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Light and Radio Radiations from a Moving Charged Particle

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ABSTRACT

Two types of electromagnetic radiation are identified: light radiation and radio radiation. Light radiation is due to aberration of electric field in the motion of a charged particle in an external electric field, where energy radiated, proportional to the square of amplitude of velocity, is the difference between change in potential energy and change in kinetic energy. This is so with electrons revolving in the electric field of the nucleus of an atom. Radio radiation, due to finite speed of light, whereby an oscillating charged particle generates a magnetic field in phase with an electric field, at a point in space, resulting in generation of energy, proportional to the square of amplitude of acceleration, as from a radio antenna. The electric field in the Poynting vector is the sum of external accelerating field and internal induction field due to acceleration of a charged particle, in accordance with Faraday's law. The induction field also acts on the same charge creating it, to produce the inertial force, equal and opposite to the accelerating force, thereby explaining the cause of inertia. Radio radiation explains the presence of Cosmic Microwave Background Radiation as a local phenomenon from within the atoms of a body.

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Introduction

A charged particle moving in an electric field, is subject to aberration of electric field. This is a phenomenon similar to aberration of light [1, 2, 3]. Taking aberration of electric field into consideration, the accelerating force **F** on a particle of charge K and constant mass m, equal to the rest mass m_o, moving at time t with velocity **v** in an electric field of intensity **E** and magnitude E, is put, in accordance with Newton's second law of motion, as:

$$\mathbf{F} = \frac{KE}{c}(\mathbf{c} - \mathbf{v}) = m\frac{d\mathbf{v}}{dt} \qquad (1)$$

where **c** is the velocity of light of magnitude c. The velocity of light **c** being an ultimate limit, is implicit in equation (1). Relative velocity (**c** – **v**) between the particle moving with velocity **v** and the electrical force transmitted with velocity of light **c**, is in the direction of the accelerating force **F**. At **v** = 0, equation (1) reduces to Coulomb's law, with **c**/c = **û** as a unit vector in the direction of the electrostatic field. Force, on a moving charged particle, is less than the force K**E** on a stationary one, the difference is radiation reaction force.

Equation (1) is the result of aberration of electric field [4]. It explains the speed of light c as a limit without recourse to the theory of special relativity and gets radiation, from an accelerated particle of charge Q and mass m, outside quantum mechanics [5-8].

Gauss's law, for an electric charge K and its electric field $\mathbf{E}_r$ at a point P distance r, passing through enclosing surface area S, gives surface integral [9, 10]:

$$K = \varepsilon_o \int_S \mathbf{E}_r.(d\mathbf{S}) \qquad (2)$$

A particle of charge K with its electrostatic field $\mathbf{E}_r$, at a point P distance r from the charge, moving with velocity **v**, relative to an observer, generates a magnetic field **H**, given by vector product [11, 12]:

$$\mathbf{H} = \varepsilon_o \mathbf{v} \times \mathbf{E}_r \qquad (3)$$

For a charged particle moving with velocity **v** in an external electric field of intensity $\mathbf{E}_o$, due to force K**E**o, power P developed, scalar product K**E**o.**v**, is given by the surface integral, as:

$$P = K\mathbf{E}_o.\mathbf{v} = \varepsilon_o \int_S \mathbf{E}_r.(d\mathbf{S})\mathbf{E}_o.\mathbf{v} = -\varepsilon_o \int_S \mathbf{E}_o \times \left(\mathbf{v} \times \mathbf{E}_r\right).(d\mathbf{S})$$
$$= -\int_S \mathbf{E}_o \times \mathbf{H}.(d\mathbf{S}) \qquad (4)$$

H is given by equation (3) and e_o is the permittivity. Vector expansion in equation (4), gives:

$$-\varepsilon_o \int_S \mathbf{E}_o \times \left(\mathbf{v} \times \mathbf{E}_r\right).(d\mathbf{S}) = -\varepsilon_o \int_S (\mathbf{E}_o.\mathbf{E}_r)\mathbf{v}.(d\mathbf{S}) +$$
$$\varepsilon_o \int_S (\mathbf{E}_o.\mathbf{v})\mathbf{E}_r.(d\mathbf{S}) \qquad (5)$$

Since velocity **v** is a vector that does not diverge, surface integrals, in equation (5), give:

$$\varepsilon_o \int_S (\mathbf{E}_o \mathbf{E}_r)\mathbf{v}.(d\mathbf{S}) = 0 \qquad (6)$$

Equations (6) and (5) give equation (4). The vector product: -**X***l* = **E**o´**H**, in equation (4), giving light power intensity or light power flow through unit area, out of surface area surrounding the moving charge *K*, or power developed in a volume enclosed by surface area *S*, surrounding the charge, is the Poynting vector.

