SOVIET RESEARCH ON THE A-VECTOR POTENTIAL AND SCALAR WAVES (U)

SUMMARY

(U) The Soviets appear to have made significant theoretical progress in dealing with the **A**-vector potential and scalar waves/fields. They have been active in the areas of the Aharonov-Bohm effect as applied to the **A**-vector potential and scalar fields as applied to solving force related problems in the early universe. Although application of the **A**-vector potential in the immediate future might be possible depending on current research, application of any scalar field concepts is out of the question. Soviet progress in this area should be carefully followed. Advancements in this work may provide the basis for whole new concepts in communications, transportation, and perhaps "stealth applications."

SOVIET RESEARCH ON THE A-VECTOR POTENTIAL AND SCALAR WAVES (U)

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1. Introduction (U)

(U) The Soviets have a number of theoretical research programs dealing with the **A**-vector potential and scalar waves. The **A**-vector potential is defined as the potential of the magnetic field. The theoretical ideas for the vector potential were first developed by James C. Maxwell, a 19th century theoretical physicist. Today Maxwell's equations form the basis of electromagnetic theory. This tech brief will discuss the theoretical aspects of the **A**-vector and the Aharonov-Bohm effect associated with it. The scalar wave ideas will be discussed in the same context. Since these ideas are at the forefront of modern physics, immediate applications are apparent only in a limited number of areas. The future potential, however, could be immense.

(U) At one time it was believed that **A** had no real physical significance but over the years this viewpoint has been altered, although some theoretical physicists still believe there is no significance to the **A**-vector. These same physicists while believing that **A** is not real believe that the Aharonov-Bohm effect is real. The argument in this case is whether the **A**-vector is termed to be gauge invariant. Many other Soviet and US physicists, however, (see references 66, 67, and 68 for US) believe that the only way to explain the Aharonov-Bohm effect (see paragraph 2., Background) is to designate the **A**-vector potential as a real field. This might entail a new interpretation of electromagnetic theory; only time will tell if this is the case. If it turns out that indeed the **A**-vector, or some other related potential, is the cause of the Aharonov-Bohm effect, then it might have the following potential advantages for a communications/detection system:

- Will contain potentially more information per channel than an electromagnetic field.
- In the case of an oscillating dipole (two-pole electromagnetic field) far field approximation, **A** falls off as $\sim 1/r$ vs $1/r^2$ (where r is distance from the source) for the electromagnetic field (reference 63).
- The powerless transmission of a signal.

(U) Extensive Soviet research on the **A**-vector potential could have any of the following implications:

- Potential use in advanced communication systems/solid state switching devices.
- New enlightment in classical and quantum physics.
- Change the dielectric constant/magnetic permeability on the skin of an aircraft, thereby making it radar invisible for a particular bandwidth of frequencies (references 21 and 22).

(U) Soviet interest in scalar waves can only be established to the point of saying that scalar fields are used as primitive devices to derive other fields and to study the interaction between a basis scalar field and other force fields. For example the **A**-vector potential can be mathematically derived from a scalar field S in a far-field approximation.

2. Background (U)

(U) In 1959 Aharonov and Bohm in their classic paper pointed out a rather unique but counterintuitive consequence of the appearance of the vector potential in the standard quantum-mechanical treatment of electromagnetic interactions. The magnetic field **B** is derived from the magnetic potential **A** by taking what is termed the vector CURL of **A**; i.e., CURL **A** = **B** where both **A** and **B** are vectors. The authors noted that the vector potential will affect the phase of an electron wavefunction with observable effects even when the electron is restricted to regions of space where the electric and magnetic field intensities vanish. In this original paper the authors suggested the following experiment: Let an electron beam in a vacuum be split coherently so that it travels from a common source to a common detector by two different paths. Depending upon the details of the two paths, the reunited coherent beams will exhibit interference effects at the detector. The Aharonov-Bohm configuration provides no electric or magnetic fields anywhere along either path. The only field present is the vector potential **A**. The magnetic field itself is confined to a long solenoid that threads between the two paths in a region excluded to the electrons. If standard quantum mechanics is correct, then the interference pattern between the reunited beams depends on the vector potential field strength **A** governed by the current in the long thin solenoid. The observed phase shift is predicted to be on the order of ch/e where h is Planck's constant, e is the charge of the electron, and c is the speed of light. Since the wavelengths in question are very small, the observation of this effect would require an exceedingly tiny solenoid. But, since the early 1960's this effect has been observed so many times its reality is not in doubt. See Figure 1 for an experimental setup of this concept.

