

Force of a Hertz-Dipole on a Stationary Charge

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This paper shows a derivation of the forces of a HERTZ dipole antenna acting on a resting, stationary charge. The demonstrated derivation does not use the magnetic field concept but uses the forces between resting, moving and accelerating charges only. In the second part of the paper a comparison with the standard derivation known from literature is presented.

Introduction

In 1888 Heinrich Rudolf HERTZ^{[5]-[7]} has shown the spreading of electrical energy from one oscillator with spark gap to another distant electrical oscillator. At a later stage the spark gap was not used anymore and it evolved this kind of simple arrangement which is now known as HERTZ-Dipole. With this circuit HERTZ has shown the transmission of electromagnetic energy from one resonant circuit to an other in his class room.

As theoretical basis for this experiment HERTZ used the MAXWELL equations from which he derived the correct solution by applying the correct boundary conditions for the HERTZ experiment. The Hertz experiment has confirmed the theoretical predictions in an impressive manner so that it became worldwide known.

The discovery of the fact, that electromagnetic energy can travel through space as an electromagnetic wave as predicted by MAXWELL's equations was of great importance. An other important confirmation of the predictions from Maxwell's theory was the prove, that the oscillating plane of the electromagnetic wave was perpendicular to the propagation direction (transverse wave characteristics) and that in large distances there are no oscillation parallel to the propagation direction (longitudinal waves). In addition it was shown, that the electromagnetic wave can be reflected with a conducting bar grid, if the bars are parallel to the antenna, and that there are no reflections, when the bars are perpendicular to the antenna. All –this has been used as a confirmation, that there is actually an electromagnetic wave in the aether, as predicted by the theory.

The theoretical derivation of the Hertz experiment is done with the concept of electric and magnetic fields. This essay shows that the well-known effects of the so-called electromagnetic radiation can be calculated with the aid of forces between charges only, without the use of the magnetic field concept and without using an electromagnetic wave equation. The result examines clearly the cause for the different field elements near or distant to the HERTZ dipole antenna.

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Electric Forces between Charges

The author^[14] has shown, that an equation – which goes back to Wilhelm Eduard WEBER^[17] – using only forces between uniformly moving charges can be applied for the calculation of experiments, in which the acceleration of charges can be neglected.

The same procedure is now used for the calculation of the force of a HERTZ dipole antenna to an external, stationary positive charge q^+ . There are not only uniformly moving charges within a Hertz dipole. Therefore it is not possible to apply the simplified equation anymore. So we use the general equation of a LIÉNARD-WIECHERT field^[4]:

$$\frac{\mathbf{F}}{q^+} = \mathbf{E} = \frac{q_1}{4\pi\epsilon_0 (1 - \boldsymbol{\beta} \cdot \mathbf{r}^0)^3} \left\{ \frac{1 - \beta^2}{r^2} (\mathbf{r}^0 - \boldsymbol{\beta}) + \frac{1}{c^2 r} [\mathbf{r}^0 \times ((\mathbf{r}^0 - \boldsymbol{\beta}) \times \mathbf{a})] \right\}. \quad (1.1)$$

with

$$\mathbf{n} = \frac{\mathbf{r}}{r}, \quad \boldsymbol{\beta} = \frac{\mathbf{v}}{c}, \quad K = 1 - \boldsymbol{\beta} \cdot \mathbf{n},$$

The direction of the velocity and acceleration vectors are identical with the HERTZ dipole, so that (1.1) can be simplified to

$$\mathbf{E} = \frac{q_1}{4\pi\epsilon_0 (1 - \boldsymbol{\beta} \cdot \mathbf{r}^0)^3} \left\{ \frac{1 - \beta^2}{r^2} (\mathbf{r}^0 - \boldsymbol{\beta}) + \frac{1}{c^2 r} [(\mathbf{a} \cdot \mathbf{r}^0) \mathbf{r}^0 - \mathbf{a}] \right\}. \quad (1.2)$$

This field becomes with the suggested^[14] correction γ :

$$\mathbf{E} = \frac{q_1}{4\pi\epsilon_0 (1 - \boldsymbol{\beta} \cdot \mathbf{r}^0)^3} \left\{ \frac{\sqrt{1 - \beta^2}}{r^2} (\mathbf{r}^0 - \boldsymbol{\beta}) + \frac{1}{c^2 r} [(\mathbf{a} \cdot \mathbf{r}^0) \mathbf{r}^0 - \mathbf{a}] \right\} \quad (1.3)$$

To show, that the traditional results are obtainable, only the linear interactions between charges shall now be used in the following derivation. Actually there are also non-linear terms, which is by the way a ‚trademark‘ of the HERTZ dipole, what also has been mentioned by TESLA^[12]. If the linear terms are used only, then the result is independent of calculating with equation (1.2) or (1.3). A test, if the suggested correction γ will be visible in the Hertz experiment as shown with the induction experiments, is only possible, if the β -terms of a higher degree are measured. Such measurements are extremely difficult because the velocity of the conducting electrons is very small and the factors proportional to β^2 will be much smaller than this proportional to β .

