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Original article

Quantum of magnetic flux due to electron spin

Igor P. Popov
Kurgan State University, Kurgan, Russian Federation
✉ uralakademia@kurganstalmost.ru

Abstract
In 1948, F. London calculated the quantum of magnetic flux from an electric current created by a single electron. The key condition for the calculation was ascribing a quantum of kinetic momentum $\hbar$ to the electron. In 1956, L. Cooper described two-particle systems of correlated electrons (Cooper pairs) arising in conductors as a result of electron-phonon interaction. Assigning a quantum of kinetic momentum $\hbar$ to a two-particle system leads to a twofold decrease in the calculated value of the magnetic flux quantum. In 1961, B.S. Deaver and W.M. Fairbank and independently R. Doll and M. Nebauer measured the quantum of magnetic flux. The result turned out to be half as much as F. London's quantum. Since then, it has been believed that the quantum of magnetic flux is created exclusively by Cooper pairs and that it is half as much as F. London's quantum. The aim of the study is to rethink the above circumstances. The geometric shape of an electron is unknown. However, it is believed that it is neither a ball nor a sphere. This follows from the formula of its classical radius. The complete uncertainty of the electron's shape allows its spin to be consistently represented as an angular momentum generated by a material point with the mass of an electron, rotating along a circle of an indefinite radius (arbitrarily small, and its value is of no importance). This approach may have shortcomings, but it also has a significant advantage in the form of the possibility of using a ready formula for the magnetic flux created by the "current" of one electron. In reality, there is the quantum of F. London, the quantum of magnetic flux caused by the electron spin, and their superposition (quasi-quantum).
Keywords: electron, Cooper pair, quantum of kinetic momentum, quantum of magnetic flux, quantum of F. London, spin, superposition, quasi-quantum, phonon, ferromagnet
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Оригинальная научная статья

Квант магнитного потока, обусловленный спином электрона

И. П. Попов
Курганский государственный университет, г. Курган, Российская Федерация
✉ uralakademia@kurganstalmost.ru

Аннотация
В 1948 г. Ф. Лондон вычислил квант магнитного потока от электрического тока, созданного одним электроном. Ключевым условием вычисления явилось приписывание электрону кванта кинетического момента $\hbar$. В 1956 г. Л. Купер описал двухчастичные

системы коррелированных электронов (куперовские пары), возникающие в проводниках вследствие электрон-фононного взаимодействия. Приписывание двухчастичной системе кванта кинетического момента $\hbar$ приводит к уменьшению вычисляемого значения кванта магнитного потока вдвое. В 1961 г. Б. С. Дивер и У. М. Фэрбэнк и независимо Р. Долл и М. Небауэр измерили квант магнитного потока. Результат оказался вдвое меньше кванта Ф. Лондона. С тех пор считается, что квант магнитного потока создается исключительно куперовскими парами и что он вдвое меньше кванта Ф. Лондона. Цель исследования заключается в переосмыслении указанных обстоятельств. Геометрическая форма электрона неизвестна. Однако считается, что это не шар и не сфера. Это следует из формулы его классического радиуса. Полная неопределенность формы электрона позволяет непротиворечиво представить его спин в виде момента импульса, образованного материальной точкой с массой электрона, обращающейся по окружности неопределенного радиуса (сколь угодно малого, причем его величина значения не имеет). Этот подход может иметь недостатки, но он имеет и существенное достоинство в виде возможности использовать готовую формулу для магнитного потока, созданного «током» одного электрона. В действительности существуют квант Ф. Лондона, квант магнитного потока, обусловленный спином электрона, и их суперпозиция (квазиквант).

Ключевые слова: электрон, куперовская пара, квант кинетического момента, квант магнитного потока, квант Ф. Лондона, спин, суперпозиция, квазиквант, фонон, ферромагнетик

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Introduction

In 1948, F. London calculated the quantum of magnetic flux from an electric current created by one electron. The key condition for the calculation was to assign a quantum of kinetic momentum $\hbar$ to the electron.

