The Ephemeris

Focus and books

Induction Produces Aharonov-Bohm Effect

A charge e, moving with the velocity $\mathbf{v}$ through a time-constant space-varying magnetic potential field $\mathbf{A}$, experiences a force of motional induction given by $\mathbf{F} = -e(\mathbf{v}\cdot\nabla)\mathbf{A}/c$. Although the magnetic field is zero, $\mathbf{B} = 0$; this force acts on the electrons passing on the two sides of a long solenoid to produce the phase shift difference observed in the Aharonov-Bohm effect.

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1. Introduction

The Aharonov-Bohm (1959) effect is a shift in the electron interference pattern produced by an electron beam split to pass on opposite sides of a long thin solenoid, when current flows in the solenoid. It is clearly an electrodynamic effect; because no effect is produced when no current flows in the solenoid. According to the Maxwell-Lorentz theory, an electron moving outside the solenoid, where there is no magnetic field, should experience no electrodynamic force. In particular, the magnetic vector potential $\mathbf{A}$ outside of a long solenoid of radius a carrying a current per unit length η is given by

$$\mathbf{A} = \frac{2\pi\eta a^2}{cr}\mathbf{e}_\phi \tag{1}$$

where $\mathbf{e}_\phi$ is a unit vector in the direction of the current and r is the radial distance from the center of the solenoid to the point of observation. From Eq. (1) the curl and divergence of $\mathbf{A}$ are seen to vanish; thus,

$$\nabla\times\mathbf{A} = 0, \quad \nabla\cdot\mathbf{A} = 0 \tag{2}$$

Since $\mathbf{A}$ does not change with time and no static charge sources are present; the Lorentz force on an electron of charge e, moving with the velocity $\mathbf{v}$ vanishes; thus,

$$\mathbf{F}_L = -e\nabla\Phi - \frac{e}{c}\frac{\partial\mathbf{A}}{\partial t} + \frac{e}{c}\mathbf{v}\times(\nabla\times\mathbf{A}) = 0 \tag{3}$$

According to Bohm (1993) the Aharonov-Bohm effect is some sort of mysterious quantum mechanical interaction between the electrons and the magnetic potential field $\mathbf{A}$. But, in fact, a perfectly classical electrodynamic force acts on an electron moving outside of a long solenoid, the force of motional induction, which is given by

$$\mathbf{F} = -\frac{e(\mathbf{v}\cdot\nabla)\mathbf{A}}{c} \tag{4}$$

It may be seen from Eq. (1) that this force of motional induction, Eq. (4), does not vanish. The force of motional induction does not belong in Eq. (3); because it is not a conservative force, and the Lorentz force, when valid (Wesley 1990), is a conservative force.

2. Force of Motional Induction from Faraday Electromagnetic Induction

It is known empirically that an electromotive force (emf) can be induced in a closed loop given by Faraday's law of electromagnetic induction, where

$$\text{emf} = \oint\left(\frac{\mathbf{F}}{e}\right)\cdot d\mathbf{s} = -\frac{\partial\Phi}{\partial tc} \tag{5}$$

where Φ is the total magnetic flux through the loop given by

$$\Phi = \int\mathbf{B}\cdot\mathbf{n}\,da = \int(\nabla\times\mathbf{A})\cdot\mathbf{n}\,da = \oint\mathbf{A}\cdot d\mathbf{s} \tag{6}$$

Equating the integrands of Eqs. (5) and (6), the force of induction on a charge e is given by

$$\mathbf{F} = -\frac{e}{c}\frac{\partial\mathbf{A}}{\partial t} \tag{7}$$

This force is included in the Lorentz force, Eq. (3).

