9 OCTOBER 1979 (FOUO 3/79) 1 OF 2

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9 October 1979

USSR Report

PHYSICS AND MATHEMATICS

(FOUO 3/79)

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USSR REPORT

PHYSICS AND MATHEMATICS

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LASERS AND MASERS

UDC 621.378.33

EXPERIMENTAL AND THEORETICAL STUDIES OF A CLOSED-CIRCUIT GASDYNAMIC CO_2 LASER

Moscow KVANTOVAYA ELEKTRONIKA in Russian No 6, 1979 pp 71-75

[Article by G. M. Klepach, V. F. Konakh, V. A. Soldatov and V. F. Sharkov, Institute of Atomic Energy imeni I. V. Kurchatov, Moscow]

[Text] The development of a continuous-operation CO_2 gasdynamic laser in which a mixture of CO_2, nitrogen and helium circulates through a closed circuit is described. The operating parameters of the device are: gas temperature $\leq$ 1200K, compression ratio $\sim$ 6, gas flow $\leq$ 1 kg/sec. The measured value for the gain coefficient is $\sim 0.25\ m^{-1}$. It is shown that by using a closed circuit the total laser efficiency of the unit can be considerably increased, which is extremely important in the practical use of such devices in treatment of materials and in metallurgy.

Currently CO_2 gasdynamic lasers are undergoing intensive study, both theoretical and experimental [1-6]. Primary attention is being devoted to the development of units operating in the pulse ($\tau \approx$ 1 msec) and quasicontinuous ($\tau \approx$ 1-5 sec) modes, apparently because of the engineering simplicity of such units. However, it appears obvious that the most promising units for practical applications are those in which the active medium circulates through a closed circuit, giving off no gas into the atmosphere and offering the possibility of achieving high laser efficiency [7-11], which will ultimately lead to decreased energy consumption.

We used such a unit, developed at the Institute of Atomic Energy imeni I. V. Kurchatov, to study the effect of design characteristics of the individual components (nozzle, diffuser and the like) on the operating characteristics of gasdynamic lasers with prolonged ($\tau >$ 10 min) circulation of the active medium through a closed circuit.

Measurements results were compared with theoretical calculations and experimental data obtained from an open-cycle device with similar temperature, pressure and mixture characteristics [6].

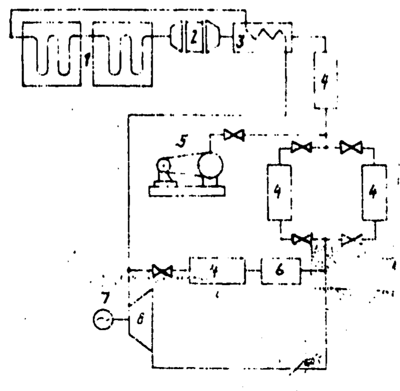

Fig. 1. Block Diagram of the Device

Description of the Experimental Apparatus

The apparatus (Fig. 1) is a closed, sealed circuit through which the active medium, a mixture of CO_2, nitrogen and helium, is circulated. The mixture, compressed sixfold in a centrifugal compressor (8), is fed through tubes to the regenerator (3), where it is heated to $T \approx 750°$ K by a counterflow of hot spent gas.

Next the gas passes through two successive heater sections (1) capable of heating it to $T \approx 1200°$ C and enters the working channel (2), where it is accelerated by the nozzle assembly to a speed of $M = 3 - 3.5$. The resulting "freezing" of the vibration levels of the nitrogen and CO_2 (001) produces the conditions for lasing in a radiation cavity with a wavelength of 10.6 microns.

The supersonic flow is slowed in a diffuser, after which the gas passes through the regenerator (3) and cooler (4), is cooled to 20° C and reaches the compressor intake. The active mixture is prepared for filling of the circuit and continuous compensation of leakage in a special tank. A bypass line with a cooler (4) and a filter (6) are provided in the circuit for constant cleaning of the mixture. The evacuation system (5) assures cleanliness of the circuit and guarantees a constant composition for the mixture. The compressor assembly (8) for helium-containing mixtures, with a compression ratio 6, has two intermediate coolers and is operated by an asynchronous electric motor (7).

The heater, designed for a miximum electric power of 180 kW, consists of two sections, whose heating elements are polished tubes made of the high-temperature alloy KhN70Yu. The tubes are heated by passing alternating current through them.

The working section (Fig. 2) consists of a forechamber, the nozzle assembly (1), the resonator (2) and the diffuser (3). The nozzle unit consists of 25 flat, shaped nozzle vanes with a critical section height of 0.8 mm. Preliminary testing of the nozzle array on an aerodynamic stand confirmed the calculations for flow after the nozzle ($M \approx 3.5$). The optical cavity of the resonator has dimensions of 3 x 15 x 10 cm. In addition to monitoring the working characteristics of the circuit (static pressure, temperature, flow rate), we measured the gain factor K_0 at a distance of 2 cm from the end of the nozzle while varying the intensity of a standard radiator.

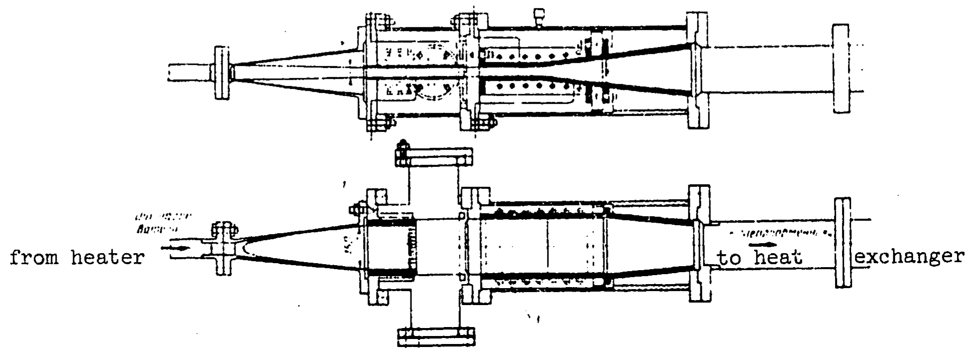

Fig. 2. Diagram of the Working Channel of the Gasdynamic Laser.

Discussion of Results

The measured parameters of the closed-circuit gasdynamic laser and the gain factor are as follows:

Composition of working mixture, moles:	$2CO_2 + 5N_2 + 3He$
Temperature of heater walls, °K:	1,270
Temperature of gas stagnation at working section inlet, °K	950
Pressure in forechamber, atm	4.2
Pressure in resonator, atm	0.1
Pressure at compressor intake, atm	1.02
Pressure at compressor outlet, atm	5
Temperature at compressor intake, °C	20
Temperature at compressor outlet, °C	80
Gas flow rate, kg/sec	0.35
Gain factor, meter $^{-1}$	0.25

The above data give a ratio of 0.024 for the static pressures in the resonator and the forechamber, which corresponds to a Mach number $M = 3.1$ at the resonator intake. At such flow rates and with a stagnation temperature $\sim$1,000° C, a specific radiant energy of $\Phi = 4\text{-}6$ kJ/kg ($K_0 = 0.3\text{-}0.6$ meter^{-1}) can be obtained [3, 4, 6].

The use of relatively low stagnation temperatures makes it impossible to achieve large energy yields from the gasdynamic laser, but it makes it possible to avoid design and process difficulties such as cooling of the tubing, use of expensive materials for construction of the circuit, dissociation of CO_2 and the like. In addition, the lifetimes of the individual assemblies are considerably increased, their reliability improved and operation simplified. Judging by the measured gain factor $K_0 = 0.25$ meter^{-1}, the energy supplied to the resonator is comparable to the calculated amount. In addition, note should be taken of the good stability of the gain factor throughout operation of the unit. It appears that the discrepancy between the theoretical and experimental values of K_0 is explainable by the nonoptimal cross section in which the gain factor was measured and by the presence of stagnant zones of hot, absorbing gas in pockets in the resonator.

We now estimate the theoretical increase in efficiency resulting from use of such a closed system [10, 11]. The electrical energy introduced into the active medium per unit mass can be determined by the formula

$$E = c_p[m(T_5 - T_4) + T_1 - T_q]. \quad (1)$$

where m is the number of compressor levels separated by intermediate coolers; T_4 and T_5 are the temperatures at the compressor intake and outlet*; T_1 is the temperature at the inlet to the nozzle assembly; T_q is the temperature at the heater inlet; and c_p is the heat capacity of the mixture at constant temperature. For an open system, this energy is given by

$$E = c_p(T_1 - T_0). \quad (2)$$

where T_0 is the ambient temperature.

For identical specific laser radiation powers, the efficiency ratio of the closed and open systems is inversely proportional to the ratio of the energies introduced:

$$\bar{\eta} = (T_1 - T_0)\,[m(T_5 - T_4) + T_1 - T_q]. \quad (3)$$

For adiabatic compression in the compressor,

$$T_5 = T_4[(x_i - 1)/\eta_K + 1]; \; x_i = \pi_{k_i}^{(k-1)\,k}. \quad (4)$$

where π_{k_i} is the degree of compression in the compressor stage, and η_K is the adiabatic efficiency of the compressor.

Clearly $\pi_{k_i}^{m} = 1/\sigma$, where σ is the coefficient of pressure recovery around the circuit. The temperature T_q is related to the level of regeneration by the simple equation

$$T_q = T_5 + \rho(T_1 - T_5) \quad (5)$$

Substituting formulas (4) and (5) into (3), we obtain

$$\bar{\eta} = \frac{1 - T_0/T_1}{(1-\rho) + (T_4/T_1)([(x_i - 1)/\eta_K](m - 1 + \rho) + \rho - 1)} \equiv \frac{1 - T_0/T_1}{(1-\rho) + B} \quad (6)$$

---

* We assume that the temperatures at the inlets and outlets of all the levels are the same.

When $B > 0$, to increase $\bar{\eta}$ the temperature at the compressor inlet (the low temperature of the cycle) must be decreased to the level $T_1 = T_0$. When $B < 0$, the temperature T_1 should be increased to the maximum possible value, which can be determined from the condition $T_5 = T_1$. This system was proposed in references 7 and 8. It does not include a regenerator, and the formula for $\bar{\eta}$ has the form

$$\bar{\eta} = (1 - T_0/T_1)[1 + \eta_K (x_i - 1)] m^{-1}. \tag{7}$$

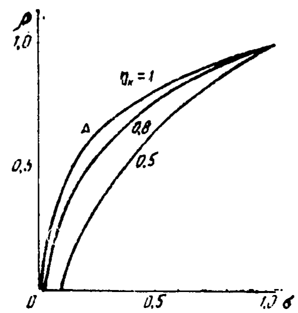

Fig. 3. Plot of ρ and σ for $m = 3$.

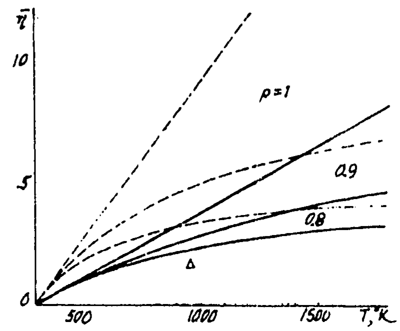

Fig. 4. Plot of $\bar{\eta}$ as a function of temperature at the input of the gasdynamic laser for $T_1 = 3000°$ K, $m = 3$, $\eta_K = 0.8$ and $\sigma = 0.2$ (solid lines) and 0.5 (dotted lines). The triangle gives the experimental value.

Fig. 3 shows solutions of the equation $B = 0$ for various compressor efficiencies. In the upper area $B > 0$, and in the lower area $B < 0$. The triangle marks the point corresponding to the experimental values of the parameters ρ and σ. The dependence of $\bar{\eta}$ on the temperature at the nozzle assembly inlet is shown in Fig. 4. The strong effect of pressure losses along the circuit and of the level of regeneration on $\bar{\eta}$ is clearly visible.

It follows from formula (6) that when $B \geq 0$,

$$\lim_{T_1 \to \infty} \bar{\eta} = \frac{1}{1 - \rho}. \tag{8}$$

Thus, to increase the effectiveness of the closed system, it is most important to increase the level of regeneration and to decrease pressure losses.

In our experiments level of pressure recovery in the diffuser was 0.26, i.e. about the same as the coefficient of pressure recovery in a normal shock wave ($\sigma = 0.3$). This value is apparently not a limiting one, and it may be increased, for example, by the use of a variable diffuser [12]. We should also like to draw attention to the necessity of cooling the working channel, the nozzle vanes and the resonator chamber. During operation, the channel is heated to 800° K; the nozzle array, even though designed for the temperature conditions of the gasdynamic laser, was still deformed by thermal expansion.

In conclusion, it must be stressed that the gasdynamic laser with circulation of the working substance through a closed circuit can have a high efficiency only if all the working parameters of the device are simultaneously made optimal. Thus it is clearly disadvantageous to make gasdynamic lasers to study physical processes in the active medium of CO_2 lasers, since this always entails variation of the working parameters over extremely wide ranges.

On the basis of our experiments we may conclude that it is technically feasible to develop an industrial continuous-operation gasdynamic CO_2 laser operating under preselected optimal working conditions. In our view, the high effectiveness of such a gasdynamic laser makes up for the expenditures on implementation of the closed circuit.

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NUCLEAR PHYSICS

UDC 621.039.51

CONSTRUCTION AND STARTUP OF THE FIRST ATOMIC REACTOR IN THE SOVIET UNION

Moscow STROITEL'STVO I PUSK PERVOGO V SOVETSKOM SOYUZE ATOMNOGO REAKTORA in Russian 1978 signed to press 11 Oct 78 pp 5-12, 66-115

[Chapters 1, 4 and 5 from book by I. F. Zhezherun, Atomizdat, 2,200 copies, 144 pp]

[Text] Chapter 1. Introduction

After the phenomenon of nuclear fission of uranium was discovered by O. Hahn and F. Strassmann in 1939, the utilization of the energy within the nucleus, which until recently had seemed a dream, began to become a real possibility. On the front line of worldwide nuclear science, Soviet physicists carried out intensive investigations of the phenomenon of fission and related questions. From that time onward, experimental studies of uranium fission by neutrons acquired a central place in I. V. Kurchatov's laboratory in the Leningrad Physical and Technical Institute. Investigations were also carried on in the Physical and Technical Institute in Khar'kov, the Institute of Physics imeni P. N. Lebedev, USSR Academy of Sciences in Moscow, and also in the Radium Institute, USSR Academy of Sciences, the Institute of Chemical Physics, the Pedagogical Institute in Leningrad and other research organizations. In 1939, Kurchatov's colleagues G. N. Flerov and L. I. Rusinov established that the fission of a uranium nucleus releases an average of 3 ±1 secondary neutrons, that neutron capture by the main uranium isotope, ^{238}U, does not lead to fission but produces the radioactive nucleus ^{239}U, and that the thermal neutrons observed in uranium fission experiments should be ascribed to the uncommon isotope ^{235}U. At the beginning of 1940. K. A. Petrzhak and G. N. Flerov discovered spontaneous fission of uranium.

Soviet theoretical physicists did not lag behind the experimentalists. For example, in the spring of 1939 Ya. I. Frenkel' had already developed the first quantitative theory of fission, and in 1939-40 Ya. B. Zel'dovich and Yu. B. Khariton developed the theory of the fission chain reaction. An extensive discussion of experimental and theoretical work on fission questions took place at the Fourth All-Union Conference on the Physics of the Atomic Nucleus and Cosmic Rays, held on 15-20 January 1939 in Khar'kov and at the Fifth All-Union Conference on the Atomic Nucleus, held on 20-26 November in Moscow.

The level of theoretical and experimental work by Soviet physicists, embracing both fission and the chain reaction, was so high that in the spring of 1940 Kurchatov could already declare, "The goal is a realistic and viable one." He repeated this idea in a report at a session of the Department of Physical and Mathematical Sciences, USSR Academy of Sciences, on 26-27 January 1940. And at the Fifth All-Union Conference on the Atomic Nucleus, where Kurchatov developed this idea further in a summary report and indicated the theoretical possibility of solving the problem of using the energy of the nucleus in the chain-reaction decay of uranium, the question of applying to the government to allocate large sums for research work was urgently raised. The military significance of the fusion chain reaction was also clear.

Kurchatov and other scientists planned to initiate expensive research. He sent the Presidium of the Academy of Sciences a plan for the expansion of work on the nuclear chain reaction. And had it not been for the war and the resulting stoppage of work, K. A. Petrzhak has noted, Soviet physicists would not have lagged behind the Americans at all, and might possibly have carried out a chain reaction before 1942. Foreign authors too have shared this opinion.

We shall not dwell further on the works on fission which were published during the prewar and wartime periods, since they have been systematically and rather fully discussed in V. V. Igonin's book "Atom i SSSR" [The Atom and the USSR], but rather will conclude our quick survey with a list of the basic results of importance for the problem of fission and the nuclear chain reaction which were known at that time and were discussed in Kurchatov's report mentioned above.

1. In fission, the uranium nucleus produces about 200 MeV of energy and emits $\nu = 2\text{-}3$ secondary neutrons. About 1 percent of these neutrons are delayed by from 0.1 to 45 seconds, with the average being about 10 seconds.

2. Under the influence of slow neutrons, only the isotope ^{235}U undergoes fission; its effective fission cross section varies approximately as $1/v$ (i.e. is inversely proportional to the velocity v of the neutron) and is equal to $(300\text{-}400) \cdot 10^{-24}$ cm^2 for thermal neutrons. The main uranium isotope, ^{238}U, undergoes fission only under the influence of fast neutrons with energies ~ 1 MeV or greater.

3. The absorption of slow neutrons by ^{238}U leads to the formation of the radioactive isotope ^{239}U and has a resonance character for energies in the tens of electron-volts. ^{239}U undergoes beta decay with a half-life of 23.5 minutes and is converted into a transuranium element with atomic number $Z = 93$. This latter beta-active element decays with a half-life of 2.3 days, forming an element with atomic number $Z = 94$, assumed to be an alpha emitter. The possibility that this last element might, like ^{235}U, undergo fission when acted upon by thermal neutrons was not ruled out.

4. The fission (decay) chain reaction of ^{235}U under the influence of thermal neutrons in a mixture of uranium and a moderator of unlimited dimensions is possible provided that

$$k_\infty \equiv \nu\varphi\theta > 1. \qquad (1.1)$$

Here ν is the number of secondary neutrons emitted by a single fission occurrence; φ is the probability of moderation of these neutrons to thermal energies; and

$$\theta = \frac{c_U \sigma_{cU}}{c_U \sigma_{cU} + c_з \sigma_{cз}} \times \frac{\sigma_{fU}}{\sigma_{cU}}$$

is the probability that the moderated neutron will be captured by the uranium rather than the moderator and will result in fission. It depends on the concentration c_U of uranium nuclei and $c_з$ of moderator nuclei in the mixture, their respective absorption cross sections σ_{cU} and $\sigma_{cз}$, and the fission cross section σ_{fU} of uranium.

Accordingly the quantity $\nu\varphi\theta$ was named the "neutron multiplication coefficient" k_∞ for an infinite medium.

The relative concentration $c_з/c_U$ of moderator nuclei in the mixture must be large in order to assure a low level of absorption by the uranium in a dangerous (resonance) energy range. Accordingly, only very small capture cross sections are allowable for the moderators (not above a critical value of approximately $3 \cdot 10^{-27}$ cm^2).

The capture cross section is $3 \cdot 10^{-28}$ cm^2. Accordingly it is possible to carry out a chain reaction in a uranium-heavy water system. The question of the suitability of ^{4}He, ^{12}C and ^{16}O as moderator nuclei remained unclear. The chain reaction in a uranium-water mixture. However, it would become possible when the content of the isotope ^{235}U in the uranium was increased by a factor of 1.9.

5. A chain reaction was impossible in the natural mixture of uranium isotopes under the influence of either fast or slow neutrons even in an infinite nedium. The chain decay of ^{235}U under the influence of fast neutrons was prevented by the phenomenon of inelastic scattering, while the chain decay of ^{235}U under the influence of slow neutrons was prevented by strong absorption of neutrons in the resonance range by ^{238}U. A chain reaction was possible in pure ^{235}U.

6. If a system consisting of a mixture of uranium and a moderator was of limited dimensions, the effect of the magniture of $\nu\varphi\theta$ was decreased as a result of the diffusion of neutrons out of the system. Near the critical conditions for a chain reaction explosion,

$$(\nu\varphi\theta)_{эф} = \nu\varphi\theta\,(1 - A/d^2), \qquad (1.2)$$

where d is the critical dimension of the system and A is a quantity depending on the neutron path length. For a spherical system, the critical radius is equal to

where l_s is the neutron free path for scattering and l_c is the free path for absorption.

$$R_{кр} = \pi \sqrt{\frac{l_s l_c/3}{\nu\varphi\theta - 1}}, \qquad (1.3)$$

7. The important role of delayed neutrons and of several self-regulating factors (e.g. thermal expansion of the system, ignition of the uranium) had been elucidated, making it possible to assure safety in experimental studies and power production use of the uranium chain reaction.

8. The use of the chain reaction to produce an explosion would require extremely fast and deep transition into the supercritical range.

The war altered the plans which Kurchatov had made. And Igor' Vasil'yevich, wishing to be of immediate assistance to the front, ceased his investigations of uranium and together with the staff of his laboratory began work on the defense of ships from magnetic mines. Scientists of the LFTI [Leningrad Physical and Technical Institute] had embarked on this problem even before the war under the leadership of A. P. Aleksandrov. But by the end of 1942, Kurchatov was leading work on the atomic problem, and the investigations of uranium fission and the chain reaction which had been interrupted by the war were renewed in 1943 in a new institute headed by him. In those years it was called Laboratory No 2, USSR Academy of Sciences, but subsequently it was renamed the Institute of Atomic Energy imeni I. V. Kurchatov (IAE).

Of the work done in Laboratory No 2 to solve the atomic problem, we will here give a brief description of only those experimental and theoretical studies which dealt primarily with the physical problems associated with the creation of the Soviet Union's first nuclear reactor. We will also make some mention of earlier studies dealing with the reactor itself. This first reactor was, as everyone knows, a reactor with natural uranium and a graphite moderator. Considerable attention was devoted to it, since this reactor was the one which most probably could be created quickly. In the initial period, research dealt with the uranium-water reactor, since Soviet physicists were not fully convinced that a chain reaction in it was impossible. At that time full confidence was reposed only in the uranium-heavy water reactor, but a considerable time would be required to obtain the necessary quantity of heavy water. The development of such reactors was later assigned to Laboratory No 2, USSR Academy of Sciences (now the Institute of Theoretical and Experimental Physics), led by A. I. Alikhanov.

Efforts to develop the uranium-graphite reactor, which began in the spring of 1943, were successfully completed when it was started up on 25 December 1946. Thus Soviet scientists, working during the war and in the postwar period, required four years to achieve the uranium fission chain reaction, just as the Americans had, even though the American scientists were working under incomparably more favorable circumstances.

The startup of the atomic reactor was the first major step on the road to mastery of the energy of the atomic nucleus.

Let us recall the dates of the subsequent important stages:
10 June 1948: startup of an industrial nuclear reactor;
23 September 1949: testing of the first atomic bomb;
12 August 1953: testing of the first hydrogen bomb;
27 June 1954: beginning of operation of the first nuclear electric power station.

These dates show that Soviet scientists were working at a rapid pace and were able not only to catch up with but to outstrip specialists in the United States. This fast pace was made possible by the intense work of the staff of Laboratory No 2 and other scientific and design organizations, factories and mines, and by the constant and particular attention given to the problem by the party and state leadership. It attests to the power of our Soviet system under which the talent of I. V. Kurchatov, organizer, scientist and statesman, shone brightly.

I. V. Kurchatov chose and carried out a successful, and in fact the only correct, scientific strategy for rapid solution of the atomic problem: that of breaking it down into successive steps and identifying the main tasks, initially attempting only the simplest macroexperiments, i.e. experiments in comparatively large systems, supported by a roughly approximate theory, later refining the macroconstants and measuring the nuclear microconstants, while developing an increasingly precise theory of nuclear reactors.

The first important tasks in Kurchatov's plan were:

Exponential macroexperiments, during which the moderating and absorptive properties of graphite were studied first, followed by the multiplication characteristics of uranium-graphite lattices. These enabled Kurchatov to develop the necessary recommendations for the graphite and uranium industries. Also included here was a theory of the exponential experiment.

Construction of the first reactor on the basis of the exponential experiments with graphite and uranium-graphite lattices. The approximate theory of critical reactor dimensions that had been developed by this time proved to be in relatively good agreement with experiment.

Startup of the first reactor, which extraordinarily expanded the possibilities for improving theory and mounting experiments in two areas: 1. comprehensive study of the reactor itself so as to obtain information on the fission chain reaction, and the conduct of experiments to optimize the uranium-graphite lattice for a large-capacity reactor; 2. use of the reactor as a unique neutron source in many experiments aimed at refining or measuring macro- and microconstants and the like.

Let us consider several moments which illustrate the gradual development of reactor theory and the improvement of physical experiments.

The first outline theory of the exponential experiment with a thermal neutron source was developed in a single-group approximation by I. I. Gur'yevich in the fall of 1943. During that summer, Ya. B. Zel'dovich had developed an "age" approximation of the moderation process in which the neutron energy E was expressed by a quantity $\tau(E)$ related to its chronological age (time to be slowed to energy E. By the beginning of 1944, I. Ya. Pomeranchuk had developed a theory of the exponential experiment in an age approximation for both a pure moderator and the uranium-graphite lattice.

Similar progress was being made on other theoretical questions. For example, the critical dimensions of the reactor (see formulas (1.2) and (1.3) obtained by Ya. B. Zel'dovich and Yu. B. Khariton before the war) were determined initially in a very rough approximation which could now also be classified as a one-group apploximation. Formula (2.69) for the critical dimensions of the reactor using an age approximation was obtained by Pomeranchuk in 1944. The idea of a two-group approximation was first enunciated and used by V. S. Fursov in 1945-1946. As a result, by the end of 1946 a theory of reactors using diffusion-age and multigroup approximations had been developed.

It was primarily by the efforts of Pomeranchuk and A. I. Akhiyezer that the foundations of the "realistic" (as it was then called) theory of reactors, subsequantly named the "heterogeneous" theory, were laid. This theory was further developed in the works of A. D. Galanin, S. M. Feynberg, G. I. Budker and A. B. Migdal.