(U) Special scalar fields (waves) (not electromagnetic) are thought to permeate the entire universe but their only utility is theoretical at this time. Electromagnetic fields can be represented by vector and scalar potentials, but the scalar field itself does not impart energy momentum under present physical conditions. The 19th century physicists Faraday, Ampere, and Volta perceived that electromagnetism originates from scalar and vector potentials. More recently, a number of Soviet researchers have done extensive theoretical work with scalar fields and the early universe. Scalar fields are considered to have a real physical significance in the early universe when coupled to a gravitational field to produce an effective gravitational force which was repulsive, which gave rise to an inflationary universe. However, the scalar field in this case is a Higgs field or special scalar field which has properties unlike that of the electromagnetic or gravitational fields. One purpose of new, high-energy accelerators is to determine if the Higgs field or perhaps some other special scalar field exist. In other aspects one US scientist has claimed that his experimental results indicate that there might be a coupling effect between an electrostatic field and a gravitational field. These experimental results are very tentative and have not been repeated by anyone else. This could indicate that scalar fields might take on some physical significance when coupled to other fields. Scalar field concepts can be tied to supersymmetry and the early universe. One Soviet has shown that certain quantum mechanical constants are also tied to supersymmetry. (See FTD Bulletin 2660P-127-71-86 dated 11 July 1986 for a discussion on supersymmetry.) Scalar fields then might have far reaching future technology applications but no immediate applications are apparent. See Appendix I for a mathematical derivation of the A-vector from a scalar field and the mathematical foundation for the A-vector from first principles.

3. Soviet A-Vector Research (U)

(U) Soviets who are prominent in A-vector potential research include E. L. Feinberg who has written a theoretical paper on the role of electromagnetic potentials in quantum mechanics. In this paper Feinberg concluded that the quantum peculiarity of the behavior of a particle, i.e., an electron, under the influence of the vector potential arises only because the energy of the system (comprised of a solenoid, ring current, and electron(s)) is directly related to the frequency of the electron wave function. If the change of the frequency is