A magnetic field **H**, changing in time *t*, due to acceleration of a particle of charge *K* and mass *m*, creates an induction electric field $\mathbf{E}_a$, given by Faraday's law, as [13, 14]:

$$\nabla \times \mathbf{E}_a = -\mu_o \frac{\partial \mathbf{H}}{\partial t} \qquad (7)$$

This $\mathbf{E}_a$ acts on the same charge creating it, to produce the inertial force KEa, such that:

$$K\mathbf{E}_a = -m\frac{\partial \mathbf{v}}{\partial t} \qquad (8)$$

So, the induction electric field $\mathbf{E}_a$ plays a vital role in electromagnetic radiation, as in equation (7) and also takes part in producing inertia as in equation (8).

An electric charge *K* with its electric field $\mathbf{E}_r$, moving with velocity **v**, in an electric field $\mathbf{E}_a$, develops a magnetic field $\mathbf{H} = \varepsilon_o$ **V** x $\mathbf{E}_r$ and power *P*, as in equation (3), thus:

$$P = K\mathbf{E}_a.\mathbf{v} = \varepsilon_o \int_S \mathbf{E}_r.(d\mathbf{S})\mathbf{E}_a.\mathbf{v} = -\varepsilon_o \int_S \mathbf{E}_a \times \left(\mathbf{v} \times \mathbf{E}_r\right).(d\mathbf{S})$$

$$= -\int_S \mathbf{E}_a \times \mathbf{H}.(d\mathbf{S}) \qquad (9)$$

The vector product: -$\mathbf{X}_r$ = $\mathbf{E}_a$´**H**, in equation (9), giving radio power intensity through unit area out of surface area surrounding the moving charge *K*, is the Poynting vector [15, 16].

The total Poynting vector -**X**, giving light radiation and radio radiation intensity, for a charged particle accelerated by an electric field, as obtained from equations (4) and (9), is:

$$-\mathbf{X} = (\mathbf{E}_o + \mathbf{E}_a) \times \mathbf{H} \qquad (10)$$

where magnetic field **H**, of a moving charged particle, is given by equation (3). The first vector product, on the right-hand side of equation (10), gives light radiation power intensity for a charged particle accelerated by an external electric field and the second vector product gives radio radiation power intensity for an oscillating electric charge.

The author showed that motion of a charged particle, in a circular orbit, under the attraction of a nucleus of charge *Q* and mass *M*, as in Rutherford's nuclear model of the hydrogen atom, is without radiation and inherently stable [17, 18]. That the nuclear model consists of 42 or 43 coplanar orbits of revolution. Radiation takes place if a revolving charged particle is dislodged from a circular orbit. It then revolves in unclosed elliptic paths, with emission of radiation in *fine structure*, before reverting to a stable circular orbit [19, 20].

Magnetic Vector Potential

A charged particle and its electric field $\mathbf{E}_r$, moving with velocity **v**, relative to an observer, generates a magnetic field **H**, given by equation (3):

$$\mu_o \mathbf{H} = \mu_o \varepsilon_o \mathbf{v} \times \mathbf{E}_r = -\mu_o \varepsilon_o \mathbf{v} \times \nabla\varphi = \mu_o \varepsilon_o \nabla \times (\varphi \mathbf{v}) = \nabla \times \mathbf{A}$$

$$\mathbf{B} = \mu_o \mathbf{H} = \mu_o \varepsilon_o \nabla \times (\varphi \mathbf{v}) = \nabla \times \mathbf{A} \qquad (11)$$

$$\mathbf{A} = \mu_o \varepsilon_o \varphi \mathbf{v} \qquad (12)$$

where *j* is the potential at a point P due to the charge, *mo* is magnetic permeability and **B** the magnetic flux intensity, the symbol s denotes the gradient of a scalar point-function, s´ denotes the curl of a vector point-function, s´**v** = 0 and **A** is the magnetic vector potential. Equation (12), in terms of potential *j* at *r* from a moving charge *K*, gives **A**, as:

$$\mathbf{A} = \frac{\mu_o K\mathbf{v}}{4\pi r} \qquad (13)$$

Let the charge *K* oscillates with angular frequency *ω*, displacement amplitude *a*, velocity amplitude $\mathbf{v}_m$ and velocity **v** at time *t*, in a constant **k**-direction, as:

$$\mathbf{v} = \mathbf{a}\omega\cos\omega t = \mathbf{v}_m \cos\omega t \qquad (14)$$