A curious situation arose in the development of a theory of resonance absorption in block systems. Since in uranium the attenuation path was considerably shorter for resonance neutrons than for thermal neutrons, even in a system with relatively fine blocks it was possible to expect a significant increase in the probability φ of avoiding resonance absorption compared with a homogeneous mixture of uranium and moderator, since such a system was a block system for resonance neutrons and a homogeneous system for thermal neutrons. In actuality, the improvement in φ was insignificant. But the changeover to thicker blocks and an awareness of the effect of multiplication of fast neutrons in ^{238}U, first pointed out by G. N. Flerov, convincingly illustrated the advantages of block systems. In such systems there were certain losses in the utilization of thermal neutrons, thus decreasing the value of θ , but the advantage stemming from decreased absorption of resonance neutrons, which increased the magnitude of φ , was significantly greater.

It is worth noting that as regards the study of nuclear chain reactions in multiplying systems with dimensions considerably smaller than critical, American and Soviet physicists, independently and in contrast to the Germans, took an identical path, that of making exponential experiments. Such experience with a system whose dimensions are extended in one direction was more fruitful than the subcritical experiments of German physicists.

The exponential experiments conducted by Kurchatov and the staff of Sector No 1 which he led, which were the results of his insistence on the necessity of finding methods for testing the suitability of materials for a reactor, were extremely fruitful. In them, the macroparameters of moderation and diffusion of neutrons in graphite were measured (first approximately, then with increasing precision), and the multiplying properties of uranium-graphite lattices were studied. It was these which, with certain alterations, were used for the neutron-physical testing of the entire mass of graphite and uranium for the reactor.

Later on, the same exponential experiments were made in systems with larger dimensions: these were the significantly more precise investigations of uranium-graphite lattices by I. M. Frank and his colleagues in the Physical Institute imeni P. M. Lebedev, USSR Academy of Sciences.

The first approximate measurements of the microparameters of uranium in Laboratory No 2 (fission and absorption cross sections, number ν of secondary neutrons per fission occurrence) were made by V. P. Zhelepov, M. S. Kozodayev and P. Ye. Spivak using Ra-alpha-Be sources. Later, Spivak and his coworkers carried out even more precise measurements of ν using the first reactor as a neutron source.

Kurchatov's role was exceptionally great in all stages of the work: in the choice of a research strategy, in determining the main tasks at each stage, as a skillful experimenter and as a physicist with astonishing intuition (the theoreticians did not consider their results to be conclusive until they had been "shaken down" in discussions with Kurchatov). It was he, for example, who foretold the phenomenon of increased neutron density at the boundary of the core and the reflector, which was not predicted by the single-group theory but was later derived by V. S. Fursov in the two-group approximation.

The experimental and theoretical investigations which are described below and which embrace some earlier work on the first reactor were performed between 1943 and 1947. As we begin the account, we will adhere as far as possible to chronological order. But for convenience we will begin with the theoretical investigations, even though they were conducted simultaneously with the experiments, so that the two approaches complemented and stimulated each other. Frequently experiments were mounted in order to test theory, and theory was developed in order to mount experiments which had been conceived.

Chapter 4. Experimental Studies in Direct Preparation for the Construction of the Uranium-Graphite Reactor

4.1 Participants in the Work

By the end of 1945, Laboratory No 2 had begun to receive increasing quantities of low-ash graphite produced by the industry especially for the uranium-graphite reactor in the form of blocks measuring 10 x 10 x 60 cm. By January 1946, the first lots of industrial cast metallic uranium, manufactured to the order of Laboratory No 2 in the form of small cylindrical slugs, had also been received. As was already clear from past experiments and had become unquestioned following publication of the calculations by G. D. Smith, success in effecting a uranium chain reaction in the planned uranium-graphite reactor depended entirely on the purity of these materials. Accordingly testing of the graphite and uranium and the distinguishing and selection of these materials in accordance "reactor" criteria were of top priority and were the heart of all preparatory work for the construction of the reactor, which was being carried out by Sector No 1 of Laboratory No 2 in 1946.

Sector No 1 was a collective of scientific workers, laboratory assistants and laborers whose task was the construction and startup of the reactor itself; it began to grow rapidly starting in January 1946. In view of the special importance of the task, it was led personally by I. V. Kurchatov, the chief of Laboratory No 2. The sector was composed primarily of former fighters at the front who had returned to peacetime labor at the end of the Great Patriotic war. The sector grew as the scale of work expanded, and between January and December 1946 its size increased from 11 to 76 people. But the backbone of the collective, on which Kurchatov relied directly in the construction of the uranium-graphite reactor, had already taken shape by March 1946. These were the scientific staff members (see photographs on pages 68 and 69):

Panasyuk, Igor' Semenovich: deputy chief of Sector No 1;

Babulevich, Yevgeniy Nikolayevich: repsonsible for development of the reactor control and protection system (SUZ);

Dubovskiy, Boris Grigor'yevich: responsible for radiation safety and ionizing radiation dosimetry;

Zhezherun, Ivan Fedos'yevich: responsible for neutron-physical testing and selection of graphite and uranium for the reactor;

Zhuravlev, Aleksey Alekseyevich: senior engineer, responsible for the design and assembly of the reactor and the models;

Konopatkin, Nikolay Matveyevich: developed detectors and automatic devices for recording ionizing radiation and participated in various experiments;

Kulakov, Vladimir Alekseyevich: took part in developing detectors and measurind devices and in various experiments;

Makarov, Nikolay Vladimirovich: responsible for the development of detectors and radio apparatus;

Shlyagin, Konstantin Nikolayevich: participant in various experiments and in the development of physical instruments and devices.

Among the scientific staff directly associated with the construction of the reactor, we should also name theoretical physicist Vasiliy Stepanovich Fursov. He was not part of Sector No 1, but he worked in close contact with the experimenters, developing the theory of various experiments and assisting in the interpretation of results. He was assisted by V. S. Anastasevich, who joined the sector in June 1946. V. V. Sklyarevskiy arrived in September and M. B.

Yegiazarov in November. A complete list of the staff of Sector No 1 who participated in the construction of the reactor is given in an appendix [of an item in the bibliography].

The working conditions were far from easy. Many, especially laboratory assistants and laborers, had to work in tents in the cold and to undergo many inconveniences, in spite of efforts by I. V. Churik, the deputy chief of the sector for administrative matters, to make conditions easier. But no one complained, everyone labored willingly, and in Sector No 1, as throughout Laboratory No 2, enthusiasm reigned. All had been drawn there by the magnificence of the task of mastering a new source of energy for man--that of the nucleus--and the United States' atomic blackmail only reinforced our striving to work at top efficiency, grudging neither time nor effort. For us, these were days of intense but joyous labor in the favorable conditions of a truly creative environment that was simply and naturally created by I. V. Kurchatov, a strict but correct leader and a sincere and warmhearted man.

I should like to digress briefly and give some personal impressions of I. V. Kurchatov. His exceptional role as scientist and organizer I have described above. What was the secret of his success as a leader? This secret became fully clear to the author only two decades later, when he had occasion to study the subject of scientific organization of scientific work and other problems of scientific leadership. This science, which has taken form in recent years through generalization of experience, has developed a large number of principles and recommendations which make it possible to develop a creative environment both in individual scientific collectives and in entire scientific research institutions (NIU).

Here are some of them:*

1. Objective evaluation of labor and recognition of individual achievements of researchers, along with the institution of awards commensurate with real achievement.

2. Minimization of organizational formalism and official leadership. After a decision concerning the main directions of work of a scientific research institution has been taken, it is desirable to allow the scientists a considerable amount of freedom within this framework and to foster joint work by individual workers and groups on a voluntary basis.

3. Explanation by the leadership of the importance, relevance and urgency of accomplishing the tasks assigned to the institution, and mobilization and comprehensive stimulation of creative activism on the part of those engaged in carrying them out.

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* I. F. Zhezherun, "Some Information from the Experience of Organizing Scientific Research and from Management Theory," (summary-compilation), OTCHET IAE, 1969.

3. Constant acquainting of staff members with the work of the institution and the tasks to be performed. The successes achieved in one part of the institution should be made known to the entire collective, because nothing raises morale like success. Periodic meetings of scientific staff, and sometimes of laboratory assistants as well, are held for this purpose.

5. Good interpersonal relationships and a high sense of responsibility. Everyone, both leadership and staff, should be made aware of the simple rule that a scientific institution, a department or a laboratory are not commanded but led, for leadership is concerned not with working time or behavior but with thought, with the thinking done by the staff members (who are not treated as subordinates).

6. A correct attitude toward new ideas and suggestions by staff members, and speedy consideration of these. If a proposal is rejected for some reason, a written response by the person rejecting it should always encourage the originator to test his idea. Fear of failure should be eliminated at all costs, because a man who fears failure cannot be creative.

7. Stimulation of the creative activity of scientific workers requires a difficult problem or another mind of equal ability. Accordingly any collective, even the smallest, should provide the scientific worker with colleagues for discussion.

When the author studied these principles and recommendations, he discovered with amazement that I. V. Kurchatov had used them in his practical work, even though they had not yet been formulated. How, then, had he come by them? We can answer the question if we keep in mind that the main problem of scientific organization of scientific work can be formulated, briefly and simply, as follows: how to make the scientist happy and productive. Happy, because an unhappy scientist cannot do truly creative and productive work! And Kurchatov, as a leader with great human qualities, intuitively sensed these principles.

He constantly maintained within the collective a sense of the urgency of the tasks assigned to Laboratory No 2, not only in the meetings and conderences. but also in the scientific subdivisions, which he visited regularly, usually at the end of the working day. When he met a staff member in the laboratory he always expressed an interest in how matters were proceeding and generally concluded the conversation with the words "Don't get engrossed," which meant "Don't get distracted by minor details: get the main task done and go on to the next." At his regular scientific seminars, in which both eminent scientists and ordinary scientific staff members took part, all scientific questions that had arisen and all reports on completed work were extensively discussed. In addition to the seminars, lecture series on pressing problems were frequently organized; Kurchatov took part in these. The scientific life of Laboratory No 2 was a rich one. And for us it not only served as a great scientific school but gave everyone a sense of participation in great undertakings and of responsibility for their success.

The organization of new scientific subdivisions, which was generally preceded by large-scale preparatory work, was carried out by Kurchatov, generally on a voluntary basis. Frequently his scientific leadership took the form of advice or suggestions. He often took a new idea or proposal which had originated in the staff and developed and enriched it, but he always indicated publicly who the initiator of the idea was. If it turned out not to be correct, Igor' Vasil'yevich saw no shame in excusing an ordinary scientific staff member. All of this won him great trust and had a most favorable effect on the creative activity of the staff.

I should like in particular to stress the great and almost magical stimulative effect Igor' Vasil'yevich had on the staff members. His contacts with them, which were extensive and were made on his own initiative, inspired people, encouraged creative thought, and stimulated a search for new solutions and new ideas and for ways of overcoming all difficulties in the name of success.

We all knew I. V. Kurchatov as a man who took extraordinary joy in living and who was always ready for an ebullient jest, but who was always fair and attentive to the needs of his colleagues, and in spite of the press of his duties, accessible to scientists, laboratory assistants and laborers alike. His sense of humor seems never to have left him. Not long before his death, for example, he gave one of the reactors under construction the joking designation DOUD-3 (which meant "before the third attack"--the third crisis of the serious illness which he now had no hope of escaping).

I. V. Kurchatov knew how to draw people out and to draw them to him.

The experiments in the preparation, construction and startup of the reactor, as well as work on the reactor itself, were conceived by I. V. Kurchatov and carried out by him together with his closest associates, the scientific staff of Sector No 1. Chief among these was I. S. Panasyuk, who organized all the sector's practical work and frequently acted as a "transmission belt" from Kurchatov to the personnel of the sector. Panasyuk's inexhaustible energy and persistence, his understanding of the experiments and knowledge of theory were frequently the key to smooth and harmonious work in the sector. This work was based on the principles of mutual assistance and support, and accordingly many staff members who are not listed as authors of the reports included in the bibliography at the end of this book took part in investigations in the sector. In a number of cases it was possible to establish the names of these participants (including laboratory assistants) on the basis of work materials, laboratory logbooks and other sources preserved in the IAE archives and to identify them in the text after the names of the writers of the reports. Naturally, the primary author of all the work of Sector No 1 described below was Kurchatov, even though, as a man of great modesty, he somtimes removed his name from the list of authors.

To proceed, let me note that the graphite produced for the uranium-graphite reactor generally (with the exception of a few of the first lots) satisfied the requirements established for it. Matters did not go as well with the uranium: the first lot was contaminated and not suitable for the reactor. But a chemical analysis of the impurities in the uranium and the ongoing neutron-physical testing described below enabled the industry to carry out their assignment successfully, as a result of which the production of pure uranium was quickly organized.

Mastering the production of graphite and uranium suitable for an atomic reactor was a great achievement for our country's industry. It would have been impossible without the most active participation of a number of scientific institutions. Since we cannot dwell on this subject, we will note only the great contribution to this achievement made by members of Laboratory No 2: V. V. Goncharov, B. V. Kurchatov, N. F. Pravdyuk, A. R. Striganov, M. I. Pevzner and others. Goncharov, Pravdyuk and factory workers N. A. Aleksandrov, G. K. Bannikov and V. V. Kotikov were awarded an author's certificate for a method of producing pure graphite. The contribution of members of other institutions is partially reflected in the report by Academician A. P. Vinogradov to the International Conference on Peaceful Uses of Atomic Energy held in Geneva in 1955.*

4.2 Neutron-Physical Testing of the Graphite for the Uranium-Graphite Reactor

Testing of the graphite supplied by the factories for use in the reactor consisted of measuring the diffusion length for thermal neutrons, which made it possible to calculate the effective absorption cross section. In addition, chemists determined the ash content of each lot. In the first lots, the diffusion length was measured by I. S. Panasyuk and I. F. Zhezherun with the participation of laboratory workers A. K. Kondrat'yev and B. A. Pryadekhin, using the exponential method already descibed, in a 5-7 ton graphite prism. But the fact that use of this method required a large quantity of graphite made differentiation and rejection difficult, since initially the weight of many lots was considerably less than 5 tons. Accordingly, a relative method for rejection, involving the comparison of graphite to be tested with graphite that had been chosen as a standard, was developed.

The theory for the procedure was developed by V. S. Fursov. It is extremely simple. Suppose that on the long axis of a rectangular prism consisting of standard graphite, a source is placed at point O and a neutron detector at point I (Fig. 4.1) with the distance between them such that the thermal neutron density $N_э$ measured by the detector can be represented solely by the basic harmonic. If now we replace a part of the prism of thickness h by graphite whose absorption cross section is to be determined and measure the neutron density at point I, we obtain from the condition of equality of neutron density and flux at the boundaries of the inset h the equation

$$\delta \equiv \frac{N}{N_э} = \frac{4\frac{\gamma_э D_э}{\gamma D}\exp(\gamma_э h)}{\left(1+\frac{\gamma_э D_э}{\gamma D}\right)^2 \exp(\gamma h) - \left(1-\frac{\gamma_э D_э}{\gamma D}\right)^2 \exp(-\gamma h)}, \quad (4.1)$$

* Industrial workers who rendered great service in mastering the production of pure uranium included N. M. Virko, Yu. N. Golovanov, P. S. Zaytsev, A. N. Kallistov, N. F. Kvaskov and S. I. Zolotukh.

where D and $D_э$ are the diffusion coefficients, and γ and $\gamma_э$ are the decrements of attenuation of thermal neutrons for the sample and standard graphite respectively ($\gamma \equiv L_{00}^{-1}$; see formula (2.25)).

If the scattering cross section of the sample and standard graphite are the same, then $D_э/D$ is equal to the inverse ratio of their densities $d/d_э$ (or of the weights of the graphite in the insert space). In cases of practical importance, where δ and $d/d_э$ differ from unity by less than 10 percent, equation (4.1) can be simplified as follows:

$$\frac{\sigma}{\sigma_э} = \frac{[\gamma_э - (1/h)\ln\delta]^2 - \pi^2(a^{-2}+b^{-2})}{\gamma_э^2 - \pi^2(a^{-2}+b^{-2})}\left(\frac{d_э}{d}\right)^2, \qquad (4.2)$$

where a and b are the effective cross-sectional dimensions of the prism and σ and $\sigma_э$ are the absorption cross sections of the sample and standard graphite respectively.

The sensitivity of the method is given by the formula

$$\Delta\frac{\sigma}{\sigma_э} \approx \frac{2\gamma(d_э/d)^2}{\gamma_э^2 - \pi^2(a^{-2}+b^{-2})}\frac{\Delta\delta}{h}. \qquad (4.3)$$

When a = b = 120 cm and h = 60 cm, a deviation in σ of 3-4 percent from the value obtained for the standard graphite leads to a change of 1 percent in δ .

A picture and a diagram of the prism for testing the graphite by the comparative method are presented in Fig. 4.2. The neutron detector, a BF_3 chamber, was located in the center of the prism (point 0), and the source alternately at points I_1 and I_2 on the sides containing the sample and standard graphite (shaded area).

To determine the practical applicability of the method, several lots of graphite were tested by two methods, the comparative and the exponential. Table 4.1 shows the spectrum average absorption cross section obtained during this testing.

Table 4.1. Absorption Cross Section σ_c of Graphite Measured by the Comparative and Exponential Methods (x 10^{-27} cm^2)

Graphite Variety	Measurements by comparative method				Exponential method, prism made from three insets
	Inset 1	Inset 2	Inset 3	Average	
B81	3.1 ±0.3	3.3 ±0.3	3.5 ±0.4	3.3 ±0.3	3.4 ±0.2
S21	3.3 ±0.4	3.8 ±0.4	3.6 ±0.4	3.5 ±0.3	3.7 ±0.2
S28	3.5 ±0.4	3.5 ±0.3	3.1 ±0.3	3.4 ±0.3	3.6 ±0.2

It is clear from the table that both methods give the same results within the limits of error. Although the comparative method shows a tendency to produce a value for σ_c which is 3-5 percent low (which may have resulted from an error

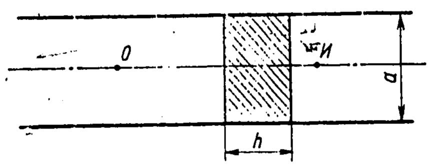
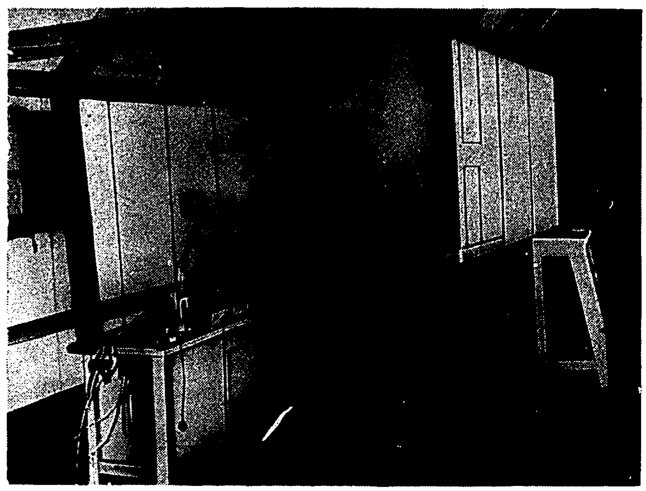


Fig. 4.1 Comparative Method of Testing Graphite.

0: source; I: neutron detector; a: prism cross section; shaded part of prism with thickness h is standard graphite replaced by sample to be tested.



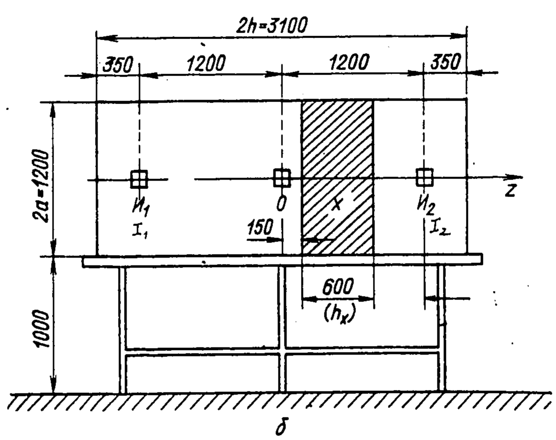


Fig. 4.2. Appearance (a) and Diagram (b) of Experiment for Testing Graphite by the Comparative Method. (0: neutron detector; I_1 and I_2: locations of alternating placement of neutron source; inset of graphite to be tested is shown shaded).

in measuring σ_c for the standard graphite, and which thus represents a systematic error in the values of σ_c, the comparative method nonetheless has the advantage of allowing the testing of small lots (1.5-2 tons of graphite) and thus of achieving better differentiation. And the systematic error can be allowed for in the final results.

The checking of the graphite was conducted round-the-clock in a special tent set up for the purpose in a group consisting of scientific staff member I. F. Zhezherun, laboratory assistants I. P. Afonin, V. K. Losev, A. I. Pivovarov, N. L. Chinnov and others, and a brigade of laborers. Some 99 lots of graphite with a weight of about 600 tons were tested by these methods, 80 percent of them by the comparative method. The absorption cross section σ_c was above $5 \cdot 10^{-27}$ cm^2 in only 5 percent of the lots. For the rest of the graphite it was $(3\text{-}5) \cdot 10^{-27}$ cm^2, averaging $3.7 \cdot 10^{-27}$ cm^2. The ash content varied in the range 0.005-0.04 percent and the density from 1.62 to 1.72 g/cm^3 (averaging 1.69 g/cm^3).

Analysis of the measurements identified a correlation between the absorption cross section and the ash content of the graphite: the lower the ash content the lower the absorption cross section (Fig. 4.4). This was correct on average both for different lots of graphite and for graphite in a single lot, since the ash content distribution of the graphite in a lot depended on the position in the furnace during graphitization. There were exceptions to this general tendency associated with differences in the chemical composition of the impurities in the graphite (ash).

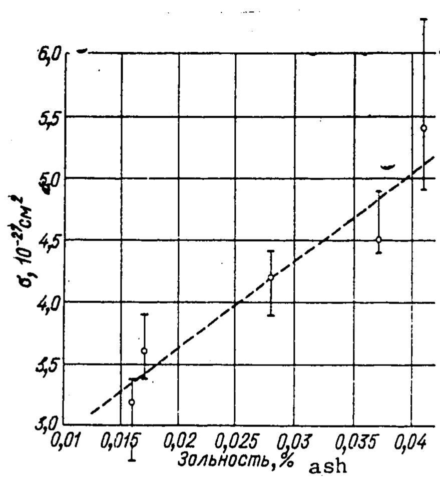


Fig. 4.4. Results of graphite testing by the comparative method. The points represent average absorption cross section σ_c and ash content of groups of lots of graphite (all the graphite tested was divided into 5 groups by magnitude of cross section).

Chemical analysis of the impurities was conducted in Sector No 3 of Laboratory No 2 under B. V. Kurchatov, by N. F. Pravdyuk with the participation of A. M. Yeremicheva, V. I. Novgorodtseva and R. V. Novikova on dozens of lots of graphite. Almost half of the elements in Mendeleyev's periodic table were found in the ash. The contribution to the total absorption cross section made by the impurities, given by formula (3.3), was in agreement with the measurements of σ_c, although there was not exact coincidence owing to the incompleteness of the chemical analysis data. The impurities which were found increased the absorption cross section of the carbon in various lots of graphite by $(0.35-0.85) \cdot 10^{-27}$ cm^2 (without allowance for absorption by nitrogen in the air which was in the pores of the graphite). In lot B17, for example, where σ_c was above $5 \cdot 10^{-27}$ cm^2, the contribution of impurities to the cross section was as follows: boron $0.31 \cdot 10^{-27}$ cm^2; iron, aluminum, calcium, magnesium and silicon, $0.019 \cdot 10^{-27}$ cm^2; rare elements, $0.008 \cdot 10^{-27}$ cm^2; water, $0.20 \cdot 10^{-27}$ cm^2. In lot B47 the contribution made by oxygen absorbed by the graphite alone came to $0.25 \cdot 10^{-27}$ cm^2.

We note that the comparative method was so simple and convenient that with certain changes it was subsequently adopted for the testing of reactor graphite in the plants themselves.

In October 1946 the lots of graphite which were shown to be most homogeneous in cross section (average cross section $\bar{\sigma}_c = 3.9 \cdot 10^{-27}$ cm^2) in testing by the comparative method were used to construct a 365-ton graphite cube with dimensions $6 \times 6 \times 6$ meters (Fig. 4.5) for more precise measurements of diffusion length. These measurements were conducted by I. F. Zhezherun, N. M. Konopatkin, V. A. Kulikov, I. S. Panasyuk and K. N. Shlyagin. An Ra-alpha-Be neutron source with an activity of 200 or 2,000 mCi was placed at the center of the cube and detectors (BF_3 chambers or indium foil) were placed at different distances from the source. The measurement results are shown in Fig. 4.6. It is clear that $\ln [N(r) r]$ is a linear function of the distance r over a wide range, in agreement with formula (2.23), which is correct for an infinite medium. Analysis of the linear part of the graph gave a diffusion length $L = 48.5 \pm 1.0$ cm, in agreement with the average absorption cross section (for $\sigma_{tr} \approx \sigma_s = 4.83 \cdot 10^{-24}$ cm^2 and a graphite density of 1.69 g/cm^3) of $\bar{\sigma}_c = 4.0 \pm 0.2 \times 10^{-27}$ cm^2.

The value of σ_{tr} used here (and in other measurements of diffusion length was almost identical with the exact value $\sigma_{tr} = (4.80 \pm 0.05) \cdot 10^{-24}$ cm^2 obtained much later from measurements of the diffusion coefficient by the pulse method.

4.3 Exponential Experiments with the Uranium-Graphite Lattice

After the first lot of metallic uranium was delivered it became possible to set up the long-awaited exponential experiments with a uranium-graphite lattice, the theory for which had been developed by I. Ya. Pomeranchuk as early as January 1944. These experiments were conducted by I. V. Kurchatov and I. S. Panachuk in January-March 1946.

