Leucippus supplemented this idea with the idea of a plurality of worlds, an idea which was alien to Greek thinking in cosmology prior to this time. Also at this time was conceived the idea of an inner structure of things, defined by primary structural units from which the world was built. Right in this spirit Empedocles rearranged the ancient notions about four primordial elements. Leucippus approached this problem in a manner differing from that of Empidocles. He transferred the opposition of limited—limitless, which was basic for Greek thought, from the cosmic scheme to the microscopic scheme. In this process, the opposition of cosmos to chaos became an opposition of the smallest material particles—atoms—to empty space. Indivisible, impenetrable, always invariant atoms express in the final analysis the Greek idea of the limited; with this is connected the fact that it is the form that is the basic and essentially singular positive attribute of atoms. Conversely, the idea of the limitless turns out to be naturally conceived empty space without boundaries and without inner divisions. It is clear from Aristotelian texts concerning atomic theory that this was precisely the situation; they are all shot through with the idea of dualism of the full and the empty, the existent and the non-existent, atoms and empty space.

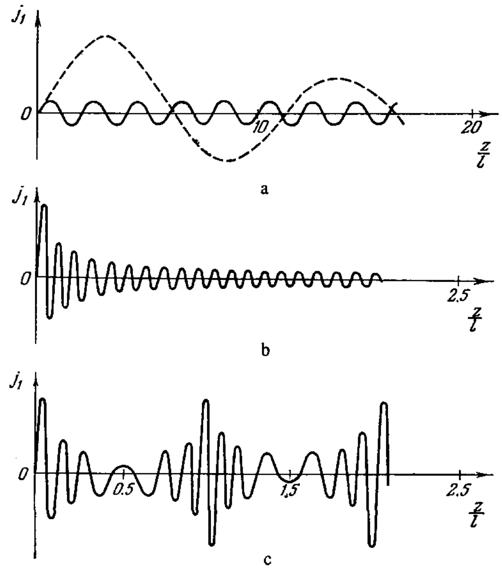
The above-mentioned peculiarities of the concepts of the early atomic theory still do not characterize it fully. Another aspect of the atomistic hypothesis is the eternal motion of atoms "leaving traces of themselves in all directions." This aspect cannot be explained on the basis of only speculations with the ideas of the limited and the limitless; it is necessary here to seek a parallel or a graphic model taken from life. Aristotle's work "About the Soul" explains this model to us—these are the dust particles that are airborne and that become visible only in a ray of the sun. This analogy, which doubtless is the property of the founder of atomic theory, was the subject of lively discussion by later authors.

Thus, the considerations which guided the creators of the atomistic doctrine in Greece was a mixture of abstract speculations and inferences that were made on the basis of graphic analogies.

D. A. Varshalovich and M. I. D'yakonov, Quantum Theory of the Modulation of the Electron Beam at Optical Frequencies.

The modulation of a beam of electrons at radio frequencies has been investigated thoroughly both theoretically and experimentally and is widely used in radio engineering. So far as the optical range is concerned, the modulation was attained here only quite recently in the experiments of Schwarz and Hora[1]. A beam of fast electrons with energy E_0 = 50 keV passed through a thin film placed in the field of a light wave of a laser. The resultant modulation led to the appearance of luminescence with the frequency of the laser radiation when the beam impinged on a nonluminescent metal screen.

The appearance of the modulation in this experiment[1] can be explained in the following way. In the field of the laser wave the material of the film is polarized and surface charges develop. Through interaction with these charges the electron loses (or acquires) energy and momentum as a result of the stimulated emission (or absorption) of photons. These processes become possible only when an additional body—the film—is present. In a certain sense the surfaces of the film can be likened to a pair of grids to which has been applied a potential difference U sin ωt varying at the optical frequency ω.



Dependence of the amplitude of the alternating electron-current component j_1 at frequency ω on the distance z. a) $V/\hbar\omega = 0$, the dashed line represents the classical theory, the continuous line—the quantum theory; b) $V/\hbar\omega = 10$, classical theory; c) $V/\hbar\omega = 10$, quantum theory.

In the classical description, when the electron passes through the film it is accelerated or decelerated, depending on the phase of the field at the moment of crossing the surface of the film. Electrons emitted from the film at various moments of time have various velocities. The fast electrons catch up to the slower ones which were emitted earlier. This results in their spatial bunching in such a way that the current density is modulated at the frequency ω and its harmonics. The electron velocities in a modulated beam are distributed in the interval from $v(1 - U/2E_0)$ to $v(1 + U/2E_0)$, where v is the initial velocity of the electrons. The continuous character of the velocity distribution leads to attenuation of the modulation at distances $z \gg l_0$, where $l \sim vE_0/\omega U$.

According to quantum mechanics, the electron which has passed through the film does not have a definite energy and momentum. Its wave function is a superposition of the states resulting from the emission or absorption of n quanta $h\omega$ (n = 0, ±1, ±2, ...). The modulation of the density and current of the electrons is due to the interference of these states. In this way, contrary to what the classical investigation gives, the distribution of the electrons by velocity in a modulated beam has a discrete character with $\Delta v \approx vh\omega/2E_0$. This discreteness leads to a situation wherein the dependence of the modulation depth on the distance behind the film z is essentially different from the dependence obtained by classical theory. It turns out that regions where the modulation is large recur in space periodically with a period $l = 4\pi(v/\omega)E_0/h\omega$ at great distances behind the film where, according to classical mechanics, the modulation is already absent (see the diagram). Only at small distances do the results of quantum and classical investigation coincide.

In the radio-frequency range the distance l is quite large; at such a distance the spatial bunching of electrons is usually already absent owing to the nonmonochromaticity of the original beam, and the quantum effects do not appear. In the case of modulation at optical frequencies the value of l can be small. So, in the experiments by Schwarz and Hora[1] the period l according to our estimates was 0.9 cm and the distance from the film to the screen was 25 cm. Thus, the effect observed in these experiments was of a quantum nature. The spatial periodicity of the modulation with a period l, which we pointed out[2], was observed in a recent experiment (private communication from Professor H. Schwarz).

Theoretical investigation shows that when a modulated beam strikes a screen there is produced coherent monochromatic radiation at the frequency ω and its harmonics. If the diameter of the beam is greater than the wavelength of the light, then this radiation will be sharply directional.

However, as Academician Ya. B. Zel'dovich noted, there is considerable difficulty in interpreting the radiation that was observed by Schwarz and Hora[1]; under the conditions of their experiment the intensity of the incoherent transition radiation in the entire visible range of frequencies had to exceed the intensity of the coherent radiation.

The character of the radiation that can be excited by an electron beam is for the moment yet to be studied.

[1] H. Schwarz and H. Hora, Appl. Phys. Lett. **15**, 349 (1969).

[2] D. A. Varshalovich and M. I. D'yakonov, ZhETF Pis. Red. **11**, 594 (1970) [JETP Lett. **11**, 411 (1970)]; Zh. Eksp. Teor. Fiz. **60**, 90 (1971) [Sov. Phys.-JETP **33**, 51 (1971)].

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