РОЗДІЛ II
Теоретична фізика

УДК 539.104:537.311.33:535.1

Petro Trokhimchuck,
Iryna Dmytruk

Problem of Coherence in Modern Theoretical Physics*

The problem of coherence in modern theoretical physics is discussed. Classical and quantum conceptions of coherence, including uncertainty principles, are analyzed. Problem of coherence in Relaxed Optics (RO) is represented as a problem of creation and change of coherent structures. Problems of coherence breakdown, including phase coherence, and its applications in modern physics, including RO, are discussed too.

Key words: coherence, theoretical physics, Relaxed Optics, Rayleygh principle, uncertainty principles, coherent structures, coherence breakdown.

Introduction. The problem of a coherence (from Latin word coaherens – is being in bond) is one of the central problems of modern optics. This problem has three representations and applications in classic, quantum and relaxed optics and other chapters of modern physics [11;12].

In physics coherence is an ideal property of waves that enables stationary (i.e. temporally and spatially constant) interference. It contains several distinct concepts, which limit cases that never occur in reality but allow the understanding of the physics of waves, and has become a very important concept in quantum physics. More generally, coherence describes all properties of the correlation between physical quantities of a single wave, or between several waves or wave packets [1–14].

Quantum theory of coherence is based on the concept of harmonic oscillator.

An analogy between classical and quantum concepts of coherence was demonstrated on the basis N. Bohr modification of Rayleygh principle and uncertainty principle. Concept of harmonic oscillator allows determining minimal possible difference between incoherent and coherent part of energy. This concept is basis for the Heisenberg, Robertson, Heisenberg – Robertson and Schrödinger – Robertson uncertainty principles [10; 13].

Roughly speaking, pure coherence is corresponded of resonance of proper phenomenon and therefore coherence theory is the theory of resonance processes and phenomena.

Concept of coherence was used in RO as concept of coherent structures. Therefore this question is discussed too.

Basic results and discussions

In classical optics basic principle of coherence is Rayleygh criterion [1, p. 580]

$$\Delta k_x \Delta x = \Delta k_y \Delta y = \Delta k_z \Delta z = \Delta\omega \Delta t = 1, \tag{1}$$

where $\Delta k_x, \Delta k_y, \Delta k_z, \Delta x, \Delta y, \Delta z, \Delta\omega, \Delta t$ – changes of wave numbers, coordinates, frequency and time properly. This criterion is used for the separation of the spectral lines. Formally spatial part of Eq. (1) may be used as criterion of spatial coherence and time part – as criterion of temporal coherence. Strictly speaking, for the separation of spectral lines sign = before 1 must be change on sign $\geq$, and for coherence – on sign $\leq$. These conditions for coherence have next form:

---

[*] Друкується в авторській редакції

$$\Delta k_x \Delta x \le 1, \quad \Delta k_y \Delta y \le 1, \quad \Delta k_z \Delta z \le 1, \tag{1a}$$

$$\Delta \omega \Delta t \le 1. \tag{1b}$$

Eq. (1a) is condition of spatial coherence, Eq. (1b) – condition of temporal coherence.

Basic principle of Quantum Mechanics (uncertainty principle) and basic principle of quantum theory of coherence (Quantum Optics) are receiving from Eq. (1) after here multiplication by Planck's constant $\hbar$ according by N.Bohr [1, p. 580]. Therefore we have:

$$\Delta p_x \Delta x = \Delta p_y \Delta y = \Delta p_z \Delta z = \Delta E \Delta t \le \hbar, \tag{2a}$$

$$\Delta p_x \Delta x = \Delta p_y \Delta y = \Delta p_z \Delta z = \Delta E \Delta t \ge \hbar, \tag{2b}$$

where Δp_x, Δp_y, Δp_z, ΔE – changes of proper components of linear momentum and energy. Eq. (2a) may be represented as the basic principle of Quantum theory of coherence and Eq. (2b) is the uncertainty principle.

Spatial and temporal coherence can not be divided separately. Therefore in classical optics the difference between spatial and temporal coherence (phase coherence) $\varphi = \vec{k}\vec{r} - \omega t$ is used.

In classic optics coherence is the coordinate passage in space and times few oscillate or wave processes, which is appeared for its addition.