A diagram of the experiment is given in Fig. 4.7. First a prism measuring $99 \times 99 \times 350$ cm was built from graphite blocks to measure the diffusion length,

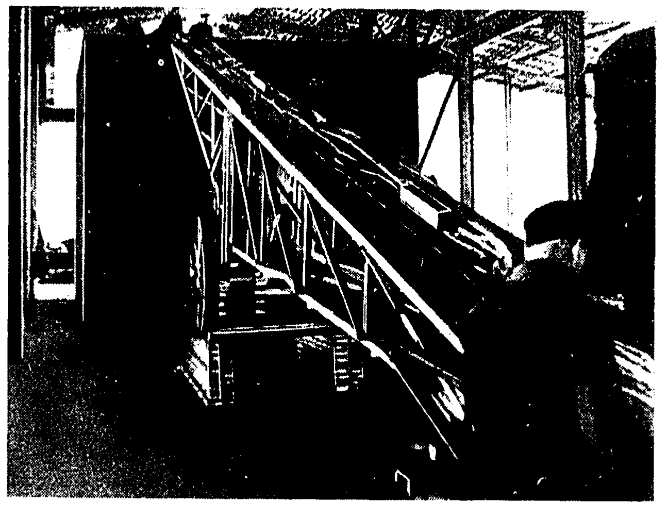


Fig. 4.5 Assembly of the 365-Ton Graphite Cube

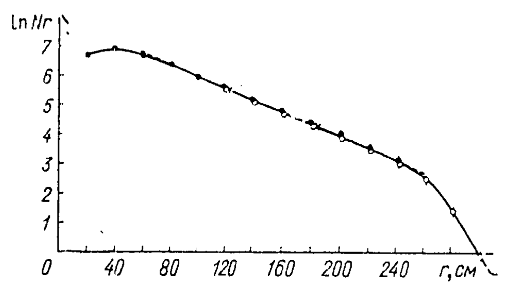


Fig. 4.6 Measurements of the Thermal Neutron Density N(r) Along the Axis of the 365-Ton Cube.

Key: •, measurements by BF_3 chamber with source activity of 200 mCi;
o, measurements by BF_3 chamber with source activity of 2,000 mCi;
X, measurements of indium foil.

which proved to be $L = 48 \pm 2$ cm (with a graphite density of 1.68 g/cm^3). Next, holes were drilled in some of the blocks and in them were placed cylindrical slugs of uranium 32 mm in diameter and 100 mm long. Thus a uranium-graphite lattice with a cubic elementary cell, filling all or almost all of the prism, was created. The lattice filled almost all of the prism at the beginninng of the experiments, when there was insufficient uranium, and a graphite layer was left in part of the prism. However, as V. S. Fursov showed, with the proper location of the neutron sources this prism too could be considered homogeneous.

The neutron density on the axis of the prism at rather large distances from the source, where the higher harmonics had died out, was determined by the equation

$$N(z) = \text{const} \exp(-\gamma z), \qquad (4.4)$$

where γ is the decrement of attenuation of the main harmonic

$$\gamma^2 = \pi^2(a^{-2} + b^{-2}) - (k_\infty - 1)/(L^2 + k_\infty \tau) = B_\perp^2 - \varkappa_0^2 \qquad (4.5)$$

and is determined by the effective cross-sectional dimensions of the prism and the lattice parameters.

During measurement, the neutron detector (a BF_3 chamber) was placed on the prism axis at a distance ~ 50 cm from the lower base, and the Ra-gamma-Be source on the axis at a distance of 99-156 cm from the detector. At such distances, the corrections for the effect of the end of the prism and the higher harmonics could be ignored. The neutron density ratio $\delta = N(z)/N(z + \Delta z)$ for $\Delta z = 22$ cm was as follows:

1. In a lattice with a cubic cell measuring 22 x 22 x 22 cm, containing 400 kg of uranium and with a concentration ratio of carbon to uranium nuclei $c_C/c_U = 250$ $\delta = 2.66 \pm 0.02$; since $B_\perp^2 = 1.88 \cdot 10^{-3}$ cm^2, for the lattice $\varkappa^2 < 0$ and $k_\infty < 1$.

2. In a lattice with a body-centered cubic cell of the same dimensions containing 800 kg of uranium, with $c_C/c_U = 125$ $\delta = 250 \pm 0.02$, $\varkappa^{-1} = 80 \pm 5$ cm and $k_\infty > 1$.

3. In a lattice with a cubic cell measuring 22 x 22 x 22 cm, in which the uranium slugs were replaced by aluminum cylinders with an equivalent neutron absorption and containing a mixture of boron and paraffin, $\delta = 3.64 \pm 0.04$, and for the diffusion length in the lattice a value of $L = 25$ cm was obtained.

4. In a lattice with a body-centered cubic cell and with the uranium slugs replaced as in par. 3, $\delta = 4.53 \pm 0.04$, which gives a value of $L = 18 \pm 0.2$ cm for the diffusion length.

The measurements make it possible to find k_∞ by formula (4.5) and θ by the formula

$$L^2 = (1 - \theta) L_0^2, \qquad (4.6)$$

where L_0 and L are the diffusion lengths for neutrons in graphite and in the lattice. Accordingly the values $k_\infty = 0.90 \pm 0.02$, $\theta = 0.73 \pm 0.03$ and $k_\infty = 1.09 \pm 0.02$, $\theta = 0.06 + 0.03$ were found for the cubic and body-centered cubic lattices respectively.

In addition, the blocking coefficient was also determined: the ratio of the average densities of thermal neutrons in graphite and in uranium. This quantity proved to be equal to 1.75 ± 0.25 for the body-centered cubic lattice.

4.4 Neutron-Physical Testing of the Uranium

The exponential experiments with the uranium lattices in a prism measuring 99 x 99 x 350 cm described in section 4.3 and other experiments in prisms measuring 210 x 120 x 310 cm conducted with other lots of uranium slugs measuring 32 and 35 mm indicated that for a body-centered cubic lattice with a spacing of 20 cm the multiplication coefficient k_∞ 1. It is true that certain experiments gave values $k_\infty = (1.09 \pm 0.02) - (1.11 \pm 0.02)$, i.e. slightly higher values. This may have resulted from errors in the experiments, primarily losses through neutrons, or from the approximate nature of the values of L and τ in formula (4.5).

However, it was clear that the purity of the uranium and graphite used in these experiments was sufficient to produce a chain reaction in a uranium-graphite reactor built from them. It was only necessary to conduct careful testing and selection of the uranium delivered for the reactor, since according to chemical analysis it was not uniform and some lots among the first to be produced were considerably contaminated.

It was possible to test the uranium in the exponential experiments. But in order to measure k_∞ in such an experiment with the necessary accuracy, 1.5-2 tons of uranium were needed, while the weight of the lots of uranium shipped by the factory was 120-750 kg. Accordingly, a simple comparative method analogous to that used for testing the graphite was used.

First the neutron densities from spontaneous fission N_U and $N_Э$ in two lots of uranium of equal weight (one of them used as a standard) at the centers of two identical uranium-graphite lattices measuring 120 x 120 x 130 cm were compared. Simple estimates made by I. S. Panasyuk made it possible to establish the relationship between $\delta = N_U/N_Э$ and k_∞ for a lattice and to find a criterion of unsuitability ($k_\infty < 1$). But the low density of spontaneous neutrons made it impossible to measure δ with the required accuracy in an acceptable time period, although differences between lots (with δ varying by 7 ± 3 percent from unity) were noted.

A more convenient and sensitive method was that of making the measurements in a nonuniform graphite prism, the theory of which was developed by V. S. Fursov. Considering the distribution of neutrons in a prism similar to that shown in Fig. 4.1 but with the shaded area occupied alternately by the sample and standard uranium, he established that

$$\delta \equiv \frac{N_U}{N_Э} = \left(\frac{\gamma_U D_U + \gamma D}{\gamma_Э D_Э + \gamma D}\right)^2 \exp\left[(\gamma_U - \gamma_Э)\, h\right], \qquad (4.7)$$

where D, $D_Э$, D_U and γ, $\gamma_Э$, and γ_U are the coefficients of diffusion and decrements of attenuation for the graphite part of the prism, the standard lattice and the lattice being tested. The first multiplier is close to 1, and accordingly

$$\delta \approx \exp\left[(\gamma_U - \gamma_Э)\, h\right]. \qquad (4.8)$$

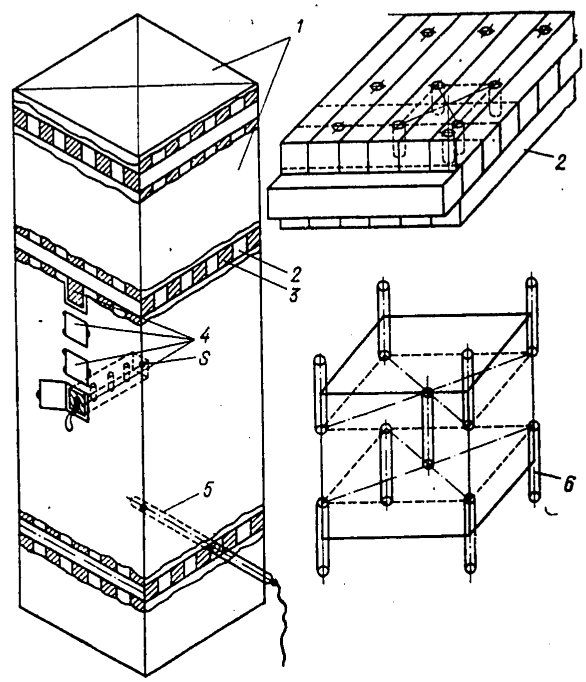


Fig. 4.7. Diagram of the Exponential Experiment with a Uranium-Graphite Lattice.

Key: 1. Cadmium covering of prism;
2. Graphite blocks;
3. Graphite blocks with cylindrical uranium slugs;
4. Movable graphite blocks for placement of Ra-gamma-Be **neutron** source;
5. Channel for detector (BF_3) chamber);
6. Cylindrical slugs of metallic uranium.

The sensitivity of the method with a prism having cross-sectional dimensions of $a = b = 120$ cm and an inset breadth of $h = 120$ is as follows: a 1-percent change in k_∞ causes a 2.5-3 percent change in δ .

Testing of the uranium by this method was done in a prism whose arrangement is shown in Fig. 4.8. The 36 horizontal channels in the prism could hold 432 slugs ($\sim$ 750 kg) of metallic uranium or the corresponding quantity of briquets

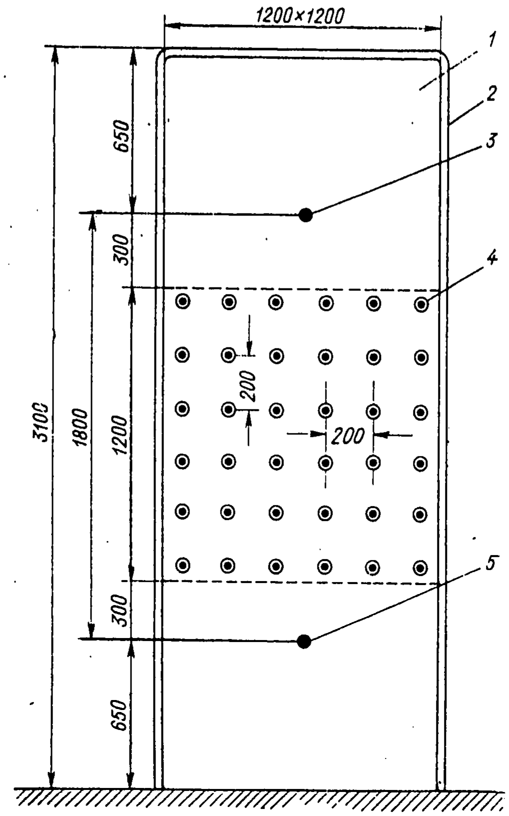


Fig. 4.8. Diagram of a Prism for Neutron-Physical Testing of Uranium

Key: 1. Graphite prism measuring 1200 x 1200 x 3100 mm;
2. Cadmium prism covering;
3. Ra-alpha-Be neutron source;
4. Channels for uranium slugs;
5. Neutron detector (BF_3 chamber).

of uranium oxide. If a lot contained a smaller number of slugs, they were located only in the central part of the prism. The Ra-alpha-Be neutron source with an activity of 500 or 2,000 mCi was located on the prism axis in the upper part; the detector (a BF_3 chamber) was located in the lower part on the axis of the prism at a distance of 180 cm from the source.

The thermal neutron density N_U, i.e. the pulse rate from the detector as recorded by a radio device, was compared with the standard $N_э$, which was given by the count rate of the same detector when it was located in the center of a large (dimensions ~ 1 m) paraffin drum with an Ra-alpha-Be source with an activity of 50 mCi. The drum was well shielded from external radiation by stone and boron.

The prism was used to test all uranium products intended for the first reactor: 30 tons of metallic uranium cylinders (slugs) 35 mm in diameter and 100 mm long; 4.5 tons of the same cylinders with a diameter of 32 mm; 9.5 tons of compressed uranium dioxide (UO_2) in the form of spheres $\sim$ 80 mm in diameter; and 2.5 tons of U_3O_8 in the form of briquets measuring 49 x 58 x 68 mm. The measurements of the ratio $\delta = N_U/N_э$, which was called the "physical index" of a lot of uranium, ranged from 1.15 ± 0.02 to 1.80 ± 0.03 (figured for 432 slugs in a lot) for all products tested, including UO_2 and U_3O_8. A lot with an index $\delta < 1.3$ was rejected, since the multiplication coefficient for a lattice would in this case be $k_\infty < 1$.

The physical testing of the uranium was conducted by a group consisting of scientific staff member I. F. Zhezherun, laboratory assistants I. P. Afonin, B. G. Bulatov, V. I. Dedyulin, Yu. A. Mokin and H. L. Chinnov, and a brigade of workers from the beginning of 1946 until the startup of the reactor, using the same tent as was used for testing the graphite. This was extremely laborious and intense round-the-clock work which required repeated testings of all products, since the characteristics by which it would have been possible to subdivide a product for loading into the prism were not yet known.

Initially the loads were made up in order of manufacturer's number for the uranium slugs and in order of their arrival at Laboratory No 2. It turned out that the lots which were produced later were of better quality, since the production technology was being steadily improved. However, measurements of the physical index did not detect the improvement: all lots had about the same average quality and it was impossible to grade the uranium according to quality. The reason for this, as was later understood, was that slugs of good and poor quality uranium were present in roughly equal quantities in each lot. For the next test, the loads were made up according to the results of chemical analysis of iron content conducted at the plant. The measurements of δ were in the range 1.41-1.64 and showed no correlation with the content by weight of impurities, which varied from lot to lot by from 0.15 to 0.41 percent or more.

In the third test, uranium produced by different shops in the plant was assigned to different loads. In this case it turned out that the first shop usually produced uranium of significantly better quality (physical index ranging from 1.52 to 1.79) than the second (index from 1.17 to 1.51). This was a complete surprise to the plant specialists, since they saw no difference in the production technology in the two shops. The discovery of this fact and additional segregated testing of the uranium produced by different shifts and in different furnaces to arrange the production of good uranium (with an index $\delta = 1.64$-1.80).

The cause of the poor quality of some of the uranium, as discovered after careful selective chemical analysis of several lots, was in most cases a slight admixture of strongly neutron-absorbing elements: cadmium, boron and lithium. For example, for two lots with a boron content of $5 \cdot 10^{-3}$ percent by weight, the index δ was 1.35-1.38. The lots containing only a tenth to a fiftieth that quantity had an index $\delta = 1.64$-1.80.

Testing of the oxides (UO_2 and U_3O_8) found no significant difference among lots of these materials and indicated that they were of high purity and suitable for the reactor.

Thus neutron-physical testing of the uranium products not only made it possible to carry out careful differentiation, grading and classification by quality, but also led to an improvement in the uranium production technology. Later it made possible efficient disposition of the uranium in the reactor which was being built, making its startup a success. Without this grading, the mixture of uranium products from different shops would have been unsuitable for initiation of a chain reaction.

4.5 The Effect of the Crystalline Structure of Graphite and Uranium on Its Total Cross Section

In May-October 1946, K. N. Shlyagin and I. S. Panasyuk measured the total neutron interaction cross sections σ_t of various samples of graphite and uranium which had been delivered for the uranium-graphite reactor, in order to identify the dependence of these cross sections on the crystal structure. The measurements were made with the neutron gun already described (see Fig. 3.3) using water as a moderator. The graphite scattering samples had a thickness of 3-4 g/cm^2 and those of uranium 10-21.2 g/cm^2.

The measurements were as follows:

1. For samples of industrial (artificial) graphite with a density of 1.5-1.7 g/cm^3 with randomly oriented crystalline grains measuring 10^{-5}-10^{-6} cm, the cross sections σ_t were $(4.58$-$4.94) \cdot 10^{-24}$ cm^2, i.e. almost almost identical within the limits of error.

2. For samples of refined natural graphite with a density of 2.06-2.08 g/cm^3 with a layered, partially ordered distribution of crystalline grains (plates) with a size of slightly less than 0.1 cm, $\sigma_t = (4.20 \pm 0.12) \cdot 10^{-24}$ cm^2 with the incident neutron beam perpendicular to the plates.

3. For a sample of metallic uranium with crystalline grains measuring no greater than $3 \cdot 10^{-3}$ cm (average $1.6 \cdot 10^{-3}$ cm; Fig. 4.9a), $\sigma_t = (16.02 \pm 0.38) \times 10^{-24}$ cm^2.

4. For a sample of metallic uranium subjected to additional heat treatment (heating to 670° C followed by fast cooling) with crystalline grain dimensions not exceeding $8.8 \cdot 10^{-3}$ cm (average $3.3 \cdot 10^{-3}$ cm; see Fig. 4.9b), $\sigma_t = (15.48 \pm 0.40) \cdot 10^{-24}$ cm^2.

5. For a sample of powdered uranium metal, $\sigma_t = (16.67 \pm 0.48) \cdot 10^{-24}$ cm^2.

The measurements in (2) were corrected by $0.08 \cdot 10^{-24}$ cm^2 to allow for the moisture in the sample, while for cases (3) and (4) the correction was 0.6 x 10^{-24} cm^2 to allow for the presence of other elements in the samples. The impurities in the samples of metallic uranium were not determined.

A comparison of the measurements (1) and (2) for graphite samples and (3) and (4) for samples of uranium indicated that increased crystal grain diameters could significantly decrease the cross section. But for the uranium and graphite furnished for the reactor by the industry, these effects could be neglected and the following cross section values assumed: $\sigma_t = (4.8 \pm 0.2)$ x 10^{-24} cm^2 for graphite and $\sigma_t = (15.8 \pm 0.4) \cdot 10^{-24}$ cm^2 for uranium. The uranium capture cross section was then taken as $\sigma_c = (5.9 \pm 1) \cdot 10^{-24}$ cm^2 and the fusion cross section σ_f as $(2\text{-}3) \cdot 10^{-24}$ cm^2.

The number ν of secondary neutrons per fission of the ^{233}U or ^{235}U nucleus by slow neutrons or of a ^{238}U nucleus by fast neutrons was measured by V. P. Dzhelepov and M. S. Kozodayev. They determined that $\nu_M\ (^{233}U)/\nu_M\ (^{235}U) = 1.27 \pm 0.10$ and $\nu_6\ (^{238}U)/\nu_6\ (^{235}U) = 1.19 \pm 0.09$.

4.6 Determining the Geometric Dimensions of the Reactor

The planned reactor was intended to produce a nuclear chain reaction per se, and for the experimental study of reactor physics and of questions which might arise in the construction of a high-power industrial uranium-graphite reactor. With the task formulated thus, a cooling system was superfluous for the first reactor, which was called the "physical reactor" (F-1), and the problems of protection from radiation were relatively easy to solve.

Thus the physical reactor was seen by its creators as an efficient facility consisting of the uranium-graphite lattice, graphite, and remote-controlled control rods which, for radiation protection purposes, would be placed, for example, in a pit at a certain depth in the ground. The quantity $k_{eff} - 1$ was to be made lower than the proportion of delayed neutrons β. To save materials, the uranium-graphite lattice area must have the shape of a sphere surrounded by a spherical graphite insulator and installed in a graphite cylinder for stability. It was proposed that the thickness of the insulation layer by 80 cm. This meant that the critical radius of the reactor would be decreased by an amount equal to the diffusion length $L = 48$ cm.

The exponential experiments with the uranium-graphite lattice and the results of neutron-physical testing of the graphite made it possible to estimate the critical dimensions of the reactor even during physical testing of the uranium. These dimensions had to be known before construction of the pit in the reactor building, which was originally called "Building K" ("reactor [kotel] building"), and later conventionally called the "Installation Shops."

As noted above, the physical testing detected a considerably nonuniformity in the quality of the uranium delivered for the reactor; the measured physical index δ corresponded to a value of k_∞ for the uranium-graphite lattices (with a concentration ratio of carbon and uranium nuclei ~ 100) ranging from

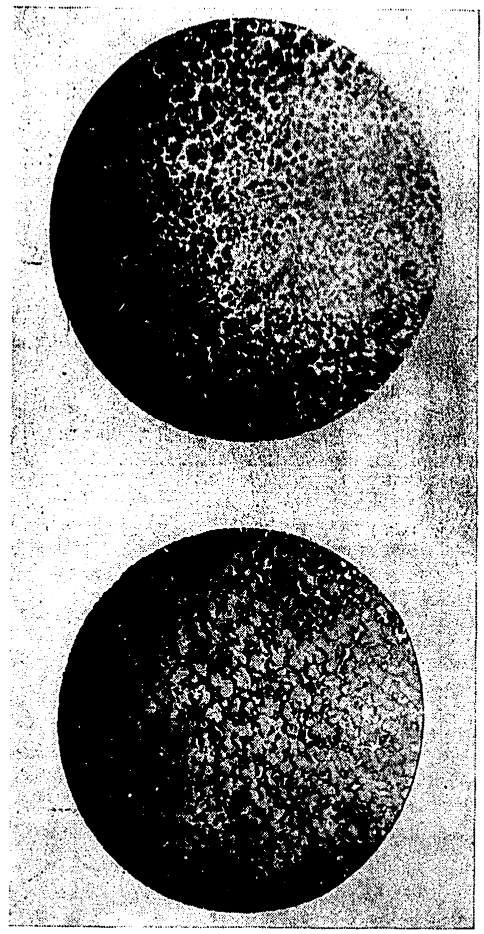


Fig. 4.9 Microphotographs of polished sections of metallic uranium before heating (top), with crystallite dimensions not exceeding $3 \cdot 10^{-3}$ cm (average $1.6 \cdot 10^{-3}$ cm), and after heating to 670° C and rapid cooling (bottom), with crystallite dimensions not exceeding $8.8 \cdot 10^{-3}$ cm (average $3.3 \cdot 10^{-3}$ cm).

1.09 for the best lots to 1.0 for the worst (nonrejected). The critical radius R_{cr} of the spherical reactor with $k_{\infty} = 1.09$, $\tau = 320$ cm^2 and $L^2 = 324$ cm^2 was 2 meters according to formula (2.64). But we could not wait until the industry delivered the necessary quantity of good-quality uranium, and so it was decided to build the reactor making maximum possible use of the available uranium and graphite. As a result we could calculate R_{cr} only approximately. Assuming that the available materials could be used to build a lattice $k_{\infty} = 1.04$-1.05, according to formula (2.64) R_{cr} would be equal to 3.5-4 meters. Taking account of the insulation layer and the shape of the reactor, its dimensions would increase to 8.5-9 meters and the total weight of the materials to $\sim$ 550 tons ($\sim$ 50 tons of uranium and 500 tons of graphite). Starting from these data we worked out the design of the reactor building and the dimensions of the pit, which were taken as 10 x 10 x 10 meters.

4.7 Development of the Monitoring and Measuring Instruments

The measuring instruments for the experiments described above (physical testing of the graphite and uranium) and the future startup of the reactor and for monitoring their operation were developed in Sector No 1 by N. V. Makarov, the leader of the radio engineering group, I. S. Panasyuk, K. N. Shlyagin and N. Ye. Yukovich, with the participation of N. M. Konopatkin and V. A. Kulikov, and were manufactured by them with the help of laboratory assistants and workers in the glassblowing and mechanical shops. The sensors of these instruments were most frequently neutron detectors and less often detectors of other ionizing radiation (electrons and gamma rays).

The neutron detectors were glass or metal ionization chambers filled with BF_3. The gas BF_3 was prepared by heating a mixture of KBF_4 and B_2O_3 in a simple apparatus (Fig. 4.10), was purified and was fed directly to the chamber to be filled or to a cylinder for storage. Preparation of the BF_3 and filling of the chambers were generally done by senior laboratory assistant N. Ye. Yukovich. The chambers were cylindrical with 2 or 3 electrodes in the form of coaxial cylinders. The chambers were developed and manufactured in a series of models with working volumes from 30 to 4,000 cm^3. Some of them are shown in Figs. 4.11-4.1.

The small-sized chambers operated in the pulse mode and were used for counting neutrons. This type of chamber, with the first pulse amplifier (preamplifier) cascade, was placed in a small-diameter tube 1-4 meters long (depending on the measuring conditions), and was connected by a long multistrand cable to the main amplifier. The amplified pulses were shaped and counted by a scaler (divider) circuit with a mechanical register at the output.

Several such counting units were manufactured. Figs. 4.14 and 4.15 show two of them: No 2 in a portable form and No 3 in a desk configuration. The overall gain factor for the amplifiers was 50,000 and the scaling coefficient was 32-1024. Fig. 4.16 shows the circuit of one of the amplifiers using 6SQ7 tubes. The preamplifier, which is not shown, consisted of miniature tubes of the "acorn" 954 type. The filament circuits of the tubes in units 1 and 2 were powered by batteries. In unit 3, all circuits were driven by the power system

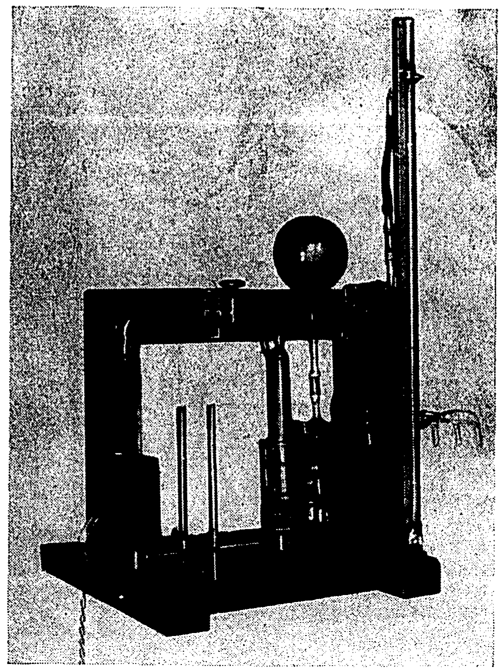


Fig. 4.10. Apparatus for Preparing Boron Trifluoride (BF_3).