It is found empirically that the manner or way that the $\mathbf{A}$ field is increased (or decreased) in the loop is a matter of indifference. If a magnet is moved with a velocity $\mathbf{v}$ into a loop, an emf is induced. Or, if a loop is moved toward a magnet, an emf is induced in the loop. Empirically it is, thus, necessary to include in Eq. (7) the possibility of increasing the apparent time rate of change of the $\mathbf{A}$ field by virtue of the motion of the charge or by virtue of the motion of the source of the $\mathbf{A}$ field. In particular, to fit empirical fact Eq. (7) must be generalized to read

$$\mathbf{F} = -\frac{e}{c}\frac{d\mathbf{A}}{dt} = -\frac{e}{c}\frac{\partial\mathbf{A}}{\partial t} - \frac{e(\mathbf{v}\cdot\nabla)\mathbf{A}}{c} \tag{8}$$

For the case of $\partial\mathbf{A}/\partial t = 0$, of interest for the Aharonov-Bohm effect, the force of motional induction on a moving charge e becomes simply the second term on the right of Eq. (8), as already presented in Eq. (4).

It is important to note that the force of motional induction, Eq. (4), which is empirically established by Faraday induction, is not a part of the Lorentz force, Eq. (3). The nonconservative force of motional induction must be handled separately.

3. Force of Motional Induction from the Weber Potential

Contrary to the Maxwell theory, which fails many empirical tests (Wesley 1990), Weber (1846) electrodynamics is empirically correct for slowly varying effects and slowly moving charges. The Weber theory is based upon the velocity dependent potential W for a charge e at $\mathbf{r}$ and a charge q' at $\mathbf{r}'$ given by

$$W = \frac{eq'}{R}\left[1 - \frac{(dR/dt)^2}{2c^2}\right] \tag{9}$$

where $R = |\mathbf{r}-\mathbf{r}'|$ is the separation distance. Neglecting the Coulomb potential here and neglecting the negligibly small velocity squared terms, $(\mathbf{v}\cdot\mathbf{R}/cR)^2$ and $(\mathbf{v}'\cdot\mathbf{R}/cR)^2$, where $\mathbf{v}$ is the velocity of the charge e and $\mathbf{v}'$ is the velocity of the charge q', the Weber potential, Eq. (9), becomes

$$W = \frac{eq'(\mathbf{v}\cdot\mathbf{R})(\mathbf{v}'\cdot\mathbf{R})}{c^2R^3} \tag{10}$$

For a closed current loop source, the case of interest here, where $q'\mathbf{v}' = I'd\mathbf{s}'$, Eq. (10) may be integrated to yield the net potential

$$W = \frac{eI'}{c^2}\oint \mathbf{v}\cdot\frac{d\mathbf{s}'}{R} \tag{11}$$

For a volume distribution of such closed current loops, where $I'd\mathbf{s}' = \mathbf{J}'d^3r'$, the Weber potential* becomes

$$W = \frac{e}{c^2}\int \mathbf{v}\cdot\left(\frac{\mathbf{J}'}{R}\right)d^3r' = \frac{e\mathbf{v}\cdot\mathbf{A}}{c} \tag{12}$$

from the definition of the vector potential $\mathbf{A}$ in terms of the current distribution $\mathbf{J}'$.

* The Weber potential here, Eq. (11), happens to equal the negative of the nonphysical pseudo-potential that is introduced to rescue the usual ad hoc Lagrangian formalism needed to yield the Lorentz force (Goldstein 1950).

To obtain the force implied by Eq. (12) the rate that energy is taken from the potential W for a constant velocity $\mathbf{v}$ equals the rate that work is done on the charge e; thus,

$$-\frac{dW}{dt} = -\frac{e\mathbf{v}\cdot d\mathbf{A}}{c\,dt} = \mathbf{v}\cdot\mathbf{F} \tag{13}$$

This means that the force of motional induction on e for the case of interest, where $\partial\mathbf{A}/\partial t = 0$, is given by

$$\mathbf{F} = -\frac{e(\mathbf{v}\cdot\nabla)\mathbf{A}}{c} \tag{14}$$

which is in agreement with the empirical observations of Faraday induction, as given by Eq. (4).