In 1956, L. Cooper described two-particle systems of correlated electrons (Cooper pairs [1-3]) arising in conductors due to electron-phonon interaction [4-6]. Assigning a quantum of kinetic momentum $\hbar$ to a two-particle system leads to a halving of the calculated value of the magnetic flux quantum.

Neither F. London nor L. Cooper took into account magnetic fluxes caused by electron spins in their calculations.

In 1961, B.S. Deaver and W.M. Fairbank and independently R. Doll and M. Nebauer measured the quantum of magnetic flux [7, 8]. The result was half that of F. London.

Since then, it has been believed that the quantum of magnetic flux is created exclusively by Cooper pairs [9] and that it is half the quantum of F. London.

The purpose of the study is to establish the spin magnetic flux of an electron.

The relevance of the work is determined by the fact that the spin magnetic flux of an electron, being the basis of the intrinsic magnetic field of ferromagnets, has not yet been established. The problem here is that the generally accepted concept of electron spin does not allow it to be calculated. Therefore, it becomes necessary to make additional temporary (working) assumptions.

Materials and methods

The geometric shape of the electron is unknown. However, it is believed that it is not a ball or a sphere. This follows from the formula for its classical radius

$$r_e = \frac{\mu_0 e^2}{4\pi m_e}.$$

Here μ_0 is the magnetic constant, e is the electron charge, and m_e is the electron mass. In the case of a sphere, the formula would look like

$$r_e = \frac{3}{5}\frac{\mu_0 e^2}{4\pi m_e}.$$

In the case of a sphere, the formula would look like

$$r_e = \frac{1}{2}\frac{\mu_0 e^2}{4\pi m_e}.$$

The complete uncertainty of the electron's shape allows us to consistently represent its spin as an angular momentum generated by a material point with the mass of an electron, rotating in a circle of an indefinite radius (arbitrarily small, and its value is of no importance; the proposed assumption is not considered as competing with the known descriptions of the electron spin, for example, in the works of Belinfante or [10]). This approach may have shortcomings, but it also has a significant advantage in the form of the possibility of using a ready-made formula for the magnetic flux created by the "current" of one electron, obtained in [11] according to the scheme

$$E = \frac{I\Phi}{2},$$

$$I = \frac{e}{T},$$

$$T = \frac{2\pi R}{v},$$

$$E = \frac{m_e v^2}{2},$$

$$\Phi = \frac{2\pi R m_e v}{e}.$$

Finally

$$\Phi = \frac{2\pi R p}{e}. \quad (1)$$

Here E is the energy, I is the electron current, T is the electron rotation period, R is the radius of the laboratory tube (in the experiments of B.S. Deaver, W.M. Fairbank, R. Doll and M. Nebauer), v is the linear velocity of a single electron, p is the momentum of a single electron.

Results and Discussion

First derivation of the formula for the quantum of magnetic flux caused by the electron spin

The electron spin is [12, p. 224; 13, p. 252]

$$L_{es} = \frac{\sqrt{3}}{2}\hbar. \tag{2}$$

Taking into account (1), the quantum of magnetic flux caused by the electron spin is equal to

$$\Phi_{es} = \frac{2\pi Rp}{e} = \frac{2\pi L_{es}}{e} = \frac{2\pi}{e}\frac{\sqrt{3}}{2}\hbar.$$

Finally

$$\Phi_{es} = \frac{\sqrt{3}}{2}\frac{h}{e}. \tag{3}$$

Note 1. The classical radius (r_e) is not used in the calculations of the article and therefore does not affect the results. It is mentioned solely to illustrate the uncertainty of the electron shape.

Note 2. There is no need to choose *R* for formula (1). The radius is not included in the resulting formula (3) for the spin quantum of magnetic flux ("dissolved" in the spin). Therefore, its value is of no importance. At least, it can be assumed that it is large enough to prevent the development of excessive energy.

Experimental verification of the spin quantum of magnetic flux

The circular current in a laboratory tube formed by one electron creates a magnetic flux

$$\Phi_L = \frac{2\pi\hbar}{e} = \frac{h}{e}. \tag{4}$$

This is the formula of F. London [14].