Oscillations are called coherent if its phase difference is stable (or change according to some law) in time and for an addition it determined an amplitude of summary oscillation^

Harmonic oscillation may be represented in the next form:

$$V(t) = A\cos(\omega t + \varphi), \tag{3}$$

where basic characteristics of an oscillation – amplitude A, frequency ω and phase φ are constant.

For the addition two oscillations with one frequency ω and various amplitudes A_1, A_2 and various phases φ_1, φ_2 the resulting harmonic oscillation has frequency ω too. An amplitude of this oscillation:

$$A_s = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos(\varphi_1 - \varphi_2)}, \tag{4}$$

may be change from $A_1 + A_2$ to $A_1 - A_2$ and it depending on phase difference $\varphi_1 - \varphi_2$.

For the cardinal estimation the coherency of oscillations a correlative function $R(\tau)$ was introduced, where τ is time interval of the change of phase in interval $\varphi_1 - \varphi_2 < \pi$.

An amplitude of the addition two oscillations from one source with time interval τ has next form:

$$A_s = \sqrt{A_1^2 + A_2^2 + 2A_1A_2R(\tau)\cos\overline{\omega}\tau}, \tag{5}$$

where $\overline{\omega}$ is average frequency of an oscillation.

Value of τ, for its $R(\tau) = 0{,}5$, is called the time of coherency or period of harmonic train.

For the propagation of plane electromagnetic wave in homogeneous matter phase of oscillation is constant at the time τ_0. In this time wave is propagated on distance $c\tau_0$, where c is the velocity of light. This distance $l_{coh} = c\tau_0$ is called the length of coherency or length of train.

A notion of coherency is used for the representation autooscillations with constant amplitude.

For the representation of coherent properties wave in the perpendicular direction to a direction of wave propagation the notions of coherent space and coherent length are introduced. Coherent length may be determined with the help of correlative function $R_\perp(l)$, where l is the corresponding space size. Condition $R_\perp(l) = 0{,}5$ is determined size or radius of coherence. All space of wave propagation may be fractured on the regions with constant coherence. The volume of its region (coherent volume) is determined as multiplication the length of coherence l_{coh} on the area of figure, which is bounded of line $R_{\perp}(l) = 0{,}5R_{\perp}(0)$.

In general case the correlative function isn't be pure time or space. But in experiment these two cases may be discriminated: Michelson interferometer is example of temporal coherence and Yung interference – spatial coherence. In mathematical sense for this case the correlation function may be represented in the next form:

$$R(r,t) = R_1(r)R_2(t). \tag{6}$$

The conception of coherence is used for the representation wave properties electrons, neutrons and other particles. In this case the coherence is called the directional coordinated flux of particles.

The Hanbary Brown – Twiss stellar interferometer (Fig.1) allows measuring the fluctuations of intensity, which fall into detector, only. This experiment is differed from Michelson method. It is detected the mean value from multiplication from two probabilistic intensities but no one. A signal of quadratic detector [11, p.217] is proportional to value:

$$\left|E^{(+)}(r_1,t)\right|^2 = |A|^2 + |B|^2 + AB^* e^{i(k-k')r_1} + A^* B e^{-i(k-k')r_1}. \tag{7}$$

This signal isn't included of quick oscillation the detected wave, but mean value from this transforming signal doesn't include interference component (since mean value $\left\langle AB^* \right\rangle = 0$). Hanbary Brown and Twiss interferometer multiplied these two transformed signals and after this it measuring statistic mean value. Mean value from the multiplication of two intensities of type (7) may be represented in the next form:

$$\left\langle \left|E^{(+)}(r_1,t)\right|^2 \left|E^{(+)}(r_2,t)\right|^2 \right\rangle = \left\langle \left(|A|^2 + |B|^2\right)^2 \right\rangle + 2\left\langle |A|^2 |B|^2 \right\rangle \cos[(k-k')(r_1-r_2)], \tag{8}$$

where next conditions were taken into account: $\left\langle |A|^2 A^* B \right\rangle = 0, \quad \left\langle |B|^2 AB^* \right\rangle = 0$ and other.