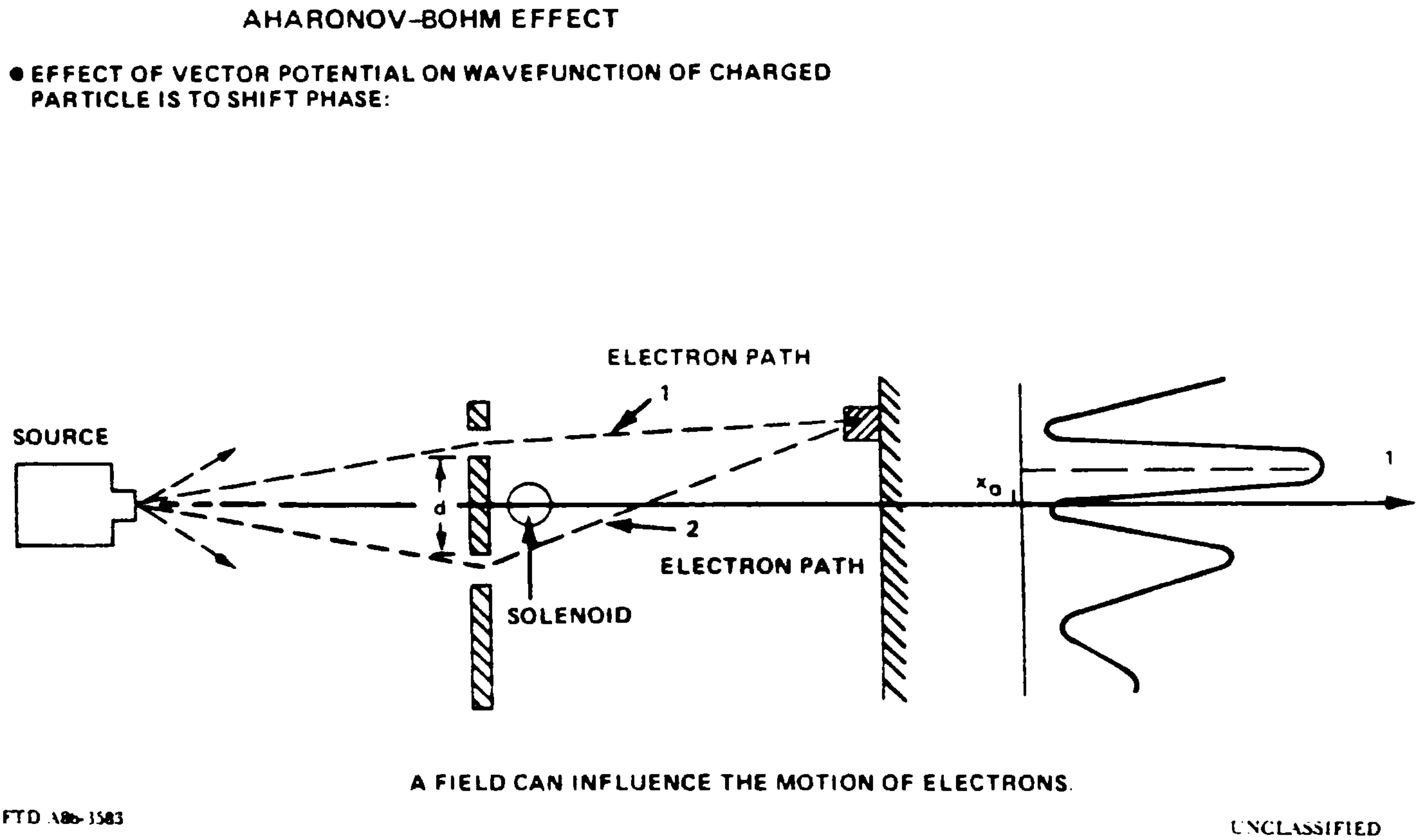

Fig. 1 (U) A-Field can Influence the Motion of Electrons

different in different parts of the wave packet, then there can be an interference effect. It is the A-vector potential which shifts the phase

(U) P. Frolov and V. D. Skarzhinsky of the P. N. Lebedev Physical Institute, Moscow, have developed procedures which will help them understand the vector potential effect. In this procedure the two investigators considered the effects of a magnetic field that was switched on. In this manner they wanted to observe its influence on quantum states for the scattering of an electron wave packet. This allows one to separate the classical aspects of an induced electric field on the electron from the purely quantum mechanical effects connected with the vector potential (Aharonov-Bohm effect).

(U) L. E. Gendenshtein of the Kharkov Physicotechnical Institute, Academy of Sciences of the Ukrainian SSR, has developed mathematical proof by using the A-vector potential demonstrating that the electron's normal magnetic moment (the Bohr magnetron) is based on supersymmetry arguments. In this concept the superpartners are states reflected in space with the direction of the spin and velocity reversed. Supersymmetry then might tie many of the physical constants of nature together and provide an in-depth understanding of the vector potential.

(U) Ya. I. Kogan and A. Yu. Morozov of the Institute of Theoretical and Experimental Physics use a three-dimensional photodynamics scheme to describe a long range effect of the Aharonov-Bohm type.

(U) V. L. Lyuboshitz and Ya. A. Smorodinskii of the Joint Institute for Nuclear Research, Dubna, USSR, have investigated the Aharonov-Bohm effect and the scattering of electrons as a function of both the geometry of the system and a change of phase of the electron wave function. In this research they discovered that the scattering is not only a function of the vector potential but also of the shape and orientation of the solenoid used in the experiment.

(U) Ye. M. Serebryanyy of the Lebedev Institute (FIAN) has developed a method for calculating vacuum polarization due to the Aharonov-Bohm effect. By performing this theoretical study he has demonstrated that the vector potential affects the structure of the space-time continuum.

