National Academy of Sciences of Belarus
Ministry of Education of the Republic of Belarus
B.I.Stepanov Institute of Physics of NASB
SO «Belarussian physical society»
Belarusian Republican Foundation for Fundamental Research

International Conference «Spins & Photonic Beams at Interface» (SPBI'2011)

in the framework of Fedorov Memorial Symposium

Book of abstracts and programme

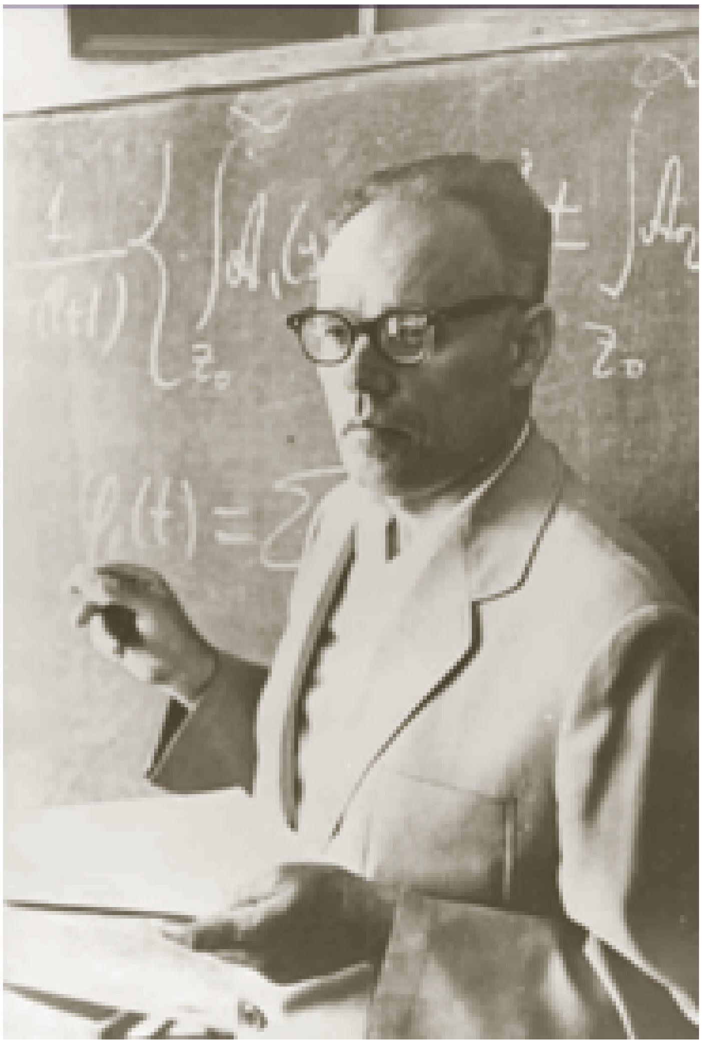
September 25–26, 2011
Minsk, Belarus

Sunday, September 25			Monday, September 26		
Hall A			Hall B		
Su25A(A)	**SPBI I**			10:00 – 13:00 **PLENARY TALKS OF III CONGRESS OF PHYSICISTS OF BELARUS** (talks will be given in Russian)	A
	Sergei Kilin Valerii Filippov	9.50			
	Vladimir Fedoseyev	10.30			
	11:00 – 11:30 Coffee break				
Su25B(A)	**SPBI II**				B
	Gerd Leuchs	11.30			
	Jean-Michel Menard	12.00			
	Shuichi Murakami	12.30			
13:00 – 14:00 Lunch					
Su25C(A)	**SPBI III**		Mo26B(B)	**SPBI V**	C
	Jacek Furdyna	14.00		Vladimir Belyi	
	Alexander Bekshaev	14.30		Igor Litvin	
	Chun-Fang Li	15.00		Igor Bondarev	
	Young Kim	15.30		Andrey Lavrinenko	
16:00 – 16:30 Coffee break					
Su25D(A)	**SPBI IV**		Mo26C(B)	16:30 – 18:20 **FEDOROV MEMORIAL SYMPOSIUM** (talks will be given in Russian)	D
	Vladimir Man'ko	16:30			
	Natalia Korolkova	17:00			
	Yakov Shnir	17:30			
	Yu. Kurochkin	18:00			

Hall A – conference hall at Rector's Office of Belarusian State Unvirsity (Nezavisimosti ave., 4)

Hall B – great conference hall at Presidium of National Academy of Sciences of Belarus (Nezavisimosti ave., 66)

Fedor Ivanovich Fedorov
1911—1994



This conference is dedicated to the 100th anniversary of the birth of Belarusian and soviet physicist Fedor Ivanovitch Fedorov. Fedorov's scientific heritage is immensely diverse. It includes various branches of theoretical physics: from investigations on acoustics and optics of different media to high energy physics. This conference is connected with Fedorov's discovery of transversal shift of reflected light. The 1955's paper, in which Fedorov formulated this effect for the first time, was published in Russian. Its English translation is missing. To fill up this gap, leading to certain difficulties for most of the scientists, working in this field,we start this book of abstracts of SPBI'2011 by publication of the original F. I. Fedorov's paper and its translation into English by D. Pustokhod.

Chair of SPBI'2011
Sergei Kilin

Доклады Академии наук СССР
1955. Том 105, № 3

ФИЗИКА

Ф. И. ФЕДОРОВ

К ТЕОРИИ ПОЛНОГО ОТРАЖЕНИЯ

(Представлено академиком А. А. Лебедевым 27 V 1955)

Явление полного отражения представляет большой принципиальный интерес и ему посвящено значительное число теоретических и экспериментальных работ (см., например, ([1])), однако все исследования ограничиваются случаем, когда падающий свет линейно поляризован перпендикулярно или параллельно плоскости падения. Лишь в работе ([5]) Вигрефе рассмотрел случай, когда азимут колебаний χ падающей линейно поляризованной волны отличен от 0 или $\pi/2$. Уже в этом случае обнаруживаются некоторые принципиальные особенности явления, не имеющие места в частных случаях $\chi = 0$ или $\chi = \pi/2$. Однако в работе ([5]) содержатся ошибки, и её результаты остались почти незамеченными [1]. Общий случай полного отражения при произвольной эллиптической поляризации падающей волны до сих пор не рассматривался. Между тем, как показано ниже, его рассмотрение позволяет выяснить некоторые принципиальные, ранее неизвестные стороны явления полного отражения.