4. The Force of Motional Induction Is Not Conservative

To stress the nonconservative character of the force of motional induction, Eq. (4), it may be shown that the work done on a charge depends upon its path for the Aharonov-Bohm situation. In particular, two different paths may be considered that carry charges from the same two end points, from $x = -\infty$ to the point at $x = b$, $y = 0$, as indicated in Fig. 1. Path I is taken along the line $y = -b$ to $x = 0$ and then along the quarter circle of radius b from $\phi = -\pi/2$ to $\phi = 0$. Path II is taken along the line $y = +b$ to $x = 0$ and then along the quarter circle of radius b from $\phi = +\pi/2$ to $\phi = 0$.

For this mathematical example the velocity may be taken as constant in the x direction, $\mathbf{v} = v\mathbf{e}_x$. The force of motional induction from Eqs. (4) and (1) becomes

$$\mathbf{F} = -e(\mathbf{v}\cdot\nabla)\mathbf{A} = \frac{Kv\cos\phi}{r^2}\mathbf{e}_\phi \tag{15}$$

where K is a constant given by

$$K = \frac{2\pi e\eta a^2}{c^2} = \frac{e\Phi}{2\pi c} \tag{16}$$

where $\Phi = 4\pi^2\eta a^2/c$ is the total magnetic flux in the solenoid. The work done in going from $x = -\infty$ to $x = 0$ is given by

$$\int_{-\infty}^{0} F_x\,dx = \pm Kvb\int_{-\infty}^{0}\frac{x\,dx}{(x^2+b^2)^2} = \mp\frac{Kv}{2b} \tag{17}$$

where the upper sign is for path I, below the solenoid, and the lower sign is for path II, above the solenoid. The work in going along a circular path from $x = 0$, $y = \mp b$ to $x = b$, $y = 0$ is given by

$$\int F\cdot\mathbf{e}_\phi\,b\,d\phi = \frac{Kv}{b}\int_{\mp\pi/2}^{0}\cos\phi\,d\phi = \pm\frac{Kv}{b} \tag{18}$$

The net work done along the two paths are then given by

$$\text{Work along path I} = \frac{Kv}{b}, \quad \text{Work along path II} = -\frac{Kv}{b} \tag{19}$$

Thus, the force of motional induction is not conservative for this mathematical example, and therefore, not in general.

5. Derivation of the Aharonov-Bohm Phase Difference

The phase changes in the two electron waves passing on opposite sides of the solenoid may be readily computed. Considering the Wesley (1965) wave for a free particle,

$$\Psi = \sin\left[\frac{\mathbf{p}\cdot(\mathbf{r}-\mathbf{v}t)}{\hbar}\right] \tag{20}$$

where $\mathbf{p}$ is the momentum and $\mathbf{v}$ the velocity of the electron, the path length of the two electron beams is the same on the two sides of the solenoid, so a phase difference can only arise due to a time-of-travel difference. The phase change Θ of an electron wave along a path where the momentum $\mathbf{p}$ can change as a function of position is given from Eq. (20) by

$$\Theta = -\int \frac{(\mathbf{p}\cdot\mathbf{v})\,dt}{\hbar} = -\int \frac{\mathbf{p}\cdot d\mathbf{s}}{\hbar} \tag{21}$$

From Eq. (8) and Newton's second law

$$\frac{d\mathbf{p}}{dt} = -\frac{e}{c}\frac{d\mathbf{A}}{dt} \tag{22}$$

Integrating Eq. (22) yields

$$\mathbf{p} = -\frac{e\mathbf{A}}{c} + \mathbf{p}_o \tag{23}$$

where $\mathbf{p}_o$ is a constant of integration. Since only the phase differences are of interest and $\mathbf{p}_o$ is a constant, Eqs. (21) and (23) yield

$$\Theta = \left(\frac{e}{c\hbar}\right)\int \mathbf{A}\cdot d\mathbf{s} \tag{24}$$