(U) In 1981, Boris Altshuler, Arkady Aronov, and Boris Spivak of the Leningrad Nuclear Physics Institute made theoretical predictions concerning the Aharonov-Bohm effect in metal rings. The question which the Soviets were asking was whether this quantum interference effect could be observed in ordinary condensed matter such as normal metals or conductors. The predictions, in this case, for a supercooled metal indicates the electron phase shift should be ch/2e which is one-half of what it is in the normal Aharonov-Bohm effect. The factor of 2 indicates that the supercurrents are composed of "Cooper pairs of electrons." Cooper pairs of electrons are indicative of a superconducting state. Yu. V. Shavin (Institute of Solid Physics, Moscow) and his son D. Yu. Shavin (Institute of Physical Problems, Moscow) have done the experimental work which verified the theoretical work done by Boris Althuler et al. See references 1-14 for further information related to Soviet research on the Aharonov-Bohm effect.

(U) As an added note it is important to mention S. Olariu of the Central Institute of Physics, Bucharest/Magurele, Romania. He has made significant contributions in the area of quantum effects of the vector potential and electromagnetic fields. S. Olariu has written a 433-page paper on "The quantum effects of electromagnetic fluxes," which appeared in the *Reviews of Modern Physics*, Vol. 57, No. 2, April 1985. He concluded that quantum interference effects have been shown to be significant, but it remains to be seen whether this will entail a major change in our conception of electromagnetism.

(U) The Soviets demonstrate a tremendous interest in researching the theoretical and experimental aspects of the AB effect. Such research may have far-reaching future technology applications.

4. Near Term Application of the Aharonov-Bohm Effect (U)

(U) The Soviets have applied their understanding of the Aharonov-Bohm effect to solving a number of problems related to electromagnetic characteristics in systems. Examples of this include computer induction dynamic systems with a magnetic drive, solving the vector potential boundary conditions for electrical machinery, calculating the magnetic field of a conductor, calculating the magnetic-susceptibility for molecular bonds, and solving a number of magnetohydrodynamic (MHD) problems. See references 15-24 for further information on Soviet work in these areas.

5. Superconducting Quantum Interference Devices (SQUID) (U)

(U) SQUID devices are composed of two Josephson junctions supercooled to cryogenic temperatures. Soviet research on SQUID devices has been intensive since the early 1970's. The purpose of this text is just to mention some of the Soviets working in this area. S. A. Belonogov et al. of Moscow Energetics Institute has conducted research involving phase modulation in complex SQUID circuits. High sensitivity was made possible by modifying the SQUID circuits and phase modulating the RF signal used. V. A. Khlus of the Physico Technical Institute of Low Temperatures, Academy of Sciences of the Ukrainian SSR, Kharkov, has investigated nonequilibrium phenomena in a superconducting point contact on the properties of a high frequency (HF) SQUID. O. V. Snigirev of Moscow State University has done one-contact microwave-frequency SQUID investigations where he found that the optimum energy sensitivity was dependent on the normalized inductance L. L = 1 was considered optimum. In four papers V. K. Kornev et al. of Moscow State University have done extensive work on microwave SQUIDs, quantum chaos in a SQUID, and High-Speed Electronic Analog of Josephson Contacts and SQUIDs. V. D. Kuznetsov et al. of the Mendeleev Institute of Chemical Technology, Moscow, has used SQUID devices to measure magnetic susceptibility of a weakly magnetic substance at the boiling point of liquid helium. The only information suggesting that the Soviets have used SQUID devices to measure the Aharonov-Bohm effect is mentioned in paragraph 3. SQUID devices then have the potential to be used as long range sensors having a remarkable degree of sensitivity across the RF and microwave region. They also have the potential to be used as a sensor to detect the vector-potential field as discussed in paragraph 6. See references 25-35 for further information on Soviet research in this area.

6. Possible Future Technology Application (U)

(U) A possible setup for a future communications system using the A-vector potential is shown in Figure 2. The basic equipment consists of an A-vector transmitter and a receiver SQUID device.