Вследствие линейности уравнений Масквелла и граничных условий поля падающей, отраженной и преломленной волн всегда можно разложить на сумму соответствующих составляющих, параллельных и перпендикулярных плоскости падения. В случае неполного отражения на границе прозрачных изотропных сред аналогичное разложение справедливо также для плотности энергии w и вектора Умова — Пойнтинга $\mathbf{P}$. Однако в общем случае для w и $\mathbf{P}$, квадратично зависящих от $\mathbf{E}$ и $\mathbf{H}$, такое разложение невозможно. Именно с этим обстоятельством связаны принципиальные отличия полного отражения в общем случае поляризации падающей волны от случая её линейной поляризации при $\chi = 0$ или $\chi = \pi/2$.

Интересующие нас соотношения получаются в наиболее простой и компактной форме, если вести все расчёты в векторном виде, не переходя к компонентам. Уравнения Максвелла для плоских волн

$$\mathbf{E} = \mathbf{E}_0 e^{i\phi}, \quad \mathbf{H} = \mathbf{H}_0 e^{i\phi}, \quad \phi = \omega\left(t - \frac{1}{c}\,\mathbf{m}\right) \tag{1}$$

в немагнитных средах имеют вид

$$\mathbf{D} = \varepsilon\mathbf{E} = -[\mathbf{mH}], \quad \mathbf{H} = [\mathbf{mE}] \quad (\mathbf{m}^2 = \varepsilon). \tag{2}$$

Здесь $\mathbf{m} = n\mathbf{n}$ — вектор рефракции ([3],[4]); n — показатель преломления; $\mathbf{n}$ — единичный вектор волновой нормали. Плотность электрической и магнитной энергии и вектор Умова — Пойнтинга выражаются формулами

$$w_e = \frac{\varepsilon}{32\pi}(\mathbf{E} + \mathbf{E}^*)^2, \quad w_m = \frac{1}{32\pi}(\mathbf{H} + \mathbf{H}^*)^2, \tag{3}$$

$$\mathbf{P} = \frac{c}{16\pi}[\mathbf{E} + \mathbf{E}^*,\, \mathbf{H} + \mathbf{H}^*]. \tag{4}$$

[1]Работа ([5]), например, не цитируется в обзоре ([1]), её результаты не учтены также в известной монографии Борна ([2]), содержащей в связи с этим ошибочное утверждение (см. сноску на стр. 6).

Относя индексы 0, 1, 2 к падающей, отраженной и преломлённой волнам соответственно, можно написать геометрические законы отражения и преломления в виде

$$[\mathbf{m}_0\mathbf{h}] = [\mathbf{m}_1\mathbf{h}] = [\mathbf{m}_2\mathbf{h}] = \mathbf{a}, \tag{5}$$

где $\mathbf{h}$ — единичный вектор нормали к поверхности раздела. Отсюда следует

$$\mathbf{m}_i = [\mathbf{h}\mathbf{a}] + \eta_i\mathbf{h}, \quad \eta_i = \mathbf{m}_i\mathbf{h}_i, \quad \eta_1 = -\eta_0, \quad \eta_2 = \sqrt{n_2^2 - \mathbf{a}^2} \tag{6}$$

($n_0 = n_1$, n_2 — показатели преломления обеих сред). Электрическое поле каждой из трёх волн может быть написано в виде

$$E_i = A_i\mathbf{a} + B_i[\mathbf{n}, \mathbf{a}]. \tag{7}$$

Формулы Френкеля для амплитуд A_i, B_i имеют вид

$$\frac{A_0}{\mathbf{a}[\mathbf{m}_1\mathbf{m}_2]} = \frac{A_1}{\mathbf{a}[\mathbf{m}_2\mathbf{m}_0]} = \frac{-A_2}{\mathbf{a}[\mathbf{m}_0\mathbf{m}_1]}, \tag{8}$$

$$\frac{B_0/A_0}{\mathbf{n}_0\mathbf{n}_2} = \frac{B_1/A_1}{\mathbf{n}_1\mathbf{n}_2} = \frac{B_2/A_2}{\mathbf{n}_2\mathbf{n}_2}. \tag{9}$$

Полное отражение имеет место при условии $n_2^2 - \mathbf{a}^2 \leq 0$, откуда следует

$$\mathbf{m}_2 = \mathbf{m}' + i\mathbf{m}'' = [\mathbf{h}\mathbf{a}] - i\eta\mathbf{h}, \quad \eta = +\sqrt{\mathbf{a}^2 - n_2^2}. \tag{10}$$

При этом комплексный вектор $\mathbf{m}_2$ будет нелинейным ($[\mathbf{m}_2\mathbf{m}_2] \neq 0$), а преломленная волна — неоднородной ([4]).

На основании (2), (4) получаем общие выражения выражения для плотности энергии и вектора Умова — Пойнтинга неоднородных волн в изотропном немагнитном диэлектрике:

$$w = w_e + w_m = w' + w'', \quad w'' = \frac{\varepsilon}{16\pi}(\mathbf{E}^2 + \mathbf{E}^{*2}), \tag{11}$$

$$w' = \frac{1}{16\pi}((\varepsilon + |\mathbf{m}|^2)|\mathbf{E}|^2 - |\mathbf{m}\mathbf{E}^*|^2), \tag{12}$$

$$\mathbf{P} = \mathbf{P}' + \mathbf{P}'', \quad \mathbf{P}'' = \frac{c}{16\pi}(\mathbf{E}^2 \cdot \mathbf{m} + \mathbf{E}^{*2} \cdot \mathbf{m}^*), \tag{13}$$

$$\mathbf{P}' = \frac{c}{16\pi}(|\mathbf{E}|^2(\mathbf{m} + \mathbf{m}^*) - [\mathbf{m} - \mathbf{m}^*, [\mathbf{E}\mathbf{E}^*]]). \tag{14}$$

Очевидно, величины w', $\mathbf{P}'$ не содержат фазового множителя $e_{i\phi}$, а w'', $\mathbf{P}''$ содержат $e^{\pm i\phi}$. Поэтому, для средних значений $\overline{w}$ и $\overline{\mathbf{P}}$ имеем: $\overline{w} = w'$, $\overline{\mathbf{P}} = \mathbf{P}'$. Можно показать, что линейная поляризация определяется условием $[\mathbf{E}\mathbf{E}^*] = 0$, а круговая — условием $\mathbf{E}^2 = 0$ ([4]). В общем же случае полуоси эллипса колебаний по величине и направлению совпадают с вещественной и мнимой частями вектора

$$\mathbf{E}_r = \sqrt{\frac{|\mathbf{E}^2|}{\mathbf{E}^2}}\mathbf{E}. \tag{15}$$