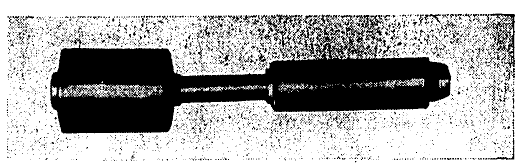
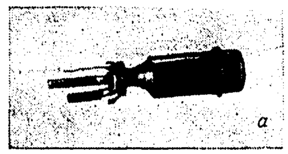


Fig. 4.12. Metal Pulse BF_3 Ionization Chamber, 300 cm^3, With Preamplifier.



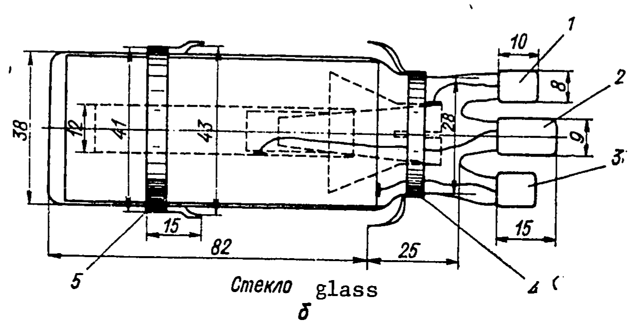


Fig. 4.11. Appearance (a) and diagram (b) of a glass pulse ionization chamber with volume of 60 cm^3.

Key: 1. Lead connected to guard ring;
2, 3. Brass leads connected to inner and outer cylindrical electrodes;
4, 5. Snap rings for installing chamber (dimensions in mm).

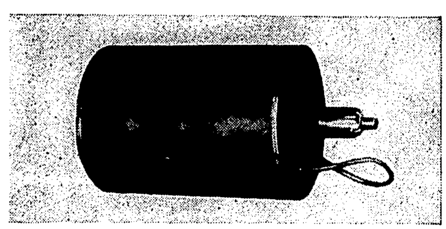


Fig. 4.13. Metal Current-Mode BF_3 Ionization Chamber, 1000 cm^3.

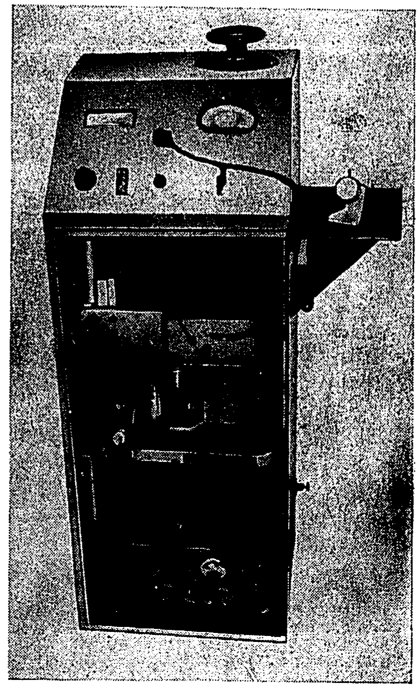


Fig. 4.14. Counter Unit No 2.

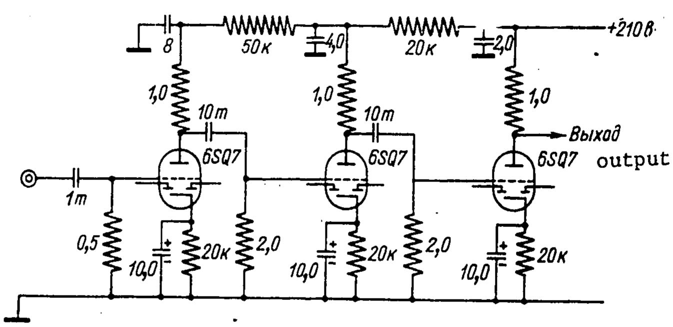


Fig. 4.16. Circuit of a Counter Amplifier Using 6SQ7 Tubes. Preamp Not Shown.

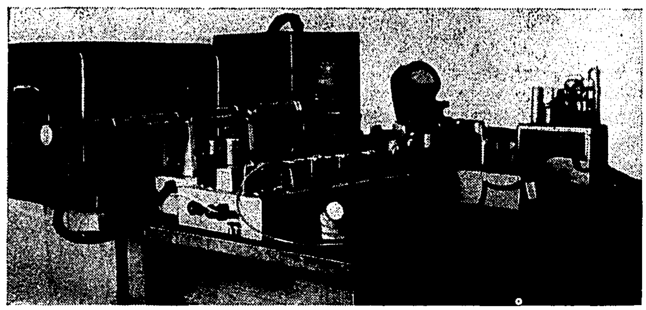


Fig. 4.15. Counter Unit No 3.

voltage. The high voltage fed to the ionization chambers was 500-1000 V. The units were quite simple and convenient to operate, even though they were far from perfection, having low resolution. Nonetheless, they served for experimental studies, the startup of the reactor and monitoring of its power level.

The large chambers were connected directly to a sensitive galvanometer ($\sim 10^{-8}$ A per scale division) and operated in a continuous current mode. Some of them, filled with argon or air, were intended for recording beta and gamma radiation. These continuous current chambers were used for monitoring the operation of the reactor at powers above 1 W and emergency protection, and also for dosimetric purposes. One of them, with good linearity, which was developed and manufactured by K. N. Shlyagin and was known as the "Shlyagin chamber" when it was put into operation, was later used during the long-term operation of the reactor.

Special notice should also be taken on one more detector of neutrons, which was the ancestor of the current DPZ's (direct-charging detectors). This detector was developed in accordance with a suggestion of I. S. Panasyuk after the startup of the reactor and was then called the "silver chamber" (and later a "neutron electric current generator").* It looked like a flat capacitor made of two thin plates of silver separated by an insulator (Fig. 4.17), and was used to monitor the operation of the reactor. Electric current was produced in it by emission from the plates of beta particles resulting from radioactive decay of silver isotopes formed by absorption of neutrons. No power supply was required by this detector.

* The first model of the silver chamber was designed, manufactured and tested by M. B. Yegiazarov.

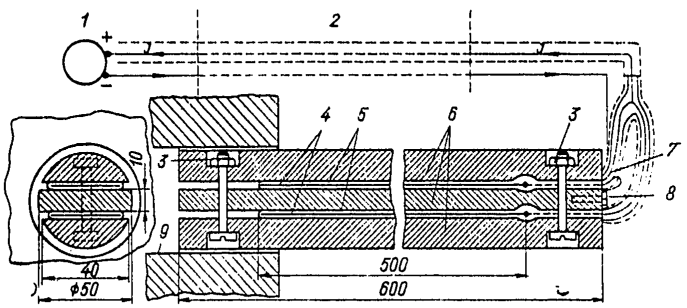


Fig. 4.17. The silver chamber: a neutron detector operating without an external power supply.

Key: 1. Sensitive galvanometer;
2. Overhead electrical cable;
3. Aluminum bolts;
4. Silver foil, 0.1 mm thick;
5. Capacitor paper, total thickness 1 mm;
6. Graphite;
7. Insulated leads;
8. Lead contact with graphite;
9. Nuclear reactor channel.

The detectors were calibrated by measuring the activity of a gold foil indicator which had been irradiated in various places in the reactor. To measure the activity of such indicators, another type of unit was developed, with a sensor consisting of a Geiger-Mueller counter.

The reactor temperature was monitored by a system of iron Constantan thermocouples developed by N. F. Pravdyuk, B. H. Romanov and K. N. Shlyagin. The thermometers were mounted in blocks of uranium and graphite located in various parts of the reactor.

4.8 Radiation Safety and Dosimetry

It was clear that even when working at low powers the planned uranium-graphite reactor would be a powerful source of penetrating radiation, several times stronger than the sources then known: X-ray tubes, linear accelerators and cyclotrons. Accordingly the questions of measuring the level of ionizing radiation and assuring radiation safety during operation of the reactor were a subject of attention long before it was started up and were studied in Sector No 1 by I. S. Panasyuk, B. G. Dubovskiy and the dosimetry group which they led, consisting of senior laboratory assistant A. N. Vantorin and laboratory assistants A. A. Aleksandrov and G. F. Shavkutenko.

Approximate calculations indicated that a uranium-graphite reactor of the planned dimensions operating at a power of P watts would produce the following radiation fluxes in 1 second: $1.5 \cdot 10^6$ P of fast neutrons; $1.5 \cdot 10^8$ P of thermal neutrons; $3 \cdot 10^8$ P of gamma radiation. The level of radiation danger from the reactor's gamma radiation could be evaluated on the basis of experience with X-ray tubes and the international tolerance (maximum permissible) dose of external radiation for X-rays, which had been adopted before 1941 and was equal to 0.15 roentgens per day (at present the maximum permissible dose is considerably less). No such norms had been developed for neutrons and other radiation. The first task of the dosimetry group was to estimate such norms, to determine the radiation level of the reactor and its component parts, and to develop methods and instruments for dosimetry with this radiation.

The maximum permissible norms were evaluated jointly with medical specialists through analysis of: the level of exposure of humans to cosmic rays and natural radioactive components of the soil and atmosphere; the experience with medical use of radioactive water; the experience of work with Ra-gamma-Be and Ra-alpha-Be neutron sources, linear accelerators and cyclotrons; and estimations of the slowing down and absorption of neutrons in the human organism and of the production of other radiation in this process. This analysis made it possible to establish the following maximum permissible norms: 10 fast neutrons per cm^2 per second (with energies equivalent to neutrons from Ra-alpha-Be sources); 1,600 thermal neutrons per cm^2 per second; 10^4 gamma quanta per cm^2 per second; 10^9 Ci of beta- and gamma- active substances per liter of air. These were the first approximate determinations (which today have been refined) and served as estimates for planning the reactor and assuring radiation safety during its operation.

To measure gamma ray intensity and doses, B. G. Dubovskiy and I. S. Panachuk developed a portable dosimeter. After testing several models of one-time and integrating dosimeters, the most convenient type was chosen; a schematic is given in Fig. 4.18. Fig. 4.19 is a diagram of a removable ionization chamber for the dosimeter, made of plexiglass and coated on the inside with a thin layer of Aquadag to assure conductivity. The chamber was connected to the instrument console by a long multistrand cable and could be placed in any part of the reactor. Plexiglass was used because its effective nuclear charge was close to that for air.

This integrating dosimeter was used in the startup of the reactor and in the first phase of operation. Various models were supplied with power from the electrical system or from batteries. The radiation dose I was determined from the discharge time t of capacitor C and the saturation current in the ionization chamber (with correction for the background discharge time t_Φ in the absence of radiation), i.e.

$$I = \text{const}\,(t^{-1} - t_\Phi^{-1}). \qquad (4.9)$$

At the end of each discharge, a mechanical number register 3 went into operation, after which the capacitor was recharged. To decrease t_ϕ, the capacitor and the central electrode of the chamber were insulated from the other parts with amber. For the same reason, the "acorn" type tube with a large screen-cathods resistance ($\sim 10^{13}$ ohms) was selected. The instrument was calibrated using a small Ra source. The instrument was similar to the Strauss Mechanion dosimeter, but had the following advantages over the latter: 1. simplicity of setup and operation; 2. considerably greater sensitivity from microroentgens/second to roentgens/second, while the Mechanions only work from milliroentgens/second to roentgens/second. In addition, the instrument used simple parts and accessible materials, which significantly lowered the cost of mass production. This instrument was the prototype for a dosimeter which later was industrially produced.

Radioactive contamination of the air in the reactor building was measured by the same dosimeter using a special ionization chamber. The chamber was placed at a distance from the reactor. It had a system of pipes and filters to feed in air taken from any desired place in the reactor building or in the reactor itself.

Intensity measurement and dosimetric monitoring of neutron radiation could be carried out with the counter units described above or by the dosimeters, with use of a BF_3 ionization chamber in the continuous-current regime. In the latter case, the measurements gave the total ionization effect produced by neutrons and gamma radiation. Later, during operation of the reactor, dosimetric monitoring was conducted using foil indicators which were sensitive to thermal neutrons (indium) or fast neutrons (sulfur). Dosimeters for thermal and fast neutrons were also developed.

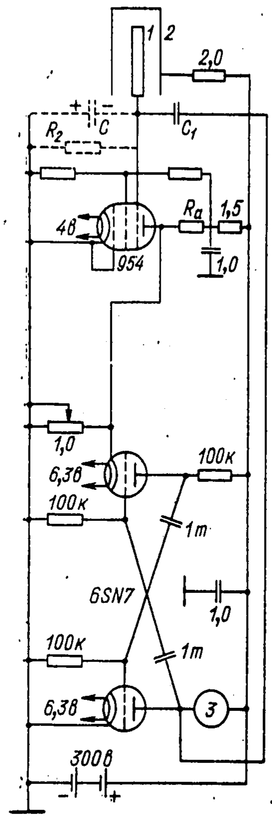
In addition to dosimetry for overall radiation from the reactor, calculations and measurements were made of the radioactivity induced in individual reactor components (control rods, concrete pit and the like).

Chapter 5. The Construction and Startup of the Reactor

5.1 The Reactor Building

The planning and construction of the building for the reactor were conducted by the capital construction department (OKS) of Laboratory No 2, headed by Architect A. F. Zhigulev. The building was ready in June 1946, and as previously mentioned was called Building K (Figs. 5.1 and 5.2). The construction of the building is described in references 5 and 82 [not reproduced].

The dimensions of Building K were as follows: area about 15 x 40 meters, height 8.5 meters above ground level. The majority of the building was taken up by the main hall (10), in the eastern part of which was a concrete pit (1) for the reactor. The area of the pit was 10 x 10 meters and its depth 7 meters. It was impossible to make it deeper than 7 meters because of subsurface water.



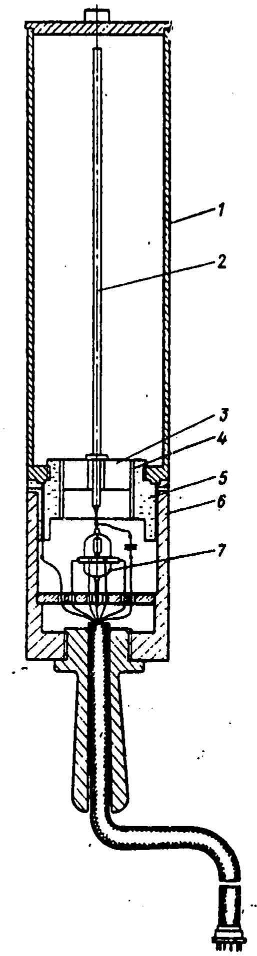


Fig. 4.18. Schematic of Dosimeter.

Key: 1, 2. Internal and external electrodes of removable ionization chamber;
3. Mechanical counter for discharges of capacitor C.

Fig. 4.19. Diagram of Plexiglass Dosimeter CHamber.

Key: 1, 2. Electrodes;
3. Insulator (amber);
4, Protective ring;
5. Sleeve;
6. Ebonite;
7. Acorn 954 tube.

Fig. 5.1 Building K.

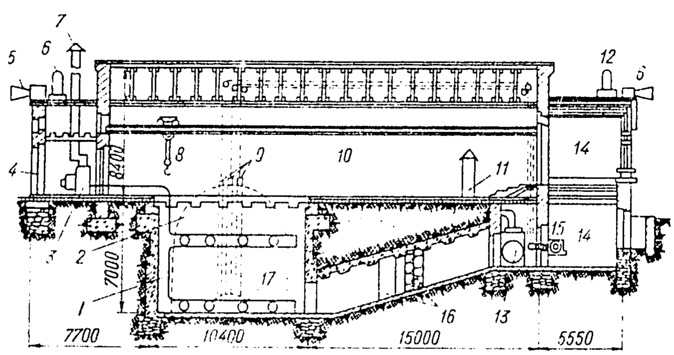


Fig. 3.2. Longitudinal Section of Building K.

Key: 1. Pit (10 x 10 x 7 m); 2. Reactor; 3, 7, 17. Exhaust ventilation system; 5, 6, 12. Light and sound radiation danger signals; 8. Hoisting crane; 9. Control and emergency rods; 10. Main hall; 11, 13. Convective ventilation system; 14. Laboratory quarters; 15; Winch for moving control and protective system rods; 16. Passage to reactor pit through laboratory.

On the west the hall was adjoined by a two-story laboratory building (14), the lower story of which was underground. The distance from the laboratory to the pit was 15 meters. The upper floor of the laboratory was separated from the hall by a wall.

The underground story of the laboratory, intended for service personnel during operation of the reactor, was well protected. It was separated from the pit not only by reinforced concrete walls, but also by a thick layer of soil and sand. The pit could be reached from the laboratory only through a narrow zigzag passage (16) composed of thick layers of lead and blocks of a mixture of paraffin and boric acid. The experimental testing of the protective ability of the passage, performed by S. A. Baranov, indicated that it assured safe working conditions in the laboratory. The underground part of the laboratory communicated with the upper floor and the main hall via stairwells. The outer entrance to the laboratory was at some distance from the building and was also underground.

The materials required for the reactor were brought into the building through gates (4) and were lowered into the pit by an overhead traveling crane (8).

The building was equipped with water central heating, running water and a sewer system, and accordingly automated signaling was provided in case of a breakdown resulting in entry of water from these systems into the pit. Electric power was supplied to Building K from two independent substations so that in case one failed it would be possible to switch immediately to the other. This redundancy was necessary in order to assure a continuous power supply to the radio and electrical systems for control and monitoring of the chain reaction in the reactor. In the improbable instance of a breakdown of both substations, an emergency supply from batteries was provided, with the necessary apparatus installed in the building.

Before assembly of the reactor, the pit was equipped with a system of radiation monitoring and signaling based on the dosimeters described above. This system was controlled from the underground laboratory which, in addition to the indicating and signaling instruments located here, was later equipped with facilities for light (red beacon) and sound (siren) signaling located on the roof and in other places in the building.

To prevent contamination of the air in Building K by radioactive gases, gaseous products of the fission of uranium diffusing from the reactor or components of the air which had become radioactive under the influence of neutrons from the working reactor, exhaust and convective ventilation were provided. The exhaust system consisted of a double exhaust fan (3), a network of exhaust pipes (17) in the walls of the pit, and a pipe (7) through which the air was discharged into the atmosphere. The convective system consisted of a ventilator fan (13), a calorifier for heating clean atmospheric air and a pipe (11) from feeding it into the building.

When the passages in the ventilation system were fully open, the rate of air circulation in the building was 7,000 m^3/hr. Experience with the reactor indicated that this was sufficient for operation at a power not exceeding 10 kW.

For higher powers, all working personnel left the building and monitoring and control of the reactor were carried out by remote control from a console located about 1 km from Building K.

5.2 The Reactor Control and Protective System (SUZ)

The system for controlling the chain reaction in the reactor was extremely simple. Accordingly it required no advance development and was installed in Building K during the building of the reactor models. The simplicity of the system, as followed from a theoretical discussion of reactor kinetics by Ya. V. Zel'dovich and M. S. Kozodayev (see section 2.5), was determined by the fact that the effective multiplication coefficient k_{eff} of the planned reactor was to exceed unity by an amount smaller than the quantity of delayed neutrons (i.e. $k_{eff} - 1 < \beta$. Approximate calculations by A. S. Panasyuk and B. G. Dubovskiy indicated that if $k_{eff} - 1 \leq (2\text{-}3) \cdot 10^{-3}$, the regulation and attenuation of the reaction in the reactor could be carried out by a single absorbing rod 3-4 cm in diameter.

The regulation and protective system was constructed and installed by Ye. N. Babulevich and his assistants I. I. Volodin, A. M. Volkov and N. A. Klemenkov. It included a total of three absorbing rods : a control rod (Fig. 5.3) and two emergency rods, as they were then called. The control rod was a duralumin tube 55 mm in diameter which contained sheet cadmium rolled into a tube of smaller diameter.

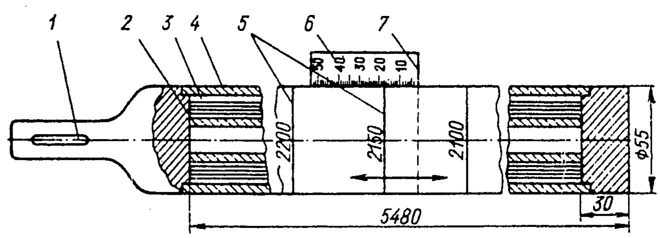


Fig. 5.3. Diagram of Cadmium Control Rod.

Key: 1. Opening for cable;
2, 4. Duralumin tubes;
3. Cylindrical cadmium layer;
5. Divisions on surface of rod for determining depth of insertion into reactor;
6. Additional scale (not connected to rod);
7. Reading level.

On the surface of the duralumin tube were inscribed divisions which indicated the depth to which the rod was inserted into the reactor. The emergency rods differed from the control rod only in having no divisions, since they were to be lowered into the reactor for their full length.

The rods were suspended above the pit on steel cables so that the middle control rod was directly above the center of the pit (and after construction of the reactor, over its center), while the two other emergency rods were located symmetrically with respect to the central rod and 60 cm away from it. The rod cables passed over pulleys in the loft of the building and into the underground laboratory and were attached to winches (15) (see Fig. 5.2), which were manually and electromechanically operated. Each winch could be switched to free movement, when the rod would be lowered by its own weight (in about 1.5 seconds) to its lower position.

The emergency rods were suspended from their cables by electromagnets. If the current in these ceased, the rods would be released from the cables and would fall freely (in 1 second) into the reactor. A device installed in the loft made it possible to refasten the rods to the cables after they had fallen. The control console is shown in Fig. 5.4. It also included a system for indicating the position of the emergency rods.

Accordingly the reactor control and protective system enabled an operator in the underground laboratory to carry out all required displacements of the control rods: to lower and raise all the rods by winches, to carry out the same operations with electric drive using pushbutton switches and magnetic starters, to lower the control and emergency rods into the reactor by releasing the brake levers of the winches, to drop the emergency rods into the reactor by disconnecting them from the cables by means of the emergency drop button (the rods would also be dropped spontaneously if the power to Building K failed), to connect the rods, once they had dropped, with their cables again by remote control, and to determine the position of the emergency rods according to signal indicators and to establish approximately (with an error of approximately ±5 cm) the depth to which the control rod was inserted into the reactor by the number of turns of cable around the winch.

The depth to which the control rod was inserted at the beginning of operation could be determined only at the surface of the reactor by means of the markings on the rod, which presented a certain inconvenience. Accordingly, A. A. Zhuravlev, R. S. Silakov, I. I. Volodin and N. A. Klemenkov later designed and installed a special optical system which made it possible to determine the depth of insertion rather accurately (with an error of ±0.5 mm) from the control console in the underground laboratory.

The control and protective system which has been described was used at startup and in the first period of operation. At that time it still lacked units for automatic maintenance of the power level of the reactor, since it was easy for the reactor operator level by means of the indications on the control and measuring instruments. It also proved sufficient to have only one breakdown rod, and the channel for the second which then became available was then used as an experimental channel.

To control the reactor during work at high power, a second control console was installed in another building about 1 km away from Building K. Its layout was extremely simple, but nonetheless the instruments and accessories on this console made possible reliable control of the reactor at a power of 1 W and above. Many major long-distance startups were conducted for various purposes without a single failure, thus indicating the serviceability of the control and protective system and the monitoring and measuring instruments as well as the ease of controlling the reactor.

5.3 The Investigation of Reactor Models

The task of starting up the reactor in the shortest possible time with maximum use of the materials that had been furnished for it at the time was extremely important. But since, as already noted in section 4.6, it was impossible to make a theoretical calculation of the dimensions of the planned reactor with the necessary precision, owing to the nonuniform quality of the uranium and graphite, it was decided to determine these dimensions experimentally through studies of reactor models. According to the conception of the experiment, these models, in contrast to the uranium-graphite lattices which had been used in the model exponential experiments described above, were to be of significantly greater dimensions and to have the same spherical shape and reflector thickness as in the planned reactor.

From the expressions giving k_{eff} and R_{cr} for a spherical reactor (formulas (2.64)-(2.68)) follows the equation

$$R^2_{эф}/J_ц \approx \mathrm{const}\,(R^a_{кр} - R^a). \qquad (5.1)$$

(also used by E. Fermi in the startup of the first American reactor), where R^a is the radius of the model (counting the reflector); R^a_{cr} is the critical radius of the reactor; $J_ц \equiv J_ц\,(R_{eff})$ is the neutron density (from spontaneous fission of uranium) in the effective center of the model; and R_{eff} is the effective radius. When $R^a \approx R^a_{crit}$, equation (5.1) corresponds to a straight line intersecting the abscissa at the point $R^a = R^a_{cr}$. Thus, after measuring the neutron density at the center of several models of differing radii it was possible to determine the critical radius of the planned reactor.

The model experiments were conducted between July and October 1946 by I. S. Panasyuk, A. A. Zhuravlev, V. A. Kulakov, N. M. Konopatkin and K. N. Shlyagin with the participation of laboratory assistants and workers. The model was built in the pit of Building K. The cores of the models consisted of body-centered cubic uranium-graphite lattices with an elementary cell dimension of 20 x 20 x 20 cm and a concentration ratio of carbon and uranium nuclei $\sim$ 100, with slugs of the best grades of uranium and blocks of the best varieties of graphite located near the center. The reflector thickness was 80 cm. The models were constructed by A. A. Zhuravlev. It was he who led the brigade of workers in the assembly and disassembly of the models. The dimensions of each successive model were determined by the quantity of uranium available at the time of construction. Naturally, all the models were subcritical and were built without the use of absorbing rods, with the exception of the largest model, No 4. Fig. 5.5 shows the measurement of neutron density in Model No 1, and Fig 5.6 shows the process of assembling Model No 3.

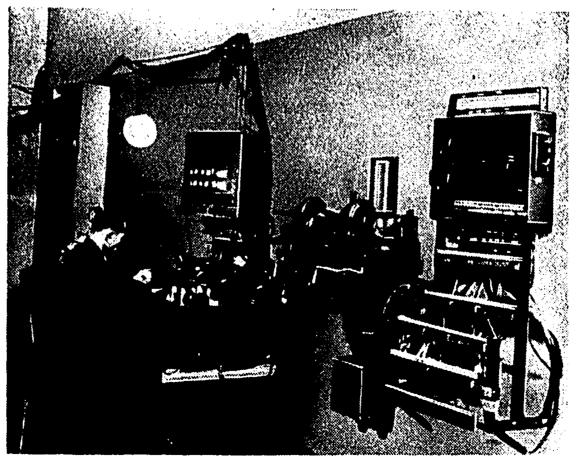


Fig. 5.4. The Control Console of the Control and Protective System.