7. Soviet Research on Scalar Waves (U)

(U) As previously mentioned Soviet research in the area of scalar waves/fields is purely theoretical. The numerous theoretical areas covered include using scalar wave equations to solve component problems for Maxwell's equations, solving Einstein's gravitational field equations to find the amount of energy radiated in the form of gravitational waves, studying quantum particle production due to an intense gravitational field, and reducing Maxwell's equations to a scalar equation, and solving the interaction problem between the

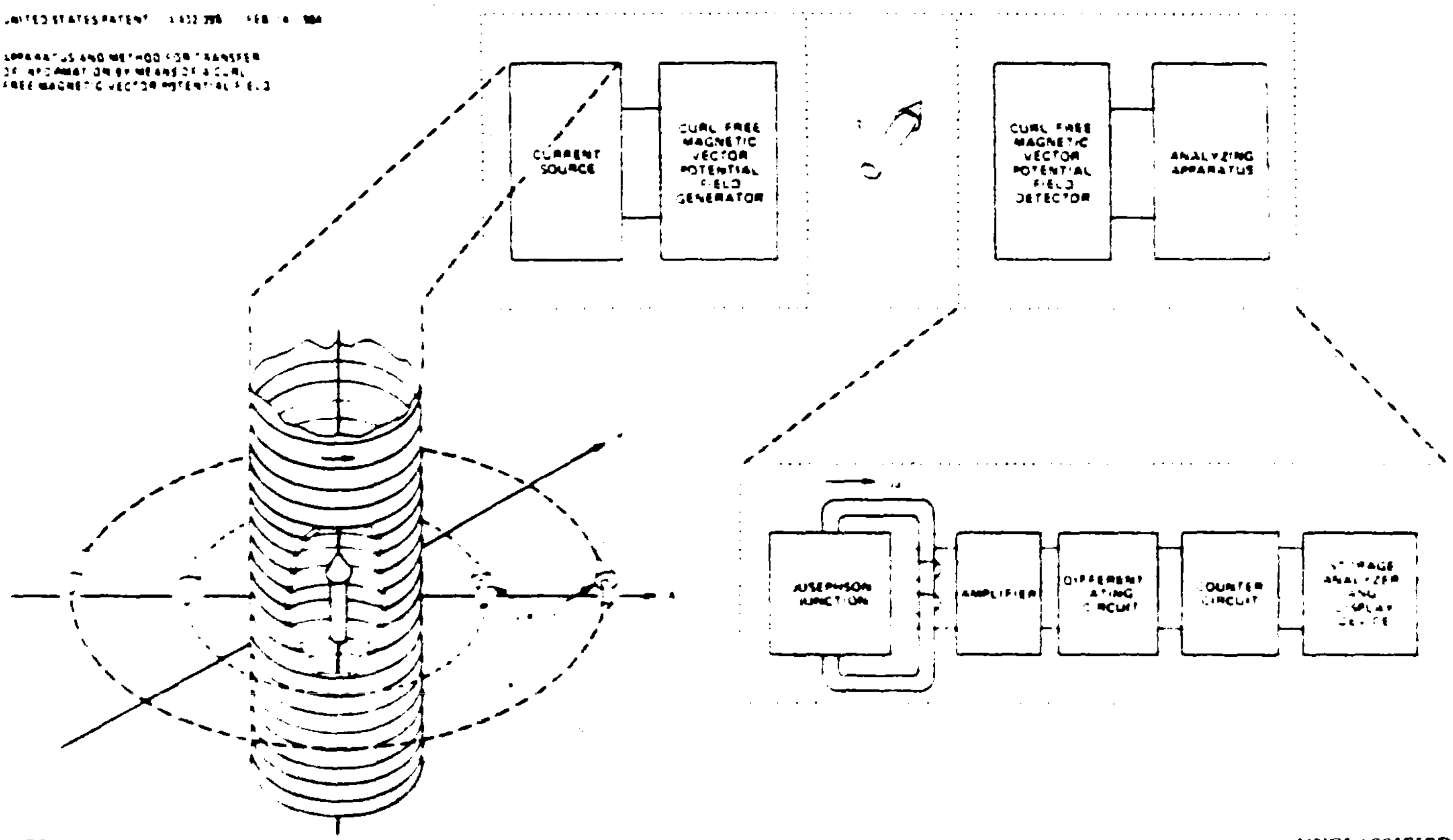

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Fig. 2 (U) Magnetic Detection by A-Vector Potential Design electromagnetic scalar equation and a gravitational field, etc. The reader is referred to references 36-45 and 52-62 for further information on Soviet research on these topics.