Согласно (13) вектор $\mathbf{P}''$ описывает эллипс в плоскости, параллельной плоскости комплексного вектора $\mathbf{m}_2 = \mathbf{m}' + i\mathbf{m}''$, т. е. плоскости падения. Используя (15), можно убедиться, что полуоси эллипса пропорциональны и параллельны $\mathbf{m}'$ и $\mathbf{m}''$. Таким образом, полный вектор потока энергии во второй среде дважды за период описывает конус, который направлен в ту же сторону от плоскости падения, что и вектор $\mathbf{P}'$. Из (14) следует, что в общем случае при полном отражении средний поток энергии в преломлённой волне не параллелен плоскости падения, но имеет перпендикулярную к ней компоненту, связанную с членом $[\mathbf{m}_2 - \mathbf{m}_2^*, [\mathbf{E}\mathbf{E}^*]]$ [2]. Эта компонента равна нулю для обычного отражения ($\mathbf{m}_2 = \mathbf{m}_2^*$) и в случае $A_0 = 0$ или $B_0 = 0$. Кроме того она исчезает при $[\mathbf{E}\mathbf{E}^*] = 0$, т. е. когда вектор $\mathbf{E}_2$ является линейным (^{4}). Согласно (7), (9) этот боковой поток равен нулю также при условии $\frac{B_0^*/A_0^*}{B_0/A_0} = \frac{\mathbf{m}_2^*\mathbf{m}_0}{\mathbf{m}_2\mathbf{m}_0}$ — отсюда определяется лишь разность фаз составляющих A_0, B_0, отношение же их модулей может быть произвольным. Вигрефе (^{5}) впервые обратил внимание на наличие бокового потока энергии при полном отражении, но только для линейно поляризованного падающего света [3]. Между тем, при заданной энергии падающей волны и фиксированном угле падения боковой поток достигает максимума, когда $\frac{B_0^*/A_0^*}{B_0/A_0} = -\frac{\mathbf{m}_2^*\mathbf{m}_0}{\mathbf{m}_2\mathbf{m}_0}$, т. е. при некоторой эллиптической поляризации падающего света. В случае линейной поляризации падающей волны при $\chi = 45°$ боковой поток энергии через полосу шириной в 1 см, неограниченно простирающуюся от плоскости раздела во вторую среду параллельно плоскости падения, равен

$$S_{2\,\text{бок}} = S_0 \frac{\lambda_0}{2\pi} \frac{\sin 2\psi \sqrt{\sin^2\psi - n^2}}{(1-n^2)(\operatorname{tg}^2\psi - n^2)}. \tag{16}$$

Здесь S_0 — поток энергии падающей волны через нормальную к нему площадку в 1 см^2; λ_0 — длина волны света в первой среде в сантиметрах; ψ — угол падения; $n = n_2/n_1$ — относительный показатель преломления. Указанный боковой поток энергии должен вызывать специфическое боковое световое давление, поскольку в падающей волне он отсутствует и, следовательно, соответствующая компонента электромагнитного импульса поля не сохраняется. Однако, согласно (16), для видимого света $S_{2\,\text{бок}}/S_0 \sim 10^{-5}$, ввиду чего практически обнаружить этот эффект затруднительно.

Отметим кроме того, что, вследствие наличия этой боковой компоненты, при полном отражении в общем случае отраженный луч должен смещаться не только вдоль плоскости падения, что было подтверждено опытами Гооса и Хенхен (^{9}), но и в перпендикулярном к ней направлении.

Из (14), (10) следует, что $\mathbf{P}_2'\mathbf{h} = \mathbf{P}_2\mathbf{h} = 0$. Таким образом, поток энергии внутрь второй среды в среднем отсутствует, что и позволяет говорить о полном отражении. При этих условиях наличие поля во второй среде в случае неограниченной во времени и пространстве волны можно объяснить лишь за счёт члена $\mathbf{P}_2''$ (13), который даёт переменный поток энергии через границу раздела, равный в среднем нулю. Однако, в случае круговой поляризации преломлённой волны ($\mathbf{E}_2^2 = \mathbf{E}_2^{*2} = 0$) $\mathbf{P}_2'' = 0$ и, следовательно, $\mathbf{P}_2'\mathbf{h} = 0$, т. е. полностью отсутствует не только средний, но и мгновенный поток энергии через границу раздела. В этом случае обычное объяснение наличия поля во второй среде становится полностью несостоятельным, что показывает принципиальную недостаточность теории полного отражения, не учитывающей ограниченности падающей волны в пространстве или во времени. На основании (7)—(9), (15) легко показать, что этот особый случай имеет место при такой эллиптической поляризации падающей волны, когда отношение полуосей эллипса колебаний равно относительному показателю преломления и, следовательно, не зависит от угла падения. Угол χ, образуемый большой осью эллипса колебаний падающей

[2]В книге Борна (^{2}) ошибочно утверждается, что при полном отражении поток энергии во второй среде направлен параллельно плоскости падения (стр. 62).

[3]В работе (^{5}) ошибочно утверждается, что боковой поток энергии всегда направлен влево от плоскости падения, независимо от положения плоскости поляризации падающего линейно поляризованного света (стр. 470). На самом деле из (14), (7), (9) следует, что направление боковой компоненты потока меняется на противоположное при изменении знака азимута колебаний падающей волны.

волны с нормалью к плоскости падения (**a**), определяется формулой

$$\lg 2\chi = \pm \frac{2\eta_0 \eta n_1 n_2}{\eta_0^2 n_2^2 - \eta^2 n_1^2}. \tag{17}$$

При падении под предельным углом полного отражения $\chi = 0$, а при скользящем падении $\chi = \pi/2$. Разность фаз δ компонент A_0 и B_0 ($B_0/A_0 = |B_0/A_0|e^{i\delta}$) определяется соотношением $\operatorname{tg}\delta = \pm \mathrm{a}^2/\eta_0\eta$. При этом эллипс колебаний отраженной волны имеет те же размеры, форму и направление обращения, что и в падающей волне, отличаясь лишь противоположным знаком χ.

В опытах Квинке ([6]) и Галля ([7]) была обнаружена зависимость глубины проникновения света во вторую среду при полном отражении от поляризации падающей волны. Эта зависимость полностью объясняется на основании теории Эйхенвальда (см., например, ([8])), поскольку Квинке и Галль рассматривали стандартный случай линейно поляризационного падающего света при $\chi = 0$ и $\chi = \pi/2$ [4]. Очевидно, аналогичное экспериментальное исследование для указанного выше особого случая эллиптической поляризации падающей волны должно представить значительный интерес.

