field acts like a current, generating 'vortex' of magnetic field
  - Faraday induction: changing magnetic field induces (negative) vortex of electric field
  - Lenz's law: negative feedback loop between electric and magnetic fields

fields act upon particles Lorentz force: force due to electromagnetic field

- electric force: same direction as electric field
- magnetic force: perpendicular both to magnetic field and to velocity of charge
- charged particles move
  - current is movement of particles
- charged particles generate more electric and magnetic fields; cycle repeat

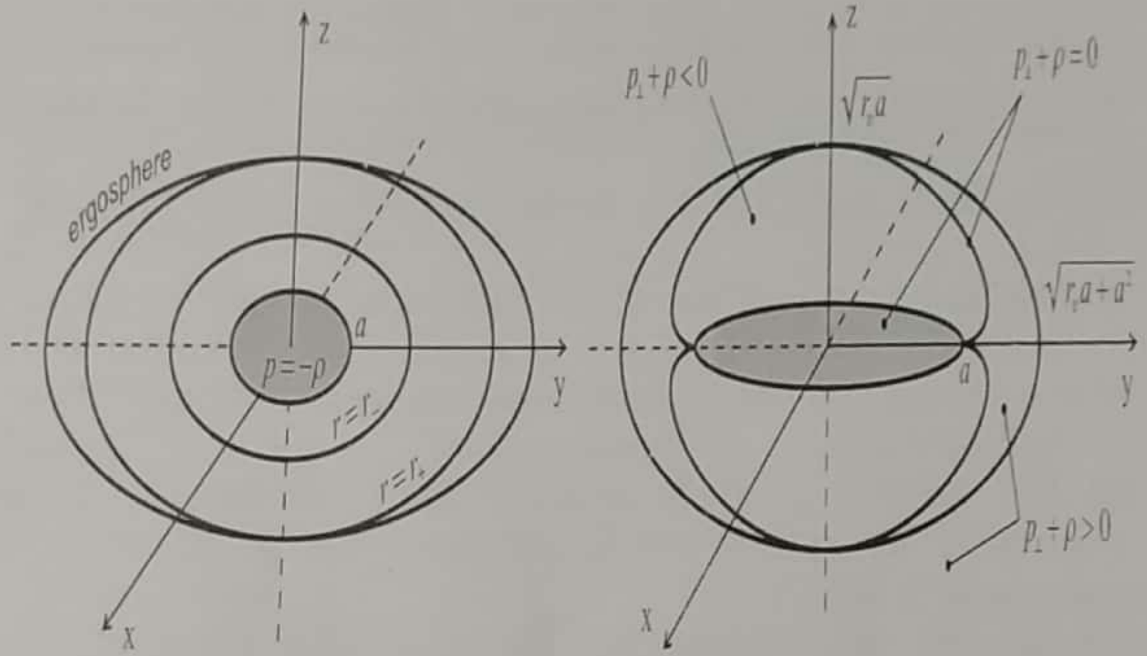


Image of dynamics of EME (electromagnetic fields)

MATHEMATICAL DESCRIPTION

There are different mathematical ways of representing the electromagnetic field. The first one views the electric and magnetic fields as three-dimensional vector fields. These vector fields each have a value defined at every point of space and time and are thus often regarded as functions of the space and time coordinates. As such, they are often written as $\mathbf{E}(x, y, z, t)$ *(electric field) and* $\mathbf{B}(x, y, z, t)$ *(magnetic field).*

*If only the electric field (**E**) is non-zero, and is constant in time, the field is said to be an electrostatic field. Similarly, if only the magnetic field (**B**) is non-zero and is constant in time, the field is said to be a magnetostatic field. However, if either the electric or magnetic field has a time-*

dependence, then both fields must be considered together as a coupled electromagnetic field using Maxwell's equations. With the advent of special relativity, physical laws became susceptible to the formalism of tensors. Maxwell's equations can be written in tensor form, generally viewed by physicists as a more elegant means of expressing physical laws.

The behavior of electric and magnetic fields, whether in cases of electrostatics, magnetostatics, or electrodynamics (electromagnetic fields), is governed by Maxwell's equations. In the vector field formalism, these are:

(Gauss's law)

(Gauss's law for magnetism)

(Faraday's law)

(Maxwell–Ampère law)

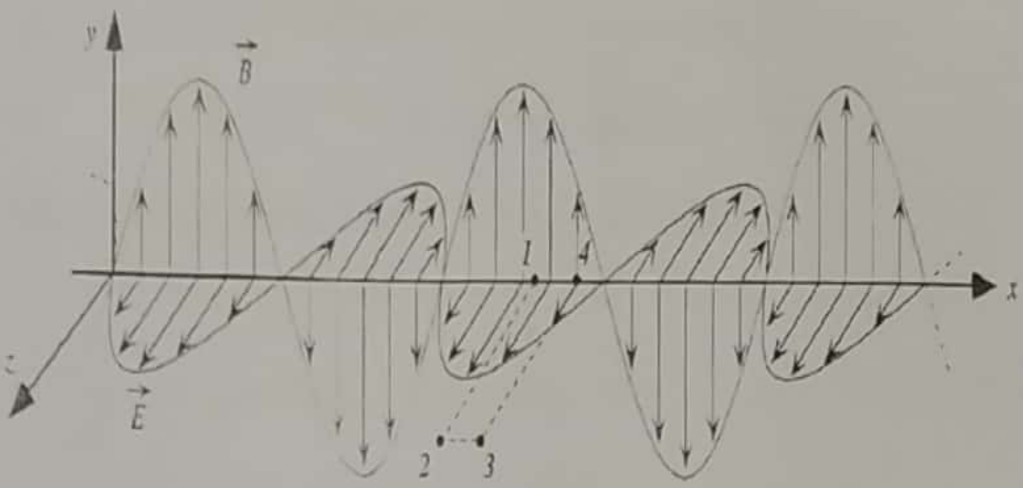
where is the charge density, which can (and often does) depend on time and position, is the permittivity of free space, is the permeability of free space, and ***J*** *is the current density vector, also a function of time and position. The units used above are the standard SI units. Inside a linear material, Maxwell's equations change by switching the permeability and permittivity of free space with the permeability and permittivity of the linear material in question. Inside other materials which possess more complex responses to electromagnetic fields, these terms are often represented by complex numbers, or tensors.*

The Lorentz force law governs the interaction of the electromagnetic field with charged matter.

When a field travels across to different media, the properties of the field change according to the various boundary conditions. These equations are derived from Maxwell's equations .

wave propagating through empty space. The electric field is parallel to the *z*-axis; the magnetic field is parallel to the *y*-axis.

Str. y. i, iJ = f,sinfb+ nrJ i   Btz, y, ‹, i) = *B*,sin(h + miJ ›



PROPERTIES OF THE FIELD

Reciprocal behavior of electric and magnetic fields

The two Maxwell equations, Faraday's Law and the Ampere-Maxwell Law, illustrate a very practical feature of the electromagnetic field. Faraday's Law may be stated roughly as 'a changing magnetic field creates an electric field'. This is the principle behind the electric generator.

Ampere's Law roughly states that 'a changing electric field creates a magnetic field'. Thus, this law can be applied to generate a magnetic field and run an electric motor.