It is only mentioned here that the famous light speed experiment of Albert MICHELSON and Eduard MORLEY^[9] to measure the dependency of the relative motion of the earth to the aether is such a measurement to find terms proportional to β^2 with a high accuracy. And exactly this experiment, which has not proven any influence of the relative motion against an aether, has at the end lead to the use of the relativistic correction factor in physics. It is for example used in the definition of the length dilatation.

HERTZ dipole antenna

The famous oscillator named to Heinrich HERTZ consists of two metal balls, which are connected electrically through an alternating current source. With sufficient high frequencies and small currents it is possible to remove the balls, as it is normally done in high frequency applications.

With an applied alternating current the balls are charged and recharged each opposite to the other with the oscillation frequency $\omega = 2\pi f$. For a charge q^+ in an average distance r to the dipole antenna Q^+-Q^- the following figure applies:

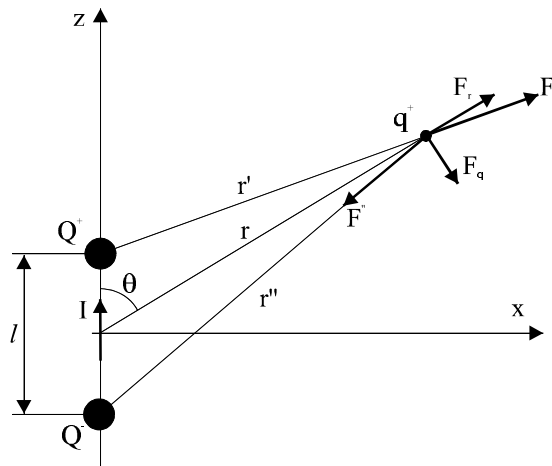


Figure 1: HERTZ Dipol

The following calculation is done with the average distance r for simplification. For the condition $l \ll r$ the two distances r' and r'' can be expressed with r according to the geometry below.

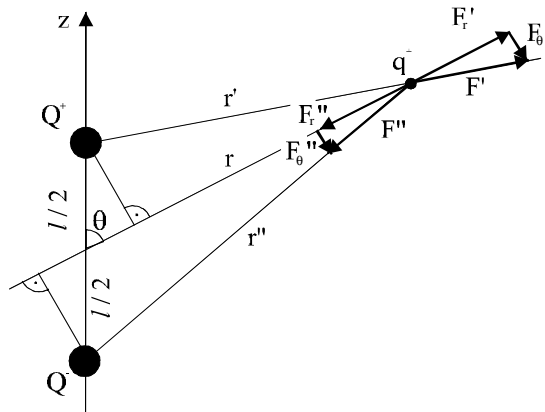


Figure 2: Geometry of a HERTZ Dipol

By neglecting all terms with l^2/r^2 and higher orders, the distances become for $l \ll r$:

$$\begin{aligned}
r' &\cong r - \frac{l}{2} \cos \theta & r'' &\cong r + \frac{l}{2} \cos \theta \\
\frac{1}{r'} &\cong \frac{1}{r} \left(1 + \frac{l}{2r} \cos \theta \right) & \frac{1}{r''} &\cong \frac{1}{r} \left(1 - \frac{l}{2r} \cos \theta \right) \\
\frac{1}{r'^2} &\cong \frac{1}{r^2} \left(1 + \frac{l}{r} \cos \theta \right) & \frac{1}{r''^2} &\cong \frac{1}{r^2} \left(1 - \frac{l}{r} \cos \theta \right)
\end{aligned} \tag{1.4}$$