Физико-технический институт
Академии наук БССР

Поступило
8 XII 1954

ЦИТИРОВАННАЯ ЛИТЕРАТУРА

[1] А. А. Коробко-Стефанов. Усп. физ. наук, **42**, 433 (1950). [2] М. Борн, Оптика, 1937. [3] Ф. И. Фёдоров, ДАН, **84**, 1171 (1952). [4] Ф. И. Фёдоров, 102, №**1**, (1955). [5] A. Wiegrefe, Ann. PHys., **45**, 465 (1914). [6] G. Quincke, Pogg Ann., **127**, 1, (1866). [7] W. D. Harkins, Phys. Rev., **15**, 73 (1920). [8] A. König, Handb. d. Phys., **20**, 1929, S. 141. [9] F. Goos, H. Lindberg-Hänchen, Ann. Phys., **1**, 333 (1947); **5**, 251 (1949).

[4]В обзоре ([1]) ошибочно утверждается, будто этот вопрос до сих пор остаётся открытым (стр. 459—460). На самом деле он давно разрешён (см., например, ([8])).

Doklady Akademii Nauk SSSR
1955. Vol. 105, # 3

PHYSICS

F. I. FEDOROV

TO THE THEORY OF TOTAL REFLECTION

(Presented by academician A. A. Lebedev on 27 V 1955)

(Translated by D. Pustakhod)

The effect of total reflection is of great fundamental interest and it has been the objective of many theoretical and experimental papers (eg., [1]), however all research is limited to the case that the incident light is linearly polarized perpendicularly or in parallel to the plane of incidence. Only Wiegrefe alone [5] has considered the case that the oscillation azimuth χ of linear polarized incident wave is different from 0 or $\pi/2$. Even in this case some fundamental features of this phenomena which are not observed in special cases $\chi = 0$ or $\chi = \pi/2$ are revealed. There are however few mistakes in [5], and its results remained almost unnoticed [5]. A general case of total reflection for arbitrary elliptical incident polarization has not been approached yet. Meanwhile, as discussed below, its consideration allows one to discover some fundamental, previously unknown properties of total reflection.

As a consequence of linearity of Maxwell equations and boundary conditions, one can always break down incident, reflected and refracted fields into a sum of corresponding components that are parallel and perpendicular to the plane of incidence. In case of partial reflection on the boundary between transparent isotropic media an analogous representation holds for energy density w and Poynting vector $\mathbf{P}$. However, in general case such a decomposition for w and $\mathbf{P}$ is impossible, as soon as they are quadratically dependent on $\mathbf{E}$ and $\mathbf{H}$. It is this reason that is responsible for vital distinction of total reflection in general case of incident light polarization and in linear polarization case at $\chi = 0$ or $\chi = \pi/2$.

The relations of interest are expressed in the simplest and most compact form if all calculations are made in vector form, not in component from. The Maxwell equations for plane waves

$$\mathbf{E} = \mathbf{E}_0 e^{i\phi}, \quad \mathbf{H} = \mathbf{H}_0 e^{i\phi}, \quad \phi = \omega\left(t - \frac{1}{c}\,\mathbf{m}\right) \tag{1}$$

in non-magnetic media take the form

$$\mathbf{D} = \varepsilon\mathbf{E} = -[\mathbf{mH}], \quad \mathbf{H} = [\mathbf{mE}] \quad (\mathbf{m}^2 = \varepsilon). \tag{2}$$

Here $\mathbf{m} = n\mathbf{n}$ is the refraction vector [3,4]; n is the index of refraction; $\mathbf{n}$ is the unit wave normal vector. An electric and magnetic energy density and Poynting vector are expressed by

$$w_e = \frac{\varepsilon}{32\pi}(\mathbf{E} + \mathbf{E}^*)^2, \quad w_m = \frac{1}{32\pi}(\mathbf{H} + \mathbf{H}^*)^2, \tag{3}$$

$$\mathbf{P} = \frac{c}{16\pi}[\mathbf{E} + \mathbf{E}^*,\ \mathbf{H} + \mathbf{H}^*]. \tag{4}$$

[5] Paper [5], for example, is not cited in the review [1], its results are also overlooked in a well-known M. Born's monograph [2], which contains a misstatement in connection with this (see a footnote on p. 10).

Denoting the incident, reflected and refracted waves respectively by indices 0, 1, 2, one can write the geometrical laws of reflection and refraction as

$$[\mathbf{m}_0\mathbf{h}] = [\mathbf{m}_1\mathbf{h}] = [\mathbf{m}_2\mathbf{h}] = \mathbf{a}, \tag{5}$$

where $\mathbf{h}$ is the unit normal to the interface. Hence it follows that

$$\mathbf{m}_i = [\mathbf{h}\mathbf{a}] + \eta_i\mathbf{h}, \quad \eta_i = \mathbf{m}_i\mathbf{h}_i, \quad \eta_1 = -\eta_0, \quad \eta_2 = \sqrt{n_2^2 - \mathbf{a}^2} \tag{6}$$

($n_0 = n_1$, n_2 is the indices of refraction of either media). One can write an electric field for each of three waves as

$$E_i = A_i\mathbf{a} + B_i[\mathbf{n}, \mathbf{a}]. \tag{7}$$

Fresnel equations for amplitudes A_i, B_i have the form

$$\frac{A_0}{\mathbf{a}[\mathbf{m}_1\mathbf{m}_2]} = \frac{A_1}{\mathbf{a}[\mathbf{m}_2\mathbf{m}_0]} = \frac{-A_2}{\mathbf{a}[\mathbf{m}_0\mathbf{m}_1]}, \tag{8}$$

$$\frac{B_0/A_0}{\mathbf{n}_0\mathbf{n}_2} = \frac{B_1/A_1}{\mathbf{n}_1\mathbf{n}_2} = \frac{B_2/A_2}{\mathbf{n}_2\mathbf{n}_2}. \tag{9}$$

The total reflection occurs when $n_2^2 - \mathbf{a}^2 \leq 0$, whence it follows that

$$\mathbf{m}_2 = \mathbf{m}' + i\mathbf{m}'' = [\mathbf{h}\mathbf{a}] - i\eta\mathbf{h}, \quad \eta = +\sqrt{\mathbf{a}^2 - n_2^2}. \tag{10}$$

In this case the complex vector $\mathbf{m}_2$ will be nonlinear ($[\mathbf{m}_2\mathbf{m}_2] \neq 0$), whereas refracted wave will be non-uniform [4].