Behavior of the fields in the absence of charges or currents

Maxwell's equations take the form of an electromagnetic wave in a volume of space not containing charges or currents (free space)

– that is, where and J are zero. Under these conditions, the electric and magnetic fields satisfy the electromagnetic wave equation:

$$\Delta U = -\int_A^B qE.dr$$

$$\text{or} \quad \Delta U/q = -\int_A^B E.dr$$

$$\text{or} \qquad \Delta V = -\int_A^B E.dr$$

which proves equation 1.

Since ΔV represents a finite change in V therefore an infinitesimally small change in V i.e dV should be written without the integral

$$dV = -E.dr \qquad 4)$$

James Clerk Maxwell was the first to obtain this relationship by his completion of Maxwell's equations with the addition of a displacement current term to Ampere's circuital law.

RELATION AND COMPARISON

Being one of the four fundamental forces of nature, it is useful to compare the electromagnetic field with the gravitational, strong and weak fields. The word 'force' is sometimes *replaced* by 'interaction' because *modern particle physics models electromagnetism as an exchange of particles known as gauge bosons.*

Electromagnetic and gravitational fields

Sources of electromagnetic fields consist of two types of charge – positive and negative. This contrasts with the sources of the gravitational field, which are masses. Masses are sometimes described as gravitational charges, the important feature of them being that there are only positive masses and no negative masses. Further, gravity differs from electromagnetism in that positive masses attract other positive masses whereas same charges in electromagnetism repel each other.

The relative strengths and ranges of the four interactions and other information are tabulated below:

Theory	**Interaction**	**mediator**	**Relative Magnitude**	**Behavior**	**Range**
Chromodynamics	*Strong interaction*	gluon	10^{38}	1	10^{-15} m
Electrodynamics	*Electromagnetic interaction*	photon	10^{36}	$1/r^2$	infinite
Flavordynamics	*Weak interaction*	*W and Z bosons*	10^{25}	$1/r^5$ to $1/r^7$	10^{-18} *m*
Geometrodynamics	*Gravitation*	*graviton (hypothesised)*	10^{0}	$1/r^2$	*infinite*

APPLICATIONS

Static E and M fields and static EM fields.

When an EM field (see electromagnetic tensor) is not varying in time, it may be seen as a purely electrical field or a purely magnetic field, or a mixture of both. However the general case of a static EM field with both electric and magnetic components present, is the case that appears to most observers. Observers who see only an electric or magnetic field component of a static EM field, have the other (electric or magnetic) component suppressed, due to the special case of the immobile state of the charges that produce the EM field in that case. In such cases the other component becomes manifest in other observer frames.

A consequence of this, is that any case that seems to consist of a "pure" static electric or magnetic field, can be converted to an EM field, with both E and M components present, by simply moving the observer into a frame of reference which is moving with regard to the frame in which only the "pure" electric or magnetic field appears. That is, a pure static electric field will show the familiar magnetic field associated with a current, in any frame of reference where the charge moves. Likewise, any new motion of a charge in a region that seemed previously to contain only a magnetic field, will show that the space now contains an electric field as well, which will be found to produces an additional Lorentz force upon the moving charge.

Thus, electrostatics,as well as magnetism and magnetostatics, are now seen as studies of the static EM field when a particular frame has been selected to suppress the other type of field, and since an EM field with both electric and magnetic will appear in any other frame, these "simpler" effects are merely the observer's. The "applications" of all such non-time varying (static) fields are discussed in the main articles linked in this section.

Time-varying EM fields in Maxwell's equations

Main articles: near and far field, near field optics, virtual particle, dielectric heating, and Electromagnetic induction

An EM field that varies in time has two "causes" in Maxwell's equations. One is charges and currents (so-called "sources"), and the other cause for an E or M field is a change in the other type of field (this last cause also appears in "free space" very far from currents and charges).

An electromagnetic field very far from currents and charges (sources) is called electromagnetic radiation (EMR) since it radiates from the charges and currents in the source, and has no "feedback" effect on them, and is also not affected directly by them in the present time (rather, it is indirectly produced by a sequences of changes in fields radiating out from them in the past). EMR consists of the radiations in the electromagnetic spectrum, including radio waves, microwave, infrared, visible light, ultraviolet light, X-rays, and gamma rays. The *many commercial applications of these radiations are discussed in the named and linked articles.*

A notable application of visible light is that this type of energy from the Sun powers all life on Earth that either makes or uses oxygen.

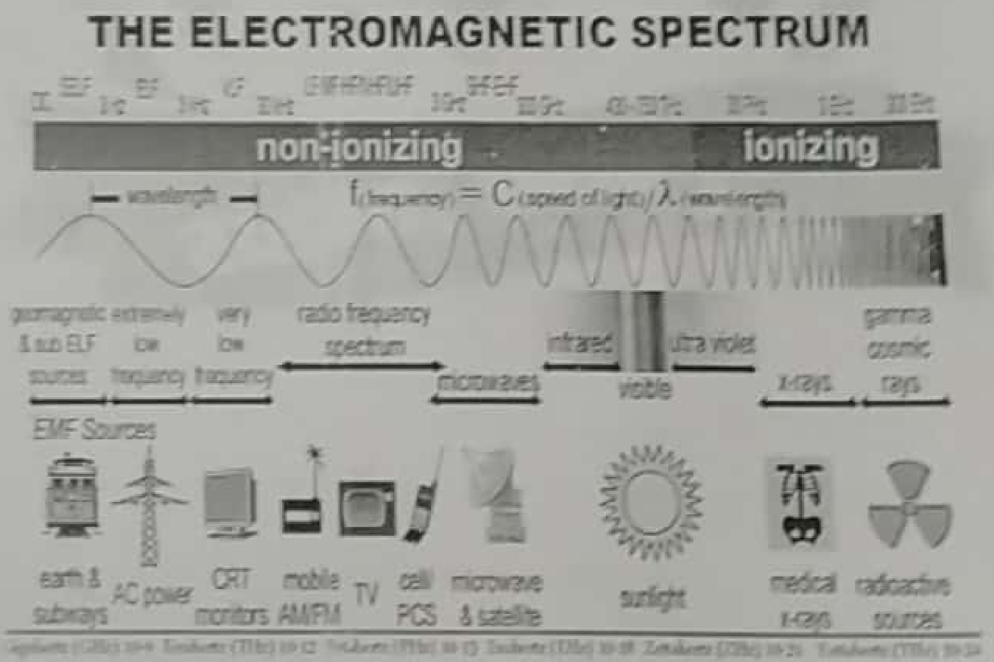
A changing electromagnetic field which is physically close to currents and charges (see near and far field for a definition of "close") will have a dipole characteristic that is dominated by either a changing electric dipole, or a changing magnetic dipole. This type of dipole field near sources is called an electromagnetic near-field.

Changing electric dipole fields, as such, are used commercially as near-fields mainly as a source of dielectric heating. Otherwise, they appear parasitically around conductors which absorb EMR, and around antennas which have the purpose of generating EMR at greater distances.

Changing magnetic dipole fields (i.e., magnetic near-fields) are used commercially for many types of magnetic induction devices. These include motors and electrical transformers at low frequencies, and devices such as metal detectors and MRI scanner coils at higher frequencies. Sometimes these high-frequency magnetic fields change at radio frequencies without being far-field waves and thus radio waves; see RFID tags. See also near-field communication. Further uses of near-field EM effects commercially may be found in the article on virtual photons, since at the quantum level, these fields are represented by these particles. Far-field effects (EMR) in the quantum picture of radiation are represented by ordinary photons.