As usual in literature the force on the charge q^+ shall be decomposed into the component F_r in the direction of \mathbf{r} and in the perpendicular component F_θ . The total charge is the sum of COULOMB's force F_1 of the poles Q^+ and Q^- , of the velocity depending force F_2 and of the acceleration depending force F_3 , which is caused by the current I between the charges Q^+ and Q^- . The COULOMB force of F_1' and F_1'' with the distances r' and r'' can be formulated depending on the angle θ for $l \ll r$ like:

$$\begin{aligned}
\frac{F'}{r'} &= \frac{F'_\theta}{\frac{l}{2} \sin \theta} = \frac{F'_r}{r - \frac{l}{2} \cos \theta} \Rightarrow F'_\theta = F' \frac{l}{2r} \sin \theta; \quad F'_r = F' \\
\frac{F''}{r''} &= \frac{F''_\theta}{\frac{l}{2} \sin \theta} = \frac{F''_r}{r + \frac{l}{2} \cos \theta} \Rightarrow F''_\theta = F'' \frac{l}{2r} \sin \theta; \quad F''_r = F''
\end{aligned} \tag{1.5}$$

On both poles Q^+ and Q^- the number of negative charges vary with time, while the positive charges remain constant. For the opposite oscillation of the poles the time function of their charge and of the current between these charges can be proposed with the oscillation frequency ω as:

$$Q^+(t) = \hat{Q} e^{i\omega t} \quad Q^-(t) = -\hat{Q} e^{i\omega t} \tag{1.6}$$

$$I(t) = \frac{dQ(t)}{dt} = i\omega \hat{Q} e^{i\omega t} \tag{1.7}$$

The COULOMB force of the two poles on q^+ is:

$$\frac{F_1'}{q^+} = \frac{\hat{Q} e^{i\omega t}}{4\pi\epsilon_0 r'^2} \mathbf{r}'^0 \quad \frac{F_1''}{q^+} = -\frac{\hat{Q} e^{i\omega t}}{4\pi\epsilon_0 r''^2} \mathbf{r}''^0 \tag{1.8}$$

With (1.4) follows:

$$\begin{aligned}
\frac{F_1'}{q^+} &= \frac{\hat{Q} e^{i\omega t}}{4\pi\epsilon_0} \frac{1 + \frac{l}{r} \cos \theta}{r^2} \left[\mathbf{r}_r^0 + \frac{l}{2r} \sin \theta \mathbf{r}_\theta^0 \right], \\
\frac{F_1''}{q^+} &= \frac{\hat{Q} e^{i\omega t}}{4\pi\epsilon_0} \frac{1 - \frac{l}{r} \cos \theta}{r^2} \left[-\mathbf{r}_r^0 + \frac{l}{2r} \sin \theta \mathbf{r}_\theta^0 \right].
\end{aligned} \tag{1.9}$$

Then the sum of forces of the two poles is with (1.7)

$$\frac{F_1}{q^+} = -\frac{I(t)l}{4\pi\epsilon_0} \left[\frac{2i}{\omega r^3} \cos \theta \mathbf{r}_r^0 + \frac{i}{\omega r^3} \sin \theta \mathbf{r}_\theta^0 \right] \tag{1.10}$$

This interim result shows only a proportionality to $1/r^3$. Next the influence of the moving charges is considered. The complete formulation of the LIENARD-WIECHERT field (1.1) gives beside to the accelerating term also the electric field of a charge moving with the velocity \mathbf{v} with the retarded distance r and with respect to the charge q^+ . For time varying currents – thus also for changing velocities – the successful^[14] applied equation (1.3) used for uniformly moving charges at the present position is not valid anymore, because of the changing velocity. Thus it is necessary to use the velocity depending term of the LIENARD-WIECHERT field.

The current shall be no function of propagation direction \mathbf{z} (i.e. $\lambda = 2\pi c/\omega \ll r$). So for at a given time all free electrons in the conductor element between Q^+ and Q^- have the same velocity and acceleration. The forces to q^+ are caused of the relative to the wire l resting charges q_1^+ and of the moving charges q_1^- . Does the velocity \mathbf{v} not depend on the actual position along z , then for a wire ,cell‘ consisting of a wire-ion q_1^+ and a wire-electron q_1^- the forces are:

$$\frac{d\mathbf{F}_2^-}{q^+} = \frac{q_1^-}{4\pi\epsilon_0(1-\boldsymbol{\beta} \cdot \mathbf{r}^0)^3} \frac{1-\beta^2}{r^2} (\mathbf{r}^0 - \boldsymbol{\beta}) \quad \text{und} \quad \frac{d\mathbf{F}_2^+}{q^+} = \frac{q_1^+}{4\pi\epsilon_0 r^2} \mathbf{r}^0 \quad (1.11)$$

and the total force

$$\frac{d\mathbf{F}_2}{q^+} = \frac{e}{4\pi\epsilon_0(1-\boldsymbol{\beta} \cdot \mathbf{r}^0)^3} \frac{1}{r^2} \left\{ \left[1-\beta^2 - (1-\boldsymbol{\beta} \cdot \mathbf{r}^0)^3 \right] \mathbf{r}^0 - (1-\beta^2) \boldsymbol{\beta} \right\} \quad (1.12)$$