Any change in velocity **v**, at the location of the charge, will take time *r*/*c* to reach a pint P distance *r* away, at the speed of light c. In this case the magnetic vector potential (equation 13) at P must be replaced by the retarded potential $\mathbf{A}_r$, thus:

$$\mathbf{A}_r = \frac{\mu_o K\mathbf{v}_m}{4\pi r}\cos\omega\left(t - \frac{r}{c}\right) \qquad (15)$$

where *t* is the present time at P and (*t* – *r*/*c*) is the retarded time.

A Charged Particle under free Oscillation

In free oscillation, there is no external electric field and the Poynting vector becomes:

$$-\mathbf{X} = \mathbf{E}_a \times \mathbf{H} \qquad (16)$$

The induction field $\mathbf{E}_a$ may be due an external force wiggling the charge *K* about. Let the charged particle oscillate with angular frequency *ω*, displacement amplitude ***a*** and velocity amplitude $\mathbf{v}_m$. The charge sets up a potential *φ*, generates a magnetic field **H**, magnetic vector potential $\mathbf{A}_r$ and induction electric field $\mathbf{E}_a$ at a point P distance r_1 away from the charge.

Equation (7) gives:

$$\nabla \times \mathbf{E}_a = -\mu_o \frac{\partial \mathbf{H}}{\partial t} = -\frac{\partial \mathbf{B}}{\partial t} = -\frac{\partial}{\partial t}\nabla \times \mathbf{A}_r$$

$$\mathbf{E}_a = -\frac{\partial \mathbf{A}_r}{\partial t} \qquad (17)$$

Equation (11) gives:

$$\mathbf{H} = \frac{1}{\mu_o}\nabla \times \mathbf{A}_r = -\frac{1}{\mu_o}\hat{\mathbf{u}} \times \frac{\partial \mathbf{A}_r}{\partial r} \qquad (18)$$

where $\hat{\mathbf{u}}$ is a unit vector in the radial direction of spherical coordinates. Radio power across surface area **S**, surrounding the oscillating charge, is given by equations (17) and (18), as:

$$\int_S (\mathbf{E}_a \times \mathbf{H}).(d\mathbf{S}) = -\frac{1}{\mu_o}\int_S \left\{ \frac{\partial \mathbf{A}_r}{\partial t} \times \left(\hat{\mathbf{u}} \times \frac{\partial \mathbf{A}_r}{\partial r} \right) \right\}.(d\mathbf{S}) =$$

$$-\frac{1}{\mu_o}\int_S \left\{ \left((d\mathbf{S}) \times \frac{\partial \mathbf{A}}{\partial t} \right) . \left(\hat{\mathbf{u}} \times \frac{\partial \mathbf{A}}{\partial r} \right) \right\} \quad (19)$$

where $\mathbf{A}_r$ is the magnetic vector potential in the **z**-direction and $\hat{\mathbf{u}}$ a unit radial vector. Equation (19) gives power developed P_r, as:

$$P_r = \int_S (\mathbf{E}_a \times \mathbf{H}).(d\mathbf{S}) = -\frac{1}{\mu_o}\int_S \left\{ \left((d\mathbf{S}) \times \frac{\partial \mathbf{A}_r}{\partial t} \right) . \left(\hat{\mathbf{u}} \times \frac{\partial \mathbf{A}_r}{\partial r} \right) \right\} =$$

$$-\frac{1}{\mu_o}\int_S \frac{\partial A_r}{\partial t}\frac{\partial A_r}{\partial r}\sin^2\theta(dS) \quad (20)$$

where *q* is the angle between the magnetic vector potential $\mathbf{A}_r$, in the **z**-direction, and the radial $\hat{\mathbf{u}}$-direction. Equation (20) is useful for calculating radio power radiation.
Equation (15) gives:

$$\frac{\partial \mathbf{A}_r}{\partial t} = -\omega \frac{\mu_o K \mathbf{v}_m}{4\pi r}\sin\omega\left(t - \frac{r}{c}\right) \quad (21)$$