From (2), (4) we have general relations for energy density and Poyting vector of non-uniform wave in an isotropic non-magnetic dielectric:

$$w = w_e + w_m = w' + w'', \quad w'' = \frac{\varepsilon}{16\pi}(\mathbf{E}^2 + \mathbf{E}^{*2}), \tag{11}$$

$$w' = \frac{1}{16\pi}((\varepsilon + |\mathbf{m}|^2)|\mathbf{E}|^2 - |\mathbf{m}\mathbf{E}^*|^2), \tag{12}$$

$$\mathbf{P} = \mathbf{P}' + \mathbf{P}'', \quad \mathbf{P}'' = \frac{c}{16\pi}(\mathbf{E}^2 \cdot \mathbf{m} + \mathbf{E}^{*2} \cdot \mathbf{m}^*), \tag{13}$$

$$\mathbf{P}' = \frac{c}{16\pi}(|\mathbf{E}|^2(\mathbf{m} + \mathbf{m}^*) - [\mathbf{m} - \mathbf{m}^*, [\mathbf{E}\mathbf{E}^*]]). \tag{14}$$

Apparently, quantities w', $\mathbf{P}'$ do not contain phase factor $e_{i\phi}$, while w'', $\mathbf{P}''$ contain $e^{\pm i\phi}$. Therefore, for mean values $\overline{w}$ and $\overline{\mathbf{P}}$ we have: $\overline{w} = w'$, $\overline{\mathbf{P}} = \mathbf{P}'$. It can be shown, that linear polarization is determined by $[\mathbf{E}\mathbf{E}^*] = 0$, whereas circular polarization is by $\mathbf{E}^2 = 0$ [4]. But in general case the oscillation ellipse semiaxes are equal in magnitude and direction with the real and imaginary components of vector

$$\mathbf{E}_r = \sqrt{\frac{|\mathbf{E}^2|}{\mathbf{E}^2}}\mathbf{E}. \tag{15}$$

According to (13), vector $\mathbf{P}''$ traces an ellipse in the plane, parallel to the plane of complex vector $\mathbf{m}_2 = \mathbf{m}' + i\mathbf{m}''$, i. e. plane of incidence. Using (15), one can make sure, that ellipse semiaxes are proportional and parallel to

$\mathbf{m}'$ and $\mathbf{m}''$. Hence, the total energy flux vector in the second medium twice a period traces a cone, which is pointed the same direction from the plane of incidence as vector $\mathbf{P}'$. From (14) it follows that in general case of total reflection the average energy flux in the refracted wave is not parallel to the plane of incidence: it has a perpendicular component associated with the term $[\mathbf{m}_2 - \mathbf{m}_2^*, [\mathbf{EE}^*]]$ [6]. This component equals to zero for the common reflection ($\mathbf{m}_2 = \mathbf{m}_2^*$) and in case that $A_0 = 0$ or $B_0 = 0$. Moreover, it disappears at $[\mathbf{EE}^*] = 0$, i. e. when vector $\mathbf{E}_2$ is linear [4]. According to (7), (9) this lateral flux also equals to zero with the constraint $\frac{B_0^*/A_0^*}{B_0/A_0} = \frac{\mathbf{m}_2^*\mathbf{m}_0}{\mathbf{m}_2\mathbf{m}_0}$ is this defines only phase difference of the components A_0, B_0, while the modules ratio of these components is unrestricted. Wiegrefe [5] was the first to pay attention to the presence of lateral flux in total reflection, but only for the case of linearly polarized incident light [7]. Meanwhile, at given incident wave energy and angle of incidence the lateral flux peaks at $\frac{B_0^*/A_0^*}{B_0/A_0} = -\frac{\mathbf{m}_2^*\mathbf{m}_0}{\mathbf{m}_2\mathbf{m}_0}$, i. e. at some elliptical polarization of incident light. In case of linear polarization of incident wave at $\chi = 45°$ the lateral energy flux through a stripe of 1 cm wide that stretches in the second medium from the interface to infinity and is parallel to the plane of incidence equals to

$$S_{2\,side} = S_0 \frac{\lambda_0}{2\pi} \frac{\sin 2\psi \sqrt{\sin^2\psi - n^2}}{(1-n^2)(\mathrm{tg}^2\,\psi - n^2)}. \tag{16}$$

Here S_0 is the incident wave energy flux through a perpendicular area element of 1 cm^2; λ_0 is the optical wavelength in the first medium expressed in centimeters; ψ is the angle of incidence; $n = n_2/n_1$ is the relative index of refraction. The lateral energy flux specified should lead to a specific lateral light pressure, as far as the lateral flux in the incident wave is nil, and therefore a corresponding component of electromagnetic field momentum is not conserved. However, in view of the fact that according to (16), $S_{2\,side}/S_0 \sim 10^{-5}$ for visible light, it is difficult to detect this effect in experiment.

It is notable that as a consequence of presence of this lateral component, the reflected beam in the general case of total reflection must be displaced not only lengthwise of the plane of incidence, that was confirmed by the experiments of Goos and Hänchen [9], but in a direction orthogonal to the mentioned plane as well.

It follows from eq. (14), (10) that $\mathbf{P}_2'\mathbf{h} = \mathbf{P}_2\mathbf{h} = 0$. Therefore, the energy flux into the second medium equals to zero in average, which allows one to speak about the total reflection. Under these conditions the field presence in the second medium in case of unlimited in time and space wave is attributable to the term $\mathbf{P}_2''$ (13), which gives an equal to zero in average alternating energy flux through the interface. However, in case of circularly polarized refracted wave ($\mathbf{E}_2^2 = \mathbf{E}_2^{*2} = 0$) $\mathbf{P}_2'' = 0$ and, therefore, $\mathbf{P}_2'\mathbf{h} = 0$, i. e. not only average flux, but an instant energy flux through the interface equals to zero as well. Here the common explanation of the field presence in the second medium becomes entirely inconsistent, showing the fundamental inadequacy of the total reflection theory, which ignores the boundedness of an incident wave in space or time. From (7)—(9), (15)

[6] In Born's monograph [2] it is mistakenly stated, that in total reflection the energy flux in the second medium is directed in parallel to the plane of incidence (p. 62).