In all, four models were constructed (Table 5.1, Fig. 5.7). The neutron density J_4 in each model was measured by counters with BF_3 chambers (in the standard neutron-field devices already described) and by the activity of indium foil. Points 1-4 in Fig. 5.7 give the values of the ratio R^2_{eff}/J_4 for all four models as a function of their radii. Point 3 for Model No 3 "fell out" of the smooth course of the curve. Later it was found that reject uranium slugs had happened to find their way into the central zone of Model No 3, resulting in a significant lowering of J_4 . Nonetheless, the extrapolation of the graph to its intersection with the abscissa, shown in Fig. 5.7, led to the unequivocal conclusion that the critical radius of the reactor was close to 3 meters, i.e. $R^a_{cr} \approx 300$ cm. Accordingly there was no need to build models of larger dimensions, the more so since the value of R^a_{cr} which was obtained was in agreement with the theoretical estimate that $R_{cr} = 3.5$-4 m. In actuality, owing to the low quality of uranium located on the periphery of the reactor, the critical radius proved to be somewhat larger than 3 meters.

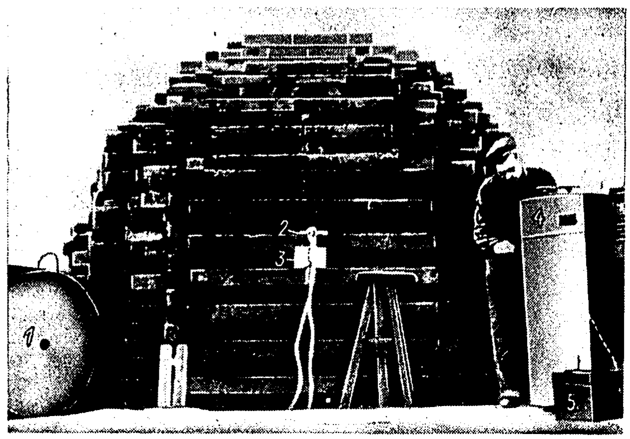


Fig. 5.5 Measuring the Neutron Density at the Center of Model No 1.

Key: 1. Opening for BF_3 chamber in drum with standard thermal neutron field;
2. BF_3 chamber with transfer cascade;
3. Pulse amplifier;
4. Counter unit control console;
5. Battery.

Table 5.1 Data on Subcritical Reactor Models.

Number	Date of construction	Core radius, meters	Weight of uranium, t	Weight of graphite, t	$\frac{R^2_{eff}}{J_4}$
1	1 Aug. 1946	90	1.4	32	1350
2	25 Aug. 1946	150	6.3	86	1125
3	15 Sep. 1946	180	10.4	188	1080
4	15 Oct. 1946	290	24.6	290	440

Fig. 5.6. The Assembly of Model No 3.

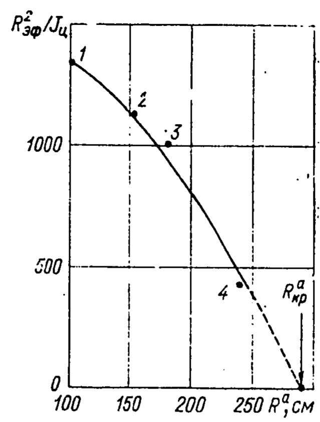


Fig. 5.7. Measurement Results From Four Subcritical Reactor Models.

5.4 The Construction and Startup of the Reactor

As mentioned above, it was proposed to build the reactor in the most economical form, that of a sphere, resting on a cylinder of the same diameter. In view of the results of the model experiments, the radius R^a of the reactor core was taken as 3 meters and the thickness of the insulation there as 0.8 meters. Thus the total radius of the reactor was 3.8 meters, and the effective radius of the core $R_{eff} = R^a + L = 3.5$ meters. Such a reactor required about 400 tons of graphite and 50 tons of uranium. By the end of the model experiments, we had just over half the required amount of uranium, But since it was still arriving continuously from the plant and was ready for use following running neutron-physical testing, the construction of the reactor was begún on 15 November 1964.

The design of the reactor was extremely simple: it consisted of horizontal layers 10 cm thick. This also determined the procedure for building the reactor, in which the layers were built up one on another. The insulation was made of rectangular bricks measuring 10 x 10 x 60 cm and weighing about 10 kg; the core was made of the same bricks, with holes into which cylindrical uranium slugs (32 or 35 mm in diameter, 100 mm high) or briquets of uranium oxide were placed. The arrangement of the core is shown in Fig. 5.8. It was a uranium-graphite lattice with an elementary cell in the form of a cube measuring 20 x 20 x 20 cm, with uranium placed at the corners and at the center The concentration ratio of uranium and carbon nuclei in the lattice with slugs of metallic uranium was 80-100. The reactor design is sufficiently clear from Figs. 5.9 and 5.10, which show it in horizontal and vertical section. The boundaries of the reactor and its core in the upper part of the structure, which were not precisely adhered to in construction, are shown by dots. The reactor design was developed by A. A. Zhuravlev together with V. I. Merkin, N. S. Bogachev and T. A. Lopovko, the chief and engineers of Sector No 6. A. A. Zhuravlev, whom we have called the first reactor designer, also led the brigade of workers who built the reactor and the models. He was assisted in this by engineer V. M. Zvereva (Kutukova) and technicians S. S. Rusakov, R. S. Silakov and G. N. Eyza.

The plan for the reactor consisted of 76 layers: 60 with graphite and uranium (core) and 16 (8 above and 8 below) only with graphite (the insulation). In Fig. 5.9, the layers are numbered in the order of their assembly. Also visivle are the loading zones for uranium of different grades. The best grade, with the highest index δ , was located in the center, and the worse the farthest from the center. Uranium oxides were placed on the periphery of the reactor. The graphite was distributed in the reactor according to the same principle.

The plan called for 3 vertical cylindrical channels for the control and protection rods and 5 horizontal channels for monitoring and measuring instruments and various experiments. The vertical channels, 57 mm in diameter, penetrated into the reactor to the 18th layer and were located in the central part: that for the control rod directly in the center and those for the emergency rods at a distance of 60 cm from the center. The horizontal channels passed

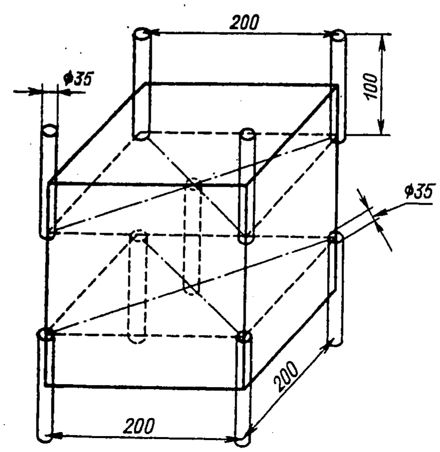


Fig. 5.8. Diagram of the Elementary Cell of the Reactor Core.

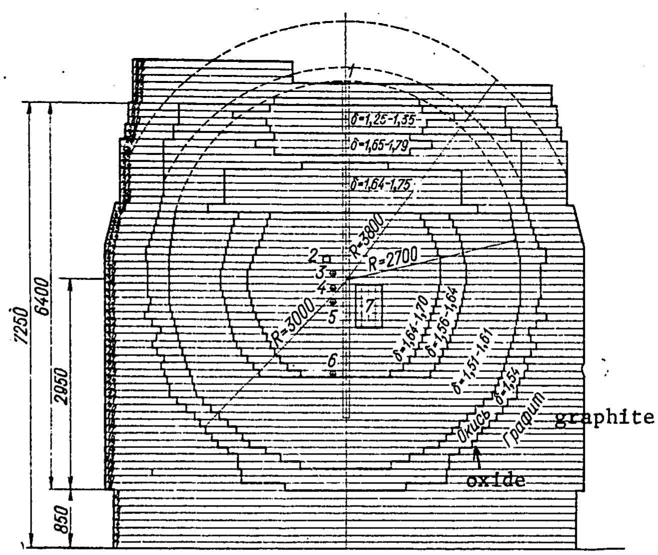


Fig. 5.9. Vertical Section of the Physical Reactor.

Key: 1. Central channels for control rods; 2-6. Horizontal channels; 7. Experimental tunnel with 400 x 600 mm cross section; δ. Index of uranium charge from physical testing.

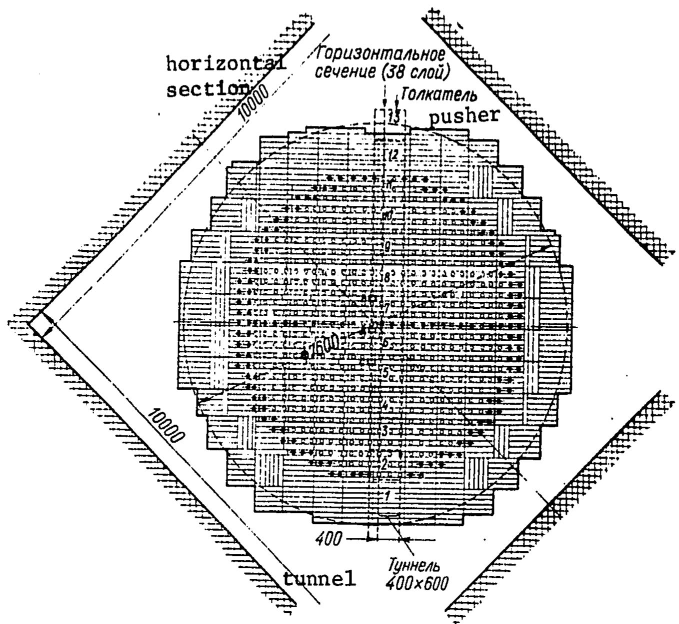


Fig. 5.10. Horizontal Section of the Physical Reactor.

Key: 1-13: Tunnel insets, 40 x 40 x 60 cm; A. Control rods; B, C: Emergency rods. •: Uranium oxide; o: Metallic uranium.

all the way through the reactor, also near its center. Three of them were cylindrical, with diameters of 32 mm (one) and 57 mm (two) while two were square with a cross section of 10 x 10 cm. The horizontal channels could if necessary be filled with graphite rods of the proper dimensions.

Also planned was a horizontal tunnel with cross-sectional dimensions of 40 x 60 cm which was to pass through the reactor's center (see Fig. 5.9). It was to be filled with insets 60 cm long consisting of the standard lattice, so that the reactor structure would not be disrupted.

A few words on the design of the tunnel. It was to make possible the placing near the center of the reactor the necessary materials and devices for experimental studies. Before construction of the tunnel, the question of its location was frequently discussed. Many proposals were made, but they all called for introducing extra absorbers into the tunnel (aluminum or steel frames, various kinds of strips and casings and the like), which was extremely undesirable in terms of the main task, the quick startup of the reactor. These shortcomings

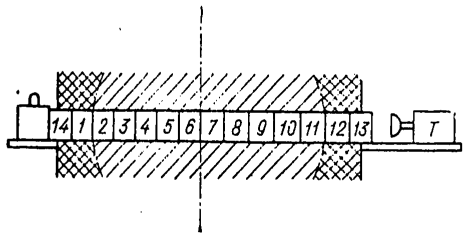


Fig. 5.11. System for Shifting the Contents of the Experimental Reactor Tunnel.

were not shared by the risky but clever suggestion of Ye. N. Babulevich, that of displacing the inserts filling the tunnel, i.e. the entire lining of the tunnel, by means of a pusher at one of the vertical areas (40 x 60 cm) driven by an electric motor. Here the individual tunnel insets, measuring 40 x 60 x 60 cm, would be sequentially pushed out of the reactor on the side opposite from the pusher. The inset which had been pushed out of the tunnel would fall into a container and be brought back by a crane to the pusher on the other end of the tunnel (Fig. 5.11). Thus, in order to shift all the insets or to replace one of them it would be necessary to conduct 14 successive operations in which the lining of the tunnel was pushed along (i.e. the number of insets needed to fill the entire tunnel).

The risk of this proposal was that some inset might become wedged in the tunnel and put it out of commission. In addition, there was a danger that the bottom of the tunnel might suffer heavy abrasion. But prolonged operation of the tunnel after the startup of the reactor confirmed the reliability of its design, which was clearly the result of the properties of graphite ("greasiness" and plasticity).

Moving ahead, let us note that the presence of the tunnel made it possible to place various inserts in the center of the reactor and to carry out extremely important experiments.* The reactor was built almost exactly according to the plans, with the channels and the experimental tunnel. A certain change was made only in the upper part, resulting from the desire to increase the surface for the conduct of various experiments.

Let me now proceed to a description of the construction of the reactor itself, in which practically all of the collective of Sector No 1, from the scientific staff to the laboratory assistants and workers, took part: some carried out running neutron-physical testing of the uranium and classified it by quality, others transported the uranium and graphite to the assembly site, a third group built the reactor layer by layer, a fourth group kept the monitoring and measuring instruments in working condition, a fifth group followed the readings and

* A procedure for similar experiments was developed much later for the American PCTR reactor.

measured the neutron density at the required points in the reactor, a sixth group processed the measurements and graphed them, and so on.

The assembly of the first 25 layers (8 layers of lower insulation and 17 layers of uranium oxides, metallic uranium and graphite) was done without special precautions and with a small amount of measurement. The positions of the various layers of uranium and graphite were strictly adhered to in accordance with maps of each layer and its design characteristics.

Through the 25th layer passed the first horizontal channel, at the center of which was located a neutron detector: a pulse-type BF_3 chamber. The signals from this detector were recorded by a counter and were reproduced as clicks throughout Building K. Other neutron detectors were located in various places within the reactor and on its surface as the number of layers increased. One of the BF_3 chambers, working in the continuous-current mode, was placed near the center of the reactor. In addition, the neutron density was also measured periodically by the activity $J_{\text{и}}$ of indium foil placed in the central region of the assembled part of the reactor. The largest values of $J_{\text{и}}$ from the detector located at its effective center were plotted on a graph.

The rods of the control and protective system and the dosimetric meters for radiation monitoring and the neutron and gamma ray detectors located in the pit and at various placed in building K were put in operating condition.

Thus, by the instrument readings it was possible to judge the state of the reactor during its assembly, and using the results of theoretical studies by V. S. Fursov it was possible to determine from the graph of $J_{\text{и}}$ (R) how far away the assembled part of the reactor was from the critical dimensions. Thus it was already unnecessary to plot a graph of inverse multiplication simular to that shown in Fig. 5.7.

V. S. Fursov had shown that the neutron density N in the finished part of a spherical reactor with a radius near to the critical value R_{cr} would increase hyperbolically with the number of uncompleted layers Δ h, i.e.

$$N(r) = \frac{QR_{\text{кр}}^4}{\pi^2 D (R_{\text{кр}} - h_{\text{кр}})} \frac{1}{\Delta h} f(r), \qquad (5.2)$$

where $D = D_0 + \tau/T$ is the effective diffusion coefficient (see formula (2.56)); Q is the power of the source of spontaneous fission neutrons; and h_{cr} is the height (at the center) at which the reactor will become critical. This means that if, after addition of Δ h layers, the neutron density was doubled, the reactor would become critical with addition of an equal number of layers.

Starting with the 38th layer, each subsequent layer was put in with lowered control and protection rods, whose channels were about 2 meters deep with the completion of this layer. A moment in the assembly process is shown in Fig. 5.13. Now, after assembly of the next 1 or 2 layers, the rods were lifted and the neutron density, i.e. the count rate from the units with BF_3 chambers, was measured. When the rods were drawn out after assembly of the 58th layer, a temporary increase (up to saturation) of the count was observed. This phenomenon indicated that the reactor was already not far from the critical state. In fact, it was clear from the graph of $J_ц$ (R) (see Fig. 5.12) that when the number of completed layers increased from 53 to 58, i.e. by 5 layers, the neutron density $J_ц$ would approximately double. Thus the reactor would become critical on assembly of the 62nd or 63d layer.

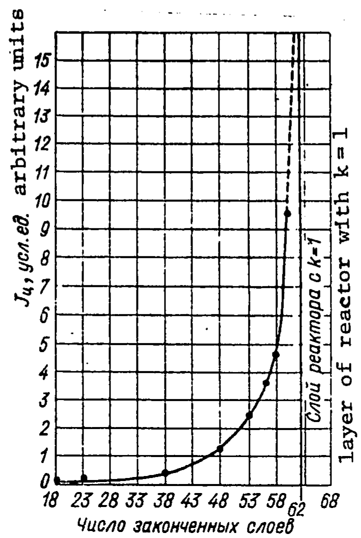


Fig. 5.12. Neutron density at the effective center of the completed part of the reactor ($J_ц$) as a function of the number of completed layers.

When the control and protective rods were raised after assembly of the 60th layer, a comparatively large increase in the count rate was observed, reaching saturation after 1-2 minutes. The count rate at saturation was twice as large as the value observed after assembly of the 58th layer. Thus there was every ground for expecting that the reactor would become critical after assembly of the 62nd layer, i.e. significantly earlier than assumed in the plans.

At 15 hours on 25 December 1946, the 62nd layer was assembled. Some 45.07 tons of uranium and about 400 tons of graphite had been placed in the reactor (Table 5.2).

Preparations for the startup began under the leadership of I. V. Kurchatov. The emergency rods were drawn completely out of the reactor and left in the raised position (from this position they could be dropped into the reactor in 1 second. Next the control rod was raised 10-20 cm and the neutron density in the reactor measured. The measurement procedure was as follows: with the emergency rods lowered into the reactor, the control rod was raised to a specified level l calculated from the surface of the 62nd layer and indicating the length of rod remaining in the reactor. Next the emergency rods were

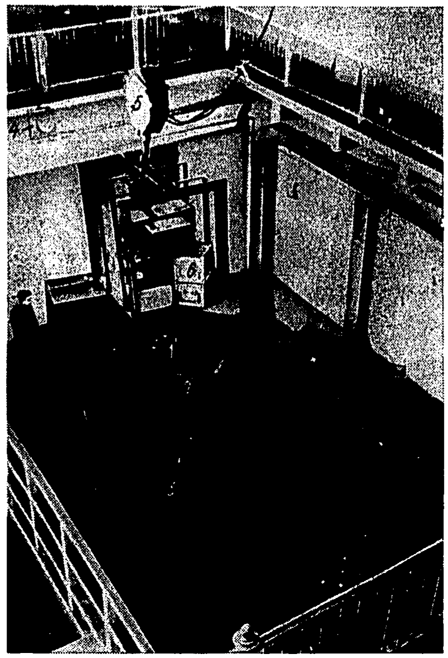


Fig. 5.13. During Assembly of the Reactor.

Key: 1, 2, 3. Channels for control and protective rods.
1', 2', 3'. Control rods.
4. Loudspeaker connected with startup unit.
5. Hoist crane block.
6. Cells containing uranium.
7. Ventilating system pipes.

quickly (in 2 or 3 seconds) drawn out of the reactor and the measurements of the count rate begun; the results were entered on the graph. When saturation was reached, the emergency rods were lowered into the reactor. The control rod was pulled out farther to the next specified mark, then the emergency rods were again raised and the procedure repeated.

Fig. 5.14 shows the results of these measurements. The numbers on the curve indicate the depth of insertion of the control rod into the reactor. It is clear that the count rate, which is proportional to the neutron density, increased after removal of the emergency rods. With $L \geqslant 2600$ mm, the rate of growth decreased, and after a certain time reached saturation. This indicated that under the conditions in question the effective multiplication coefficient of the reactor $k_{eff} < 1$. For $L = 2600$ mm the neutron density increased almost

Table 5.2. Quantity of Uranium and Its Oxides in the Reactor After Assembly of the 62nd Layer.

Type	Weight per briquet or slug, kg	Number	Total weight, tons
1. Uranium oxide (briquets in form of rectangular parallelepiped, 49 x 58 x 67 mm)	0.88	3143	2,77
2. Uranium oxide (briquets in form of spheres with diameter 80 mm)	1.18	7473	8.80
3. Metallic uranium (in form of cylinders 100 mm long and 32 mm in diameter)	1.40	2503	3.50
4. Metallic uranium (in form of cylinders 100 mm long and 35 mm in diameter)	1.70	17523	30.00
Total			45.07

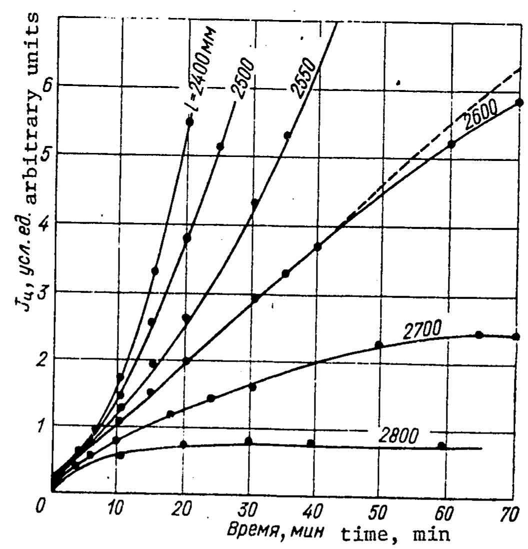


Fig. 5.14. Measurements of neutron density in the reactor after assembly of the 62nd layer. The numbers beside the curves inducate the depth of insertion of the control rod into the reactor.

linearly, which as V. S. Fursov had shown corresponded to $k_{eff} = 1$. With $L < 2600$ mm, the neutron density increased exponentially, which occurs when $k_{eff} > 1$ and indicates that a chain reaction is proceeding in the reactor.

Thus, the "realistic and viable goal" foretold by I. V. Kurchatov had been achieved. A self-maintaining uranium fission chain reaction had been instituted in the Soviet Union's uranium-graphite reactor, which had just been constructed. This happened for the first time at 18 hours on 25 December 1946.

Of course, many scientific staff members who were responsible for individual parts of the work and were at their work places hastened to Building K. The author of this survey, whose work site was about 100 meters from Building K in the tent in which the continuous neutron-physical testing of the uranium was proceeding, was in the underground reactor laboratory at the moment when I. V. Kurchatov drew up the graph of the run at $L = 2600$ mm. During the first startups of the reactor, conducted directly under the leaderhip of I. V. Kurchatov and continuing until late at night, N. I. Pavlov, scientific staff members I. S. Panasyuk, Ye. N. Babulevich, B. G. Dubovskiy, I. F. Zhezherun, A. A. Zhuravlev, N. V. Makarov and K. N. Shlyagin and laboratory assistants A. K. Kondrat'yev and R. S. Silakov were in the underground laboratory. G. F. Shavkutenko was called to Building K to replace a sensor on one of the dosimeters which had ceased to function. Other laboratory assistants too came in.

For all of us, this was a stirring and joyous evening. With restraint, as was proper in a work situation, but warmly and sincerely, we congratulated each other on this extraordinary and special "birth." It was pleasant to participate in such a historic event and to be a witness to it. But we understood well that the meritorious service performed by each of us consisted not in being present in the underground laboratory when the reactor was started, but rather in a real contribution to its creation.

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THE PROBLEM OF OPTIMAL PROCESSING OF LIGHT FIELDS DISTORTED BY A TURBULENT ATMOSPHERE

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[Text] The probability functional for a light field from an extended source of noncoherent wide-band radiation is synthesized for a situation with atmospheric phase distortions, assuming a large signal-to-noise ratio. A physical interpretation of the algorithms for optimal processing which maximize the function in question is given.

The authors' previous work [1] on the synthesis of algorithms for optimal processing of light fields distorted by a turbulent atmosphere and with a large signal-to-noise ratio limited itself to discussing only a point source of coherent monochromatic radiation. The present paper generalizes this discussion to the case of observation of an extended source of noncoherent wide-band radiation.

In this case it is easy to see that with a fixed atmospheric phase fluctuation $\Theta(\vec{\rho}, \omega) = (\omega/c) S(\vec{\rho})$, the field $E(\vec{\rho}, t)$ at the aperture of a telescope is a stationary normal random process with a zero mean and a correlation function given by the equation

$$(1) \quad R(\vec{\rho}_1, \vec{\rho}_2, t_1, t_2) = \frac{1}{(2\pi)^2} \int_{-\infty}^{\infty} \int_{S_0} J(\vec{r}, \omega) \times \exp\left\{ i\frac{\omega}{c}[S(\vec{\rho}_1) - S(\vec{\rho}_2)] \right\} \exp\{-i\omega(t_1 - t_2)\} \times H_\omega(\vec{\rho}_1 - \vec{r}) H_\omega^*(\vec{\rho}_2 - \vec{r}) d\vec{r}\, d\omega + N_0 \delta(\vec{\rho}_1 - \vec{\rho}_2) \delta(t_1 - t_2),$$

where $\vec{\rho}$ is the radius vector of the position of a point in the plane of the telescope aperture; $S(\vec{\rho})$ is the eikonal; $J(\vec{r}, \omega) = J(\vec{r}) J(\omega)$; $J(\vec{r})$ is the spatial distribution of the intensity of the source; $J(\omega)$ is the spectral density of the source radiation;

$$(2) \qquad H_\omega(\vec{\rho}-\vec{r})=\frac{i\frac{\omega}{c}}{2\pi R_d}\exp\left\{i\frac{\omega}{c}R_d+i\frac{\omega}{2R_d c}|\vec{\rho}-\vec{r}|^2\right\};$$

R_d is the distance to the source; S_0 is the area of projection of the source on the image plane (the plane passing through the source and perpendicular to the line of observation; $\vec{r}$ is the radius vector in the image plane; and N_0 is the power spectral density of the background radiation in a unit solid angle.