$$\frac{\partial \mathbf{A}_r}{\partial r} = -\frac{\mu_o K \mathbf{v}_m}{4\pi r^2}\cos\omega\left(t - \frac{r}{c}\right) + \frac{\omega}{c}\frac{\mu_o K \mathbf{v}_m}{4\pi r}\sin\omega\left(t - \frac{r}{c}\right) \quad (22)$$

$$\frac{\partial \mathbf{A}_r}{\partial t}\frac{\partial \mathbf{A}_r}{\partial r} = \left\{ \frac{-\omega\mu_o K \mathbf{v}_m}{4\pi r}\sin\omega\left(t - \frac{r}{c}\right) \right\} \left\{ -\frac{\mu_o K \mathbf{v}_m}{4\pi r^2}\cos\omega\left(t - \frac{r}{c}\right) + \frac{\omega}{c}\frac{\mu_o K \mathbf{v}_m}{4\pi r}\sin\omega\left(t - \frac{r}{c}\right) \right\} \quad (23)$$

Equation (23) consists of a term with $sin^2\omega\ (t - r/c)$, which is responsible for radiation. The other terms with $sin2\omega\ (t - r/c)$, pertain to kinetic energy and potential energy of the oscillating particle. The radiation term, containing a steady state, is:

$$\frac{-1}{c}\left(\omega\frac{\mu_o K \mathbf{v}_m}{4\pi r}\right)^2 \sin^2\omega\left(t - \frac{r}{c}\right) = \frac{-1}{2c}\left(\omega\frac{\mu_o K \mathbf{v}_m}{4\pi r}\right)^2 \left\{1 - \cos 2\omega\left(t - \frac{r}{c}\right)\right\} \quad (24)$$

Equation (19) gives radiated power, P_r, as:

$$P_r = \int_S \frac{\mu_o}{2c}\left(\omega\frac{K\mathbf{v}_m}{4\pi r}\right)^2 \sin^2\theta(dS)$$

$$= \int_{\theta=0}^{\theta=\pi}\int_{\varphi=0}^{\varphi=2\pi} \frac{\mu_o}{2c}\left(\omega\frac{K\mathbf{v}_m}{4\pi r}\right)^2 r^2\sin^3\theta(d\varphi)(d\theta) = \left(\frac{\mu_o K^2\omega^2 v_m^2}{12\pi c}\right) \quad (25)$$

where the element of surface area

$(dS) = r^2 sinq(dj)$ and $\int_0^\pi \sin^3\theta(d\theta) = \frac{4}{3}$.

Charged Particle Accelerated by a Constant Field

Let a particle of charge *K* move with speed v and acceleration dv/dt at time *t*, along an electric field of constant magnitude *E* in the **x**-direction. In this case, equation (1), in view of aberration of electric field, gives accelerating force as:

$$\mathbf{F} = K\mathbf{E}\left(1 - \frac{v}{c}\right) = m\frac{d\mathbf{v}}{dt}$$

Work done by the force **F**, in time (dt), at speed v, in a displacement $(dx) = v(dt)$, is:

$$Fv(dt) = KEv(dt)\left(1 - \frac{v}{c}\right) = m\frac{dv}{dt}v(dt) \quad (26)$$

Equation (26) means that for rectilinear motion in time (dt), potential energy $KEv(dt)$ lost, by an accelerated charged particle, minus the kinetic energy $mv(dv)$ gained, is energy $(dR) = \frac{KEv^2}{c}(dt)$ radiated. This gives radiation power $R_p = (dR/dt)$ in rectilinear motion, as:

$$R_p = \frac{KEv^2}{c} \quad (27)$$

At the speed of light vc, energy radiated in time *t*, is $KEct$, equal to the potential energy lost, with constant moving mass as the rest mass. Even in an accelerating electric field, the speed of light $v = c$ is an ultimate limit, as the accelerating force becomes equal and opposite to the radiation reaction force. It is emission of radiation that makes all the difference.