Other

- *Electromagnetic field can be used to record data on static electricity.*
- *Old televisions can be traced with electromagnetic fields.*



HEALTH AND SAFETY

The potential effects of electromagnetic fields on human health vary widely depending on the frequency and intensity of the fields.

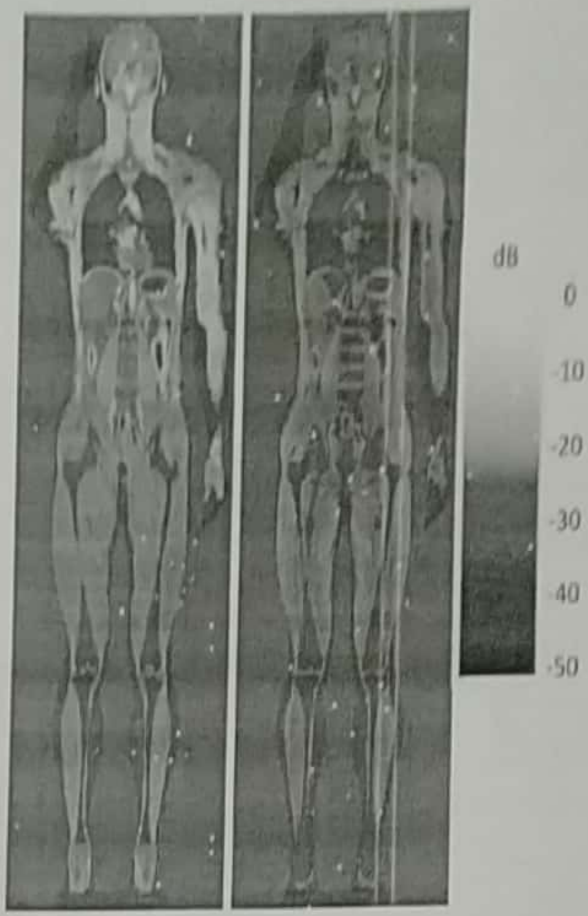
The potential health effects of the very low frequency EMFs surrounding power lines and electrical devices are the subject of on-going research and a significant amount of public debate. The US National Institute for Occupational Safety and Health (NIOSH) and other US government agencies do not consider EMFs a proven health hazard. NIOSH has issued some cautionary advisories but stresses that the data are currently too limited to draw good conclusions. In 2011, The WHO/International Agency for Research on Cancer

(IARC) classified radiofrequency electromagnetic fields as possibly carcinogenic to humans (Group 2B), based on an increased risk for glioma, a malignant type of brain cancer, associated with wireless phone use.[1]

Employees working at electrical equipment and installations can always be assumed to be exposed to electromagnetic fields. The exposure of office workers to fields generated by computers, monitors, etc. is negligible owing to the low field strengths. However, industrial installations for induction hardening and melting or on welding equipment may produce considerably higher field strengths and require further examination. If the exposure cannot be determined upon manufacturers' information, comparisons with similar systems or analytical calculations, measurements have to be accomplished. The results of the evaluation help to *assess possible hazards to the safety and health of workers and to define protective measures. Since electromagnetic fields may influence passive or active implants of workers, it is essential to consider the exposure at their workplaces separately in the risk assessment. On the other hand, radiation from other parts of the electromagnetic spectrum, such as ultraviolet light and gamma rays, are known to cause significant harm in some circumstances. For more information on the health effects due to specific electromagnetic phenomena and parts of the electromagnetic spectrum, see the following articles:*

- *Static electric fields: see Electric shock*
- *Static magnetic fields: see* MRI#Safety
- Extremely low frequency (ELF): see Power

- Radio frequency (RF): see Electromagnetic radiation and health
- Mobile telephony: see Mobile phone radiation and health
- Light: see Laser safety
- Ultraviolet (UV): see Sunburn, Photokeratitis
- Gamma rays: see Gamma ray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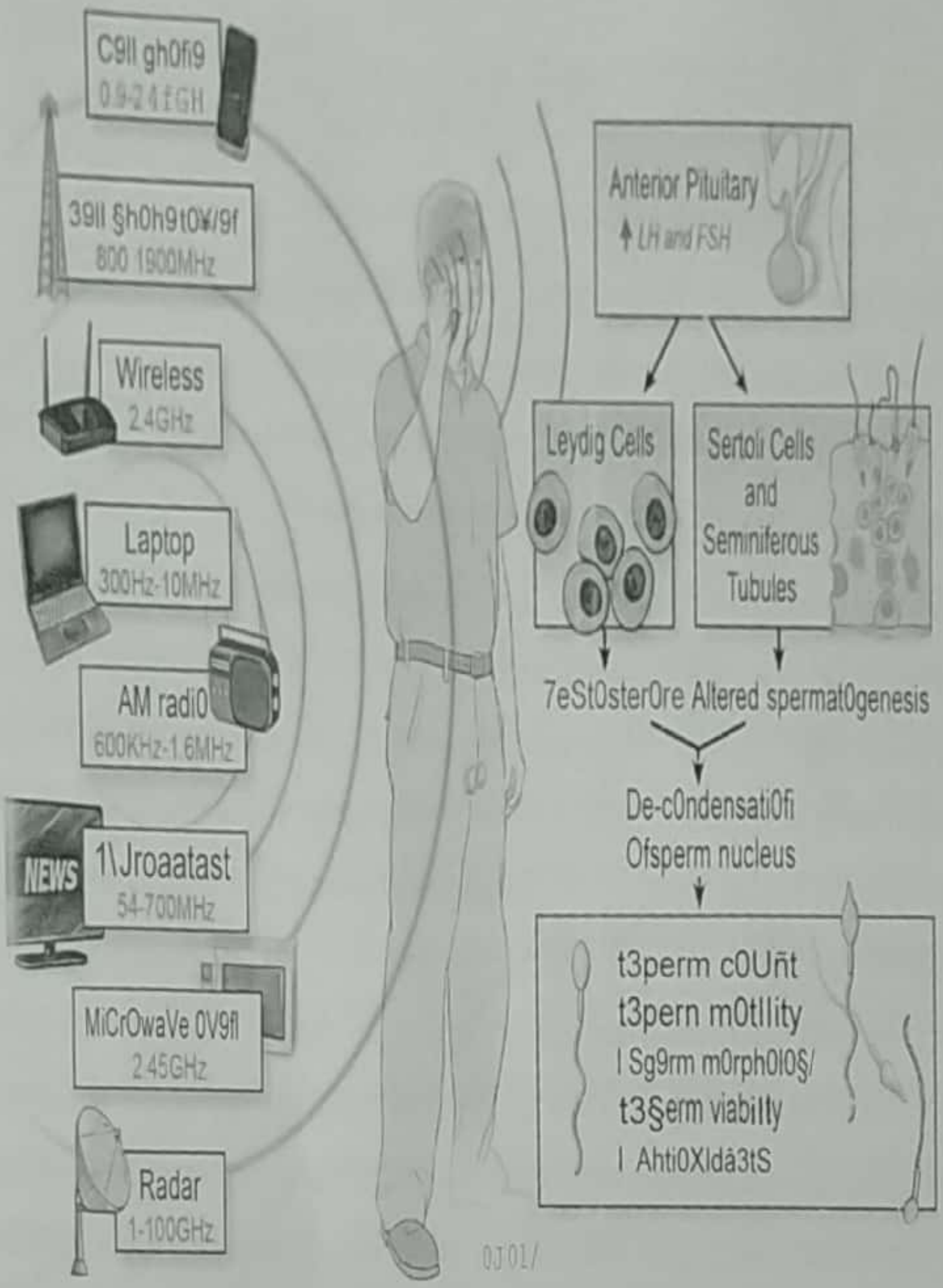
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ELECTROMAGNETISM

"Electromagnetic Force" redirects here. For a description of the force exerted on particles due to electromagnetic fields, see Lorentz force.