The electron spin can have only two projections on the direction of the magnetic field of the flow (4), namely

$$L_{esB} = \pm\frac{\hbar}{2}.$$

Due to the law of conservation of angular momentum, the spin is opposite to the orbital angular momentum. Therefore

$$L_{esB} = -\frac{\hbar}{2}.$$

Therefore, the magnetic flux due to the electron spin is subtracted from the flux (4) (its projection).

Thus, in 1961, B.S. Deaver, W.M. Fairbank, R. Doll and M. Nebauer measured the orbital quantum of the magnetic flux of ONE electron minus the projection of the spin quantum of the magnetic flux (through the end surfaces of their laboratory tubes

$$\frac{h}{e} - \frac{h}{2e} = \frac{h}{2e}. \tag{5}$$

This is a quasi-quantum, not a quantum from a Cooper pair.

$$\Phi_0 = \frac{h}{2e}. \tag{6}$$

The coincidence of the measured value (5) with (6) is completely random.

However, this coincidence is a reliable experimental verification of formulas (1), (3)–(5) and the accepted assumption about the electron spin.

Second derivation of the formula for the quantum of magnetic flux caused by the electron spin

Both the quantum of magnetic flux of F. London (4) and the quantum from the Cooper pair (6) can be represented in the form

$$\Phi_q = \frac{h}{q} = \frac{2\pi\hbar}{q}.$$

Finally

$$\Phi_q = \frac{2\pi}{q} L_q,$$

where q is the charge, L_q is the quantum of kinetic momentum.

Substituting the charge of the electron and its kinetic momentum (spin) (2) into this formula directly yields

$$\Phi_{es} = \frac{2\pi}{q} L_q = \frac{2\pi}{e} \frac{\sqrt{3}}{2} \hbar.$$

Finally

$$\Phi_{es} = \frac{\sqrt{3}}{2} \frac{h}{e}.$$

Coincides with (3), which is also a reliable verification of formulas (1), (3)–(5) and the accepted assumption about the electron spin.

Conclusion

In [15-17] it is shown in detail that attributing a quantum of kinetic momentum $\hbar$ to a Cooper pair of electrons is unacceptable. Therefore, the related formula for the quantum of magnetic flux from a Cooper pair (6) is equally unacceptable [18].

In reality, there is a quantum of F. London (4), a quantum of magnetic flux (3) due to the electron spin, and their superposition (5) (quasi-quantum).

It (quasi-quantum) was measured in 1961.

The main result of the work, which constitutes scientific novelty: the spin magnetic flux of an electron is

$$\Phi_{es} = \frac{\sqrt{3}}{2} \frac{h}{e}.$$

It is the basis of the intrinsic magnetic field of ferromagnets.

At the same time, the assumptions about the electron spin adopted in the work did not affect the final result and therefore can be considered temporary (working) and not opposed to the generally accepted concept of spin.

The practical significance of the work is determined by the following. It is known that magnetic flux quantization manifests itself on a macroscopic scale. . In the experiments of B.S. Deaver, W.M. Fairbank, R. Doll and M. Nebauer, the magnetic field strength turned out to be weaker than the Earth's magnetic field strength by only five times. This creates good prospects for creating a new generation of computers using spin magnetic fluxes of electrons.

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About the author

Igor P. Popov – Cand. Sci. (Technology), Associate Professor, Department of Theoretical, Experimental Physics and Computer Methods of Physics, Kurgan State University, Kurgan, Russian Federation, ORCID: 0000-0001-8683-0387, SPIN: 9668-2780, e-mail: uralakademia@kurganstalmost.ru

Сведения об авторе

ПОПОВ Игорь Павлович – к. т. н., доц. каф. теоретической, экспериментальной физики и компьютерных методов физики, ФГАОУ ВО «Курганский государственный университет», г. Курган, Российская Федерация, ORCID: 0000-0001-8683-0387, SPIN: 9668-2780, e-mail: uralakademia@kurganstalmost.ru

Conflict of interests

The author declares no relevant conflict of interests

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