With the suppression of all non linear terms of \mathbf{v} , what is allowed for low velocities, equation this reduces to

$$\frac{d\mathbf{F}_2}{q^+} = \frac{e \mathbf{v}}{4\pi\epsilon_0 c r^2} \left[3 \cos \theta \mathbf{r}_r^0 - \mathbf{v}^0 \right] \quad (1.13)$$

From figure 2 follows $\mathbf{v}^0 = \cos \theta \mathbf{r}_r^0 - \sin \theta \mathbf{r}_\theta^0$. Thus

$$\frac{d\mathbf{F}_2}{q^+} = \frac{e \mathbf{v}}{4\pi\epsilon_0 c r^2} \left[2 \cos \theta \mathbf{r}_r^0 + \sin \theta \mathbf{r}_\theta^0 \right] \quad (1.14)$$

what can be enlarged to a wire element of length $d\xi$ to

$$\frac{d\mathbf{F}_2}{q^+} = \frac{N_1 A_1 e v(t_r) d\xi}{4\pi\epsilon_0 c r^2} \left[2 \cos \theta \mathbf{r}_r^0 + \sin \theta \mathbf{r}_\theta^0 \right] = \frac{I(t_r) d\xi}{4\pi\epsilon_0 c r^2} \left[2 \cos \theta \mathbf{r}_r^0 + \sin \theta \mathbf{r}_\theta^0 \right] \quad (1.15)$$

and is finally integrated over the path l to the velocity depending force \mathbf{F}_2 :

$$\begin{aligned} \frac{\mathbf{F}_2}{q^+} &= \frac{I}{4\pi\epsilon_0 c} \left[2 \cos \theta \mathbf{r}_r^0 + \sin \theta \mathbf{r}_\theta^0 \right] \int_{-\frac{l}{2}}^{\frac{l}{2}} \frac{1}{r^2} \left(1 + \frac{2\xi}{r} \cos \theta \right) d\xi \\ \frac{\mathbf{F}_2}{q^+} &= \frac{Il}{4\pi\epsilon_0} \left[\frac{2}{cr^2} \cos \theta \mathbf{r}_r^0 + \frac{1}{cr^2} \sin \theta \mathbf{r}_\theta^0 \right] \end{aligned} \quad (1.16)$$

At the end the influence of the accelerating charges is examined. Again the acceleration shall not be a function of z . Then equation (1.2) can be applied to all free, accelerating electrons q^- in the wire:

$$\frac{d\mathbf{F}_3}{q^+} = \frac{dq^- a(t)}{4\pi\epsilon_0 c^2 r} \left[(\mathbf{r}^0 \cdot \mathbf{a}^0) \mathbf{r}^0 - \mathbf{a}^0 \right] = \frac{N_1 A_1 q^- \frac{dv}{dt} d\xi}{4\pi\epsilon_0 c^2 r_\xi} \left[\cos \theta \mathbf{r}_r^0 - \cos \theta \mathbf{r}_r^0 + \sin \theta \mathbf{r}_\theta^0 \right] \quad (1.17)$$

$$\frac{d\mathbf{F}_3}{q^+} = \frac{i\omega I d\xi}{4\pi\epsilon_0 c^2 r_\xi} \sin \theta \mathbf{r}_\theta^0 \quad (1.18)$$

With $l \ll r$ and with integration of all wire elements $d\xi$ it follows for the force \mathbf{F}_3 :

$$\frac{\mathbf{F}_3}{q^+} = \frac{i\omega I}{4\pi\epsilon_0 c^2} \sin \theta \mathbf{r}_\theta^0 \int_{-\frac{l}{2}}^{\frac{l}{2}} \frac{1}{r} \left(1 - \frac{\xi}{r} \cos \theta \right) d\xi = \frac{i\omega I l}{4\pi\epsilon_0 c^2 r} \sin \theta \mathbf{r}_\theta^0 \quad (1.19)$$

what results in the total acceleration depending force \mathbf{F}_3 :

$$\frac{\mathbf{F}_3}{q^+} = \frac{I l}{4\pi\epsilon_0} \frac{i\omega}{c^2 r} \sin \theta \mathbf{r}_\theta^0 \quad (1.20)$$