For this gaussian field, the conditional probability function may be obtained, similarly to reference 1, in the form

$$(3) \qquad \bar{\Lambda}[E(\vec{\rho},t)/S(\vec{\rho})]=\exp\left\{-\frac{1}{2}\frac{1}{(2\pi)^2}\int_{-\infty}^{\infty}d\omega\int_{S_A}\int_{S_A}W(\vec{\rho}_1,\vec{\rho}_2,\omega)\times\right.$$
$$\left.\times E(\vec{\rho}_1,\omega)E^*(\vec{\rho}_2,\omega)\exp\left\{i\frac{\omega}{c}[S(\vec{\rho}_1)-S(\vec{\rho}_2)]\right\}d\vec{\rho}_1\,d\vec{\rho}_2\right\},$$

where S_a is the area of the telescope aperture;

$$(4) \qquad W(\vec{\rho}_1,\vec{\rho}_2,\omega)=\int_{S_0}V(\vec{r},\omega)H_\omega(\vec{\rho}_1-\vec{r})H_\omega^*(\vec{\rho}_2-\vec{r})\,d\vec{r};$$

$$(5) \qquad V(\vec{r},\omega)=-\frac{1}{N_0}\frac{J(r,\omega)/N_0}{1+J(\vec{r},\omega)/2\pi N_0};$$

$$(6) \qquad E(\vec{\rho},\omega)=\int E(\vec{\rho},t)e^{i\omega t}\,dt.$$

To find the absolute functional $\Lambda[E(\vec{\rho},t)]$ by averaging the conditional functional (3) over all possible realizations of $S(\vec{\rho})$, we use the method of reference 4. We temporarily put the problem in discrete form, for which purpose we break down the region S_a into n intersecting regions p, q, each with an area equal to Δ. In this case the functional (3) is approximated by the function $\Lambda_n[E(\vec{\rho},t)/S(\vec{\rho})]$ given by the equation

$$(7) \qquad \Lambda_n[E(\vec{\rho},t)/S(\vec{\rho})]=\exp\left\{\frac{1}{2}\lambda\int_{-\infty}^{\infty}d\omega\sum_{p,q=1}^{n}W_{pq}'(\omega)\times\right.$$
$$\left.\times\exp\left\{i\frac{\omega}{c}[S_p-S_q]\right\}\right\},$$

where $S(\vec{\rho}_p,\vec{\rho}_q)=S_{p,q}$;

$$(8) \qquad \lambda=-\frac{1}{(2\pi)^2}V(\vec{r},\omega);$$

$$(9) \qquad W_{pq}'(\omega)=W(\vec{\rho}_p,\vec{\rho}_q,\omega)E(\vec{\rho}_p,\omega)E^*(\vec{\rho}_q,\omega)\Delta^2/\lambda.$$

It is clear that when $n \to \infty$, $\Delta \to 0$ the function $\Lambda_n[E(\vec{\rho}, t)/S(\vec{\rho})]$ approaches the functional $\Lambda[E(\vec{\rho}, t)/S(\vec{\rho})]$, and accordingly we start by averaging (7) over the ensemble of realizations of $S(\vec{\rho})$, after which we take the resulting equation to the specified limits.

Taking account of the gaussian statistics of atmospheric phase fluctuations, we have

$$\Lambda_n[E(\vec{\rho},t)]=\langle\Lambda_n[E(\vec{\rho},t)/S(\vec{\rho})]\rangle_S= \tag{10}$$

$$=\frac{|R^{-1}|^{1/2}}{(2\pi)^{n/2}}\underbrace{\int\cdots\int}_{n}\exp\left\{\frac{1}{2}\sum_{p,q=1}^{n}\left[\lambda\int_{-\infty}^{\infty}d\omega W_{pq}'(\omega)\times\right.\right.$$

$$\left.\left.\times\exp\left\{i\frac{\omega}{c}[S_p-S_q]\right\}-R_{pq}^{-1}S_pS_q\right]\right\}dS_1\ldots dS_n,$$

where the matrix R^{-1}, the inverse of the matrix R, is given by the equation

$$\sum_{j=1}^{n}R_{pj}R_{jq}^{-1}=\delta_{pq}, \tag{11}$$

where δ_{pq} is the Kronecker symbol and $R_{pq}=R(\vec{\rho}_p, \vec{\rho}_q) = \langle S(\vec{\rho}_p)S(\vec{\rho}_q)\rangle$.

Since we are concerned with a large signal-to-noise ratio $Q=J(\vec{r},\omega)/2\pi N_0 \gg 1$, by treating the noise level as small we can use the steepest descent method to calculate integral (10).

For this purpose we expand the exponential term in (7) in the form of a Taylor series through the quadratic terms in the vicinity of the n-dimensional point $\{S_1, S_2, \ldots, S_n\}$, where the function

$$F(S_1,S_2,\ldots,S_n)=\sum_{p,q=1}^{n}\int_{-\infty}^{\infty}d\omega W_{pq}'(\omega)\times \tag{12}$$

$$\times\exp\left\{i\frac{\omega}{c}[S_p-S_q]\right\}$$

attains its maximum.

Then it is easy to see that (10) is transformed into

$$\Lambda_n[E(\vec{\rho},t)]\simeq\exp\left\{\frac{1}{2}\lambda\sum_{p,q=1}^{n}\int_{-\infty}^{\infty}d\omega W_{pq}'(\omega)\times\right. \tag{13}$$

$$\left.\times\exp\left\{i\frac{\omega}{c}[\hat{S}_p-\hat{S}_q]\right\}\right\}\times$$

$$\times\frac{|R^{-1}|^{1/2}}{(2\pi)^{n/2}}\int\exp\left\{-\frac{1}{2}\lambda(S-\hat{S})^{+}B(S-\hat{S})-\frac{1}{2}S^{+}R^{-1}S\right\}dS,$$

where S and $\hat{S}$ are n-dimensional vectors with components $S=\{S_1, S_2, \ldots, S_n\}$

and $\hat{S} = \{\hat{S}_1, \hat{S}_2, \ldots, \hat{S}_n\}$; (+) is the transformation sign; and B is a matrix with the elements

$$(14)\quad B_{pq}=\delta_{pq}2\,\mathrm{Re}\int_{-\infty}^{\infty} d\omega W_{pq}'(\omega)\exp\left\{i\frac{\omega}{c}[\hat{S}_p-\hat{S}_q]\right\}\times$$
$$\times\frac{\omega^2}{c^2}-2\,\mathrm{Re}\int_{-\infty}^{\infty} d\omega W_{pq}'(\omega)\exp\left\{i\frac{\omega}{c}[\hat{S}_p-\hat{S}_q]\right\}\frac{\omega^2}{c^2}.$$

The system of equations to determine the value of the vector $\hat{S}$, obtained by setting the derivative $\partial F(S_1, S_2, \ldots, S_n)/\partial S_p$ equal to zero for all $p=1, 2, \ldots, n$, can by simple manipulations be written in the form

$$(15)\quad \mathrm{Im}\sum_{q=1}^{n}\int_{-\infty}^{\infty} d\omega W_{pq}'(\omega)\exp\left\{i\frac{\omega}{c}[\hat{S}_p-\hat{S}_q]\right\}=0$$

for all $p=1, 2, \ldots, n$. We note that the precision of the approximation when we make the change from (10) to (13) is greater the more probable the value $\hat{S}$ is for S. Further, by introducing the n-dimensional vector $f=\{f_1, f_2, \ldots, f_n\}$ satisfying the equation

$$(16)\quad (R^{-1}+\lambda B)f=\lambda B\hat{S},$$

and letting H stand for the matrix which is the inverse of the matrix $R^{-1}=\lambda B$, we obtain by simple manipulations of (13)

$$(17)\quad \Lambda_n[E(\vec{\rho},t)]\simeq\left\{\frac{1}{2}\lambda\sum_{p,q=1}^{n}\int_{-\infty}^{\infty} d\omega W_{pq}'(\omega)\times\right.$$
$$\left.\times\exp\left\{i\frac{\omega}{c}[\hat{S}_p-\hat{S}_q]\right\}\right\}\times$$
$$\times\exp\left\{-\frac{1}{2}\int_0^{\lambda}\mathrm{Sp}\,BH d\lambda\right\}\exp\left\{-\frac{1}{2}\lambda\hat{S}^{+}V\hat{S}\right\},$$

where

$$(18)\quad \frac{1}{2}\int_0^{\lambda}\mathrm{Sp}\,BH d\lambda=\ln\left(\frac{|R^{-1}|^{1/2}}{|R^{-1}+\lambda B|^{1/2}}\right),$$

where the matrix V satisfies the equation

$$(19)\quad V+\lambda VRB=B.$$

It is easy to see that the matrix V, as well as matrix B, is degenerate and has the property that

$$(20)\quad \sum_{p=1}^{n}V_{pq}=0.$$

Solving equation (19) by means of (20) we obtain

$$(21) \qquad V_{pq}=\frac{1}{\lambda}\left(R_{pq}^{-1}-\frac{\sum_{k=1}^{n}R_{pk}^{-1}\sum_{l=1}^{n}R_{ql}^{-1}}{\sum_{k,l=1}R_{kl}^{-1}}\right)=\frac{1}{\lambda}\tilde{R}_{pq}^{-1}.$$

Now, taking (17) to the limit $n \to \infty$, $\Delta \to 0$ and making use of (21) and of the fact that (18) does not depend on a specific instance of the field used, we obtain

$$(22) \qquad \Lambda[E(\vec{\rho},t)]\simeq K\exp\left\{-\frac{1}{2}\frac{1}{(2\pi)^2}\int_{-\infty}^{\infty}d\omega\int_{S_A}\int_{S_A}W(\vec{\rho}_1,\vec{\rho}_2,\omega)\times\right.$$
$$\times E(\vec{\rho}_1,\omega)E^*(\vec{\rho}_2,\omega)\exp\left\{i\frac{\omega}{c}[\hat{S}(\vec{\rho}_1)-\hat{S}(\vec{\rho}_2)]\right\}d\vec{\rho}_1\,d\vec{\rho}_2-$$
$$\left.-\frac{1}{2}\int_{S_A}\int_{S_A}\tilde{R}^{-1}(\vec{\rho}_1,\vec{\rho}_2)\hat{S}(\vec{\rho}_1)\hat{S}(\vec{\rho}_2)\,d\rho_1\,d\vec{\rho}_2\right\},$$

where K is some constant which is independent of the instance of the field in question;

$$(23) \qquad \tilde{R}^{-1}(\vec{\rho}_1,\vec{\rho}_2)=R^{-1}(\vec{\rho}_1,\vec{\rho}_2)-\frac{\int_{S_A}\int_{S_A}R^{-1}(\vec{\rho}_1,\vec{\rho}_3)R^{-1}(\vec{\rho}_2,\vec{\rho}_4)\,d\vec{\rho}_3\,d\vec{\rho}_4}{\int_{S_A}\int_{S_A}R^{-1}(\vec{\rho}_1,\vec{\rho}_2)\,d\vec{\rho}_1\,d\vec{\rho}_2};$$

and $R^{-1}(\vec{\rho}_1, \vec{\rho}_2)$ is given by the integral equation

$$(24) \qquad \int R(\vec{\rho}_1,\vec{\rho}_2)R^{-1}(\vec{\rho}_2,\vec{\rho}_3)\,d\vec{\rho}_2=\delta(\vec{\rho}_1-\rho_3).$$

The equation for $\hat{S}(\vec{\rho})$ is obtained from (15) by passing to the same limit $n \to \infty$, $\Delta \to 0$:

$$(25) \qquad \operatorname{Im}\left\{\int_{-\infty}^{\infty}d\omega E(\vec{\rho}_1,\omega)\exp\left\{i\frac{\omega}{c}\hat{S}(\vec{\rho}_1)\right\}\int_{S_A}W'(\vec{\rho}_1,\vec{\rho}_2,\omega)\times\right.$$
$$\left.\times E^*(\vec{\rho}_2,\omega)\exp\left\{-i\frac{\omega}{c}\hat{S}(\vec{\rho}_2)\right\}d\vec{\rho}_2\right\}=0.$$

We note that in the general case equation (25) leads to a nonunique solution for the phase $\Theta(\rho,\omega)=(\omega/c)S(\rho)$, determined with a precision within $2\pi m$. In addition, the specific form of the inverse correlation function $\tilde{R}^{-1}(\vec{\rho}_1, \vec{\rho}_2)$ given in (23) is ultimately a consequence of the fact that the function $\Theta(\vec{\rho})$ can also be measured with an accuracy only within $2\pi m$. It is easy to see that precisely because of this structure of $\tilde{R}^{-1}(\vec{\rho}_1, \vec{\rho}_2)$, the probability functional (22) becomes insensitive to this constant, which does not exist in practice.

In terms of the physical interpretation of the optimal operations leading to maximization of the functional (22), the discussion may proceed in two ways, and accordingly there are two different possible schemes of optimal processing.

In the first case, the optimal processing consists of breaking down the entire frequency interval of the received radiation into areas $\Delta\omega$, each with a central frequency of ω_j, followed by correlated filtering of the frequency spectrum $J(\omega)$ in these areas. Then the realization of (23) amounts to the formation of two quantities Z_1 and Z_2:

$$Z_1=\frac{1}{2\pi N_0}\int_0^T dt\sum_{j=1}^{M}\Delta\omega\int_{S_0} d\vec{r}\,\Big|\int_0^t\int_{S_A} E(\vec{\rho}_1,t_1)\times \tag{26}$$

$$\times\exp\Big\{i\frac{\omega_j}{c}\hat{S}(\vec{\rho}_1)\Big\}H_{\omega_j}(\vec{\rho}_1-\vec{r})\,h_{\omega_j}(t-t_1)\,d\vec{\rho}_1\,dt_1\Big|^2,$$

$$Z_2=\int_{S_A}\int_{S_A}\hat{S}(\vec{\rho}_1)\hat{S}(\vec{\rho}_2)\hat{R}^{-1}(\vec{\rho}_1,\vec{\rho}_2)\,d\vec{\rho}_1\,d\vec{\rho}_2, \tag{27}$$

where H_{ω_j} is the frequency characteristic of the physically realized light filter, coordinated in the band $\Delta\omega$ with the frequency distribution of the received radiation.

The optimal processing consists in the fact that in the individual frequency intervals $\Delta\omega$, adaptive retuning of the active optical elements by $\exp\{i(\omega/c)\hat{S}(\vec{\rho})\}$ occurs, and the images of the source which are formed during focusing, coordinated filtering in the area $\Delta\omega$ and quadratic detection are compared with models S_0 of the expected shape of the image of the source. For each model S_0, changed simultaneously on all frequency channels, a synchronous retuning of the active optical elements is carried out in such a way as to maintain a maximum at the output of the unit which sums the signals from the individual frequency channels. This results in a quantity analogous to the "sharpness" function of an image [2], and thus the overall processing may be classified as adaptive, with maximization of the "sharpness" function.

The second possible implementation of (22) is based on an analytic solution of equation (25):

$$\hat{S}(\vec{\rho})=-\frac{c}{\omega_j}\arg E(\vec{\rho},\omega_j)+\frac{c}{\omega_j}\hat{\Psi}(\vec{\rho},\omega_j)-\frac{1}{2R}|\vec{\rho}|^2, \tag{28}$$

where

$$\hat{\Psi}(\vec{\rho},\omega_j)=\arg\int_{S_0}\lambda\exp\Big[-i\frac{\omega_j}{Rc}\vec{\rho}\vec{r}\Big]\,dr.$$

When (28) is substituted into (26) and (27), the equations for Z_1 and Z_2 are transformed, ignoring some unimportant multipliers, into the form

$$Z_1=\frac{1}{2\pi N_0}\int\limits_{S_0} d\vec{r}\sum_{j=1}^{N}\Delta\omega\left|\iint\limits_{S_A}\right|\int\limits_0^T E(\vec{\rho},t)e^{-i\omega_j t}\times \tag{29}$$

$$\times dt\left|e^{i\tilde{\Psi}(\vec{\rho},\omega_j)}\exp\left\{-i\frac{\omega_j}{Rc}\vec{\rho}\vec{r}\right\}d\vec{\rho}\right|^2,$$

$$Z_2=\iint\limits_{S_A S_A}\left[\frac{1}{2R}|\vec{\rho}_1|^2-\frac{c}{\omega_j}\Psi(\vec{\rho}_1,\omega_j)+\frac{c}{\omega_j}\arg E(\vec{\rho}_1,\omega_j)\right]\times \tag{30}$$

$$\times\left[\frac{1}{2R}|\vec{\rho}_2|^2-\frac{c}{\omega_j}\Psi(\vec{\rho}_2,\omega_j)+\frac{c}{\omega_j}\arg E(\vec{\rho}_2,\omega_j)\right]R^{-1}(\vec{\rho}_1,\vec{\rho}_2)d\vec{\rho}_1\,d\vec{\rho}_2.$$

Here, as previously, the optimal processing is of multi-channel type, but in the present case, a spectrally filtered, short-exposure linear nonreference hologram is recorded in each frequency channel. Next, each such hologram, containing only amplitude information from the source, is illuminated by coherent light corresponding to the frequency ω_j, together with a standard phase screen $\Psi(\vec{\rho},\omega_j)$ consisting of the expected phase and field distribution from the source at the aperture and obtained through correlation processing on the atmospherically distorted phase field from the source (arg E) by formation and maximization of Z_2. This processing of (29) and (30) differs from the previously considered adaptive processing with maximization of the "sharpness" function of the image (in (26) and (27)) and can be classified as generalization of adaptive processing with direct recording of the phase front [3] to the case of observation of extended sources in the absence of a reference point source. On the basis of the synthesis we may conclude that for a large signal-to-noise ratio, adaptive processing of atmospherically distorted light fields is optimal.

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A QUANTUM MODEL OF RADIO WAVE SCATTERING IN MATTER WITH HYPEREXCITED ATOMS

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[Article by N. D. Ustinov, Ye. S. Nektarov and V. V. Sychev

[Text] The criteria for existence of atoms with a maximum level of excitation during the action of corpuscular radiation on matter are derived and the quasicontinuous nature of the resonance scattering spectrum of radio waves in highly excited collisional media is demonstrated. Using a quantum approach, adequate estimates for several anomalous radio wave scattering effects in the ionospheric plasma are proposed. Directions for further research in the field are discussed.

Introduction

Until recently, the physics of radiation interaction with matter employed assumptions about atomic excitation levels whose principal quantum number n did not exceed 10, since classical kinetics does not admit the existence of a weakly bound state of the outer electron if the binding energy becomes less than the energy of collision with neighboring particles or if the dimensions of the orbit of such an electron exceed the interatomic distance in the medium. Sections 1 and 2 of the present article describe the classical problems of the existence of excited atoms.

When mass-spectrometer studies of particle beams revealed the existence of atoms with high excitation levels ($n = 16-20$; see reference 1) and when multiphoton pumping of rarefied media followed by microwave irradiation led to the detection of hyperexcited atoms ($n \lesssim 69$) [2], investigation of their properties became a high-priority physical problem.

Quantum-mechanical methods have been used to study different cases of the interaction of highly excited atoms with neighboring particles in collisional media [1], and calculation formulas allowing calculation of effective ionization cross sections of such atoms have been derived (see section 3).

These data in turn may be used to obtain equations which give the lifetimes of excited atoms in collisional media and make it possible to determine the laws governing the existence of atoms in the maximum possible excitation states, determined in terms of the state parameters of the media. Solutions of these problems, as well as methodological questions involved in determining the concentration of superexcited atoms in matter, are the subject of section 4.

The maximum excitation level of a medium determines the lower boundary of its characteristic modes for resonance radiation, a mathematical expression for which is derived in section 5; for hyperexcited media this boundary is in the radio spectrum. The same section discusses problems of the natural broad-spectrum and broad-band nature of interactions of hyperexcited matter with radio waves on the basis of known laws of the density distribution of components of matter over the excitation levels and of radiation density distributions within resonance lines under the influence of the Doppler, impact and Stark broadening mechanisms as well as of external electric and magnetic fields.

Thus quantum radiophysical effects during electron transitions in excited atoms must also appear during the propagation of radio waves in natural or artificial hyperexcited media such as circumstellar or circumplanetary plasmas and excitation regions formed during the movement of hypersonic bodies in planetary atmospheres or during electrical discharges. A brief discussion of such possibilities and a methodology for the approach to calculation of quantum radiophysical effects in equilibrium media are found in section 6.

The quantum model for scattering of radio waves by hyperexcited atoms in non-equilibrium media suggests itself as a possibility for explaining certain anomalous propagation effects of medium and short radio waves in the earth's ionosphere. Section 7 gives a numerical estimate of the parameters of radioatoms which are resonant in this range and of the broad-band nature of quantum scattering of radio waves in the ionosphere, as well as presenting an expirical evaluation of the effective resonance interaction cross section of radioatoms with radio quanta.

1. The Characteristics of Isolated Hyperexcited Atoms

It is well known that the formalism of quantum mechanics allows the existence of an isolated atomic system with an unlimited number of discrete energy levels produced, for example, during the excitation of higher electron states in hydrogen-like atoms. The energy spectra of hyperexcited atoms are described by the Born formula [3]:

$$\nu_{n,n-1} \approx 2Rn^{-3}, \qquad (1)$$

where ν is the frequency of transitions between levels n and $n-1$; R is the Rydberg constant; and n is the principal quantum number.

In accordance with this formula, in correspondence to electron transitions in the radio frequency range of 10^{11}-10^{6} Hz there exist excitation levels with $n = 10-1000$ for atoms (radioatoms), analogous to those for optical transitions ($n < 10$). Here we should note that as the excitation level of the atom increases, the dimensions of the external orbit relative to the ionic shell increase:

$$a_n \quad a_0 n^2 \qquad (2)$$

(a_0 is the first Bohr radius (for a nonexcited atom), and in addition the lifetime of the atom relative to spontaneous deexcitation increases; for example, for transitions between neighboring states [4], we have, from (1) and (2),

$$\tau_{n,n-1} = \hbar c^3 (ea_n)^{-2} \nu^{-3} \approx \hbar c^3 (8e^2 a_0^2 R)^{-1} n^5, \qquad (3)$$

where e is the electron charge.

Estimates made from these formulas indicate that with a high excitation level, on the order of 100-1000, gigantic atoms (hyperatoms) with dimensions of 10^{-4}-10^{-2} cm are formed; these are capable of existing in a noncollisional medium for $10 - 10^6$ seconds, while the lifetimes of optically excited atoms do not exceed 10^{-8}-10^{-7} seconds.

2. Classical Problems of the Existence of Highly Excited Atoms in Collisional Media

The binding energy between the external electron and the ion shell is

$$E_n = ze^2 (2a_n)^{-1} = J_H z^2 n^{-2}, \qquad (4)$$

where z is the charge of the ion shell; and J_H is the ionization potential of a hydrogen-like atom. In a hyperatom, $E_n = 10^{-3} - 10^{-5}$ eV, while in weak optical excitation the binding energy is about 1 eV.

Thus, even in a cold collisional medium, e.g. at $kT \sim 0.001$ eV ($T \sim 10$ K), the existence of hyperatoms is problematical from the point of view of classical physics if we assume that practically every collision with a free electron will knock a weakly bound electron with a binding energy less than kT out of the atom. In addition, classical physics assumes that the outer electron, moving in an orbit whose dimensions exceed the interatomic distance in the substance ($a_n > N^{-1/3}$, where N is the density) is not distinguishable from a free electron, and so highly excited an atom is not distinguishable from an ionized one [5]. For example, on the basis of this criterion hyperatoms with $n = 100$ can exist in the earth's atmosphere at altitudes above about 100 km (since $N \sim 10^{12}$ cm^{-3} at these altitudes, $N^{-1/3} \sim 10^{-4}$ cm), while kinetic considerations based on the results of the quantum mechanics of particle interaction decrease this boundary to altitudes of about 50 km, as will be shown below.

In classical physics, limiting estimates for the stability of highly excited atoms during collisions can be derived using the equation for the adiabaticity factor

$$a_n \nu / v \gtrless 1, \qquad (5)$$

where ν is the orbital frequency of an electron in the hyperatom (coinciding with the radiation frequency in neighboring transitions); and v is the speed of approach of colliding particles. The upper and lower conditions refer respectively to elastic and nonelastic collisions. If we substitute into (5) the value of ν from (1) and $v = (kTm^{-1})^{1/2}$ (where m is the mass of the particle), we obtain criteria for the stability of highly excited atoms with the critical excitation level

$$n_{кр} \simeq 2Re_0(kTm^{-1})^{-1/2}. \qquad (6)$$

Estimates based on this equation indicate that in a medium with, for example, $kT \sim 1$ eV, atoms with $n = 100$ will be stable relative to atom-atom collisions, while atoms will be stable with respect to electron-electron collisions only for $n < 10$. However, such estimates are excessively categorical, since they do not take into account wave processes of particle interaction and fine interference effects in spatial interactions between them.

3. The Comet Model of Hyperatoms in Matter

The quantum-mechanical approach to the problem of existence of highly excited atoms in continuous media makes it possible to study different instances of the stability of spatial Coulomb binding in such atoms during the interaction of particles with both the outer electron and the ionic shell (i.e. by using the "comet" model for movement of the external electron through surrounding particles on a closed orbit relative to the ionic shell) and to obtain quantitative expressions for the ionization cross section of highly excited atoms.

Thus, when an atom collides with the external electron of an excited atom, the ionization cross section of the latter is [1]:

$$\sigma_{i\,(n)}^{e^*a} = \begin{cases} \sigma_{ea}\left[1 - E_n\,(2m_e v_a^2)^{-1}\right] & \text{for} \quad m_e v_a^2 \gg E_n, \qquad (7) \\ \sigma_{ea}\cdot 256\sqrt{2}\,(15\pi)^{-1}\,(m_e v_a^2 E_n^{-1})^{5/2} & \text{for} \quad m_e v_a^2 \ll E_n, \qquad (8) \end{cases}$$

where σ_{ea} is the elastic scattering cross section of the electron in the atom; v_a is the speed of collision of the atom; and m_e is the mass of the electron.

When an atom collides with the ionic shell of an excited atom [1],

$$\sigma_{i\,(n)}^{i^*a} = \begin{cases} 4{,}77\,[\hbar n\beta\,(m_{a^*}v_a)^{-1}]^{1/2} & \text{for} \quad v_a \gg e^2(\hbar n)^{-1}, \qquad (9) \\ \sigma_3\cdot 128\sqrt{2}\,(30\pi)^{-1}\,(\hbar n e^{-2}\Delta v)^5 & \text{for} \quad v_a \ll e^2(\hbar n)^{-1}, \qquad (10) \end{cases}$$

where m_{a*} is the mass of the ionic shell; β is the polarizability of the atom; $\sigma_3 = 2\pi e v_a^{-1}(\beta\mu_{a*a}^{-1})^{1/2}$ is the polarization capture cross section (μ_{a*a} is the reduced mass); and Δv is the change in velocity of the ionic shell as a result of capture by the atom.

In a collision with a rotating molecule, the ionization energy is transferred to the excited atom by nonelastic scattering of its outer electron by the molecule (which transitions into a less excited rotational state). In a collision with a dipolar molecule, for example, the effective ionization cross section of highly excited atoms with $n \gg 10$ is [1]:

$$\sigma_i^{e^*M\,(D)}\Big|_{n \gg 10} \approx 3{,}2a_0^{-1}\,(\mu_{a^*M}m_e^{-1})^{1/2}D^2B^{1/2}T^{-1/2}; \qquad (11)$$

and in a collision with a tetrapolar molecule,

$$\sigma_i^{e^*M\,(Q)}\Big|_{n \gg 10} \approx 0{,}74\,(ea_0)^{-2}\,(\mu_{a^*M}m_e^{-1})^{1/2}Q^2\,(BT^{-1})^{1/2}. \qquad (12)$$

Here D and Q are the dipole and quadrupole moments of the molecules and B is the rotational constant.