[7] In article [5] it is mistakenly stated, that lateral energy flux is alway directed to the left from the plane of incidence, regardless of the direction of polarization of linearly polarized incident light (p. 470). In fact it follows from (14), (7), (9), that the direction of the lateral flux component reverses as the incident light oscillation azimuth changes its sign.

it can easily be shown, that this particular case occurs at an elliptical polarization of an incident light such that oscillation ellipse semiaxes ratio equals to the relative index of refraction and, therefore, is independent of the angle of incidence. An angle χ between the major axis of oscillation ellipse of the incident wave and the incidence plane normal (**a**), is determined by

$$\lg 2\chi = \pm\frac{2\eta_0\eta n_1 n_2}{\eta_0^2 n_2^2 - \eta^2 n_1^2}. \tag{17}$$

$\chi = 0$ in case of incidence at a critical angle of total reflection, and $\chi = \pi/2$ at glancing incidence. The phase difference δ of the components A_0 and B_0 ($B_0/A_0 = |B_0/A_0|e^{i\delta}$) is given by $\operatorname{tg}\delta = \pm \mathrm{a}^2/\eta_0\eta$. In this case the oscillation ellipse of the reflected wave has the same size, shape and direction of circulation as that of the incident wave, differing only in sign of χ.

The dependence of the depth of light penetration into the second medium in total reflection from the incident wave polarization was discovered in the experiments of Quincke [6] and Gall [7]. This dependency is entirely explained on the basis of Eichenwald theory (eg., see [8]), as far as Quincke and Gall considered the standard case of linearly polarized incident light at $\chi = 0$ и $\chi = \pi/2$ [8]. It is evident, that an analogous experimental study for the specified above special case of elliptical polarization of the incident wave is of much interest.

Physical Technical Institute
Academy of Sciences of the BSSR

Received
8 XII 1954

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[8] In the review [1] it is mistakenly stated, that this issue still remains unsolved (p. 459—460). In fact, it has long been resolved (eg., see [8]).

Su25A(A)

SPINS & PHOTONIC BEAMS AT INTERFACE I – hall A, 09:50

Presider: Sergei Kilin

09:50 Su25A(A)1–267

Opening talk

Sergei Kilin

National Academy of Sciences of Belarus, 66 Nezavisimosti Ave., Minsk, Belarus

E-mail: kilin@presidium.bas-net.by

10:00 Su25A(A)2–253

Fedorov-Imbert Shift

Valerii Filippov

B.I.Stepanov Insitute of Physics, National Academy of Sciences of Belarus, 68 Nezavisimosti Ave., Minsk, Belarus

E-mail: filippov@dragon.bas-net.by

The history of discovery and investigation of the transverse light beam shift at total internal and partial reflection is presented. Comparison is done for results followed from different theoretical approaches for calculation of the transverse shift (method of energy-flux conservation, stationary-amplitude method and plane-wave representation).

10:30 Su25A(A)3–254

Transverse shifts of the reflected and refracted light beams and the dynamical processes associated

Vladimir Fedoseyev

Institute of Physics, University of Tartu, Estonia

E-mail: fedo@fi.tartu.ee

The dynamical aspects of the transverse shifts (TSs) of the reflected and refracted light beams are discussed. The prediction of the TS of a totally reflected beam (Fedorov 1954) was based just on the dynamical arguments. Namely, Fedorov has pointed out that the transverse power flow (TPF), once it takes place inside the evanescent waves in a reflecting medium, should entail the TS of the reflected beam. In my talk, the general analysis of the relation between the TS and TPF phenomena is presented. Again, the connection between the TSs of the secondary beams and the transformation of the angular momentum at the reflection and refraction is analyzed. The conservation laws for some components of the linear and angular Minkowski momenta are employed. It is pointed out that two mechanisms of the TSs of the secondary beams can take place at partial reflection. The comparison of the features of the spin-dependent TSs and the TSs dependent on an intrinsic orbital angular momentum of the incident beam is given.

11:00–11:30 Coffee-break

Su25B(A)

SPINS & PHOTONIC BEAMS AT INTERFACE II – hall A, 11:30

Presider: Natalia Korolkova

11:30 Su25B(A)1–255

Geometric spin-Hall effect of light in highly focused vector beams

Andrea Aiello, Peter Banzer, Thomas Bauer, **Gerd Leuchs**,
Norbert Lindlein and Martin Neugebauer

Max Planck Institute for the Science of Light, Erlangen, Germany, and Institute of Optics, Information and Photonics, University Erlangen-Nuremberg, Germany

E-mail: leuchs@physik.uni-erlangen.de

In a recent paper [1] it has been shown that a polarization dependent intensity shift of the Bary center of a beam is found when observing from a tilted reference frame. This can be interpreted as a purely geometric effect (gSHEL). We investigate the geometric SHEL in highly focused vector beams. The highly focused beam consists of left-handed and right-handed circularly polarized light generated by a split aperture. We use a sub-wavelength nano-particle for probing the focal field distribution experimentally. First results of these measurements are shown and compared to an alytical calculations.

[1] A. Aiello et al., PRL 103, 100401 (2009)

12:00 Su25B(A)2–250

Ultrafast optical imaging of the spin Hall effect of light in semiconductors

Jean-Michel Menard

Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Universitätsstraße 31, 93053 Regensburg, Germany

E-mail:
jean-michel.menard@physik.uni-regensburg.de

The spin Hall effect of light at an air-semiconductor interface is resolved by imaging the subwavelength lateral shift of the circularly polarized components of a non-normally incident light beam. Three fundamentally different interaction mechanisms are used to demonstrate our imaging technique: (1) Pauli-blocking in GaAs; (2) free-carrier absorption in silicon; and (3) two-photon absorption in GaAs.

12:30 Su25B(A)3–256

Spin Hall effect of electron and light

Shuichi Murakami

Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan

E-mail: murakami@stat.phys.titech.ac.jp

We formulate the physics of spin Hall effect in terms of the Berry phase and explain how it emerges for light, as well as for other particles like electrons and magnons. We also introduce experimental reports related with these various spin Hall effects.

13:00–14:00 Dinner

Su25C(A)

SPINS & PHOTONIC BEAMS AT INTERFACE III – hall A, 14:00

Presider: Gerd Leuchs

14:00 Su25C(A)1–257

Optical Manipulation of Spin States in Semiconductor Quantum Dots

Jacek Furdyna

University of Notre Dame, 225 Nieuwland Science Hall, Notre Dame, IN 46556, USA

E-mail: furdyna@nd.edu

Electronic states in semiconductors, which naturally depend on electron spin, can be directly manipulated by the angular momentum of circularly polarized light (often also referred to as the spin state of light). When applied to electronic states in quantum dots (QDs), this process of light-electron interaction provides a useful handle for investigating optical processes occurring in QDs. Additionally, in recent years this spin-dependent interaction has also been proposed as an important mechanism on which to base future quantum information applications. In this talk we will focus on spin properties of electronic states in semiconductor QDs. Here we will give special emphasis to QDs comprised of diluted magnetic semiconductors, in which spin effects are dramatically enhanced, making manipulation of electronic states by the spin state of light particularly effective. We will begin by discussing the light-spin interactions in single QDs of several different types. We will then present results obtained on pairs of coupled QDs positioned at neighboring interfaces, and we will show that controlling the spins in one QD can be used to manipulate the spin states in the neighboring QD. Finally, we will conclude by speculating how the Fedorov effect could be used for manipulating spin-dependent electronic states in self-organized QDs for the purpose of processing information on the nanoscale.