It may be noted from Eq. (1) that $\mathbf{A}$ may be expressed as the gradient of a scalar ζ; thus,

$$\mathbf{A} = \left(\frac{\Phi}{2\pi}\right)\nabla\zeta \quad \text{where} \quad \zeta = \ln r \tag{25}$$

where $\Phi = 4\pi^2\eta a^2/c$ is the magnetic flux in the solenoid. The integral in Eq. (24) is thus independent of the path as long as the origin is not enclosed. Integrating $\mathbf{A}\cdot d\mathbf{s}$ once around a closed circle that includes the origin yields from Eq. (1)

$$\oint \mathbf{A}\cdot d\mathbf{s} = \Phi \tag{26}$$

Thus, comparing the phase change, Eq. (24), along path I′ from $x = -\infty$ to $x = +\infty$ along $y = -b$, below the solenoid, in the direction of $\mathbf{A}$ (where the geometry is indicated in Fig. 1), with the phase change along path II′ from $x = -\infty$ to $x = +\infty$ along $y = +b$, above the solenoid, counter to the direction of $\mathbf{A}$, then gives the phase difference of interest

$$\Delta\Theta = \left(\frac{e}{c\hbar}\right)\left[\int_{I'} - \int_{II'}\right]\mathbf{A}\cdot d\mathbf{s} = \frac{e\Phi}{c\hbar} \tag{27}$$

This phase difference, Eq. (27), is the difference producing the shift in the interference pattern observed (Peshkin & Tonomura 1989).

6. Weber Potential, the Force of Motional Induction, and the Phase as Functions of the Electron Position

The quantities of interest for the Aharonov-Bohm effect as functions of position along the electron path may be approximated by considering the charge e to move with a constant velocity $\mathbf{v} = v\mathbf{e}_x$. The Weber potential from Eqs. (12) and (1) then becomes

$$W = \pm\frac{Kvb}{(x^2+b^2)} \tag{28}$$

where the upper sign is for path I′, below the solenoid in the direction of $\mathbf{A}$, and the lower sign is for path II′, above the solenoid counter to the direction of $\mathbf{A}$, and where K is given by Eq. (16). This result (28) is shown in Fig. 2.

The component of the force of motional induction in the x direction from Eqs. (4) and (1) is given by

$$F_x = \pm\frac{Kvbx}{(x^2+b^2)^2} \tag{29}$$

where the upper sign is for path I′ below the solenoid and the lower sign is for path II′ above the solenoid. This result (29) is also shown in Fig. 2.

The phase change Θ, as given by Eqs. (24) and (1), becomes

$$\Theta = \mp\left(\frac{K}{\hbar}\right)\tan^{-1}\left(\frac{b}{x}\right) \tag{30}$$

where again the upper sign is for path I′ and the lower sign for path II′. This result (30) is also shown in Fig. 2. The net phase difference $\Delta\Theta$ between paths I′ and II′ at $x = +\infty$ is seen to be

$$\Delta\Theta = \frac{4\pi^2\eta a^2}{c^2} \cdot \frac{K}{\hbar} = \frac{2\pi K}{\hbar} = \frac{e\Phi}{c\hbar} \qquad (31)$$

in agreement with Eq. (27) and the observations.

7. Some Conclusions

It may be seen from Fig. 2 that an electron, passing below the solenoid in the direction of **A**, climbs a potential hill, which causes it to take longer to reach its destination, where it then arrives with a greater phase change $+\Delta\Theta/2$. An electron, passing above the solenoid counter to the direction of **A**, crosses a potential valley, causing it to take less time to reach its destination, where it then arrives with a smaller phase change $-\Delta\Theta/2$. The net phase difference between the two paths is $\Delta\Theta$. The Aharonov-Bohm effect, thus, measures essentially the time difference necessary for electrons to traverse the two paths on opposite sides of the solenoid. No quantum mechanical effect per se is involved.