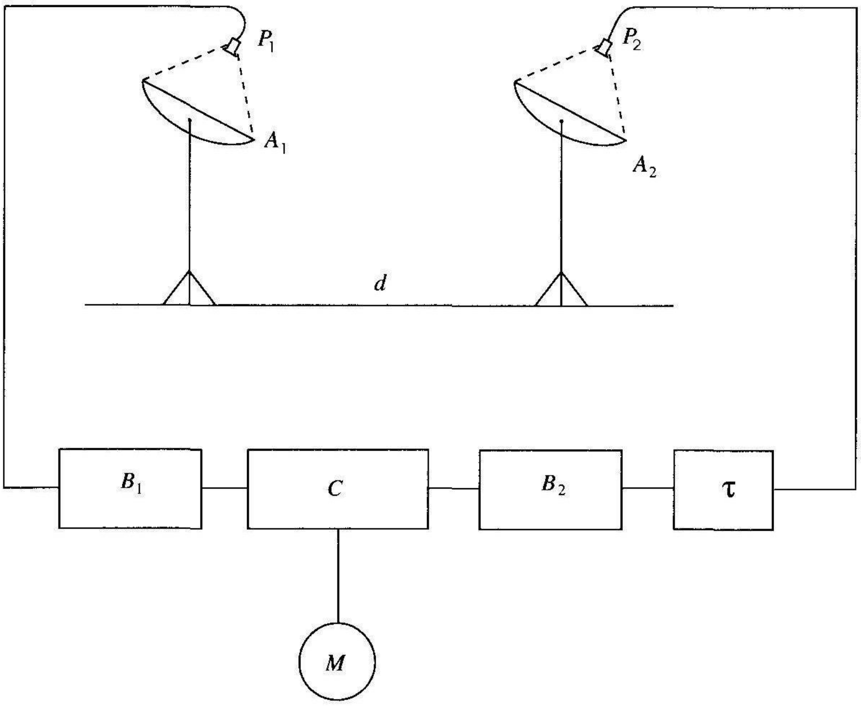

Fig. 1. *Schematic diagram of Hanbury Brown – Twiss stellar intensity interferometer [11, p. 217]. Here* P_1 *and* P_2 *are the photodetectors,* A_1 *and* A_2 *are the mirrors,* B_1 *and* B_2 *are the amplifiers,* τ *is the delay time,* C *is a multiplier, and* M *is the integrator*

Though interferometric experiments are interpreted with help of universe average but in these experiments time averaging is realized too. But time averaging is more difficult as universe average. For the time averaging interferometric measurements necessity give into account that plane waves aren't absolute monochromatic in general case. It allow to conclude that A and B are stochastic time functions $A(t)$ and $B(t)$.

Role of coherence in Quantum theory is more important as in Classic theory. Phase in Quantum (Wave) Mechanics is the basic characteristics of wave functions, unitary (canonic) transformations and scattering matrix. Roughly speaking coherence in Quantum theory was beginning by d'Broglie, more precisely his concept of wave–corpuscular dualism (particle is the standing wave).

Quantum theory of coherence is based on the idea by E. Schrödinger (1927) and was developed by R. Glauber and E.C.D. Sudarshan [2–7; 9]. Quantum harmonic oscillator is the basis of quantum theory of coherence. Coherent state of electromagnetic field may be represented with help of displaced vacuum state:

$$|\alpha\rangle = \hat{D}(\alpha)|0\rangle,$$

where $\hat{D}(\alpha) = \exp\left(\alpha\hat{a}^{+} - \alpha^{*}\hat{a}\right)$ is the shift operator, $\hat{a}, \hat{a}^{+}$ are the annihilation and creation operators. Coherent state is an eigenvector of the annihilation operator $\hat{a}$ with eigenvalue α [6, p.189].

Phase of wave functions in quantum mechanics has a deeper physical content than in classical physics. It includes energy and momentum characteristics of proper physical interaction. Therefore coherence is one of important notion of Quantum Mechanics. Roughly speaking wave functions of exponential form with phase term in form $\vec{p}\vec{r} - Ht$ are coherent functions, where H – Hamiltonian of system. Hamiltonian of system is the full energy of system. Therefore, the coherence of the process or phenomenon is related to the fundamental physical quantities of energy and momentum. These functions after additional transformations may be used as orthonormalized basis of Quantum Mechanics. Therefore we can represent each quantum state as function from coherent states. Representation of coherent states is more physical as, for example, Fock representation. These two representations are bonded with help next formula [6, p. 191]:

$$|\alpha\rangle = e^{-|\alpha|^2/2} \sum_{n=0}^{\infty} \frac{\alpha^n}{\sqrt{n!}} |n\rangle, \tag{9}$$

where $|\alpha\rangle$ – coherent state, $|n\rangle$ – Fock state.

