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ЭЛЕКТРОННО-ДЫРОЧНОЕ ВЗАИМОДЕЙСТВИЕ В УГЛЕРОДНЫХ СЛОЯХ, ПОЛУЧЕННЫХ ТРЕНИЕМ

Исследованы оптические свойства слоев углерода, их спектры поглощения и пропускания, полученных трением графита о поверхность диэлектрической подложки. Обнаружено, что физическое поведение подобных углеродных слоев подобно поведению твердотельных слоев. Обнаружено также, что на оптические свойства этих слоев большое влияние оказывает взаимодействие электронов и дырок, которое определяется поглощением света квазичастицей электронно-дырочной пары. По особенностям оптических спектров сделано заключение, что в слоях, полученных путем трения графита, существует подслой упорядоченного кристаллического графена.

Ключевые слова: углерод, слой, графит, графен, экситон.

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ELECTRON-HOLE INTERACTION IN CARBON LAYERS OBTAINED BY RUBBING

The optical properties, spectra of absorption and transmission, of carbon layers obtained by rubbing graphite against the surface of a dielectric substrate are studied for the first time. It is revealed that the physical behavior of obtained layers is identical to that of solid-state layers. It is also found that the electron-hole interaction has great influence on layer’s optical properties, determining light absorption by excitons, electron-hole pairs. By the pecularities of optical spectra it is concluded that in carbon layers obtained by rubbing a sub-layer of ordered crystalline graphene is present.

Keywords: carbon, layer, graphite, graphene, exciton.

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A SIMPLE METHOD TO OBTAIN THE RELATIONS BETWEEN THE TRANSMISSION AND REFLECTION AMPLITUDES OF THE LEFT AND RIGHT SCATTERING PROBLEMS

The proposed approach regarding the relations between the transmission and reflection amplitudes of the left and right scattering problems has an explicit advantage compared to the method of the subject relations received based on the group theory (see, for example, [1]).

Keywords: left and right scattering problems, transmission and reflection amplitudes, Wronskian of the Schrodinger equation.

In this work, it is shown that the well known relations between the transmission and reflection amplitudes of the left and right scattering problems can be obtained as a result of the Wronskian constancy of the Schrodinger equation. As a linear independent solution, the wave functions describing the left and right scattering problems are considered.

First of all, let's discuss two kinds of motions: finite and infinite. In case of finite motion, the wave function should be normalized to Dirac delta function, namely:

$$\int_{-\infty}^{+\infty} \varphi_k(x)\,\varphi^*{}_{k'}(x)dx = \delta(k-k') \tag{1}$$

and as to infinite movement the following one is true:

$$\int_{-\infty}^{+\infty} \varphi_n(x)\,\varphi^*{}_{n'}(x)dx = \delta_{nn'} \tag{2}$$

Considering that the measure unit of the δ(k) function is the meter, the $\varphi_k(x)$ function will be immeasurable considering all the above mentioned.

It is well known that any dimensional quantum mechanics motion of the stationary character is described by the one-dimensional Schrodinger equation:

$$\frac{d^2\varphi_k}{dx^2} + \left(k^2 - u(x)\right)\varphi_k = 0, \tag{3}$$

where $k = \sqrt{2mE}/\hbar$, $u(x) = 2mU(x)/\hbar^2$and E, $U(x)$ are the total and potential energies.

The asymptotic behavior of the solutions of Eq. (3) when $u(x \to \pm\infty) \to 0$ for a potential takes place can be generally written

$$\varphi(x,k) = \frac{1}{\sqrt{2\pi}}\frac{1}{\sqrt{a^*a + d^*d}}\begin{cases} a\exp\{ikx\} + b(k)\exp\{-ikx\}, & x \to -\infty, \\ c(k)\exp\{ikx\} + d\exp\{-ikx\}, & x \to +\infty. \end{cases} \tag{4}$$

Here, for any potential form of $u(x \to \pm\infty) \to 0$ the factor

$$\frac{1}{2\pi}\frac{1}{\sqrt{a^*a+d^*d}} \tag{5}$$

provides the normalization condition of the scattering wave functions (see, for example, [2]), which does not depend on the potential form (see Eq. (1)).

If one takes in Eq. (4)$a = 1$, d= 0(a wave falls to potential from its left side and there is no wave falling on a barrier from the right side), then$c = T(k)$, $b = R(k)$will be the transmission and reflection amplitudes. Then the wave function $\varphi(x,k)$of the asymptotic behavior Eq.(4) will correspond to the left scattering problem:

$$\varphi_{left}(x,k) = \frac{1}{\sqrt{2\pi}}\begin{cases} \exp\{ikx\} + R(k)\exp\{-ikx\}, & x \to -\infty, \\ T(k)\exp\{ikx\}, & x \to +\infty. \end{cases} \tag{6}$$

For the right scattering problem (a wave falls to a potential from its right side only and there is no wave falling on a barrier from its left side) in Eq. (4) it should be taken $a = 0$, $d = 1$and $c = P(k)$,$b = S(k)$, so that

$$\varphi_{right}(x,k) = \frac{1}{\sqrt{2\pi}} \begin{cases} S(k)\exp\{-ikx\}, & x \to -\infty, \\ \exp\{-ikx\} + P(k)\exp\{ikx\}, & x \to +\infty, \end{cases} \tag{7}$$

where $S(k)$, $P(k)$are the transmission and reflection amplitudes of the right scattering problem.

To note that $\varphi_{left}(x, -k)$and $\varphi_{right}(x, -k)$ functions are Schrodinger equation solutions, their definition will be derived from Eq. (6) and Eq. (7) respectively. It is worthy to notice that $\varphi(x, -k) = \varphi^*(x, k)$.