14:30 Su25C(A)2–251

Internal energy flows and optical beam transformations at the interface

Alexander Bekshaev

I.I. Mechnikov National University, Dvorianska 2, 65082 Odessa, Ukraine

E-mail: bekshaev@onu.edu.ua

Any propagation or transformation of light fields is accompanied by the internal energy redistribution. The total energy flow (field momentum density, Poynting vector) can be divided into spin part associated with the polarization and orbital part associated with the spatial inhomogeneity. The energy flows express the essence of the internal and external degrees of freedom of the light field and provide natural means for description and analysis of the processes in which separate degrees of freedom interact and mutually transform. In particular, the spin-orbit and orbit-orbit interactions in the processes of beam focusing, scattering and transmission through a plane boundary are analyzed.

15:00 Su25C(A)3–258

On the angular momentum of photons: introduction of barycenter position characterized by a new kind of degree of freedom

Chun-Fang Li

Shanghai University, 99 Shangda Road, 200444 Shanghai, China

E-mail: cfli@shu.edu.cn

The transversality condition imposed on free electromagnetic radiations means that the extrinsic degree of freedom, the momentum, in the three-component wavefunction is correlated with the intrinsic degree of freedom, usually believed to be the spin. With such a representation, called Maxwell representation, it is difficult to understand the physical meaning of photon's spin and orbital angular momentum. In this talk, a distinct representation formalism called Jones representation is advanced by introducing a quasi unitary transformation. In this representation, the two-component wavefunction has independent extrinsic and intrinsic degrees of freedom. The extrinsic degree of freedom is the momentum as usual. But the intrinsic degree of freedom turns out to be the helicity, which, traditionally defined as the projection of the spin in the momentum direction, shows up as the projection of the Stokes vector in the momentum direction.

It is shown with the Jones representation that the spin and orbital angular momentum are both related with the momentum and helicity, but are different nevertheless. The spin depends only on the momentum and helicity. It is aligned with the momentum direction and has the helicity as its magnitude. The orbital angular momentum, however, depends not only on the momentum and helicity, but also on a new kind of degree of freedom, expressed by a constant unit vector I. In fact, the entire orbital angular momentum with respect to the origin splits into two parts. One is the orbital angular momentum of the barycenter with respect to the origin. The other is the orbital angular momentum with respect to the barycenter. It is the former that depends on the I, which results from the dependence of barycenter position on the I.

15:30 Su25C(A)4–259

Poincarè Sphere and Decoherence Problems

Young Kim

University of Maryland, College Park, Maryland 20742, USA

E-mail: yskim@umd.edu

It is noted that the four Stokes parameters obey the symmetry of Einstein's energy-momentum four-vector. While the radius of the original Poincaré sphere corresponds to the magnitude of the momentum, the energy-like component defines an outer sphere with a larger radius. It is shown that the difference between the larger and conventional radii is determined by the decoherence parameter between two orthogonal components of the optical wave.

For the case of four-momentum, the difference is determined by the particle mass. Thus, the decoherence parameter plays a fundamental role in the extended Poincaé sphere, as fundamental as the particle mass in Einstein's relativity.

16:00–16:30 Coffee-break

Su25D(A)

SPINS & PHOTONIC BEAMS AT INTERFACE IV – hall A, 16:30

Presider: Igor Bondarev

16:30 Su25D(A)1–260

Standard quantum mechanics with probability instead of wave function

Vladimir Man'ko

Lebedev Physical Institute, Russian Academy of Sciences, Russia

E-mail: manko@sci.lebedev.ru

New formulation of usual quantum mechanics is presented where the measurable experimentally probability is used instead of wave function and density operator for describing quantum state.

Connection with quantum tomography is discussed.

Basic equations (von Neumann evolution equation and energy level equation) are given in the form of the eqwuations for the probability.The analogous new representation of classical statistical mechanics is introduced by using integral Radon transform of standard probability density on phase space and Liouville equation is rewriten for the tomographic probability distribution describing classical state .It is shown that states both in quantum and classical mechanics can be described by the same tomographic probability distributions in the introduced tomographic approach. As inverse application of the Radon transform it is shown that the states in both classical and quantum mechanics can be described by wave function and density operator.

The difference of classical and quantum states is elucidated in both tomographic and Hilber space pictures.

The new recent experiments to check foundations of quantum mechanics are analised and the routin homodyne detection of quantum photon states is proposed as test of accuracy with which all the uncertainty relations (Heisenberg,Robertson-Schroedinger, entropic, etc.) are established being expressed in the discovered tomographic form.

17:00 Su25D(A)2–252

Quantum correlations beyond entanglement in quantum and classical information theory

Natalia Korolkova

University of St. Andrews, UK

E-mail: nvk@st-andrews.ac.uk

17:30 Su25D(A)3–261

Fractal dynamics of kinks in 1+1 dimensions

Yakov Shnir

Trinity College, Dublin, Ireland

E-mail: Shnir@maths.tcd.ie

We present a numerical study of the process of production of kink-antikink pairs in the collision of particle-like states in the one-dimensional ϕ^4 model. It is shown that there are 3 steps in the process, the first step is to excite the oscillon intermediate state in the particle collision, the second step is a resonance excitation of the oscillon by the incoming perturbations, and finally, the soliton-antisoliton pair can be created from the resonantly excited oscillon. It is shown that the process depends fractally on the amplitude of the perturbations and the wave number of the perturbation. We also present the effective collective coordinate model for this process. Considering kink-antikink collisions in the one-dimensional non-integrable scalar ϕ^6 model we reveal a resonant scattering structure, thereby providing a counterexample to the standard belief that existence of such a mode is a necessary condition for multi-bounce resonances in general kink-antikink collisions. We investigate the two-bounce windows in detail, and present evidence that this structure is caused by existence of bound states in the spectrum of small oscillations about a combined kink-antikink configuration.