Equations (1a), (1b) and (2a) aren't selected coherent and incoherent part of interaction. Roughly speaking it is the condition of interference two waves. But these correlations aren't allowed to select only coherent or incoherent part of this interaction. This problem was resolved in quantum theory of coherence (Quantum Optics). In this chapter of modern physics concept of harmonic oscillator is basis [6, p. 89]. Therefore uncertainty principle has next form:

$$\Delta p_x \Delta x = \Delta p_y \Delta y = \Delta p_z \Delta z = \Delta E \Delta t \geq \hbar/2. \tag{10}$$

It is connected with minimal (zero) energy of harmonic oscillator $\hbar\omega/2$. This energy is corresponded the energy of incoherent part of electromagnetic field, other words difference between full energy of field and coherent part of energy [6, p.194]. Thus quantized theory of coherence can tell the difference between incoherent and coherent part of energy. This fact are corresponded to the quantum mechanical zero-point energy of the harmonic oscillator.

Uncertainty principle may be represented in next form [10, p. 50; 13, p. 277]:

$$\sigma_q \sigma_p \geq \hbar^2/4, \tag{11}$$

and its H. P. Robertson generalization for random dynamical variables [14].

$$\sigma_A \sigma_B \geq \left|\left\langle\left[\hat{A}\hat{B}\right]\right\rangle\right|^2 / 4, \quad \sigma_C = \left\langle\left(\Delta\hat{C}\right)^2\right\rangle \equiv \left(\delta C\right)^2, \quad \Delta\hat{C} = \hat{C} - \langle C\rangle. \tag{12}$$

In modern interpretation formulas (12) are corresponded of uncorrelated states. In 1930 E. Schrödinger and H. P. Robertson [13, p. 277] received the generalization of formula (12)

$$\sigma_A\sigma_B \geq \left|\left\langle\left[\hat{A}\hat{B}\right]\right\rangle\right|^2 \Big/ 4\left(1-r^2\right), \tag{13}$$

where

$$r = \sigma_{AB} \Big/ \sqrt{\sigma_A\sigma_B} \tag{14}$$

is correlation coefficient of quantities A and B and $|r| \leq 1$:

$$\begin{gathered}\sigma_{AB} = \left\langle\left\{\Delta A, \Delta B\right\}\right\rangle \Big/ 2 \equiv \left\langle\left(\left(\left\langle\hat{A}\right\rangle - \langle A\rangle\right)\left(\hat{B} - \langle B\rangle\right)\right) + \left(\left(\hat{B} - \langle B\rangle\right)\left(\hat{A} - \langle A\rangle\right)\right)\right\rangle \Big/ 2 = \\ = \left(\left\langle\hat{A}\hat{B} + \hat{B}\hat{A}\right\rangle\right)\Big/ 2 - \langle A\rangle\langle B\rangle\end{gathered} \tag{15}$$

– mutual correlation of quantities A and B, which are corresponded of average value of error operators $\Delta\hat{K} = \hat{K} - \langle K\rangle$.

Schrödinger-Robertson uncertainty principle (13) is generalization of Heisenberg –Robertson uncertainty principle (12) for the case of correlated states and reduce to it for *r*=0 [13, p. 277].

Schrödinger-Robertson uncertainty principle [13, p.277] was used for analysis of motion of particle with coordinate *q*(*t*) and linear momentum *p*(*t*) in the field of harmonic oscillator $V(t) = Mq^2(t)\omega^2(t) \big/ 2$. Process of decreasing a frequency of oscillation $\omega(t)$ is caused to increasing of correlation coefficient *r*(*t*):

$$r(t) = \left\langle q\hat{p}_q + \hat{p}_q q\right\rangle \Big/ 2\delta q\delta p_q \tag{16}$$

and the change of uncertainty principle

$$\delta q\delta p_q \geq \hbar \Big/ 2\sqrt{1-r^2}, \tag{17}$$

where $\delta q \equiv \sqrt{q^2}$, $\delta p_q \equiv \sqrt{p_q^2}$. Formally [13, 277] the change of correlation coefficient in uncertainty principle may be represented as simple substitution $\hbar \to \hbar^* \equiv \hbar \big/ \sqrt{1-r^2}$. At the absence of correlation $(r \to 0)$ quantity $\hbar^* \to \hbar$, and uncertainty principle has classical Heisenberg form:

$$\delta q\delta p_q \geq \hbar/2. \tag{18}$$

For formation the strongly correlated state of particle with $|r| \to 1$ the disperses of coordinate $\left\langle q^2\right\rangle$, momentum $\left\langle p^2\right\rangle$ and its product are increased indefinitely. It is caused the more effective penetration of particle to sub-barrier region $V(q)$ as for this particle in uncorrelated state [13, p. 278]. Practically, formula $|r| \to 1$ is corresponded the case of expansion of wave packet. Formally this concept is equivalence to the concept of symmetry breakdown.