"Electromagnetic" redirects here. Electromagnetic may also refer to the use of an electromagnet.

Electromagnetism *is a branch of physics involving the study of the* **electromagnetic force**, *a type of physical interaction that occurs between electrically charged particles. The electromagnetic force is carried by electromagnetic fields composed of electric fields and magnetic fields, and it is responsible for electromagnetic radiation such as light. It is one of the four fundamental interactions (commonly called forces) in nature, together with the strong interaction, the weak interaction, and gravitation. At high energy, the weak force and electromagnetic force are unified as a single electroweak force.*

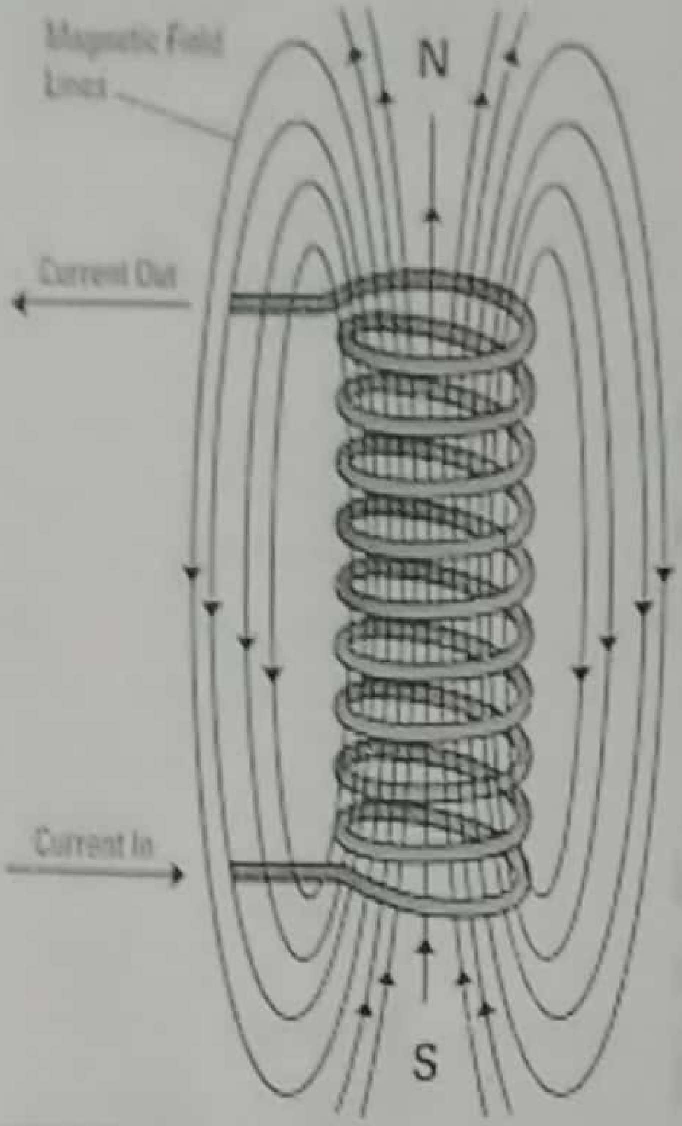
Lightning is an electrostatic discharge that travels between two charged regions.

Electromagnetic phenomena are defined in terms of the electromagnetic force, sometimes called the Lorentz force, which includes both electricity and magnetism as different manifestations of the same phenomenon. The electromagnetic force plays a major role in determining the internal properties of most objects encountered in daily life. The electromagnetic attraction between atomic nuclei and their orbital electrons holds atoms together. Electromagnetic forces are responsible for the chemical bonds between atoms which create molecules, and intermolecular forces. The electromagnetic force governs all chemical processes, which arise from interactions between the electrons of neighboring atoms. Electromagnetism is very widely used in modern.

technology, and electromagnetic theory is the basis of electric power engineering and electronics including digital technology.

There are numerous mathematical descriptions of the electromagnetic field. Most prominently, Maxwell's equations describe how electric and magnetic fields are generated and altered by each other and by charges and currents.

The theoretical implications of electromagnetism, particularly the establishment of the speed of light based on properties of the "medium" of propagation (permeability and permittivity), led to the development of special relativity by Albert Einstein in 1905.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CLASSIFICATION OF ELECTROMAGNETIC FIELDS

In differential geometry and theoretical physics, the **classification of electromagnetic fields** is a pointwise classification of bivectors at each point of a Lorentzian manifold. It is used in the study of solutions of Maxwell's equations and has applications in Einstein's theory of relativity.

The classification theorem

The electromagnetic field at a point *p* (i.e. an event) of a Lorentzian spacetime is represented by a real bivector $F = F^{ab}$ defined over the tangent space at *p*.

The tangent space at *p* is isometric as a real inner product space to $E^{1,3}$. That is, it has the same notion of vector magnitude and angle as Minkowski spacetime. To simplify the notation, we will assume the spacetime is Minkowski spacetime. This tends to blur the distinction between the tangent space at p and the underlying manifold; fortunately, nothing is lost by this specialization, for reasons we discuss as the end of the article.

The classification theorem for electromagnetic fields characterizes the bivector F in relation to the Lorentzian metric $\eta = \eta_{ab}$ by defining and examining the so-called "principal null directions". Let us explain this.

The bivector F^{ab} yields a skew-symmetric linear operator $F^a{}_b = F^{ac}\eta_{cb}$ defined by lowering one index with the metric. It acts on the tangent space at p by $r^a \to F^a{}_b r^b$. We will use the symbol F to denote either the bivector or the operator, according to context.

We mention a dichotomy drawn from exterior algebra. A bivector that can be written as $F = v \wedge w$, where v, w are linearly independent, is called simple. Any nonzero bivector over a 4-dimensional vector space either is simple, or can be written as $F = v \wedge w + x \wedge y$, where v, w, x, and y are linearly independent; the two *cases are mutually exclusive. Stated like this, the dichotomy makes no reference to the metric η, only to exterior algebra. But it is easily seen that the associated* skew-symmetric linear operator $F^a{}_b$ has rank 2 in the *former case and rank 4 in the latter case.*

To state the classification theorem, we consider the eigenvalue problem for F, that is, the problem of finding eigenvalues λ and eigenvectors r which satisfy the eigenvalue equation

The skew-symmetry of F implies that:

- either the eigenvector r is a null vector (i.e. $\eta(r,r) = 0$), or the eigenvalue λ is zero, or both.

A 1-dimensional subspace generated by a null eigenvector is called a principal null direction of the bivector.