18:00 Su25D(A)4–262

Fedorov Vector-parameter of the Systems of Polarizers

Yu. Kurochkin, V. Dlugunovich, and A. Holenkov

B.I.Stepanov Insitute of Physics, National Academy of Sciences of Belarus, 68 Nezavisimosti Ave., Minsk, Belarus

E-mail: yukuroch@dragon.bas-net.by

It was demonstrated that presentation of the coherent matrix (polarization density matrix) of the electromagnetic beams as biquaternion corresponding to the four-vector of the pseudo Euclidean space with intensity and Stokes parameters as components gives the possibility for introducing of the group transformations of such values isomorphic to the S(3.1) group. These transformations are the subset of the set of polarization Mueller matrices creating algebraic structure of semigroup. Reduction of the semigroup of Mueller matrices to the group of transformations make it possible to use the vector parameterization of transformations of the group SO(3.1) for interpretation of polar decomposition of the Mueller matrices. In this approach in particular the elements of Mueller matrices corresponding to retarders and polarizers are more simple and natural connected with there eigenpolarizations. The experimental verification of the expression for Stokes vector eigenpolarizations of the system of two polarizers via Stokes vector eigenpolarizations constituent polarizers, which obtained authors is realized.

Mo26A(B)

PLENARY TALKS OF III CONGRESS OF PHYSICISTS OF BELARUS – hall B, 9:50–13:00 (talks will be given in Russian)

Mo26B(B)

SPINS & PHOTONIC BEAMS AT INTERFACE V – hall B, 14:00

Presider: Sergei Gaponenko

14:00 Mo26B(B)1–263

Spin-to-orbital momentum conversion for Bessel beams propagating in anisotropic crystals

V. N. Belyi[1], N. A. Khilo[1], Muhanna K. Al-Muhanna[2]

[1]*B.I.Stepanov Insitute of Physics, National Academy of Sciences of Belarus, 68 Nezavisimosti Ave., Minsk, Belarus*

[2]*King Abdulaziz City for Science and Technology, Saudi Arabia*

E-mail: LOD@dragon.bas-net.by

The dynamics of spin-to-orbital angular momentum conversion for high-order circularly polarized Bessel beams propagating along the optical axes of uniaxial and biaxial crystals investigated both theoretically and experimentally. It is shown that uniaxial and biaxial crystals transform simultaneously the polarization state (spin angular momentum) and spatial structure (orbital angular momentum) of Bessel beams changing the order of dislocation on the phase front. Here in uniaxial crystal the transformation takes place of circularly-polarized Bessel vortices of the $(m-1)$ into Bessel vortices of the $(m+1)$ order. Such intensity transformation of vector Bessel beams implies that in a beam transmitted through the plate of uniaxial crystal, the overwhelming part of photons has the orbital angular momentum, which increases by 2 (per photon) in comparison with one of an incident Bessel beam. Due to this in uniaxial crystal the exchange of spin angular momentum with the matter is exactly compensated by the exchange of orbital angular momentum so that the plate made of uniaxial crystal does not experience the optical torque. Thus, in uniaxial homogeneous crystal one realized the direct conversion of spin angular momentum carried by circularly polarized Bessel beam into orbital angular momentum; at that depending on the sign of the input circularly polarization the beam topological charge increases or decreases by two units.

It has been established that the dynamics of spin-orbit coupling in biaxial crystal is essentially different. In this case the compensation is absent of spin and orbital angular momentum exchanges with biaxial crystal and optical torque appears, which influences the plate.

14:30 Mo26B(B)2–264

Intra-cavity beam shaping

Igor Litvin

CSIR National Laser Center, CSIR, Pretoria, South Africa

E-mail: ilitvin@csir.co.za

The presentation covers the current activities in the “mathematical optics” group at the National Laser Centre of South Africa in the field of laser resonators and intraЦcavity beam shaping. Currently, the key research of the group includes theoretical and experimental research in the field of intra cavity generation of laser beams with arbitrary shapes of intensity and phase, intra cavity generation of high brightness laser beams with maximum pump extraction, dynamic control and selection of both output mode and output mode parameters.

15:00 Mo26B(B)3–265

Nanotube Plasmonics

Igor Bondarev

North Carolina Central University, 1801 Fayetteville Str, Durham, NC 27707, USA

E-mail: ibondarev@nccu.edu

New universal plasmon related phenomena originating from the transverse quantization of electronic degrees of freedom in quasi-1D systems, will be discussed for small-diameter single wall carbon nanotubes exposed to external electromagnetic radiation, both in linear and in non-linear excitation regime. The effects discussed can manifest themselves both in individual semiconducting carbon nanotubes and in densely packed aligned nanotube films, both through plasmon enhanced inter-tube Casimir interactions and through the exciton-to-plasmon energy transfer tuned by applying a perpendicular electrostatic field. In the latter case, highly-intensive coherent localized surface fields plasmon-induced can be used in a variety of new tunable optoelectronic applications with individual nanotubes and composite nanotube structures, such as near-field nonlinear-optical probing and sensing, optical switching, enhanced electromagnetic absorption, and materials nanoscale modification.

The work is supported by NSF (ECCS-1045661 & HRD-0833184), NASA (NNX09AV07A), and ARO (W911NF-11-1-0189).

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15:30 Mo26B(B)4–266

Wave propagation phenomena in structured materials and problems of metamaterials homogenization

Andrey Lavrinenko

Technical University of Denmark, Oersteds Plads, Building 343, DK-2800 Kongens Lyngby, Denmark

E-mail: alav@fotonik.dtu.dk

One of the most convenient ways to describe metamaterials (MM) is to homogenize structured composites and assign them with effective parameters (EPs), provided that they can be introduced. The most common way to determine EPs in literature is to derive them from the refection/transmission spectra at a fixed incident angle (conventionally, under the normal incidence). We propose to introduce EPs by analysing wave propagation in a MM consisting of at least several unit cells (quasi-periodic). We use numerical simulations with a standard full-wave Maxwell solver and Bloch mode post-processing to retrieve EPs. We demonstrate our approach on several characteristic examples and formulate constrains on the MMs homogenization.

Mo26C(B)

FEDOROV MEMORIAL SYMPOSIUM – hall B, 16:30–18:20 (talks will be given in Russian)

International Conference
«Spins & Photonic Beams at Interface»
(SPBI'2011)

in the framework of Fedorov Memorial Symposium

Book of abstracts and programme

September 25–26, 2011
Minsk, Belarus

Editor: S. Ya. Kilin

Technical editors: A.A.Bukach, A.A.Ignatenko, A.A.Maloshtan

Подписано к печати 22 сентября 2011 г. Формат 60х90 1/16

Тип бумаги – офисная. Печать: ризография. Печ. л. ________

Уч. изд. л. _______. Тираж 90 экз. Заказ №____.

Институт физики им. Б.И.Степанова НАНБ

220072 Минск, ГСП, пр. Независимости, 68.