When excited atoms collide with electrons and ions in a plasma medium, the greatest contribution to the ionization probability of the atoms is made by processes of scattering of the plasma electrons by the outer electrons of the excited atoms and of plasma ions by ionic shells of excited atoms (in comparison with the scattering of plasma electrons by ionic shells or of external atomic electrons by plasma ions, since the proportion of the kinetic energy transferred in collisions does not exceed the mass ratio of the colliding particles).

The cross section for these interactions [6] in electron-electron collisions is

$$\sigma_{e-e} = 16\pi (e^2 m_e^{-1} v^{-2})^2 \mathcal{L}_e, \qquad (13)$$

and in ion-ion collisions

$$\sigma_{i-i} = 16\pi (e^2 m_i^{-1} v^{-2})^2 \mathcal{L}_i, \qquad (14)$$

where $\mathcal{L}_e$ and $\mathcal{L}_i$ are the Coulomb logarithms; and m_i is the mass of the ion. The numerical values of the ionization cross sections of hyperatoms for various particles are in the range $10^{-25} - 10^{-6}$ cm^2 for collisions with atoms [1, 6-9], $10^{-16} - 10^{-11}$ cm^2 for collisions with molecules, and $10^{-18} - 10^{-10}$ cm^2 for collisions with electrons and ions.

4. Conditions for Existence of Hyperatoms in Excited Media

The kinetic approach to the problem of the existence of highly excited atoms in continuous media makes it possible to formulate the problem of their production in collisions of nonexcited and weakly excited atoms and in corpuscular-ray action on the medium, the problems of change of excitation level and attainment of the limiting excitation level as a function of the composition of the medium and its state parameters, and the problems of determining the lifetimes of excited atoms and their concentrations in continuous media.

We will discuss the main problem, that of finding criteria which determine the possibility for hyperatoms with a maximum excitation level to exist in a collisional medium when the composition of the medium is known and the state parameters are specified. We use as a natural measure of the lifetime of a stimulated atom the order of magnitude of the period of rotation of its external electron around the ion shell [3, 4]

$$T_e = h m_e a_0^2 n^3 = \nu_{n,n-1}^{-1}, \qquad (15)$$

and as a measure of the duration of interaction of electromagnetic radiation with the excited atom as a resonant system we use the quantity

$$\Delta\tau_{a\text{-}r} = (2\pi)^{-1} T_e = \hbar m_e a_0^2 n^3 = \omega_{n,n-1}^{-1}, \qquad (16)$$

where $\omega_{n,\,n-1}$ is the angular frequency of the radiation.

Now we turn our attention to the fact that the duration of the dynamic existence of excited atoms from the moment of their production to the moment of their destruction by ionization in collisions with surrounding particles can be written as the inverse of the frequency of ionizing collisions

$$\Delta\tau_{a^*} = \nu_i^{-1}. \qquad (17)$$

Using the equations commonly used in physical kinetics for the frequency of collision processes, we write, in general form,

$$\nu_i = \sum_j N_j v_{a^*j} \sigma_{a^*j}, \qquad (18)$$

where N_j is the concentration of the j-th type of particle in the medium; v_{a^*j} is the rate of collision of excited atoms with particles; and σ_{a^*j} is the effective cross section for ionization of excited atoms by particles. We note in passing that the duration of the dynamic existence of excited atoms in a collisional medium is inversely proportional to their density and the effective temperature ($T_{eff} = k^{-1} m v^2_{a^*j}$) of the components of the medium or the fluxes passing through it and is determined by the qualitative composition of these components of fluxes.

For a final determination of the criteria which determine the maximum excitation levels of atoms in a collisional medium, we assume that the time of dynamic existence of such atoms is not less than the time for rotation of an external electron around the ionic shell or even than the time required for resonance interaction of a photon with an electron in an elliptical orbit around the ion in a bound-bound transition in such a system:

$$\Delta\tau_{a^*} \geqslant \Delta\tau_{a^*r}. \qquad (19)$$

Using equations (16)-(18) and (19) we obtain the maximum possible excitation level of atoms in collisional media for the general case:

$$n_{max} = \left[\hbar\left(m_e a_0^2 \sum_j N_j v_{a^*j} \sigma_{a^*j}\right)^{-1}\right]^{1/3} \qquad (20)$$

and for the case of thermodynamic equilibrium of the medium

$$n_{max} \leqslant \left\{\hbar\left[m_e a_0^2 \sum_j N_j \sigma_{a^*j} (kT\mu^{-1})^{1/2}\right]^{-1}\right\}^{1/3}. \qquad (21)$$

We now turn to the question of calculating the concentrations of hyperatoms in continuous media. For thermodynamic equilibrium of the medium, the concentration of excited atoms and their distribution over excitation levels is calculated by Boltzmann's formula:

$$N_n = N_1 n^2 \exp[-J(kT)^{-1}(1-n^{-2})], \qquad (22)$$

where N_1 is the concentration of atoms in the base state; and J is the ionization potential of the atom. Here we note that real, measurable values of the concentration of hyperatoms in such media can be attained only at temperatures of several thousand degrees; in the earth's atmosphere such local perturbations are formed, for example, in areas where shock waves or accompanying flows are formed during the motion of hypersonic meteorite bodies, and also in atmospheric electrical discharges.

If in a hot equilibrium medium hyperatoms are formed by spontaneous collisions of unexcited atoms so that their kinetic energy is converted into the energy of internal degrees of freedom of the excited atoms, together with cooling of the medium, dynamic microprocesses are the mechanism of excitation of atoms in a nonequilibrium relaxing medium.

Accordingly, the cause of production of hyperatoms in the earth's atmosphere must be the effect on it of corpuscle-ray fluxes of solar or cosmic origin, which are particularly strong during sporadic upsurges of solar activity. It is clear that effective generation of highly excited atoms in the atmosphere requires that the energy of interaction be of the same order as the energy required for ionization of air, i.e. $\gtrsim$ 10 eV for nonexcited and $\gtrsim$ 1 eV for weakly excited atoms, which is several orders of magnitude lower than the energy of corpuscle-ray fluxes. Another source for the formation of hyperatoms in the atmosphere is processes of recombination of charged particles.

The concentration of hyperatoms in a nonequilibrium medium can be determined by solving the kinetic equations

$$dN_{nj}/dt = q(N_{nj}) - r(N_{nj}), \qquad (23)$$

here N_{nj} is the concentration of excited atoms formed by interaction of the medium with the j-th component of the initiating flux; and $q(N_{nj})$ and $r(N_{nj})$ are the reaction rates for formation and loss of excited atoms in the medium under the influence of components of the initiating flux and the medium. To calculate the values of these reaction rates will require individual theoretical and experimental studies, since to our knowledge such problems have thus far not been posed in the scientific literature.

5. Characteristics of the Interaction of Hyperatoms in Matter with Radio-Frequency Radiation

Among the numerous spectroscopic effects manifesting the resonance properties of the interaction of radiation with matter with reference to hyperatoms, we must consider two main features: the natural broad-spectrum character and quasi-continuous character of resonance interaction of radio-frequency radiation with hyperexcited matter.

The broad-spectrum nature of this interaction follows from the fact that in a collisional medium a continuous distribution (a Boltzmann distribution in an equilibrium medium) of atom concentrations over the excitation levels from $n = 1$ to $n = n_{max}$ (given by equations (20) and (21)) takes place spontaneously, so that it is possible that resonance effects of the scattering of electromagnetic radiation in a wide frequency range determined by the Born equation (1) occur.

Here the lower frequency bound for the appearance of resonant scattering of radio waves in an excited substance is clearly determined by the radiation frequency of the atoms with the maximum excitation level, which can be expressed in terms of the frequency of ionization collisions by using equations (15)-(19):

$$\nu \geq \nu_{\min} = \nu_i = \sum_j N_j v_{a^*j} \sigma_{a^*j}. \tag{24}$$

Clearly this limit is determined by the density of the medium and also by the parameters for collision and ionization of excited atoms by the surrounding particles. The natural breadth of the radiation resonance lines of radioatoms is extremely small, but owing to the extremely high permeability of highly excited atoms these lines are widened considerably when even relatively weak corpuscle-ray fluxes act on the hyperexcited medium.

The breadth of the resonance lines of the statistical ensemble of excited atoms is determined by the following factors [10-12]:

1. the speed of thermal motion of the atoms (Doppler broadening):

$$\Delta\nu_{\text{д}} = 2\nu c^{-1}(2\ln 2 \cdot kTm_{a^*}^{-1})^{1/2}; \tag{25}$$

2. the free path of the atoms between collisions (impact broadening):

$$\Delta\nu_{\text{уд}} = 8r^2 N(\pi kTm_{a^*}^{-1})^{1/2}, \tag{26}$$

where r is the distance between the ion shell and the particle at the time of collision (of the same order of magnitude as the size of the hyperatom orbit during collisions of its external electron);

3. nonelastic collisions of excited atoms with electrons (kinetic Stark broadening)

$$\Delta\nu_{\text{к}} = 0{,}48 \cdot 10^{-24} \nu N_e K_n z^{-5}(n + 1/2)^7, \tag{27}$$

where N_e is the concentration of electrons in the medium and K_n is a coefficient depending on the collision parameters (for $N \approx 100$, $K_n \approx 20$).

To give a complete picture, we must also recall the broadening of radiation lines under the influence of external electrical and magnetic fields. The Stark field broadening of a line of transition between neighboring levels is

$$\Delta\nu_{\mathcal{E}} = {}^3/_8 \pi^{-2} h(mez)^{-1} n\mathcal{E} \tag{28}$$

(where $\mathcal{E}$ is the electrical field intensity). For Zeemann broadening we have

$$\Delta\nu_{\mathcal{H}} = (4\pi)^{-1} e\mathcal{H}(mc)^{-1} \tag{29}$$

where $\mathcal{H}$ is the magnetic field intensity.

In equations (26)-(28) the strong dependency of the size of the broadening on the dimensions of the hyperatoms and their degree of excitation is clearly apparent. The dense grouping of resonance lines in the radio-frequency spectrum is a sufficient condition for attainment of quasicontinuity of the resonance response of a hyperexcited medium, which as we will show below occurs even under natural conditions.

6. Propagation of Radio Waves in Hyperatomic Media

A hyperatomic medium is any substance in which, according to formulas (20) and (21), highly excited atoms with quantum transitions in the radio-frequency range can exist. The atmospheric and ionispheric layers of the earth and other planets, the photosphere of the sun and other stars, and the interstellar gas are examples of natural hyperatomic media. Artificial cool, rarefied plasma media invariably contain hyperatoms.

The propagation of radio waves in such media is naturally accompanied by appearance of the resonance mechanism of hyperatom interaction with radio waves. It is well known that the effectiveness of resonance interaction of radiation with matter increases roughly in proportion to the square of the wavelength, and accordingly even in media with negligible concentrations of hyperatoms powerful quantum effects of attenuation and intensification of radio waves are observed; the use of this mechanism offers a new way of explaining a number of anomalous effects in the propagation of radio waves in hyperexcited, i.e. hyperatomic, media. As regards plasma media, of course, this is true only of regions free of Debye screening.

We shall briefly discuss the main characteristics of the quantum mechanism occurring the the propagation of radio waves in hyperatomic media. The general law governing the intensity variation of electromagnetic radiation in matter is expressed by the Bouguer-Beer formula

$$I = I_0 \exp(\gamma l), \tag{30}$$

where I_0 and I are the intensities of the incident and transmitted radiation; l is the path length of the radiation propagating in the medium; and γ is the index of radiation intensity variation per unit path length.

It is well known that depending on the thermodynamic state of a medium, its population of excited atom response states may be either normal (when there are more absorbing states of excited atoms than radiating states), or inverted (when the opposite is true). Accordingly, given a normal population, which is the case when a substance is compressed and heated by shock waves, macroscopic effects of attenuation of the transmitted radiation describable by a negative value of γ will occur. With a population inversion in the medium, which occurs for example when the substance expands and cools in the wake of a shock wave or when charges recombine in a plasma, radiation intensification effects describable by positive values of γ will occur.

The absorption coefficient in a medium with highly excited atoms is given by the well known equation

$$\gamma = \sum_{n=n^*}^{\infty} N_n \cdot \sigma_{\nu_n}, \tag{31}$$

where n* is determined from the condition that the energy of a quantum may not be less that the transition energy in the atom; and σ_{ν_n} is the effective cross section of absorption of a quantum by the excited atom. The size of this cross section is given by the Kramers formula:

$$\sigma_{\nu_n} = 64\pi^4 (3\sqrt{3})^{-1} m_e e^{10} z^4 (ch^6 \nu^3 n^5)^{-1}. \qquad (32)$$

We note that the use of Born's formula (1) in the Kramers formula (32) makes it possible to derive the frequency dependence of the effective cross section for absorption of radio quanta by hyperexcited atoms: $\sigma_{\nu_n}(\nu^{-3}, n^{-5}) = \sigma_\nu(\nu^{-4/3})$. Then the absorption coefficient for equilibrium conditions can be calculated by means of the Kramers-Unsold formula [13]:

$$\gamma = -32\pi^4 (3\sqrt{3})^{-1} m_e e^{10} z^4 kT N (ch^6 \nu^3 J)^{-1} \exp[-J(kT)^{-1}][\exp h\nu (kT)^{-1} - 1]. \quad (33)$$

These equations can be used to describe the contribution of the resonance mechanism of scattering of radio waves in processes where they are strongly attenuated or intensified in equilibrium relaxation zones of excitation of electron transitions in the atoms of a substance traversed by shock waves or located in the expanding flow accompanying a hypersonic body.

7. Hyperatoms in the Earth's Atmosphere

As a practical example of the hyperatomic mechanism of radio wave scattering we will consider the possibility of explaining in quantum terms the anomalous instances of strong absorption of short wave and medium wave ($10^6 - 10^7$ Hz) radiation in the ionosphere during solar eruptions; these effects are: slow but extensive fading, sudden interruption of radio communications over almost the entire spectrum on the illuminated side of the earth, and also a pronounced attenuation of the intensity of cosmic radiation in this frequency range, indicating an increase in the opacity of the ionosphere to direct passage of radio waves to the earth's surface.

The primary region in which anomalous weakening phenomena come into play seems to be the D region of the ionosphere at altitudes of 50-90 km, where in addition to photoionization processes, a significant role is played by processes of inelastic interaction with corpuscular radiation (we note that the lower ionosphere is currently considered to be the least understood and least investigated region as a result of the complexity of microprocesses occurring there [14, 15]).

The extent of the attenuation frequenty exceeds 30-40 dB [16] and cannot be explained in terms of collision of free electrons in the ionospheric plasma, since even a 10- to 20-fold increase in electron concentration during solar eruptions [14-16] could lead to an additional attenuation of only 10-13 dB on a given propagation path (since the absorption coefficient in this process is directly proportional to the electron concentration [14, 17]).

We turn to an analysis of the hyperatomic mechanism of attenuation. First we deal with the question of the altitude limit for existence in the earth's atmosphere of hyperatoms with $n = 50$-1000 which are resonant at frequencies of 10^6-10^7 Hz (in accordance with Born's formula (1)). Equation (21) allows us to state that such radioatoms exist in the earth's atmosphere above an altitude of 50-60 km; in fact, substitution into this equation of the density (N 10^{15} cm^{-3}) and temperature (T 250 K) from the tables for the standard atmosphere at the altitudes in question and the ionization cross section of excited atoms in collisions with rotationally excited molecules, as the most effective mechanism for destroying hyperatoms in the atmosphere, $\sigma_{i}^{a*M} \sim 10^{-14} - 10^{-13}$ cm^2 [1, 7-9] in accordance with (11) and (12), gives the following estimate in physical-system units:

$$n_{max} \sim \{6{,}6\cdot 10^{-27}[0{,}9\cdot 10^{-27}\cdot 0{,}25\cdot 10^{-16}\cdot 10^{15}\cdot 5\cdot 10^{-14}(1{,}38\cdot 10^{-16}\times \times 250\cdot 10^{24})^{1/2}]^{-1}\}^{1/3} \sim 1000.$$

The quasicontinuity of the frequency spectrum of resonance scattering of radio waves in the atmosphere results from the impact and Stark mechanisms of broadening of the spectral lines of radioatoms, as can be shown by using formulas (26) and (27).

The relative value of impact broadening of resonance lines at an altitude of 90 km, for example, is

$$\Delta\nu_{уд}/\nu = 8\cdot 0{,}25\cdot 10^{-16}\cdot 10^{4}\cdot 10^{13}\cdot 10^{-6}[3{,}14\cdot 1{,}38\cdot 10^{-16}\cdot 250\cdot 10^{24}]^{1/2} \gtrsim 1,$$

while at lower altitudes, as follows from (26), the broadening is even greater as a result of the increasing density of the atmosphere.

Kinetic Stark line broadening in the $10^6 - 10^7$ Hz range in the ionosphere results from the quasicontinuity of the spectrum at values of $N_e \gtrsim 10^4$ cm^{-3}, as folows from (27):
$$\Delta\nu_{шт}/\nu \quad 0{,}48\cdot 10^{-24}\cdot 10^{4}\cdot 20\cdot 1\cdot(5\cdot 10^{2}+1/2)^{7} \gtrsim 1.$$

Thus the area of quasicontinuous scattering of waves in the range in question in an altitude range lower than 90 km results from the impact mechanism of line broadening, while kinetic Stark broadening will be effective in the range between 90 and 2000-3000 km, where $N_e \gtrsim 10^4$ cm^{-3} [14-16].

We now have grounds for considering that it is in the D layer of the ionosphere, the densest layer for cosmic particles penetrating the atmosphere, that the area of greatest density of hyperatoms, generated by corpuscular-ray fluxes during solar eruptions, occurs.

We further assume that the attenuation of radio waves to the extent of 40 dB, i.e. by a factor of 10^4 e^{10}, occurs at an effective path length l_{eff} 10 km. Then, using the Bouguer-Beer law (30), we obtain an expirical estimate for the absorption coefficient $\gamma \sim 10\ l_{eff}^{-1} \sim 10 \cdot 10^{-6}$ $cm^{-1} \sim 10^{-5}$ cm^{-1}, which corresponds to the relationship between the density of the resonance atoms and the cross section of their interaction with radio quanta: $\gamma_{a*} = N_{a*}\sigma_{a*r}$.

Since at present there are no theoretically determined values for these quantities in nonequilibrium processes, we may propose a rough estimate of the concentration of hyperatoms in the area in question making use of the following premises, which are based on the energetic principle. We assume that during sporadic corpuscle-ray emanations the value of the nonequilibrium concentration of hyperatoms in the D layer of the ionosphere is of the same order as the "perturbation" value of the density of free electrons (i.e. is $\sim 10^3$ cm^{-3}).

This is justifiable if we consider that energy of the same order is required for both ionization of atoms and their excitation to high levels.

Finally, we may derive an empirical estimate of the effective cross section for the process of resonance interaction of hyperatoms with radio quanta ("radions") with a frequency of $10^6 - 10^7$ Hz

$$\sigma_{a^* r} = \gamma_{a^*} N_{a^*}^{-1} \sim 10^{-5}\ \text{см}^{-1} (10^3\ \text{см}^{-3})^{-1} \sim 10^{-8}\ \text{см}^2.$$

Comparing this expirical estimate of the effective cross section for absorption of radio quanta by hyperexcited atoms with the experimental values of this quantity in the optical range ($\sigma_\phi \sim 10^{-18} - 10^{-17}$ cm^2), we find that they are in accordance with the frequency dependence of $\sigma_\nu (\nu^{-4/3})$ established by the Kramers formula (32), $\sigma_{a*r}/\sigma_{a*\phi} \sim 10^{-8}\ \text{cm}^2/10^{-17.5}\ \text{cm}^2 = 10^{9.5} \sim \sigma_\nu([\nu_r/\nu_\phi]^{-4/3}) \sim [10^{6.5}/10^{14}]^{-4/3} = 10^{10}$.

An indirect piece of evidence in favor of the hyperatomic mechanism for strong attenuation of radio waves in the earth's ionosphere is the correspondence of the duration of attenuation processes with the duration of solar eruptions, which is explainable by the short lifetime of highly excited atoms in a collisional medium.

The mechanism of resonance scattering of radio waves by hyperatoms may also be employed to explain other features of the propagation of radio waves in hyperexcited media. For example, the greater attenuation of radio waves in the daytime than at night may also be connected with the larger concentration of excited atoms in the ionosphere under the influence of solar radiation than in the night, when the main source producing them is recombination processes. The greater attenuation of the long wave section of the short and medium radio wave spectrum is in accordance with the frequency dependence of the parameters of the quantum mechanism which we are discussing.

We should note in particular that account should be taken of the possibility of existence in perturbed regions in the atmosphere of atoms with a lower excitation level ($n \sim 50$-100) when studying resonance attenuation of radio waves in the ultrashort wave and microwave ranges which are used in space radar and radio communications with spacecraft while they are in hypersonic motion in planetary atmospheres, and also in studying quantum intensification of radio waves when they are scattered in associated flows created by meteorites and falling spacecraft.

Conclusions

This article raises the question whether a quantum mechanism for the interaction of electromagnetic radiation with excited atoms can be employed to study processes of radio wave propagation in collisional media. In the applied subjects that have been discussed, the main attention has been devoted to bound-free transitions, although in principle the quantum mechanism may operate in radio wave scattering for free-free transitions (movement of free electrons in the Coulomb fields of ions and atoms) as well; moreover, the effectiveness of the latter is $h\nu/kT$ times greater than in bound-free transitions [5]. However, among the real conditions for existence of excited matter, we must take into account the role of collective effects of the interaction of radio waves with free electrons, as well as the possibility of Debye screening of certain regions of a plasma from the penetration of radio waves with a frequency lower than the Langmuir frequency.

For example, along the path of hypersonic movement of a spacecraft in a planetary atmosphere, radio communication may be disrupted not only by the "steel helmet" effect produced around the spacecraft by free electrons in the plasma which surrounds it [18] and which have a supercritical density, but also as a result of resonance attenuation of radio waves. To the extent that behind the shock wave front the speed of relaxation processes leading to the formation of hyperexcited atoms is greater than the speed of processes resulting in ionization [19], the electronic "steel helmet" has a "covering" of hyperatoms which are extremely effective in attenuating radio wave energy (given a normal population in the shock wave). Thus, in developing ways of making the plasma translucent for radio waves under such conditions, it is necessary to take into account the effect of both mechanisms of interaction of excited matter with radiation.

For a comparison of the effectiveness of interaction of electromagnetic radiation with free and bound atoms, it suffices to note that in the former case the interaction cross section is given by the Thompson value of 10^{-25} cm^2, while estimates based on the Kramers formula give a value 10^{-8} cm^2 in the radio spectrum, since only negligible concentrations of hyperexcited atoms are required for the appearance of extremely strong, macroscopically measurable quantum radiophysical effects. Thus, reference 20 demonstrates the role of fast electron nonlinearities in highly excited media during the propagation of self-focusing microwave fluxes through them.

The same mechanism may be used to explain strong radio emissions from astrophysical sources, in particular radio galaxies and quasars.

The used of a medium with highly excited atoms as a working substance in quantum electronics opens new possibilities for the conversion of electromagnetic radiation into low-energy quantum transitions, which will make it possible to cover the entire radio-frequency spectrum. It should be borne in mind that the degeneracy of energy levels in terms of orbital and magnetic moments in hyperexcited atoms will make it possible to obtain from such media significant resonance radiation powers, while the high receptivity of hyperatoms will make it possible to realize a high effectiveness for interaction with radio-frequency radiation with hyperexcited matter.

We may hope that the further development of the questions of hyperatomic physics which have been touched upon in this article will help in resolving pressing problems of radio communications, space radar, astrophysics and quantum electronics: wherever we are concerned with the propagation of radio eaves and their interaction with hyperexcited matter in its various states.

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PROBLEMS OF SUBATOMIC SPACE AND TIME

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[Annotation, preface and table of contents from book by Vladilen Sergeyevich Barashenkov, Atomizdat, 3450 copies, 200 pages]

[Text] The book is devoted to a detailed discussion of the physical and philosophical aspects of space-time relations of the microcosm. An examination is made of the experimental status of the problem, its present theoretical state and the possibilities of various generalizations: faster-than-light signal velocities, nonlinear approaches, attempts to quantize space and time, geometric concepts. Principal attention is given to microcausality and the relation between properties of space-time and laws of conservation.

The book is intended for instructors in vuzes and for scientists, physicists and philosophers interested in fundamental problems of modern natural science, and also for students taking advanced courses in physical, physicomathematical and philosophical faculties, who are acquainted with the fundamental principles of relativistic and quantum physics.

Preface

The current stage in the development of physics of microphenomena is characterized by an extraordinary influx of new experimental data. The extensive use of computing devices has enabled a considerable degree of automation of processes of measurement and preliminary analysis of the results of these measurements. Right now experiment is frequently ahead of theory, and a large number of experimental facts are finding only a phenomenological interpretation, or in the best case a semiphenomenological rough model interpretation.

A remarkable situation has come about in the current theory of microphenomena. On the one hand, the theory explains all experiments involving electromagnetic interactions with fantastic precision to the ninth or tenth decimal place, and on the other hand many actually finite quantities such as mass, charge and magnetic moment turn out to be infinite in the theory, while the strict "field equations" that describe interactions between mesons and hyperons have not been solved at all, and experimental data are described by using model approaches that differ and often do not agree with one another very well. The renormalization technique that is successfully used to eliminate divergent expressions from consideration in quantum electrodynamics is totally unsuitable in many other cases; the theory is internally contradictory. At the same time, experimental data do not contradict known physical concepts in the qualitative respect.

What is the matter here? Could it be that we have not grasped some cardinal physical idea that would enable formulation of new principles and quantitative description of the diversity of experimental facts, or is it just that we have not yet learned to solve the intricate intertwining system of operator field equations?

Under these conditions a critical analysis of the fundamentals of our physical notions takes on particular significance. Clearly such an analysis inevitably involves general procedural principles and categories. The physical and philosophical aspects of research here are uncommonly intimately related, almost merging. Therefore it is no accident that physicists are now showing considerable interest in the philosophical problems of natural science.