In Nonlinear Optics conditions of phase matching and phase synchronism are the representation of conditions of coherence. But condition of phase synchronism has spatial geometrical nature [4; 6; 9]. For example, for generation of second harmonic angle diapason of observation of maximal effect is equaled 10' – 30' [4, p. 95]. Second example is generation of laser radiation. For solid state laser angle diapason for stable resonator is equaled ~10', for unstable resonators – ~10"–20" [8, p. 9]. For semiconductor lasers this value may be large [3]. For holography we must have large value of coherent length, this value is caused of coherence of light source (lasers) [14, p. 9].

Coherence breakdown is caused a failure of proper phenomena. For our examples, it may be generation of second harmonic, lasing and holograms. Coherence breakdown is associated with symmetry breakdown.

But for the interaction light and matter we have two partners of interaction: light and matter. Symmetry and nature of light, matter and its interactions are caused the generation of proper process or phenomenon [11; 12].

The concept of coherent structures (CS) was introduced in RO [11, p. 249; 12, p. 87], chapter of modern physics of irreversible interaction light and matter.

The CS (coherent structures) are called the structures with next properties:

1) these structures have the some order and symmetry;
2) it may be source for the generation and transformation of radiation, including light, (linear and nonlinear optics);
3) it may be source for the generation and transformation of irradiated matter, including amorphous and crystal materials, (the pure effects of RO);
4) it may be source for the generation and transformation of the radiation and irradiated matter, (holography, mixed phenomena of RO);
5) it may be formed with help coherent irradiation.

Practically it is the “traces” of the interaction laser irradiation and matter in matter. These structures may be classified as first-order and second-order structures [2, p. 40]. One has various energetic and time conditions of the creation and stability. The problem of the classification and modeling of these structures may be resolved with help short-range, long-range action and mixed approximations of the interaction light and solid.

The first-order range CSs have quantum character and may be represented as photochemical or crystal photochemical processes. One of the interesting problems of these phenomena is the problem of the nonadiabatic scattering light on valent and impurities bonds. This problem in the classical physics of status solid is represented as adiabatic. In radiation physics of status solid this problem is neglected. In RO it is one of the interesting problems (the oriental effect and the creation donor layers in semiconductors [1, p. 24]).

The second-order range CS have, as rule, the wave nature (thermochemical, including annealing, plasmic, electromagnetic hydrodynamic structures, interferometrical phenomena and other [11, p. 249; 12, p. 87]).

Quantum CS may be classified as multiphotonic $(h\nu < E_g)$, including monophotonic $(h\nu \sim E_g)$, and fractured structures $(h\nu >> E_g)$; where $h\nu$ – quantum energy, E_g – band gap of irradiated materials. The experimental research in this part of physics is almost absented.

Concept of CS allows associating radiative and nonradiative parts of interaction light and matter with point of change coherent characteristics of this interaction.

Transition from one coherent state to another or from one CS to another may be represented as breakdown initial coherent state or structure respectively.

Concept of CS allows associate the light-induced phase transformations in irradiated matter with change of here coherent properties [11, p. 249; 12, p. 87]. Therefore methods of theories of phase transitions and transformations may be used for the resolutions of problems of coherence and contrarily, methods of coherence may be used for the resolutions of problems of the theory of phase transformations.

The basis of the RO is phenomenological kinetic-energy classification of the interaction of optical radiation with matter. Classification of CS is corresponded of next physical systems and phenomena: basic phenomena of RO; incommemshurate phases; polymorphoid, crystal and quasicrystal phases and other [12, p. 87].