The addition of the forces of resting charges (1.10), of moving charges (1.16) and of accelerated charges (1.20) gives the well known electric field (for $l \ll r$):

$$\frac{\mathbf{F}}{q^+} = \mathbf{E}(t_r) = \frac{I(t_r) l}{4\pi\epsilon_0} \left[\left(\frac{2}{cr^2} - \frac{i2}{\omega r^3} \right) \cos \theta \mathbf{r}_r^0 + \left(\frac{i\omega}{c^2 r} + \frac{1}{cr^2} - \frac{i}{\omega r^3} \right) \sin \theta \mathbf{r}_\theta^0 \right] \quad (1.21)$$

The derivation of has shown, that the radiating electric field \mathbf{E} of a HERTZ dipole antenna can consequently be calculated on the basis of resting, moving and accelerating charges. The particular field parts depending on the distance r shown in (1.21) can unequivocal be addressed to a corresponding cause:

In first approximation the different field parts of a HERTZ dipole antenna

- caused by *resting* charges are **proportional to $1/r^3$** ,
- caused by *moving* charges are **proportional to $1/r^2$** , and
- caused by *accelerating* charges are **proportional to $1/r$** .

Furthermore the wave characteristics can be derived from (1.21) to:

- **proportional to $1/r^3$** has transversal and longitudinal wave parts,
- **proportional to $1/r^2$** has transversal and longitudinal wave parts and
- **proportional to $1/r$** has a transversal wave part only.

Comparison with standard text books

An other possibility for calculation - as it was given in a similar form by MOON & SPENCER ^[10] – offers the potential field of the two poles Q^+ and Q^- . The necessary equation for the potential of a point charge is only valid for charges constant in time. For a changing charge, the time, which is needed by the potential change propagation to an other charge, must be taken into consideration. The retarded potential of a time varying charge is given at the distance r with:

$$\phi(r, t) = \frac{Q(t - r/c)}{4\pi\epsilon_0 r} \quad (2.1)$$

The gradient of this potential results in the electric force field between two charges:

$$\mathbf{E}(r, t) = \frac{Q(t - r/c)}{4\pi\epsilon_0 r^2} + \frac{\dot{Q}(t - r/c)}{4\pi\epsilon_0 cr} \quad (2.2)$$

The electric field of a time varying charge again points into radial direction. In addition it appears a term proportional to $1/r$, which is caused by the finite propagation speed c of a change of the potential field. Normally by experiment there are no single charges which vary in time but at least two charges. This is a consequence of the law of charge preservation. Nevertheless the retarded field of a time varying charge can be used to calculate the radiated electric field of a HERTZ dipole antenna. For the opposite oscillation of the poles with frequency ω the time function of their charge can be described as:

$$Q^+(r, t) = \hat{Q}e^{i\omega(t-r'/c)} \quad Q^-(r, t) = \hat{Q}e^{i\omega(-t+r''/c)} \quad (2.3)$$

Then the retarded COULOMB field of the two poles to q^+ is:

$$\frac{\mathbf{F}'}{q^+} = \frac{\hat{Q}e^{i\omega(t-r'/c)}}{4\pi\epsilon_0} \left(\frac{1}{r'^2} + \frac{i\omega}{cr'} \right) \mathbf{r}'^0 \quad \frac{\mathbf{F}''}{q^+} = \frac{\hat{Q}e^{-i\omega(t-r''/c)}}{4\pi\epsilon_0} \left(\frac{1}{r''^2} + \frac{i\omega}{cr''} \right) \mathbf{r}''^0 \quad (2.4)$$

With the same derivation as carried out by MOON & SPENCER ^[10], we get:

$$\frac{\mathbf{F}_1}{q^+} = \frac{I(t)l}{4\pi\epsilon_0} \left[\left(\frac{i\omega}{c^2 r} + \frac{2}{cr^2} - \frac{i2}{\omega r^3} \right) \cos \theta \mathbf{r}_r^0 + \left(\frac{1}{cr^2} - \frac{i}{\omega r^3} \right) \sin \theta \mathbf{r}_\theta^0 \right] \quad (2.5)$$

This comes close to the known radiated field (1.21) of a Hertz dipole. The terms proportional $1/r^3$ and $1/r^2$ are correctly included, but not the term proportional to $1/r$. Would equation (2.5) be valid, then a longitudinal wave with an amplitude proportional to $1/r$ is expected. But this does not correspond to the experiments.