The Aharonov-Bohm effect is produced by the classical macroscopic electrodynamic force of motional induction acting on the moving electrons. This force of motional induction can exist even when the conservative forces vanish and the magnetic field remains zero. The Aharonov-Bohm effect is, thus, not per se a quantum mechanical effect.

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Book Review

Retardation and Relativity, Oleg D. Jefimenko, Electret Scientific, Star City, 1997.

After his two previous books referred to hereafter as I,II, [*Electricity and Magnetism* (2nd Ed, Electret Scientific, 1989) and *Causality, Electromagnetic Induction and Gravitation* (Electret Scientific, Star City, 1992)], Professor Jefimenko brings a further building block to logical foundations of electromagnetism, relativity and gravitation. In each case, the author presents new and fresh approaches to the theory of the physical processes he analyses.

The book under review subtitled “New chapters in the classical theory of fields” is divided into two parts. The first part “presents the fundamentals of the theory of electromagnetic retardation with emphasis on recently discovered relations and recently developed mathematical techniques”. In particular, the author uses the time-dependent generalization of the Biot-Savart and Coulomb laws that he has previously obtained (I, pp. 514-517). The second part presents “the fundamentals of the theory of relativity based entirely” on the results of the first part. Since relativity can be considered historically as a consequence of the non-covariance of Maxwell's equations under the Galilei group, it was a logical step to go from electromagnetism to mechanics rather than to use the backwards step as usual.

Electric and magnetic fields propagate with finite velocity and electromagnetic retardation is a rather familiar concept since the principle of causality implies that “a present-time quantity (the effect) relates to one or more quantities (causes) that existed at some previous time”. It is shown in Chapter 1 how an inhomogeneous vector wave equation can be solved in terms of retarded fields and potentials and how mathematical manipulations using the Del operator can transform the retarded quantities into more tractable expressions. These results are applied in Chapter 2 to retarded electromagnetic fields and potentials.

Starting from Maxwell's equations, the inhomogeneous vector wave equations for the electric and magnetic fields are first obtained and solved as described in the previous chapter. Then, the corresponding retarded integrals are transformed as time-dependent Biot-Savart and Coulomb laws (I, pp. 515-517) with the advantage that these integrals represent now the electric and magnetic fields in terms of their causative sources: the electric charge and current distributions. They can be also transformed into surface integrals to analyse the electromagnetic field generated by a surface of discontinuity. Similar calculations are made for retarded electric and magnetic potentials that sometimes make easier the calculation of the electromagnetic field. Many examples illustrate the theory. This chapter ends with a section devoted to electromagnetic induction (a summary of Chapter 2 in II): it is shown there that there is no causal relation between time-dependent electric and magnetic fields, their common causative source is the variable electric current.

With Chapter 3, we enter in the domain of moving charges for two special cases: either an arbitrary charge distribution moving uniformly or a point charge in arbitrary motion. In both cases it is shown how the retarded integrals supply the electric, magnetic fields and potentials and that there exists a simple correlation between the electric and magnetic fields so that one has just to calculate the electric field. One may express the retarded integrals in terms of the position of the charge at the time where the fields or potentials have to be determined and it is shown how the volume and the form of the charge distribution change when one goes from the retarded to the present position: an interesting result to explain the visual shape of moving bodies.

Chapter 4 is devoted to a detailed investigation of the fields and potentials generated by a point charge moving first uniformly and second arbitrarily, the case of a line charge uniformly moving along its length also analysed here is used in Chapter 9 to discuss the Lorentz length contraction. The author obtains of course the Liénard-Wiechert potentials but with one important difference: the approximations made to get these potentials are clearly stated and justified, which is not the case for the Liénard or Wiechert derivation. For a uniformly moving point charge the electric field can be expressed in terms of the present position of the charge instead of its retarded position, leading to an expression obtained by Heaviside at the end of the last century. Similarly for a charge moving with a constant speed along a circle, it is easy to get the present position expression of the electric and magnetic fields at the center of the circle. The result is that the electric field differs from the Coulomb field so that as far as atomic systems are concerned the Coulomb law cannot be used as a rigorous basis for any atomic model.