The classification theorem characterizes the possible principal null directions of a bivector. It states that one of the following must hold for any nonzero bivector:

- *the bivector has one "repeated" principal null direction; in this case, the bivector itself is said to be null,*
- *the bivector has two distinct principal null directions; in this case, the bivector is called non-null.*

Furthermore, for any non-null bivector, the two eigenvalues associated with the two distinct principal null directions have the same magnitude but opposite sign, $\lambda = \pm v$*, so we have three subclasses of non-null bivectors:*

- *spacelike:* $v = 0$
- *timelike :* $v \neq 0$ and rank $F = 2$
- *non-simple:* $v \neq 0$ and rank $F = 4$,

where the rank refers to the rank of the linear operator F.

ELECTROMAGNETIC PROPAGATION

Radio propagation is the behavior of radio waves as they travel,or are propagated, from one point to another, or into various parts of the atmosphere. As a form of electromagnetic radiation,like light waves, radio waves are affected by the phenomena of reflection, refraction, diffraction, absorption, polarization,and scattering. Understanding the effects of varying conditions on radio propagation has many practical applications, from choosing frequencies for amateur radio communications, international shortwave broadcasters, to designing reliable mobile telephone systems, to radio navigation, to operation of radar systems.Several different types of propagation are used in practical radio transmission systems. Line-of-sight propagation means radio waves which travel in a straight line from the transmitting antenn *to the receiving antenna. Line of sight transmission is used for medium-distance radio transmission, such as cell*

phones, cordless phones, walkie-talkies, wireless networks, FM radio, television broadcasting, radar,and satellite

communication (such as satellite television). Line-of-sight transmission on the surface of the Earth is limited to the distance to the visual horizon, which depends on the height of transmitting and receiving antennas. It is the only propagation method possible at microwave frequencies and above.

At lower frequencies ithe MF, LF,and VLF bands, diffraction allows radio waves to bend over hills

and other obstacles, and travel beyond the horizon, following the contour of the Earth. These are called surface waves or ground wave propagation. AM broadcast and amateur radio stations use ground waves to cover their listening areas. As the frequency gets lower, the attenuation with distance decreases, so very low frequency (VLF) and extremely low frequency (ELF) ground *waves can be used to communicate worldwide. VLF and ELF waves can penetrate significant distances through water and earth, and these frequencies are used for mine communication and military communication with submerged submarines.*

At medium wave and shortwave frequencies (MF and HF bands) radio waves can refract from the ionosphere. This means that medium and short radio waves transmitted at an angle into the sky can be refracted back to Earth at great distances beyond the horizon – even transcontinental distances. This is called skywave propagation. It is used by amateur radio operators to communicate with operators in distant countries, and by shortwave broadcast stations to transmit internationally.

In addition, there are several less common radio propagation mechanisms,such as tropospheric scattering (troposcatter), tropospheric ducting (ducting) at VHF frequencies and near vertical incidence skywave (NVIS) which are used when HF communications are desired within a few hundred miles.

Frequency dependence

At different frequencies, radio waves travel through the atmosphere by different mechanisms or modes:

Radio frequencies and their primary mode of propagation

Band		**Frequency**	**Wavelength**	**Propagation via**
ELF	Extremely Low Frequency	3–30 Hz	100,000–10,000 km	Guided between the Earth and the D layer of the ionosphere.

SLF	Super Low Frequency	30–300 Hz	10,000 – 1,000 km	Guided between the Earth and the ionosphere.
ULF	Ultra Low Frequency	0.3–3 kHz (300–3,000 Hz)	1,000– 100 km	Guided between the Earth and the ionosphere.
VLF	Very Low Frequency	3–30 kHz (3,000– 30,000 Hz)	100– 10 km	Guided between the Earth and the ionosphere.
LF	Low Frequency	30–300 kHz (30,000– 300,000 Hz)	10– 1 km	Guided between the Earth and the

				ionosphere. Ground waves.
MF	Medium Frequency	300–3000 kHz (300,000–3,000,000 Hz)	1000–100 m	Ground waves E, F layer ionospheric refraction at night, when D layer absorption weakens.
HF	High Frequency (Short Wave)	3–30 MHz (3,000,000–30,000,000 Hz)	100–10 m	E layer ionospheric refraction. F1, F2 layer ionospheric refraction.
V	Very	30–300 MHz	10–1	Line-of-sight

HF	High Frequency	(30,000,000– 300,000,000 Hz)	m	propagation Infrequent E ionospheric (E_s) refraction. Uncommonly F2 layer ionospheric refraction during high sunspot activity up to 50 MHz and rarely to 80 MHz. Sometimes tropospheric ducting or meteor scatter
U	Ultra	300–	100–	Line-of-sight

HF	High Frequency	3000 MHz (300,000,000–3,000,000,000 Hz)	10 cm	propagation. Sometimes tropospheric ducting.
SHF	Super High Frequency	3–30 GHz (3,000,000,000–30,000,000,000 Hz)	10–1 cm	Line-of-sight propagation. Sometimes rain scatter.
EHF	Extremely High Frequency	30–300 GHz (30,000,000,000 – 300,000,000,000 Hz)	10–1 mm	Line-of-sight propagation, limited by atmospheric absorption to a few kilometers (miles)

THF	Tremendously High frequency	0.3–3 THz (300,000,000,000–3,000,000,000,000 Hz)	1–0.1 mm	Line-of-sight propagation, limited by atmospheric absorption to a few meters.[4][5]

Free space propagation

In free space, all electromagnetic waves (radio, light, X-rays, etc.) obey the inverse-square law which states that the power density of an electromagnetic wave is proportional to the inverse of the square of the distance from a point source[1]:26-19 or:

At typical communication distances from a transmitter, the transmitting antenna usually can be approximated by a point source. Doubling the distance of a receiver from a transmitter means that the power density of the radiated wave at that new location is reduced to one-quarter of its previous value.

The power density per surface unit is proportional to the product of the electric and magnetic field strengths. Thus, doubling the propagation path distance from the transmitter reduces each of these received field strengths over a free-space path by one-half.

Radio waves in vacuum travel at the speed of light. The Earth's atmosphere is thin enough that radio waves in the atmosphere travel very close to the speed of light, but variations in density and temperature can cause some slight refraction (bending) of waves over distances.

Direct modes (line-of-sight)

Line-of-sight refers to radio waves which travel directly in a line from the transmitting antenna to the receiving antenna. It does not necessarily require a cleared sight path; at lower frequencies radio waves can pass through buildings, foliage and other obstructions. This is the most common propagation mode at VHF and above, and the only possible mode at microwave frequencies and above. On the surface of the Earth, line of sight propagation is limited by the visual horizon to about 40 miles (64 km). This is the method used by cell phones,[d] cordless phones, walkie-talkies, wireless networks, point-to-point microwave radio relay links, FM and television broadcasting and radar. Satellite communication uses longer line-of-sight paths; for example home satellite dishes receive signals from communication satellites 22,000 miles (35,000 km) above the Earth, and ground stations can communicate with spacecraft billions of miles from Earth.

Ground plane reflection effects are an important factor in VHF line-of-sight propagation. The interference between the direct beam line-of-sight and the ground reflected beam often leads to an effective inverse-fourth-power ($1/_{\text{distance}^4}$) law for ground-plane limited radiation.[citation needed]

Surface modes (groundwave)

Main article: Surface wave

Ground Wave Propagation

Lower frequency (between 30 and 3,000 kHz) vertically polarized radio waves can travel as surface waves following the contour of the Earth; this is called ground wave propagation.