Surprisingly - but as normally done (for example [4]^{Eq.9.28}) – the scalar product between \mathbf{a} and \mathbf{r} according to (1.2) is suppressed and instead of (1.17) one writes

$$\frac{d\mathbf{F}_3}{q^+} = \frac{dq^- a(t)}{4\pi\epsilon_0 c^2 r} [-\mathbf{a}^0] = \frac{i\omega I d\xi}{4\pi\epsilon_0 c^2 r_\xi} [-\cos \theta \mathbf{r}_r^0 + \sin \theta \mathbf{r}_\theta^0] \quad (2.6)$$

and from that the force \mathbf{F}_3

$$\frac{\mathbf{F}_3}{q^+} = \frac{i\omega I l}{4\pi\epsilon_0 c^2 r} [-\cos \theta \mathbf{r}_r^0 + \sin \theta \mathbf{r}_\theta^0] \quad (2.7)$$

what finally leads also to the known result (1.21) of the HERTZ dipole. Instead of time varying charges the calculations are carried out with the so called HERTZ-Vektor \mathbf{p} , which basically describes the field of two charge dipoles in the direction of \mathbf{r} (see for example [1]^{p239-244}; [4]^{p.296}).

³⁰¹[1]). This traditional derivation leads exactly to the same result as equation (2.5), 0, which in turn is derived from retarded fields of two single charges. In addition the traditional derivation (for example [1]^{p.242}; [4]^{Eq.9.38}) gives for the current depending field the same result as equation (2.7).

This double derivation of the radiated field of the HERTZ dipole antenna was necessary to present the difference between the new and the traditional derivation. The reason for the differences is again – as seen with the examples of moving charges – that the electric current I of a wire element $d\xi$ once is thought to be the movement of conducting charges $q\mathbf{v}$, once it is supposed to be equal to a current density \mathbf{J} in a volume element dV and once it is considered to be equivalent to the time derivation of the HERTZ vector field $d\mathbf{p}/dt$.

Previously ^[14] it was shown, that the velocity depending part of the LIENARD-WIECHERT field (1.1) needs the correction term γ . This is basically also the case for the derivation of the velocity depending part of the HERTZ dipole, but as long as only the linear parts of β are taken into consideration, how it is done especially in the derivation of (1.13), this correction will not take effect. Therefore for $v \ll c$ the force fields between accelerated charges can be approximately expressed without the correction.

From the simplifying assumptions (1.4) used for the derivation of the radiated electric field it is furthermore to see, that also terms with higher powers of the angle θ exist, which however are disappearing compared with the field of (1.21) when $l \ll r$. Additional non linear terms are expected due to velocity depending field, which will be noticed with relativistic velocities only.

Longitudinal Waves

In the passing years the electromagnetic longitudinal waves are again subject for discussions. Some ^[8] assume, that Nikola TESLA ^[13] has worked with a such kind of waves, also because he has mentioned this. Others ^[1] suppose, that a modelling of electrodynamics with complex quaternions (LIE-Algebra) does predict scalar (longitudinal) waves, if the LORENTZ gauge

$$\nabla \cdot \mathbf{A} + \frac{\partial \phi}{\partial t} = 0 \quad (2.8)$$

is not valid. An experimental proof for such scalar (longitudinal) waves is not available these days. Recently ^[11] Konstantin MEYL has demonstrated an experiment about longitudinal waves, which also can be explained with classical high frequency circuit analysis ^[16], so that this experiment is not valid as a clear proof of longitudinal waves, too.

The experiments of Nikola Tesla – especially the ones with a nearly loss-less transmission of electrical energy from a power transmitter to a receiver in great distance – will be analyzed with the concept of forces between charges only in another paper ^[14].

Closing Remarks

It was shown that the linear field parts of a Hertz dipole can be described without the concept of a magnetic field but using only the interactions between resting, moving and accelerating charges.

The correction factor γ , which was introduced to the LIÉNARD-WIECHERT field to describe induction effects without contradictions, has in this special case of linear considerations no effect to the result. Only when calculating the non-linear terms this correction factor should influence the result. This can be tested experimentally.

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