For easy references, the left and right scattering problems' schematic presentation is attached below:

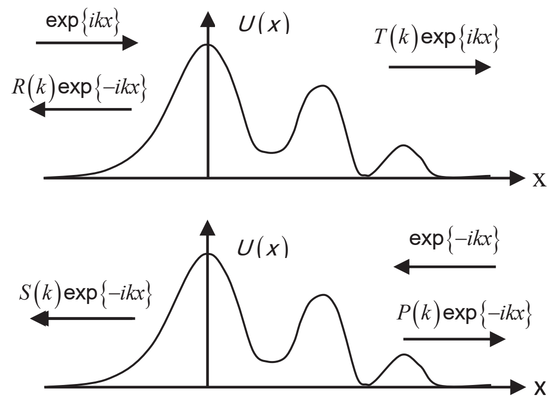

Fig. The schematic presentations of the left and right scattering problems

In the cases when the potential is missing, we will have this imaging:

$$\frac{d^2\varphi_k}{dx^2} + k^2\varphi_k = 0;$$
$$\varphi_{left} = e^{ikx}; \tag{8}$$
$$\varphi_{right} = e^{-ikx}.$$

Now let's denote$\varphi_1$and $\varphi_2$as different solutions of Eq. (3) and show that Wronskian of these solutions is constant, namely

$$W = \varphi_1 \frac{d\varphi_2}{dx} - \varphi_2 \frac{d\varphi_1}{dx} = const. \tag{9}$$

The derivation of this function will be:

$$\frac{dW}{dx} = \varphi_1 \frac{d^2\varphi_2}{dx^2} - \varphi_2 \frac{d^2\varphi_1}{dx^2} = -\varphi_1\big(k^2 - U(x)\big)\varphi_2 + \varphi_2\big(k^2 - U(x)\big)\varphi_1 = 0. \quad (10)$$

This means that W function is constant which we had to show.And as a result we can say that

$$W(-\infty) = W(+\infty). \quad (11)$$

If $\varphi_1=\varphi_{left}(x,k)$ and $\varphi_2=\varphi_{left}(x,-k)$, and therefore, when $x\to -\infty$, we will have the following wave functions: $\varphi_1 = e^{ikx} + R(k)e^{-ikx}$and $\varphi_2 = e^{-ikx} + R(k)e^{ikx}$.And taking into account Eq.(11), the following relation will be received:

$$1 - T(k)T(-k) = R(K)R(-k)$$

and if$\varphi_1 = \varphi_{left}(x,k)$ and $\varphi_2 = \varphi_{right}(x,-k)$, then $T(k) = S(k)$.

To sum up, finally for the transmission and reflection amplitudes of theleft and right scattering problems, the following relations will take place:

$$T(k)T(-k) + R(k)R(-k) = S(k)S(-k) + P(k)P(-k) = 1, \quad (12)$$

$$T(k) = S(k), T(k)P(-k) + R(k)S(-k) = 0.$$

Note that in Eq. (6), Eq. (7) the factor $1/\sqrt{2\pi}$is defined by Eq. (5) which provides the normalization condition of the scattering wave functions. It is important to mention that the wave functions of asymptotes Eq. (6), Eq. (7) can be interpreted as scattering wave functions if only the parameter k is considered as positive ($k > 0$) .

It should be mentioned that the scattering wave functions are orthogonal with respect to each other as well (see, for example, [3]);

$$\int_{-\infty}^{+\infty} \varphi_{left}(x,k)\varphi_{left}^*(x,k')dx = \delta(k - k'),$$

$$\int_{-\infty}^{+\infty} \varphi_{right}(x,k)\varphi_{right}^*(x,k')dx = \delta(k - k') \quad (13)$$

and

$$\int_{-\infty}^{+\infty} \varphi_{left}(x,k)\varphi_{right}^*(x,k')dx = 0. \quad (14)$$

These properties of the functions$\varphi_{left}(x,k)$, $\varphi_{right}(x,k)$are very important to describe different wave processes by means of their linear superposition.

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Դ.Ռ. ՈՍԿԱՆՅԱՆ

ԱՋ ԵՎ ՁԱԽ ՑՐՄԱՆ ԽՆԴԻՐՆԵՐԻ ԱՆՑՄԱՆ ԵՎ ԱՆԴՐԱԴԱՐՁՄԱՆ ԳՈՐԾԱԿԻՑՆԵՐԻ ՄԻՋԵՎ ԿԱՊԵՐԻ ՍՏԱՑՄԱՆ ՊԱՐԶ ՄԵԹՈԴ

Աջ և ձախ ցրման խնդիրների անցման և անդրադարձման գործակիցների միջև կապերի ստացման առաջարկված մոտեցումն ունի բացահայտ առավելություն խմբային տեսության նկատմամբ:

Առանցքային բառեր. աջ և ձախ ցրման խնդիրներ, անցման և անդրադարձման գործակիցներ, Շրեդինգերի վրոնսկյան հավասարում:

Д.Р. ВОСКАНЯН

ПРОСТОЙ МЕТОД ПОЛУЧЕНИЯ СВЯЗИ МЕЖДУ КОЭФФИЦИЕНТАМИ РАССЕЯНИЯ И ОТРАЖЕНИЯ ПРАВОЙ И ЛЕВОЙ ПРОБЛЕМ

Предлагаемый подход для получения связи между коэффициентами рассеяния и отражения правой и левой проблем имеет очевидное преимущество по отношению к теории групп.

***Ключевые слова**:* правая и левая проблемы, коэффициенты рассеяния и отражения, Вронскяново уравнение Шредингера.