Concept of CS allows realizing transitions from nonlinear optical processes, which can be represented as nonequilibrium phenomena, to relaxed optical processes, these processes are irreversible. This concept allows uniting in one system nonlinear and relaxed optical processes and phenomena in one system [12, p. 87]. Transitions between quantum states and between various structures are formal equivalence. This equivalence is result of saturation effect for phase transition and lasing. First process is sluggish, second is high-speed. For example, formation and creation of Bose or Fermi condensate is the effect of saturation, which is caused proper phase transition [10, p. 269]. Therefore theory of phase transitions was used for the explanation of nonlinear optical phenomena [12, p. 97]. Each nonlinear optical phenomenon may be represented as coherence breakdown of proper linear optical process, in this case mechanism of light scattering (absorption and reflection) has conclusive value [12, p.144]. But inverse problem of using laser theory for the explanation of phase transitions isn't developed. Therefore for the explanation of effects of the laser annealing and laser implantation the thermal model are used, which sometimes explain the experimental results are reversed [11]. For the resolution of this contradiction we must find new methods, which have lasing prehistory.

Difference between coherent state and coherent structures is next. Coherent state is local state of proper macroscopic system, coherent structures it is collective macroscopic state of all system. Concept of coherent state is useful for linear and nonlinear (equilibrium and nonequilibrium) processes, that due to the relatively low intensity of interaction. Concept of coherent structures may be useful for irreversible processes, that due to the relatively high intensity of interaction. For last case we can use theory of cascade processes and regimes of saturation of excitation for each term of cascade and we can examine and explain the single notion of linear and non-linear, equilibrium and non-equilibrium and irreversible interdependent processes for this case [11; 12].

Problem of transition from nonequilibrium to irreversible processes is the problem of the aging the elements of optoelectronic systems. Therefore the search of waves the transformation irreversible processes to nonequilibrium and equilibrium is one of the central problems of creation more stable optoelectronic system. But this problem is connected with structural properties and here changes of irradiated matter, which affects the reliability of the optoelectronic systems as a whole and their components.

This approach allows flaring the application on coherent conception on all aspects of problem of interaction light and matter.

Conclusions

1. Basic concepts of classic and quantum coherence are discussed.
2. Conditions of classic coherence and spectral analysis (Rayleygh principle) are analysed.
3. Was shown that uncertainty principle (N. Bohr concept) and quantum condition of coherence are formal equivalence to proper classic principles.
4. Basic types of uncertainty principles (Heisenberg, Robertson, Heisenberg – Robertson and Schrödinger-Robertson) are analysed.
5. Basic notions of quantum theory of coherence (Quantum Optics) are represented.
6. Concept of Coherent Structures and its possible applications are discussed.
7. Was shown that phase transitions may be represented as coherence breakdown.
8. An analogy between theory of phase transformations (in basic thermodynamic) and laser theory (in basic coherent theory) is observed too.

Aknowledgements

Authors thanks to prof. V. I. Vysotskiy for discussion about uncertainty principles.

References

1. Bohr N. The Quantum postulate and the Recent Development of Atomic Theory / N. Bohr // Nature, Supplement. – Vol. 121. – 1928. – P. 580–590.
2. Glauber R. J. Quantum Theory of Optical Coherence. Selected Papers and Lectures / R. J. Glauber. – New-York e.a. : Wiley@Sons, 2006. – 698 p.
3. Gribkovskiy V. P. Semiconductor lasers / V. P. Gribkovskiy. – Minsk : University Press, 1988. – 304 p. (In Russian).
4. Haken H. Laser light dynamics / H. Haken. – Moscow : Mir Publishers, 1988. – 350 p. (In Russian)
5. Mandel L. Optical Coherence and Quantum Optics / L. Mandel, E. Volf. – Moscow : Fizmatlit, 2000. – 895 p. (In Russian).
6. Perina J. Coherence of light / J. Perina. – Moscow : Mir Publisher, 1974. – 368 p. (In Russian).
7. Piecara A. H. Nowe oblicze optyki. Wprowadzenie do elektroniki kwantowej i optyki swiatla spolnego / A. H. Piecara. – Warszawa : PWN, 1968. – 262 s. (In Polish).
8. Popescu I. M. Probleme resolvate de fizica lazerilor / I. M. Popescu, A. M. Preda, C. P. Cristescu, P. E. Sterian, A. I. Lupaşcu. – Bucureşti : Editura technică, 1975. – 443 p. (In Romanian).
9. Shen I. R. Principles of Nonlinear Optics / I. R. Shen. – Moscow : Nauka Publishers, 1989. – 559 p. (In Russian).