(U) Recently, A. D. Linde of the Lebedev Physical Institute, Moscow, has developed what is termed "Chaotic Inflation" scenarios which make use of scalar fields to explain the Inflationary Universe. Briefly, theory states that the universe originated from a quantum fluctuation having the dimensions of 10^{-33} cm and an energy of 10^{19} GeV. From this quantum fluctuation the universe inflated to roughly 10^{6} orders of magnitude (which is much greater than the observable universe) driven by a repulsive gravitational force. The repulsive effect was due to a coupling between a Higgs scalar field or special scalar field Φ and a matter or gravitational field. In six papers over a 2 year period A. D. Linde describes the effects of scaler fields on the evolution of the early universe. In one paper he directly addresses the issue of the combined action of a scalar field and gravitational vacuum polarization giving rise to inflation. In other papers he addresses the ideas of supergravity to explain differing aspects of the inflation phenomena. The implications of this type of research are enormous since a better understanding of the nature of scalar and gravitational fields might bring about the development of new forces, leading to new technologies and applications not currently realizable. For further information on Soviet research in this area the reader is referred to references 46-51.

8. Ad Hoc Theories on Scalar Waves (U)

(U) There have been a number of theories (mostly US) put forth over the years concerning scalar waves. One theory states that there is order to the virtual structure of a potential vacuum and that a deterministic structure can be formed by a vector summation of finite EM fields. Summing the two EM waves is suppose to give one a scalar wave creating a deterministic vacuum structure. Summing two scalar waves at the receiving end is suppose to give back the original EM waves plus energy extracted from this deterministic vacuum structure. Quantum physics says that the vacuum is full of virtual particles but that the vacuum is in a state of constant quantum fluctuations: there is no order to the vacuum. Since scalar waves are linear fields, one cannot sum them to extract energy from the "deterministic" structure of a vacuum. If in principle energy could be extracted from the vacuum, then life would have to exist in a false vacuum state and not in a true vacuum. A false vacuum state is a state of the vacuum which is not at its lowest energy level. If one lived in a false vacuum, then attempting to extract energy from it would be catastrophic, since removing energy would create a true vacuum state which would inflate and wipe out the visible universe—the ultimate ecological catastrophe. So, the basis of some current schemes is completely untenable. Another aspect to the idea of scalar longitudinal waves is that the wave can not be a photon field. Gauge invariance forbids longitudinal photon waves moving at the speed of light.

9. Observations (U)

- (U) The Soviets have a basic research program dedicated to understanding the A-vector potential which could have possible technology applications.
- (U) The Soviets are at par with the West in their theoretical and experimental research efforts for the A-vector potential and theoretical efforts with scalar waves/fields.
- (U) Although there is no indication of any military interest in the areas of the A-vector potential and scalar waves, most of the institutes mentioned are in some way connected with military projects.
- (U) Advancements in this work may provide the basis for whole new concepts in communications, weapons, and propulsion systems. Such applications will likely be of interest to the military and most likely be cloaked in secrecy. Unexpected breakthroughs offer the possibility of current systems and strategic concepts being rendered obsolete and useless. Progress in the past several years seems to underscore this point. The potential payoff is so great as to demand a more regular and consistent evaluation.

APPENDIX I

(U) Quantum Mechanics requires the use of potentials rather than forces; i.e., **E** and **B** in the case of the electromagnetic fields. The vector potential **A** and the scaler potential ϕ are related to the **E** and **B** fields by;

$$\mathbf{E} = -\nabla\phi - 1/c\ \partial\mathbf{A}/\partial t \tag{1}$$

$$\mathbf{B} = \nabla \times \mathbf{A} \tag{2}$$

(U) Electromagnetic theory predicts the existence of potential waves traveling at the speed of light. If equations (1) and (2) are substituted into Maxwell equations;