The last chapter of the first part of the book is devoted to a conversion of retarded field and potential integrals for a time-independent uniformly moving charge distributions into present-time integrals since this form of retarded integrals makes easier the comparison with integrals for fields of stationary charges. As previously said, in the present time integrals the integration is performed, not over the retarded volume, but over the real volume that the charge distribution occupies at the moment for which the fields and potentials are to be determined. Many examples are given to illustrate the theory. Although velocity is uniform and charge density constant in time, calculations are nevertheless subtle and one has to admire Professor Jefimenko's virtuosity. But throughout the book, calculations are presented in a very detailed manner so that one has no difficulty to check them.

Let us now come to the second part of the book. Chapter 6 starts with a comparison of the Cartesian components of the present time integrals for electric and magnetic fields in the case of a uniformly moving distribution (1), with the corresponding expressions for a stationary charge (2). Then, it is shown that to change (1) into (2), one needs to apply a Lorentz transformation to co-ordinates and fields. The same transformations are valid to change (2) into (1) with an opposite velocity. One has the same result for the electromagnetic potentials of uniformly moving and stationary charge distributions. Clearly, these transformations are only prescriptions to replace quantities pertaining to uniformly moving charge distributions by quantities pertaining to stationary charge distributions, and vice versa. Chapter 7 uses these results to present the essentials of relativistic electrodynamics. The basic relativistic equations are first given for coordinates, fields, potentials, electric charge and current density.

Then, are easily obtained the transformation equations for velocity, acceleration and partial derivatives with respect to coordinates and time. It is proved that the Cartesian components of Maxwell's equations are invariant under relativistic transformations but that contrary to a general and erroneous opinion, Maxwell's equations in their vector form are not invariant. These relativistic transformations are checked on two simple problems whose solutions, already known on the basis of general electromagnetic laws, are given in the first part of the book. They are the correlation between electric and magnetic fields of a moving charge distribution and the electric field of a moving point charge. Finally several examples illustrate the Lorentz theorem of corresponding states "according to which to any electromagnetic system that is a function of space and time co-ordinates in the rest frame Σ, there corresponds an electromagnetic system in the moving frame Σ', being the same function of space and time co-ordinates (primed co-ordinates) in Σ'". Of course this theorem is a very effective tool to get the electromagnetic field of uniformly moving charge distributions from the corresponding electrostatic and magnetostatic equations.

In Chapter 8, the author presents the relativistic mechanics on the basis of already developed relations of relativistic electrodynamics. The relativistic transformations of the following quantities are discussed: Lorentz force, electromagnetic energy and momentum, mechanical momentum of a charged particle. The dubious concept of relativistic mass is brushed aside although it is known that longitudinal and transverse masses can be used as auxiliary tools. Then, using the Earnshaw theorem according to which mechanical forces are needed to balance the electric forces on a charged body, relativistic expressions for: force, energy, momentum and torque are derived from the electromagnetic counterparts of these quantities. Finally a careful analysis of the transformation equations for mechanical energy and momentum lead to the Einstein's mass-energy equation $W = mc^2$.