A Charged Particle Oscillating in a Uniform Field

Let the particle of charge *K* oscillate with angular frequency ω and velocity $\mathbf{v} = \mathbf{a}\omega\cos\omega t = \mathbf{v}_m\cos\omega t$ along an electric field of intensity E and constant magnitude E in the direction of unit vector â. The radio power radiated is given by equation (25) as:

$$P_r = \frac{\mu_o q^2\omega^2 v_m^2}{12\pi c}$$

The radiation power, as given by equation (27), is:

$$R_p = \frac{qEv_m^2}{c}\cos^2\omega t = \frac{qEv_m^2}{2c}(1 + \cos 2\omega t)$$

Average light power radiated is:

$$P = \frac{qEv_m^2}{2c} \quad (28)$$

Total power R radiated by a charged oscillating in a uniform electric field *E*, is the sum:

$$R = \frac{\mu_o q^2\omega^2 v_m^2}{12\pi c} + \frac{qEv_m^2}{2c} \quad (29)$$

An Electron Revolving Round a Nucleus

Figure 1 shows a particle of charge -*e* and mass *nm* of electronic mass *m*, revolving in orbit at angle *y* round a nucleus of charge *Q* and mass *M*. A charged particle disturbed from a stable circular nth orbit, revolves in an unclosed elliptic path with emission of radiation, at the frequency of radiation, before reverting to a stable circular orbit. The free ellipse WXYZ, is the closed path that the particle would have taken if there were no radiation.

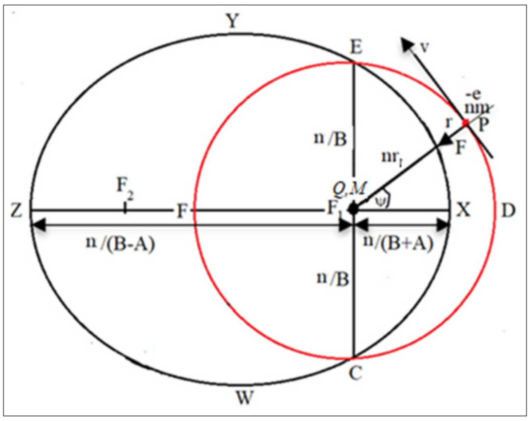

Figure 1: Free ellipse WXYZ and stable circular orbit CDEF of revolution of particle of charge -*e* and mass nm at P, of nuclear model. The *nth* stable circle CDEF has latus rectum EF_1 as radius with charge +*Q* at focus F_1.

In Figure 1, equation of the nth free ellipse, in polar coordinates, is:

$$\frac{1}{r}=\frac{B}{n}+\frac{A}{n}e^{-q\psi}\cos\psi \quad (30)$$

where A/n is the excitement in the nth orbit and A/B is the eccentricity. The excitement is due to change of potential and/or kinetic energy of a charged particle revolving in a circular orbit. An excited particle revolves in angle *y*, with emission of radiation, at the frequency of revolution, before reverting to a circular orbit of radius n/B, latus rectum of the free ellipse.

In Figure 1, centripetal force on charged particle of mass *nm* revolving with maximum speed v_1 at the perihelion X, $y = 0$, is:

$$nmv_1^2\left(\frac{A+B}{n}\right)=\frac{eQ}{4\pi\varepsilon_o}\left(\frac{A+B}{n}\right)^2 \quad (31)$$

Kinetic energy K_1 of the particle, of mass *nm*, at X, is:

$$K_1=\frac{1}{2}mnv_1^2=\frac{eQ}{8\pi\varepsilon_o}\left(\frac{A+B}{n}\right) \quad (32)$$

Force on particle of mass *nm* and charge -*e* revolving with speed v_2 at D, in the *nth* stable circle CDEF, is:

$$nmv_2^2\frac{B}{n}=\frac{eQ}{4\pi\varepsilon_o}\left(\frac{B}{n}\right)^2$$

Kinetic energy K_2 of the particle, at D in the stable circle CDEF, is:

$$K_2=\frac{1}{2}nmv_2^2=\frac{eQ}{8\pi\varepsilon_o}\frac{B}{n} \quad (33)$$

Change in kinetic energy, $K_1 – K_2$ (kinetic energy lost), is:

$$K_1-K_2=\frac{eQ}{8\pi\varepsilon_o}\frac{A}{n} \quad (34)$$

Potential energy P_1 of the particle, of mass *nm*, at the perihelion X, is:

$$P_1=\frac{-eQ}{4\pi\varepsilon_o}\frac{A+B}{n} \quad (35)$$

Potential energy P_2 of the particle, at D in the stable circle CDEF, is:

$$P_2=\frac{-eQ}{4\pi\varepsilon_o}\frac{B}{n} \quad (36)$$

Change in potential energy (potential energy gained), P1 – P2, is:

$$P_2-P_1=\frac{eQ}{4\pi\varepsilon_o}\frac{A}{n} \quad (37)$$

Difference between potential energy gained and kinetic energy lost, equation (37) – (34), the energy radiated R1, is:

$$R_1=\frac{eQ}{8\pi\varepsilon_o}\frac{A}{n} \quad (38)$$

Equation (38) gives emission of light radiation, with excitement amplitude *A*/*n*, at the frequency of revolution, from an atomic charged particle dislodged from the *nth* stable circular orbit. It now remains to consider emission of radio radiation *R*2.
In Figure 1, equation of the nth orbit, equation (30), is:

$$\frac{1}{r}=\frac{B}{n}+\frac{A}{n}e^{-q\psi}\cos\psi=\frac{B}{n}+\frac{A}{n}e^{(i-q)\psi} \quad (39)$$

An important property, of motion of a body of mass *nm* at radius *r*, from a centre of force of attraction, in a plane orbit, with angular speed *dy*/*dt* at time *t*, is the constant angular momentum *nL* in the nth orbit, so that:

$$nmr^2\frac{d\psi}{dt}=nL \quad (40)$$

Equation (39) and (40), give:

$$-\frac{1}{r^2}\frac{dr}{dt}=(i-q)\frac{A}{n}e^{(i-q)\psi}\frac{d\psi}{dt}=(i-q)\frac{A}{n}e^{(i-q)\psi}\frac{L}{mr^2}$$

$$-\frac{dr}{dt}=(i-q)\frac{A}{n}e^{(i-q)\psi}\frac{L}{m} \quad (41)$$

As an excited particle, of charge -*e*, revolves in an unclosed elliptic orbit, at a distance *r* from the nucleus of charge *Q*, it has decreasing velocity *dr*/*dt* (equation 41) in the radial direction, against a force $eQ/4peor^2$. Power *P* developed, is:

$$P=-(i-q)\frac{A}{n}e^{(i-q)\psi}\frac{L}{m}\frac{eQ}{4\pi\varepsilon_o r^2}=-(i-q)\frac{A}{n}e^{(i-q)\psi}\frac{eQ}{4\pi\varepsilon_o}\frac{d\psi}{dt} \quad (42)$$

Energy radiated after many cycles of *y*, is given by the integral:

$$R=-\int_0^\infty(i-q)\frac{A}{n}e^{(i-q)\psi}\frac{eQ}{4\pi\varepsilon_o}d\psi=-\left[\frac{A}{n}e^{(i-q)\psi}\frac{eQ}{4\pi\varepsilon_o}\right]_0^\infty=\frac{eQ}{4\pi\varepsilon_o}\frac{A}{n} \quad (43)$$

Equation (43) gives the total energy, light and radio radiations, radiated. Equation (38) giving light radiation R_1, makes radio radiation, as:

$$R_2 = \frac{eQ}{8\pi\varepsilon_o}\frac{A}{n} \quad (44)$$

Results and Discussion

- Radio radiation, with varying induction field, may be received by an antenna as microwave radiation.
- An atom emits light radiation due to motion of charged particles in the electric field of the nucleus or fields of the other electrons.
- An atom emits radio radiation due to acceleration of charged particles by the electric field of the nucleus or fields of the other electrons.
- Radio radiation, always accompanying light radiation, explains the occurrence of Microwave Background Radiation as a local phenomenon from oscillating charged particle in atoms of matter
- While light radiation is transmissible in seawater (a conductor), radio radiation is not.
- In equation (25), for a charged particle under free oscillation, the radiation power is proportional to the square of frequency, as is the case for radiation from a radio transmission antenna.
- Radio radiation, from moving electric charges in atoms of matter, may be received by an antenna, to account for microwave background radiation.
- In equation (27) for a charged particle moving along an electric field, the average radiation power, is independent of the frequency, as for power dissipation in resistors.
- Equation (38) and equation (44) show that atomic light radiation which may be perceived by the eyes, is of the same magnitude as radio radiation which may be detected by a receiver at microwave level.
- Light radiation and radio radiation should occur at the same frequencies, throughout the electromagnetic spectrum, with a difference in the detection equipment.

Conclusion

Light radiation and radio radiations are transverse electromagnetic waves, with the external electric field and internal induction electric field perpendicular to the direction of propagation in space.

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