In this mode the radio wave propagates by interacting with the conductive surface of the Earth. The wave "clings" to the surface and thus follows the curvature of the Earth, so ground waves can travel over mountains and beyond the horizon. Ground waves propagate in vertical polarization so vertical antennas (monopoles) are required. Since the ground is not a perfect electrical conductor, ground waves are attenuated as they follow the Earth's surface. Attenuation is proportional to frequency, so ground waves are the main mode of propagation atlower frequencies, in the MF, LF and VLF bands. Ground waves are used by radio broadcasting stations in the MF and LF bands, and for time signals and radio navigation systems.

At even lower frequencies, in the VLF to ELF bands, an Earth-ionosphere waveguide mechanism allows even longer range transmission. These frequencies are used for secure military communications. They can also penetrate to a significant depth into seawater, and so are used for one-way military communication to submerged submarines.

Early long-distance radio communication (wireless telegraphy) before the mid-1920s used low frequencies in the longwave bands and relied exclusively on ground-

wave propagation. Frequencies above 3 MHz were regarded as useless and were given to hobbyists (radio amateurs). The discovery around 1920 of the ionospheric reflection or skywave mechanism made the medium wave and short wave frequencies useful for long-distance communication and they were allocated to commercial and military users.[8]

Non-line-of-sight modes

Main article: Non-line-of-sight propagation

Ionospheric modes (skywave)

Main article: Skywave

Sky Wave Propagation

Skywave propagation, also referred to as skip, is any of the modes that rely on reflection and refraction of radio waves from the ionosphere. The ionosphere is a region of the atmosphere from about 60 to 500 km (37 to 311 mi) that contains layers of charged particles (ions) which can refract a radio wave back toward the Earth. A radio wave directed at an angle into the sky can be reflected back to Earth beyond the horizon by these layers, allowing long-distance radio transmission. The F2 layer is the most important ionospheric layer for long-distance, multiple-hop HF propagation, though F1, E, and D-layers also play significant roles. The D-layer, when present during sunlight periods, causes significant amount of signal loss, as does the E-layer whose maximum usable frequency can rise to 4 MHz and above and thus block higher frequency signals from reaching the F2-layer. The layers, or more appropriately "regions", are directly affected by the sun on a daily diurnal cycle, a seasonal cycle and the 11-year sunspot cycle and determine the utility of these modes. During solar maxima, or sunspot highs and peaks, the whole HF range up to 30 MHz can be used usually around the clock and F2 propagation up to 50 MHz is observed frequently depending upon daily solar flux values. During solar minima, or minimum sunspot counts down to zero, propagation of frequencies above 15 MHz is generally unavailable.

Although the claim is commonly made that two-way HF propagation along a given path is reciprocal, that is, if the signal from location A reaches location B at a good strength, the signal from location B will be similar at station A because the same path is traversed in both directions. However, the ionosphere is far too complex and constantly changing to support the reciprocity theorem. The path is never exactly the same in both directions.[7] In brief, conditions at the two end-points of a path generally cause dissimilar polarization shifts, hence dissimilar splits into ordinary rays and extraordinary rays (Pedersen rays) which have different propagation characteristics due to differences in ionization density, shifting zenith angles, effects of the

Earth's magnetic dipole contours, antenna radiation patterns, ground conditions, and other variables.

Forecasting of skywave modes is of considerable interest to amateur radio operators and commercial marine and aircraft communications, and also to shortwave broadcasters. Real-time propagation can be assessed by listening for transmissions from specific beacon transmitters.

Meteor scattering

Meteor scattering relies on reflecting radio waves off the intensely ionized columns of air generated by meteors. While this mode is very short duration, often only from a fraction of second to couple of seconds per event, digital Meteor burst communications allows remote stations to communicate to a station that may be hundreds of miles up to over 1,000 miles (1,600 km) away, without the expense required for a satellite link. This mode is most generally useful on VHF frequencies between 30 and 250 MHz.

Auroral backscatter

Intense columns of Auroral ionization at 100 km (60 mile) altitudes within the auroral oval backscatter radio waves, including those on HF and VHF. Backscatter is angle-sensitive—incident ray vs. magnetic field line of the column must be very close to right-angle. Random motions of electrons spiraling around the field lines create a Doppler-spread that broadens the spectra of the emission to more or less noise-like – depending on how high radio frequency is used. The radio-auroras are observed mostly at high latitudes and rarely extend down to middle latitudes. The occurrence of radio-auroras depends on solar activity (flares, coronal holes, CMEs) and annually the events are more numerous during solar cycle maxima. Radio aurora includes the so-called afternoon radio aurora which produces stronger but more distorted signals and after the Harang-minima, the late-night radio aurora (sub-storming phase) returns with variable signal strength and lesser doppler spread. The propagation range for this predominantly back-scatter mode extends up to about 2000 km (1250 miles) in east–west plane, but strongest signals are observed most frequently from the north at nearby sites on same latitudes.

Rarely, a strong radio-aurora is followed by Auroral-E, which resembles both propagation types in some ways.

Sporadic-E propagation

Sporadic E (Es) propagation occurs on HF and VHF bands.[8] It must not be confused with ordinary HF E-layer propagation. Sporadic-E at mid-latitudes occurs mostly during summer season, from May to August in the northern hemisphere and from November to February in the southern hemisphere. There is no single cause for this mysterious propagation mode. The reflection takes place in a thin sheet of ionization around 90 km (55 miles) height. The ionization patches drift westwards at speeds of few hundred km (miles) per hour. There is a weak periodicity noted during the season and typically Es is observed on 1 to 3 successive days and remains absent for a few days to reoccur again. Es do not occur during small hours; the events usually begin at dawn, and there is a peak in the afternoon and a second peak in the evening. Es propagation is usually gone by local midnight.

Observation of radio propagation beacons operating around 28.2 MHz, 50 MHz and 70 MHz, indicates that maximum observed frequency (MOF) for Es is found to be lurking around 30 MHz on most days during the summer season, but sometimes MOF may shoot up to 100 MHz or even more in ten minutes to decline slowly during the next few hours. The peak-phase includes oscillation of MOF with periodicity of approximately 5...10 minutes. The propagation range for Es single-hop is typically 1000 to 2000 km (600 to 1250 miles), but with multi-hop, double range is observed. The signals are very strong but also with slow deep fading.

Tropospheric modes

Radio waves in the VHF and UHF bands can travel somewhat beyond the visual horizon due to refraction in the troposphere, the bottom layer of the atmosphere below 20 km (12 miles).[10][3] This is due to changes in the refractive index of air with temperature and pressure.