10. Svidzinskiy A. V. Mathematical methods of theoretical physics / A. V. Svidzinskiy. – Vol. 2. – Kyyiv : Bogolyubov institute of theoretical physics, 2009. – 436 p. (In Ukrainian).
11. Trokhimchuck P. P. Foundations of Relaxed Optics / P. P. Trokhimchuck. – Lutsk : Volyn' University Press Vezha, 2011. – 627 p.
12. Trokhimchuck P. P. Nonlinear and Relaxed Optical Processes. Problems of interactions / P. P. Trokhimchuck. – Lutsk : Vezha-Print, 2013. – 280 p.
13. Vysotskiy V. I. Peculiarities 0f the formation and the application of correlated states in nonstationary states for low energy of interactive particles / V. I. Vysotskiy, M. V. Vysotskiy, S. V. Adamenko // JETP. – Vol. 141, No. 2. – 2012. – P. 276–287. (In Russian).
14. Ziętek B. Optoelektronika / B. Ziętek. – Toruń : Wydawnictwo universytetu Nikolaja Kopernika, 2005. – 615 s. (In Polish).

Трохимчук Петро, Дмитрук Ірина. Проблема когерентності в сучасній теоретичній фізиці. Досліджено проблему когерентності в сучасній теоретичній фізиці. Проаналізовано класичну та квантову концепції когерентності, уключаючи принципи невизначеності, а також принципи невизначеності Гейзенберга, Робертсона, Гейзенберга-Робертсона та Шрьодінгера-Робертсона, застосування принципу невизначеності Шрьодінгера-Робертсона для розв'язання задачі про нелінійний математичний маятник. Проблему когерентності в релаксаційній оптиці представлено як проблему утворення й зміни когерентних структур. Проаналізовано класифікацію когерентних структур, що відповідає класифікації явищ незворотної взаємодії оптичного випромінювання з речовиною, яка покладена в основу релаксаційної оптики. Досліджено проблеми порушення когерентності, уключаючи фазову когерентність, та їх застосування в сучасній фізиці, релаксаційній оптиці.

Ключові слова: когерентність, теоретична фізика, релаксаційна оптика, принцип Релея, принципи невизначеності, когерентні структури, порушення когерентності.

Трохимчук Петр, Дмитрук Ирина. Проблема когерентности в современной теоретической физике. Обсуждается проблема когерентности в современной теоретической физике. Проанализированы классическая и квантовая концепции когерентности, включая принципы неопределенности, принципы неопределенности Гейзенберга, Робертсона, Гейзенберга-Робертсона и Шредингера-Робертсона, а также применение принципа неопределенности Шредингера-Робертсона для решения задачи о нелинейном математическом маятнике. Проблема когерентности в релаксационной оптике представлена как проблема образования и изменения когерентных структур. Проанализирована классификация когерентних структур, что соответствует классификации явлений необратимого взаимодействия оптического излучения с веществом, что положена в основу релаксационной оптики. Исследованы проблемы нарушения когерентности, включая фазовую когерентность, и их применение в современной физике, релаксационной оптике.

Ключевые слова: когерентность, теоретическая физика, релаксационная оптика, принцип Рэлея, принципы неопределенности, когерентные структуры, нарушения когерентности.

Стаття надійшла до редколегії
15.05.2013 р.

УДК 538.9

Павло Шигорін, Ірина Дмитрук

Проблема власних функцій та власних значень у теорії нерівноважних процесів у конденсованому бозе-газі

У роботі досліджено задачу на власні функції та власні значення оператора лінеаризованого інтеграла зіткнень квантового кінетичного рівняння Больцмана для моделі слабконеідеального бозе-газу за наявності в ньому бозе-конденсату. Побудовано перші вісім ортогоналізованих та нормованих власних функцій і розраховано відповідні власні значення. Показано, що перші три власні значення дорівнюють нулю. Розглянуто можливості застосування системи власних функцій опертора лінеаризованого інтеграла зіткнень для теоретичного опису слабконерівноважних процесів у бозе-газі за наявності конденсату, зокрема для опису звукових хвиль, розрахунку кінетичних коефіцієнтів в'язкості та теплопровідності тощо.

Ключові слова: бозе-газ, квантове кінетичне рівняння Больцмана, лінеаризований інтеграл зіткнень, метод Ван Чан-Уленбека.