In Chapter 9 Professor Jefimenko analyses common misconceptions about relativity theory. As proved in Chapters 6 and 7, in relativistic electromagnetism (retardation) the Lorentz transformations are merely prescriptions to get the expressions of the electromagnetic quantities in one inertial frame when they are given in another inertial frame. So, Lorentz transformations do not generate physical transformations. For instance, as a phenomenon, Lorentz contraction does not exist. This statement is illustrated by analyzing the electric field of a uniformly moving line charge calculated directly by two different methods in Chapters 4 and 7. But this field can be also found by integration of the Heaviside field for a point charge either over the actual or over the Lorentz-contracted length of the moving charge. The agreement happens only for the first case demonstrating that Lorentz contraction is not a true physical effect. The calculations yielding retarded integrals obtained in Chapter 3 provide a solution to the controversial visual shape of a moving body: clearly it is its retarded shape. The author discusses also the electric and magnetic fields of a moving parallel-plate capacitor erroneously tackled in the majority of textbooks. Also important is his solution of the right-angle lever paradox by using real forces, such as the forces created by two interacting opposite electric charges instead of unspecified abstract forces. A careful analysis of electromagnetic forces and momenta proves then the existence of an electromagnetic torque that counterbalances exactly the mechanical torque. So, the paradox is merely a result of an incomplete statement of the problem, when instead of real physical forces one uses some abstract forces and thus fails to take into account the physical effects that take place when the forces are created by well-defined physical interaction."

Chapter 10 is devoted to an analysis of time dilation considered by Einstein as a purely kinematic relativistic effect. According to Einstein "not only clocks run slow, but time itself is dilated in systems that move with respect to the systems considered to be stationary". But a clock is a physical device and its lower rate should have a causal explanation in terms of its mechanism. The author checks this idea on twelve electromagnetic clocks based on the harmonic oscillations of a point charge in different configurations of the electric field, the period of the oscillations of these charges is compared when these clocks are at rest and moving with a uniform velocity. The results are as follows: only six clocks are running in accordance with Einstein's special relativity theory, for the others their rate depends on the type of the clock and even on the orientation of the clock relative to the direction of motion. So, contrary to Einstein's conception, the slowing down of the moving clocks is a dynamical effect. Relativity theory, based on electromagnetism, gives no information on the rate of processes other than the electromagnetic ones: it is meaningless to speak about biological effects such as aging. The Langevin twins are folklore.

But what about the μ-meson experiments interpreted as proofs of the reality of time dilation? In fact, these experiments prove that the rate of certain physical processes is slower in systems moving at high speeds. According to the author, it is prudent "to interpret these experiments as indicating the existence of certain velocity-dependent interactions in the systems under consideration similar to the electromagnetic interactions that made the clocks discussed in this chapter run slower when in motion".

The last chapter of the book is a summary of the chapters 5-8 of II in which the author presents a new theory of gravitation having strong analogies with electromagnetism along the lines suggested a long time ago by Heaviside. Suffice it to say that this theory is very different from General Relativity but does not conflict with any known experimental results. Any interested reader should consult II. An appendix on vector identities complete the book and each chapter is closed with references and interesting remarks often of historical content.

We had the Einstein relativity, the Lorentz-Poincaré relativity, we now have the Jefimenko relativity (retardation) developed from the causal solutions of Maxwell's equations and the Galilean principle of relativity. No additional postulate, hypothesis or conjecture is needed and relativistic mechanics derives consistently from relativistic electromagnetism. Professor Jefimenko must be congratulated for this fine and imaginative book, a real think-tank, that represents a synthesis of the many works he has published over the years.

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The Bookshelf

New Publications on Physics and Astronomy

Pari Spolter, **Gravitational Force of the Sun** (1993 ISBN 0-9638107-5-8, 260 pages, index, hardcover, $29.95US). Orb Publishing, 11862 Balboa Blvd. #182, Granada Hills, CA 91344-2753 USA. Tel.: 818-363-2003, Fax: 818-363-6965. E-mail: OrbPublishing@msn.com.

Paul Marmet, **Einstein's Theory of Relativity versus Classical Mechanics** (1997 ISBN 0-921272-18-9, 200 pages, index, hardcover), Newton Physics Books, 2401 Ogilvie Road, Gloucester, Ontario K1J 7N4, Canada. Email: pmarmet@joule.physics.uottawa.ca.