Invited Paper

On the issue of teaching modern optics

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The advent of laser not only gave an impetus to further development of optics, not only breathed new life into many branches of this science, not only led to the use of optics for non-optical applications but opened new ways teaching optics as well.

Nowadays you cannot teach optics without quantum electronics. But having pointed to new possibilities of optics, quantum electronics by no means revised its fundamental concepts. Moreover quantum electronics is based on fundamental concepts of the XIX–XX century optics. Its appearance, formation, and development confirmed thine, extended the sphere of their practical application, and made the bases of optics as a science more striking, spectacular and intelligible.

In fact, quantum electronics as a science is based on three fundamental concepts of physical optics.

The first is that the energy of electromagnetic radiation is packed in discrete bundles called light quanta or photons. This discreteness is best observed in the interaction of radiation with matter when photons are absorbed or emitted. The second is that photon emission at sufficiently high intensity is determined by the effect of their induced emission. And photons of stimulating and stimulated radiation are identical with the emission probability being proportional to the radiation intensity.

The third is that quanta of electromagnetic radiation obey Bose-Einstein statistics. So the number of quanta per one field oscillator is unlimited.

When one field oscillator (one mode) is filled by a great number of indistinguishable quanta, a classical coherent electromagnetic wave is formed.

We know that is was A. Einstein who formulated these concepts and quite a long time ago (1905-1924).

A consistent quantum theory was developed by P. A. M. Dirac in 1927. The most important result of this theory is that it has strictly proved the existence of induced emission, postulated by Einstein, and its coherence also intuitively anticipated by him.

So by 1927 all fundamental physical prerequisites for the appearance of quantum electronics were formulated. However it was only at the end of 1954 - the beginning of 1955 that the first quantum electronic device, an ammonia beam maser, was created. It worked in the microwave range (1.25 cm wave) though both A. Einstein and P. Dirac meant optics when they formulated their concepts of induced radiation.

Now we have a principal issue important from the point of view of education. Since J. C. Maxwell developed his electromagnetic theory of light and after brilliant experiments as H. Hertz, the wave unity of radiation in all spectrum ranges of electromagnetic oscillations varying in frequency (wavelength) only became evident to the physicists. But in the first half of this century radio and optics went different ways. In optics quantum concepts (spectroscopy) were being developed. In radiophysics wave concepts adopted from optics resulted in radiointerferometry. The unity of radio and optics was always emphasized from the point of view of the wave model. But for a long time their unity based on the quantum nature of electromagnetic radiation was not revealed. This state of things changed only with appearance and rapid development of microwave spectroscopy after the Second World War caused by intensive development of centimeter wave techniques. Reliable sources of monochromatic microwave radiation with tunable frequency, waveguides for transmitting this radiation, high Q resonant cavities, and sensitive detectors gave microwave spectroscopy some quite important, though technical, advantages. But at that time the principal difference of microwave spectroscopy from optical spectroscopy was the use of monochromatic radiations.

Without going into details but keeping in mind that for microwaves ($h\nu \ll kT$), we can definitely say it was monochromatic microwave radiation, a thorough development of the monochromatic oscillator theory - self-sustained oscillators with a positive feedback — and availability of adequate technical means that brought about the creation of first of a maser and then of a laser. The latter was the result of a natural, for radiophysics, striving for monochromatic radiation oscillators of shorter and shorter wavelengths.

From this brief of necessity historical review it follows that purely radiophysical concepts of nonlinear oscillation theory, positive or negative feedback approach monochromatic radiation directivity diagrams and so on, along with quantum mechanics, should play an important role in teaching modern optics.

Modern quantum electronics embraces a huge area, but having originated from microwave electronics, it caused most significant transformations in optics. The thing is that, though the operation of masers and lasers is based on the same principle, the difference between them is significant. In microwave physics the creation of masers[1] led to the appearance of devices which were based on a new (quantum) operation principle but had characteristics inherent in classical electronics. No doubt the masers strongly improved the parameters of radio devices. But these were in principle quantitative changes of usual qualitative properties. Such devices as coherent radioamplifiers and oscillators generators generating monochromatic waves were used in electronics before the appearance of quantum electronics.

With optics it was quite different. In optics all sources of light are quantum in their nature. The very concept of quanta was suggested when the properties of thermal optical radiation were analyzed. But before the quantum electronics concepts were formulated all optical light sources emitted non-monochromatic incoherent oscillation. There were neither coherent amplifiers of the light wave field conserving the oscillation phase nor monochromatic electromagnetic wave oscillators. Now a days intensive light waves of high spatial directivity, spectral monochromatically, and temporal coherence are widely used in optics.

That's why we have to consider the issue of teaching optics in a new way.

The thesaurus of optical courses should include the bases of quantum mechanics concerning spectroscopy. They are first of all Einstein's coefficients for spontaneous and induced transitions, matrix elements for transition operators, lifetime of states, line width, level population and its dynamics. In traditional courses of geometrical optics the experimental part should include a wide use of laser radiation for demonstrating the laws of light propagation, reflection, refraction, and scattering. It is necessary to introduce the concept of radiation mode content, to explain the processes of light beam formation, including Gaussian beams, in terms of monochromatic light defraction.

The education should ensure a clear understanding of such radiophysical concepts as resonator, feedback, amplification, generation, rectification (detection) on light oscillations, light heterodyning and some others.

Nonlinear optics, processes of harmonic generation, light selfaction should also take their place in a general course of optics.

Traditionally non-optical applications optical radiations are included into spatial courses. But optical fiber systems, quasi-optical lightguides should find their place in a course of optics due to their important applications and fundamental physical nature.

On the whole, teaching of optics cannot be modern and effective without comprising basic concepts of quantum electronics and using lasers and laser technique in the experiment.

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[1] A Nobel Prize in Physics in 1964 (C. H. Townes, A. M. Prokhorov, N. G. Basov)