Tropospheric delay is a source of error in radio ranging techniques, such as the Global Positioning System (GPS). In addition, unusual conditions can sometimes allow propagation at greater distances:

Tropospheric ducting

Main article: Tropospheric ducting

Sudden changes in the atmosphere's vertical moisture content and temperature profiles can on random occasions make UHF, VHF and microwave signals propagate hundreds of kilometers (miles) up to about 2,000 kilometers (1,200 miles)—and for ducting mode even farther—beyond the normal radio-horizon. The inversion layer is mostly observed over high pressure regions, but there are several tropospheric weather conditions which create these randomly occurring propagation modes. Inversion layer's altitude for non-ducting is typically found between 100 and 1,000 meters (330 and 3,280 feet) and for ducting about 500 to 3,000 meters (1,600 to 9,800 feet), and the duration of the events are typically from several hours up to several days. Higher frequencies experience the most dramatic increase of signal strengths, while on low-VHF and HF the effect is negligible. Propagation path attenuation may be below *free-space loss. Some of the lesser inversion types related to warm ground and cooler air moisture content occur regularly at certain times of the year and time of day. A typical example could be the late summer, early morning tropospheric enhancements that bring in signals from distances up to few hundred kilometers (miles) for a couple of hours, until undone by the Sun's warming effect.*

Tropospheric scattering (troposcatter)[edit]

Main article: Tropospheric scattering

At VHF and higher frequencies, small variations (turbulence) in the density of the atmosphere at a height of around 6 miles

(9.7 km) can scatter some of the normally line-of-sight beam of radio frequency energy back toward the ground. In tropospheric scatter (troposcatter) communication systems a powerful beam of microwaves is aimed above the horizon, and a high gain antenna over the horizon aimed at the section of the troposphere though which the beam passes receives the tiny scattered signal. Troposcatter systems can achieve over-the-horizon communication between stations 500 miles (800 km) apart, and the military developed networks such as the White Alice Communications System covering all of Alaska before the 1960s, when communication satellites largely replaced them.

Rain scattering

Rain scattering is purely a microwave propagation mode and is best observed around 10 GHz, but extends down to a few gigahertz—the limit being the size of the scattering particle size vs. wavelength. This mode scatters signals mostly forwards and backwards when using horizontal polarization and side-scattering with vertical polarization. Forward-scattering typically yields propagation ranges of 800 km (500 miles). Scattering from snowflakes and ice pellets also occurs, but scattering from ice without watery surface is less effective. The most common application for this phenomenon is microwave rain radar, but rain scatter propagation can be a nuisance causing unwanted signals to intermittently propagate where they are not anticipated or desired. Similar reflections may also occur from insects though at lower altitudes and shorter range. Rain also causes attenuation of point-to-point and satellite microwave links. Attenuation values up to 30 dB have been observed on 30 GHz during heavy tropical rain.

Airplane scattering

Main article: Airplane scatter

Airplane scattering (or most often reflection) is observed on VHF through microwaves and, besides back-scattering, yields momentary propagation up to 500 km (300 miles) even in mountainous terrain. The most common back-scatter applications are air-traffic radar, bistatic forward-scatter guided-missile and airplane-detecting trip-wire radar, and the US space radar.

Lightning scattering

Lightning scattering has sometimes been observed on VHF and UHF over distances of about 500 km (300 miles). The hot lightning channel scatters radio-waves for a fraction of a second. The RF noise burst from the lightning makes the initial part of the open channel unusable and the ionization disappears quickly because of recombination at low altitude and high atmospheric pressure. Although the hot lightning channel is briefly observable with microwave radar, no practical use for this mode has been found in communications.

Other effects

Diffraction

Knife-edge diffraction is the propagation mode where radio waves are bent around sharp edges. For example, this mode is used to send radio signals over a mountain range when a line-of-sight path is not available. However, the angle cannot be too sharp or the signal will not diffract. The diffraction mode requires increased signal strength, so higher power or better antennas will be needed than for an equivalent line-of-sight path.

Diffraction depends on the relationship between the wavelength and the size of the obstacle. In other words, the size of the obstacle in wavelengths. Lower frequencies diffract around large smooth obstacles such as hills more easily. For example, in many cases where VHF (or higher frequency) communication is not *possible due to shadowing by a hill, it is still possible to communicate using the upper part of the HF band where the surface wave is of little use.*

Diffraction phenomena by small obstacles are also important at high frequencies. Signals for urban cellular telephony tend to be dominated by ground-plane effects as they travel over the rooftops of the urban environment. They then diffract over roof edges into the street, where multipath propagation, absorption and diffraction phenomena dominate.

Absorption

Low-frequency radio waves travel easily through brick and stone and VLF even penetrates sea-water. As the frequency rises, absorption effects become more important. At microwave or higher frequencies, absorption by molecular resonances in the atmosphere (mostly from water, H_2O *and oxygen,* O_2*) is a major factor in radio propagation. For example, in the 58–60 GHz band, there is a major absorption peak which makes this band useless for long-distance use. This* *phenomenon was first discovered during radar research in World War II. Above about 400 GHz, the Earth's atmosphere blocks most of the spectrum while still* passing some - up to UV light, which is blocked by ozone - but visible light and some of the near-infrared is transmitted. Heavy rain and falling snow also affect microwave absorption.

Measuring HF propagation

HF propagation conditions can be simulated using radio propagation models, such as the Voice of America Coverage Analysis Program, and realtime measurements can be done using chirp transmitters. For radio amateurs the WSPR mode provides maps with real time propagation conditions between a network of transmitters and receivers.[12] Even without special beacons the realtime propagation conditions can be *measured: A worldwide network of receivers decodes morse code signals on amateur radio frequencies in realtime and provides sophisticated search functions and propagation maps for every station received.*[13]

Practical effects

The average person can notice the effects of changes in radio propagation in several ways.

In AM broadcasting, the dramatic ionospheric changes that occur overnight in the mediumwave band drive a unique broadcast license scheme in the United States, with entirely different transmitter power output levels and directional antenna patterns to cope with skywave propagation at night. Very few stations are allowed to run without modifications during dark hours, typically only those on clear channels in North America.[14] Many stations have no authorization to run at all outside of daylight hours.

For FM broadcasting (and the few remaining low-band TV stations), weather is the primary cause for changes in VHF propagation, along with some diurnal changes when the sky is mostly without cloud cover. These changes are most obvious during temperature inversions, such as in the late-night and early-morning hours when it is clear, allowing the ground and the air near it to cool more rapidly. This not only causes dew, frost, or fog, but also causes a slight "drag" on the bottom of the radio waves, bending the signals down such that they can follow the Earth's curvature over the normal radio horizon. The result is typically several stations being heard from another media market – usually a neighboring one, but sometimes ones from a few hundred kilometers (miles) away. Ice storms are also the result of inversions, but these normally cause more scattered omnidirection propagation, resulting mainly in interference, often among weather radio stations. In late spring and early summer, a combination of other atmospheric factors can occasionally cause skips that duct high-power signals to places well over 1000 km (600 miles) away.

Non-broadcast signals are also affected. Mobile phone signals are in the UHF band, ranging from 700 to over 2600 MHz, a range which makes them even more prone to weather-induced propagation changes. In urban (and to some extent suburban) areas with a high population density, this is partly offset by the use of smaller cells, which use lower effective radiated power and beam tilt to reduce interference, and therefore increase frequency reuse and user capacity. However, since this would not be very cost-effective in more rural areas, these cells are larger and so more likely to cause interference over longer distances when propagation conditions allow.