$$\nabla\cdot\mathbf{E} = 4\pi\rho \tag{3}$$

$$\nabla\cdot\mathbf{B} = 0 \tag{4}$$

$$\nabla \times \mathbf{B} = 4\pi/c\ \mathbf{J} + 1/c\ \partial\mathbf{E}/\partial t \tag{5}$$

$$\nabla \times \mathbf{E} = -1/c\ \partial\mathbf{B}/\partial t \tag{6}$$

And making use of the Lorentz guage condition,

$$\nabla\cdot\mathbf{A} + 1/c\ \partial\phi/\partial t = 0 \tag{7}$$

one obtains two source free potential wave equations;

$$\nabla^2\phi - 1/c^2\ \partial^2\phi/\partial t^2 = 0;\ \text{Scalar potential} \tag{8}$$

$$\nabla^2\mathbf{A} - 1/c^2\ \partial^2\mathbf{A}/\partial t^2 = 0;\ \text{Vector potential} \tag{9}$$

Equations (7), (8), and (9) form a set of equations which are equivalent in all respects to Maxwell's equations.

(U) To demonstrate what is termed the guage invariance of ϕ and **A**, let's perform a guage transformation of the following type;

$$\phi' = \phi - 1/c\ \partial S/\partial t \tag{1a}$$

$$\mathbf{A}' = \mathbf{A} + \nabla S \tag{2a}$$

Guage invariant transformation of ϕ and **A**.

Then demanding that **A**' and ϕ' satisfy the Lorentz condition, equation (7), gives;

$$\nabla\cdot\mathbf{A}' + 1/c\ \partial\phi'/\partial t = 0 = \nabla\cdot\mathbf{A} + 1/c\ \partial\phi/\partial t + \nabla^2 S - 1/c^2\ \partial^2 S/\partial t^2 \tag{3a}$$

$$\nabla^2 S - 1/c^2\ \partial^2 S/\partial t^2 = -(\nabla\cdot\mathbf{A} + 1/c\ \partial\phi/\partial t) \tag{4a}$$

All potentials in this restricted class are said to belong to the Lorentz gauge. They relate the scalar wave to the potentials.

FAR-FIELD APPROXIMATION FOR MAXWELL'S EQUATIONS

(U) For the case far away from the source, **E** = 0, **B** = 0, and $\nabla \times \mathbf{A} = 0$, then equation (1) becomes;

$$-\nabla\phi - 1/c\ \partial\mathbf{A}/\partial t = 0$$

This equation can always be satisfied with a scaler field, S;

$$\mathbf{A} = \nabla S \tag{10}$$

and

$$\phi = -1/c\ \partial S/\partial t \tag{11}$$

If equations (10) and (11) are substituted into equation (7), one obtains;

$$\nabla^2 S - 1/c^2\ \partial^2 S/\partial t^2 = 0 \tag{12}$$

which is the wave equation for S.

(U) In the Aharonov-Bohm effect, the phase change of an electron can be represented by

$$\Delta\Theta = e/\hbar c \oint d\mathbf{l}\cdot\mathbf{A}$$

as the line integral around a closed path for the interference effect. When dealing with phase changes over a time period this effect can be represented by the time integral of the scalar potential

$$\Delta\Theta = e/\hbar c \int_{t_1}^{t_2} dt\ V(\mathbf{x},t).$$

(U) But, $\oint\nabla S\cdot d\mathbf{l} = 0$ around any closed path according to Stoke's theorem. So, the scalar field takes on real significance over a time domain or perhaps coupled to other fields over a time oscillation period.

(U) In the absence of **E** and **B** fields, the vector potential can be represented by the gradient of a scalar field. The vector potential and scalar fields then are the primitive fields from which one can derive the **E** and **B** fields. The scalar fields in equation (12) replace the potential when the physical **E** and **B** fields are zero.

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(U) **A** is perhaps the field that imparts phase shifts to matter proportional to the rate at which **A** changes over distance/time and it could be detected by means of quantum interference devices (SQUIDs). The scalar waves S are so naturally elusive they are called scalar vacuum waves. The scalar field is already known to physicists in the context of quantum field theory as the Lorentz gauge which treats ϕ and **A** on the same footing and is a concept independent of coordinate systems. The reader is referred to references 63 and 64.

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