While this is generally transparent to the user thanks to the way that cellular networks handle cell-to-cell handoffs, when cross-border signals are involved, unexpected charges for international roaming may occur despite not having left the country at all. This often occurs between southern San Diego and northern Tijuana at the western end of the U.S./Mexico border, and between eastern Detroit and western Windsor along the U.S./Canada border. Since signals can travel unobstructed over a body of water far larger than the Detroit River, and cool water temperatures also cause inversions in surface *air, this "fringe roaming" sometimes occurs across the Great Lakes, and between islands in the Caribbean. Signals can skip from* the Dominican Republic to a mountainside in Puerto Rico and vice versa, or between the U.S. and British Virgin Islands, among others. While unintended cross-border roaming is often automatically removed by mobile phone company billing systems, inter-island roaming is typically not.

Empirical models

A **radio propagation model**, also known as the **radio wave propagation model** or *the **radio frequency propagation model**, is an empirical mathematical formulation for the characterization of radio wave propagation as* a function of frequency, distance and other conditions. A single model is usually developed to predict the behavior of propagation for all similar links under similar constraints. Created with the goal of formalizing the way radio waves are propagated from one place to another, such models typically predict the path loss along a link or the effective coverage area of a transmitter.

As the path loss encountered along any radio link serves as the dominant factor for characterization of propagation for the link, radio propagation models typically focus on realization of the path loss with the auxiliary task of predicting the area of coverage for a transmitter or modeling the distribution of signals over different regions

Because each individual telecommunication link has to encounter different terrain, path, obstructions, atmospheric conditions and other *phenomena, it is intractable to formulate the exact loss for all telecommunication systems in a single mathematical equation. As a result, different models exist for different types of radio links under different conditions. The models rely on computing the median path loss for a link under a certain probability that the considered conditions will occur.*

Radio propagation models are empirical in nature, which means, they are developed based on large collections of data collected for the specific scenario. For any model, the collection of data has to be sufficiently large to provide enough likeliness (or enough scope) to all kind of situations that can happen in that specific scenario. Like all empirical models, radio propagation models do not point out the exact behavior of a link, rather, they predict *the most likely behavior the link may exhibit under the specified conditions.*

Propagation of an Electromagnetic Wave

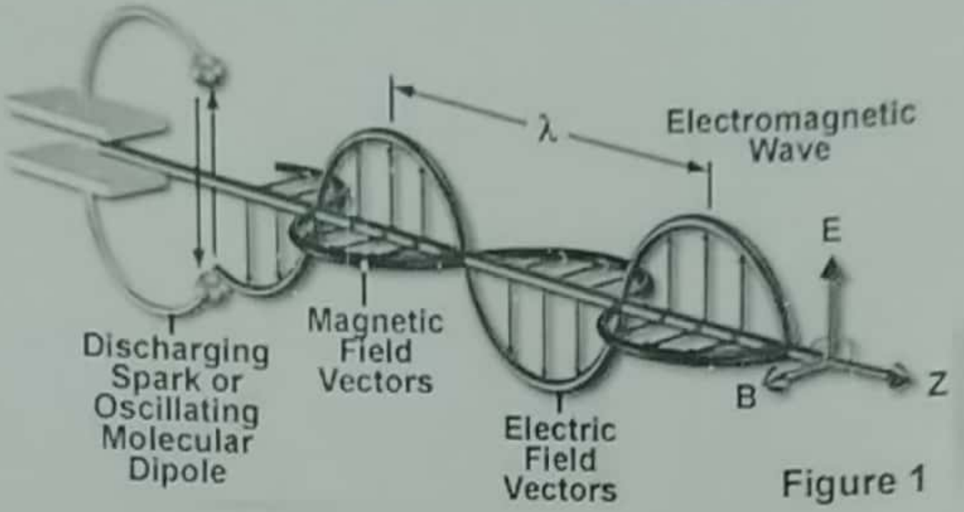

Figure 1

SUMMARY

Electromagnetic fields (EMFs) are part of the physical electromagnetic spectrum ranging from the extreme low of static magnetic fields to the extreme high of gamma rays. EMFs as discussed here focus on frequencies of 0 Hz–300 GHz, which are part of the spectrum considered to be nonionizing (Table 1). Examples of the frequencies that are part of the spectrum are electric power generation and transmission, radio frequencies (RF), and microwaves (Table 1).

Table 1 Electromagnetic spectrum

Use	***Frequency***	***Nonionizing/ionizing***	***Wavelength***
Electric	*60 Hz*	*Nonionizing*	*10 m*

Use	Frequency	Nonionizing/ionizing	Wavelength
power			
AM radio	1 MHz	Nonionizing	
FM radio	100 MHz	Nonionizing	3 m
Cell phones	1900 MHz	Nonionizing	~17 cm
Microwave oven	2450 MHz	Nonionizing	
Visible light	10^{14} Hz	Nonionizing	~500 nm
UV light	10^{15} Hz	Nonionizing Ionizing	10^{-7} m
X-rays	10^{18} Hz	Ionizing	10^{-10} m
Gamma	10^{20} Hz	Ionizing	10^{-12} m

Use	Frequency	Nonionizing/ionizing	Wavelength
rays			

Scientific and public attention focusing on the potential human health hazards of these fields has intensified over the past 30 years, initially with the belief that electric power generation and transmission were related to the development of human leukemia; the more recent focus has been on radio frequency EMF (RF-EMF), particularly the frequencies used for cellular telephones and their transmission towers. The frequencies around and above 10^{15} Hz approach and surpass the energy required to cause atomic ionization. The frequency at which EMF changes from nonionizing to ionizing is not strictly defined, but approximates the upper ultraviolet frequency range (Table 1). The energy *contained within the 0 Hz–300 GHz frequencies is not sufficient to create ionization or usually even a thermal change (unless this is specifically induced), and it is this fact that has driven much of the controversy over the existence of health effects of non ionizing EMF (NIEMF). Energy contained in EMF is occasionally presented as electronvolt energy, and it is helpful to use this as a general measure to compare energy presented by ionizing and nonionizing radiation. Table 2 shows representative electronvolt energies as a function of frequency.*

Table 2 Approximate electronvolt energies of some EM frequencies and the relationship to ionization

Frequency use	***Frequency – Hz***	***eV***

Frequency use	*Frequency –Hz*	*eV*
Radio waves	*10*	*10 (Nonionizing)*
Visible light	*10*	*1.5–3 (Nonionizing)*
Ionization		*10–12*
Hydrogen atom ionization		13.6
X-ray	10	10 (Ionizing)
Gamma rays	10	10 (Ionizing)

The proliferation of devices that generate NIEMF, recently cellular mobile phones and mobile smart devices, has resulted in an increase in the number of *humans exposed to these fields, and an increase in the constancy of exposure to these fields. Human reaction to NIEMF exposure varies from no reaction (the majority) to what is believed to be human hypersensitivity to NIEMF, a claimed reaction to NIEMF manifested by multiple medical signs and symptoms. The terms NIEMF and nonionizing electromagnetic radiation (NIEMR) are often used interchangeably, and this can cause confusion and misunderstanding when discussing human health effects. As NIEMF moves away from its source, it is radiating (becomes NIEMR). The public perception of the term radiation is often negative, and there is a tendency to assume that all radiation and its effects, whether ionizing or nonionizing, are the same and harmful. Most individuals are familiar with the consequences of* *coming into contact with an electric current, which if strong enough generates an unpleasant sensation. When we are discussing electromagnetic fields here, we are generally referring to an insensible physical force.*

REFERENCE

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