This book that we offer for the reader's perusal is devoted to a detailed discussion of the physical and philosophical aspects of the space-time relations of the microcosm. This is one of the central and most urgent problems of modern science that is involved to some extent in a real way with all fundamental problems of physics of the microcosm that are now known.

Several interesting monographs have been published in recent years, discussing different properties of microscopic space and time [Ref. 1-6]. However, the question is so complex and multifaceted that many of its very important aspects have remained unexamined. It is the author's hope that a new book will fill such gaps to some extent, the moreso as development in this area is taking place very rapidly: new experimental data are showing up, new viewpoints are forming, and... many new questions are arising. Of course the progress of modern physics is so headlong that some of the material is already out of date as the book is being published.

Since the beginning of this century the minimum space-time intervals accessible to experimental research have shrunk by more than a billion times: from molecular-atomic distances and durations of $\Delta x \approx 10^{-8}$ cm, $\Delta t \approx 10^{-18}$ s to ultrasmall scales of $\Delta x \approx 10^{-17}$ cm, $\Delta t \approx 10^{-27}$ s in modern experiments with cosmic radiation. Many images and concepts worked out on the basis of everyday macroscopic experience and taken as defining the entire structure of our thinking, what we have come to call common sense, have lost their meaning and become inapplicable. The description of physical phenomena is taking on more and more an abstract form that is like nothing else and at times seems to be just a contradiction of "common sense." The methodological element is playing a more and more important part in theoretical constructions. In this connection, a number of questions concerning the mutual relations between "pure" physics and philosophy are becoming especially acute: can philosophy as an independent science generate within itself any criteria and guidelines that will be of assistance in natural science research and in some way determine its direction, or does the role of philosophy reduce to mere interpretation and comprehension of results already available; do philosophical hypotheses have a right to exist, or is this in all instances equivalent to a switch to natural philosophy? We have mentioned only some of the questions that have arisen. The way they are answered can have a considerable effect on selecting the direction of research, and may show up in the approach taken to interpretation of observed phenomena. The introduction to the book deals with consideration of these problems and some others that are important in the subsequent exposition.

In discussing the properties of space and time, one must clearly distinguish between *real*, physical space and time that objectively exist externally to and independent of us, and *conceptual* space and time that are a reflection of the real space and time in our theories, and represent the natural science concepts of space and time. It is also very important to realize that although conceptual space and time are a reflection of certain aspects of reality, they are always to some extent abstract, and they often contain a quite considerable hypothetical element as well.

This situation is fairly obvious when dealing with abstract mathematical concepts of space, but it is much more difficult to realize (and is sometimes altogether forgotten) when considering physical theories that agree with experience. Therefore this book gives particular attention to the current state of the art in experiment.

The discussion commences with an elucidation of the kinds of space-time intervals that are accessible to experimental study at the present time, and the kind of progress that can be expected here in the not-too-distant future, say the next 10-20 years. Such an examination is absolutely necessary so that in future we can stand firmly on the ground of realistic experimental possibilities. Then with recourse to the latest experimental data an analysis is made of the kinds of changes that are to be observed in space-time relations (especially cause-and-effect relations) in the region of microscopic scales Δx and Δt accessible to modern experiment. In doing this, all conclusions are based solely on direct experimental facts without using any theoretical extrapolations or assumptions that have not already been experimentally confirmed.

An examination of this kind is all the more important right now, because in recent years research has been published that gives a quite one-sided, biased interpretation of the microscopic properties of space-time that in many cases is based on a quite subjective sorting of specific developments and generalizations, rather than on experiment.

Artificially ascribing assumed properties to natural phenomena on the basis of certain one-sided considerations that might seem quite probable at a given instant to a given author, but have not yet been confirmed by experiment, can hardly be considered a progressive approach in scientific research; such a subjective approach can lead to nothing but dead ends and confusion. At the same time, when there has been a comprehensive and objective analysis of an existing experimental situation, theoretical conjectures and assumptions, no matter how fantastic and improbable they may seem at times, have enormous heuristic force, and to a great extent determine the development of scientific research.

The part of the book devoted to discussion of the experimental situation concludes with examination of space-time symmetries and the closely related conservation laws, in particular the question of how universal these laws are (for example the law of conservation of energy).

A special chapter deals with attempts at further development and generalization of known space-time concepts: the possibilities of faster-than-light signal velocities; nonlocal, nonlinear and other theories, the "cosmological approach" in which micro-objects are taken as the result of gravitational collapse of enormous macroscopic masses, geometrodynamic attempts to reduce the entire universe surrounding us to "empty" space. Since the greater part of the material considered in this chapter is hypothetical and to a great extent not yet complete, its discussion as well is quite debatable, particularly when dealing with the significance of some theoretical area. It is possible that some approaches that seem interesting and promising at the present time will quickly die out, and research will come to the fore that now seems of little interest.

The difficulties associated with interpreting experiments on investigation of the internal structure of elementary particles, and some results found in attempts to generalize existing theories bring up the question of the characteristics that distinguish the space-time mode of existence of matter from other possible modes of existence. In a somewhat different aspect, this question is often formulated as follows: Can we be certain that on any level of organization of matter descriptions of physical phenomena in terms of space-time concepts are always applicable, or can we at least in principle admit any "nonspatial" and "nontemporal" modes of existence of matter? Physicists are now intently considering these questions, and they have found reflection in this book.

It should be pointed out at the outset that this book is not "material for light reading," since the problems discussed here involve the most profound divisions of modern elementary particle physics, and are very complicated in themselves; understanding even on a quite popularized level demands considerable concentration. The difficulties are aggrevated by the fact that there are at the present time still very few popular articles and books on elementary particle physics.

In the most difficult places references are cited to literature where a more detailed exposition can be found for the pertinent problem.

In conclusion I would like to thank Associate Member of the Soviet Academy of Sciences M. E. Omel'yanskiy, doctors of philosophical sciences Yu. V. Sachkov, I. A. Akchurin, L. B. Bazhenov, Yu. B. Molchanov and other colleagues of the Institute of Philosophy of the Academy of Sciences of the USSR for numerous discussions that stimulated the writing of this book. I am also sincerely grateful to Doctor of Philosophical Sciences A. M. Mostepanenko, and especially to Associate Member of the Soviet Academy of Sciences G. A. Svechnikov (deceased) and Professor V. S. Gott, whose talks clarified many questions that were not clear to me.

V. S. Barashenkov

REFERENCES

1. A. M. Mostepanenko, M. V. Mostepanenko, "Chetyrekhmernost' prostranstva i vremeni" [Four-Dimensionality of Space and Time], Moscow-Leningrad, "Nauka," 1966.

2. A. M. Mostepanenko, "Problema universal'nosti osnovnykh svoystv prostranstva i vremeni" [The Problem of Universality of the Fundamental Properties of Space and Time], Leningrad, "Nauka," 1969.

3. E. P. Andreyev, "Prostranstvo mikromira" [Space of the Microcosm], Moscow, "Nauka," 1969.

4. D. I. Blokhintsev, "Prostranstvo i vremya v mikromire" [Space and Time in the Microcosm], Moscow, "Nauka," 1970.

5. V. S. Luk'yanets, "Fiziko-matematicheskiye prostranstva i real'nost'" [Physicomathematical Spaces and Reality], Kiev, "Naukova dumka," 1971.

6. M. D. Akhundov, "Problema preryvnosti i nepreryvnosti prostranstva i vremeni" [The Problem of Continuity and Discontinuity of Space and Time], Moscow, "Nauka," 1974.

CONTENTS

6610
CSO: 1862

PUBLICATIONS

UDC 539.293

SEMICONDUCTOR PLASMA

Moscow PLAZMA POLUPROVODNIKOV in Russian 1979 signed to press 13 Feb 79 pp 2-4, 253-254

[Annotation, preface and table of contents from book by Vadim Vladimirovich Vladimirov, Antoniy Fedorovich Volkov and Yevgeniy Zalmanovich Meylikhov, Atomizdat, 2800 copies, 256 pages]

[Text] This is the first book in Soviet literature to be devoted to exposition of the fundamentals of semiconductor plasma physics. An examination is made of the major types of waves and instabilities in a solid state plasma (helicons, Alfven waves, screw instability, pinch effect and instabilities due to negative differential conductivity). All theoretical results are illustrated by appropriate experimental materials. The book reflects the latest advances in this area of research. Practical possibilities are pointed out for application of the investigated phenomena.

The book is intended for graduate and undergraduate physics students who are specializing in the area of physics of solid state and gas plasma, and also for scientific workers in this field.

Preface

This book is devoted to exposition of the fundamentals of semiconductor plasma physics. Several monographs have already dealt with similar subject matter. However, the book by Glicksman [Ref. 1] is principally a reference work, and besides, many new and important results came to light after its publication. The book by Stil and Vyural' [Ref. 2] examines primarily flux instabilities, which have been almost uninvestigated experimentally even to this very day, whereas too little consideration is given to magnetohydrodynamic instabilities and instabilities under conditions of negative differential conductivity that are important from a practical standpoint. The book by Plattsman and Vol'f [Ref. 3] deals chiefly with metals. The monograph by V. L. Bonch-Bruyevich et al. [Ref. 4] considers the important but narrow problem of domain instabilities in semiconductors. The recently published monograph by Yu. K. Pozhela [Ref. 5] may serve as an introduction to the problem and does not contain any detailed description of studies of major plasma effects.

In this book the authors have aimed at organic unification of theoretical and experimental results. Emphasis is placed on the relations between gas and solid state plasma, possible applications are pointed out and prospects for future research are indicated.

Chapter 1 examines problems associated with the dynamics of an electron-hole plasma in external electric and magnetic fields. Such basic concepts are introduced as carrier mobility and diffusion, quasineutrality, charge screening in a plasma, drift motion of carriers. A detailed investigation of transfer processes in plasma is made within the framework of the hydrodynamic model. A summary is given of the results of the kinetic theory relating to the Hall effect and magnetoresistance. An examination is made of the particulars of statistics and kinetics of electron gas in a quantizing magnetic field. The chapter concludes with an examination of the properties of semiconductors in a quasisteady alternating electric field (cyclotron and magnetoplasma resonances).

Chapter 2 considers waves and oscillations in an electron-hole plasma. Dispersion relations for different wave modes in a plasma are derived in the hydrodynamic approximation by using a wave equation and effective permittivity tensor. Effects involving the thermal motion of carriers are qualitatively considered and described. An examination is made of the peculiarities of waves (chiefly helicons) in a quantizing magnetic field. Different cases of wave interaction in a solid state plasma are investigated.

Chapter 3 is devoted to exposition of fundamental experimental and theoretical results on investigation of body and surface helical waves in weak and strong magnetic fields. Threshold and frequency characteristics of these waves are given, and the authors discuss the influence that semiconductor band structure has on the criterion of excitation and the frequency of a screw instability. An examination is made of nonlinear effects that accompany the development of a screw instability: hysteresis of threshold conditions of excitation, anomalous plasma resistance and so on. The possibilities for applied developments are discussed.

Chapter 4 contains an analysis of experimental and theoretical results on investigation of the pinch effect in semiconductors. The principal methods of observing the pinch effect are presented, as well as techniques for initiating this effect and problems of stability. An examination is made of pinch dynamics, its principal characteristics are calculated: the radius of the pinch channel, pinching times and so forth. The specifics of this effect are discussed under conditions of lattice heating and strong degeneration of an electron-hole plasma. An analysis is made of pulse methods of strong plasma compression in a magnetic field that increases with time (θ-pinch).

Chapter 5 examines semiconductors with negative differential conductivity. An analysis is made of mechanisms of development of N and S current-voltage characteristics in semiconductors. It is shown that the homogeneous state of the semiconductor corresponding to the falling section of the current-voltage curve is unstable. The authors present a theory of linear and nonlinear instabilities in semiconductors with negative differential conductivity. In particular the velocity and shape of moving domains (solitons) are found in semiconductors with N-shaped current-voltage characteristics, and also the shapes of current pinches in semiconductors with S-shaped current-voltage characteristics. Information on the uses of semiconductors with negative differential conductivity is given at the end of the chapter.

Thus the book does not deal with all the problems of semiconductor plasma physics. No consideration is given to effects that have had little experimental investigation, or to effects with a mechanism that has not yet been completely explained.

Chapters 1 and 2 were written by Ye. Z. Meylikhov, chapters 3 and 4 by V. V. Vladimirov, and chapter 5 by A. F. Volkov.

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1. M. Glicksman, "Solid Physics," V. 26, New York-London, Academy Press, 1971.

2. M. Stil, B. Vyural', "Vzaimodeystviye voln v plazme tverdogo tela" [Wave Interaction in a Solid State Plasma], Moscow, Atomizdat, 1973. (Translated from English).

3. F. Plattsman, P. Vol'f, "Volny i vzaimodeystviya v plazme tverdogo tela" [Waves and Interactions in a Solid State Plasma], Moscow, "Mir," 1975. (Translated from English).

4. V. L. Bonch-Bruyevich, I. P. Zvyagin, A. G. Mironov, "Domennaya neustoychivost' v poluprovodnikakh" [Domain Instability in Semiconductors], Moscow, "Nauka," 1972.

4. Yu. K. Pozhela, "Plazma i tokovyye neustoychivosti v poluprovodnikakh" [Plasma and Current Instabilities in Semiconductors], Moscow, "Nauka," 1977.

CONTENTS

6610
CSO: 1862

Acoustics

USSR UDC 534.86

EXCITATION OF ULTRASONIC VIBRATIONS BY THE ELECTROMAGNETIC ACOUSTIC METHOD AT ELEVATED TEMPERATURES

Minsk FIZICHESKIYE SVOYSTVA METALLOV I PROBLEMY NERAZRUSHAYUSHCHEGO KONTROL'YA [Physical Properties of Metals and Problems of Non-Destructive Testing] in Russian 1978 pp 114-118

TRIGUBOVICH, B. V. and BORODICH, A. K.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3, 1979 Abstract No 3Zh783 by the authors]

[Text] Based on Landau's theory, a theoretical interpretation is given of the nature of the change in magnetostrictive forces at elevated temperatures. It is demonstrated that the increase in the amplitude of ultrasonic vibrations at elevated temperatures is caused by an increase in magnetostrictive forces. References 7.
[139-8831]

USSR UDC 534-8

INVESTIGATION OF ACOUSTIC PROPERTIES OF ISOVISCOUS SUBSTANCES IN THE n-PARAFFIN GROUP

Tomsk ISSLEDOVANIYE AKUSTICHESKIKH SVOYSTV IZOVYAZKOSTNYKH VESHCHESTV V GRUPPE n-PARAFINOV in Russian manuscript deposited at VINITI 13 Nov 78 No 3468-78 Dep. 1978 12 pp

CHOLPAN, P. F., SPERKACH, V. S., SINILO, V. N. and GARKUSHA, L. N., editorial board of IZVESTIYA VUZOV, FIZIKA

[From REFERATIVNYY ZHURNAL, FIZIKA No 3, 1979 Abstract No 3Zh684 DEP. by the authors]

[Text] A study is made of density, coefficient of shear viscosity and of the absorption and rate of propagation of ultrasound in isoviscous solutions of the system n-hexane - n-tridecane. It is demonstrated that in the isoviscous pairs studied the excess absorption of ultrasound is caused by vibrational, rotational-isomeric and structural relaxation. The absorption mechanism associated with fluctuations in concentration makes an insignificant contribution for these solutions. References 6.
[139-8831]

USSR UDC 534-8

RATE OF PROPAGATION OF SOUND IN EKHB-4 ELECTROCHEMICAL PAPER

L'vov O SKOROSTI RASPROSTRANENIYA ZVUKA V ELEKTROKHIMICHESKOY BUMAGE EKHB-4 in Russian manuscript deposited at UkrNIINTI [Ukrainian Scientific Research Institute of Scientific and Technical Information] 21 Dec 78, No 1259 5 pp

YAKOVENKO, M. G., L'vov Polytechnical Institute

[From REFERATIVNYY ZHURNAL, FIZIKA No 3, 1979 Abstract No 3Zh688 DEP. by the author]

[Text] A determination is made of the values of the speed of sound (elastic wave) in EKhB-4 electrochemical paper for the longitudinal and transverse directions. An investigation is made of the influence that stress in uniaxial tensile testing, microstructure of fibers, anisotropy and moisture content have on the speed of sound. References 2.
[139-8831]

USSR UDC 534

INTRASHIP ACOUSTICS RESEARCH AND DEVELOPMENT SUMMARY

Leningrad SPRAVOCHNIK PO SUDOVOY AKUSTIKE [Marine Acoustics Handbook] in Russian Sudostroyeniye 1978 503 pp

KLYUKIN, I. I. and BOGOLEPOV, I. I.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3, 1979 Abstract No 3Zh606 K by the authors]

[Text] In this handbook the results are generalized, of scientific research and development on intraship acoustics. Noise sources on ships are discussed. The key data, methods and information are given, needed in designing, making and testing equipment for combating noise and acoustic vibration at the source of their origin, along paths of propagation and in ship areas. Discussed in detail are questions relating to sound insulation, sound absorption, vibration insulation and vibration absorption, as well as to the combined use of equipment for combating noise. An indication is given of advanced Soviet know-how relating to acoustic developments undertaken for the purpose of improving the habitability of ships and conditions for performing duties on them, as well as of the results of non-Soviet practices.
[139-8831]

9 OCTOBER 1979 (FOUO 3/79) 2 OF 2

USSR UDC 534-13;534-143;551.596

INFLUENCE OF THE PROPAGATION MEDIUM IN PARAMETERS OF BROADBAND ACOUSTIC SIGNALS IN THE SHORT-RANGE ZONE

Leningrad TRUDY LENINGRADSKOGO INSTITUTA AVIATSIONNOGO PRIBOROSTROYENIYA [Transactions of Leningrad Institute of Aviation Instrument Making] in Russian No 124, 1978 pp 134-138

ANTONOV, V. A.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3, 1979 Abstract No 3Zh765 summary]

[Text] The results are given of an investigation of the influence of reverberation interference on the parameters of broadband signals with a spaced transmitter and receiver.
[139-8831]

USSR UDC 534.86

EMPLOYMENT OF REACTIVE MATCHING CIRCUITS FOR RADIATING A SHORT ACOUSTIC PULSE

Leningrad TRUDY LENINGRADSKOGO INSTITUTA AVIATSIONNOGO PRIBOROSTROYENIYA [Transactions of Leningrad Institute of Aviation Instrument Making] in Russian No 124, 1978 pp 139-142

YERSHOVA, I. V., ZHEZHERIN, A. R., TIMOFEYEVA, V. V. and SHOSTAKOVICH, S. B.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3, 1979 Abstract No 3Zh782 summary]

[Text] The problem is discussed, of broadening the radiation band of a narrow-band piezoceramic transducer by means of a passive LC circuit. The parameters of this circuit are chosen on the condition of optimal matching of the internal resistance of the generator and the input impedance of the transducer with respect to power. An estimate is made of distortions in the shape of the radiated acoustic pulse as compared with the electrical signal of the master oscillator. Oscillograms of the acoustic signals emitted are given.
[139-8831]

USSR UDC 534-13;534-143;551.596

STRATIFICATION OF THE SOUND VELOCITY FIELD IN SEA WATER

TRUDY VSESOYUZNOGO NAUCHNO-ISSLEDOVATEL'SKOGO INSTITUTA GIDROMETEOROLOGICHESKOY INFORMATSII MIROVOGO TSENTRA DANNYKH [Transactions of the All-Union Scientific Research Institute of Hydrometeorological Information of the World Data Center] in Russian No 45, 1978 pp 105-125

KUT'KO, V. P.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3, 1979 Abstract No 3Zh752 by the author]

[Text] The types of stratification of the speed of sound in sea water and of its vertical gradient are shown. For the types, subtypes and varieties distinguished, statistical characteristics are given, in addition to a qualitative description of them. The space variability of types is evaluated quantitatively by means of root-mean-square deviations and variation factors. The key elements of the structure of the sound velocity field in the northern half of the Pacific Ocean are discussed (minimum sound velocity layer, quasi-homogeneous surface and depth layers, etc.).
[139-8831]

USSR UDC 543-8

ULTRASONIC INTERFEROMETER FOR STUDYING GASES AT LOW TEMPERATURES

Moscow UL'TRAZVUKOVOY INTERFEROMETR DLYA ISSLEDOVANIYA GAZOV PRI NIZKIKH TEMPERATURAKH in Russian manuscript deposited at VINITI 7 Dec 78, No 3724-78 Dep. 1978 5 pp

SAKHAROV, N. P. and KOZHEVNIKOV, A. S., Moscow Oblast Pedagogical Institute imeni N. K. Krupskaya

[From REFERATIVNYY ZHURNAL, FIZIKA No 3, 1979 Abstract No 3Zh682 DEP. by the authors]

[Text] A description is given of a unit for studying gases at low temperatures. An interferometer is employed with stabilized quartz crystal parallelism. The velocity and absorption of ultrasound were measured at frequencies of 518 $\pm$ 2 kHz by the method of pressure variation at temperatures of 150 to 400 K. The range of variation of parameter ν/P, characterizing rarefaction of the gas, was from 5 to $2\cdot10^4$ MHz/atm, and of the Knudsen number, accordingly, from 0.003 to 6. Studies were made of Ar and N_2 at temperatures of 293, 223 and 150 K, as calibration measurements. Comparison with available

experimental data at a temperature close to room temperature demonstrates reliable operation of the unit. With a lowering of temperature, dispersion curves shift in the direction of high values of parameter ν/P, but the limiting values of the normalized speed of sound, C/C_0 (C_0 is the Laplace speed of sound) remain constant (2.03 ± 0.3) for the entire temperature range studied. References 9.
[139-8831]

Crystals and Semiconductors

USSR UDC 535.33:621.375.8;535:530.182;778.38

MEMORY PHENOMENA IN A SOLID

Moscow AVTOMETRIYA in Russian No 4, 1978 pp 106-120

MALINOVSKIY, V. K.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D1171]

[Text] Various effects leading to a change in state of a solid subjected to optical radiation are analyzed. A number of examples are singled out where the energy of the absorbed light is either transformed into heat or causes the rearrangement of the electron structure, which is stored by an ion core (materials with phase transitions, resonance effects in solids, phenomena in ferroelectric materials and glasses). The conclusion is drawn that reversible changes with a high energy efficiency are possible only in combined structures, if the light beam plays the part of the process initiator, while gain is realized by virtue of some kind of external field. References 43. [138-8225]

USSR UDC 535.343.2

INVESTIGATION OF MECHANISMS OF ALLOWANCE OF CERTAIN d-d TRANSITIONS IN $FeBO_3$

Krasnoyarsk ISSLEDOVANIYE MEKHANIZMOV RAZRESHENIYA NEKOTORYKH d-d-PEREKHODOV V $FeBO_3$ in Russian, Preprint No 87F, Institute of Physics, Siberian Department, Academy of Sciences USSR 1978 26 pp

MALAKHOVSKIY, A. V., EDEL'MAN, I. S. and ZABLUDA, V. N.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D475]

[No text]

[146-8831]

USSR UDC 535.343.2

STUDY OF HYDROGEN BONDS IN CRYSTALS OF ALKALINE TRIHYDROSELENITES BY THE METHOD OF RAMAN LIGHT SCATTERING SPECTROSCOPY

IZVESTIYA SEVERNO-KAVKAZSKOGO NAUCHNOGO TSENTRA VYSSHEY SHKOLY, YESTESTVENNYYE NAUKI [North Caucasus University Science Center Newsletter, Natural Sciences] in Russian No 4, 1978 pp 34-42

RABKIN, L. M., TORGASHEV, V. I., SHIRKOOV, V. I., DMITRIYEV, V. P. and SHUVALOV, L. A.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D509 by the authors]

[Text] The results are given of a comparative study of the Raman light scattering spectra of crystals of a series of alkaline trihydroselenites (general formula, $A(D_x = H_{1-x})_3$, $(SeO_3)_2$, where A = Na, K, Rb, Cs, NH_4) in the region of OH-(OD) vibrations of hydrogen bonds. The features are revealed of changes in OH vibrational spectra during phase transitions. An unusual behavior of OH-(OD) bands is found in potassium trihydroselenite. The existence is established of correlated migration of the hydrogen subsystem in the series of compounds studied. The multiplet structure in the region of OH-(OD) stretching vibrations is discussed in association with the form of the hydrogen bond's potential function. The temperature dependence, V_s, of bands in a crystal of $K(D_{0.8}H_{0.2})_3$-$(SeO_3)_2$ indicates that it is not possible to explain by Fermi resonance either the structure or broadening of lines corresponding to stretching vibrations of the O-H...O chain. The possibility is discussed of the existence of combined states in crystals of $NaD_3(SeO_3)_2$ and $K(D_{0.8}H_{0.2})_3(SeO_3)_2$. References 25.
[146-8831]

USSR UDC 539.143.43;543.422.25

OPTIMAL PLANNING OF EXPERIMENTS IN SOLID-STATE NUCLEAR MAGNETIC RESONANCE

Krasnoyarsk OPTIMAL'NOYE PLANIROVANIYE EKSPERIMENTOV V YaMR TVERDOGO TELA in Russian Preprint No 192 Institute of Physics, Siberian Department, Academy of Sciences USSR 1978 44 pp

KIPERMAN, YE. M., FALALEYEV, O. V., SERGEYEV, N. A. and LUNDIN, A. G.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D565]

[Text] Experiments on nuclear magnetic resonance (NMR) in the solid state are discussed from the viewpoint of the theory of optimal planning. Optimal experiment plans are obtained for anisotropic physical magnitudes described by a tensor of second rank (rate of spin-lattice relaxation in the case of fast molecular movements), a tensor of fourth rank (second moment of NMR absorption line, rates of spin-lattice relaxation in laboratory and rotating coordinate systems), and a tensor of eighth rank (fourth moment of the NMR spectrum). Optimal plans are also constructed for the case of simultaneous measurement of the second and fourth moments of the absorption line. The plans given take into account the symmetry of crystals and aspects of the procedure of an NMR experiment.
[146-8831]

USSR UDC 537.635:537.611.43:539.124;543.422.27

PROTON MAGNETIC FIELD METER FOR AN EIGHT-MILLIMETER BAND EPR SPECTROMETER

Leningrad PROTONNYY IZMERITEL' MAGNITNOGO POLYA DLYA SPEKTROMETRA EPR 8-mm DIAPAZONA in Russian 1978 manuscript deposited at VINITI 2 Jan 79, No 54-79 Dep

SOBOLEVSKIY, V. K. and SHTEL'MAKH, K. F., Leningrad Polytechnical Institute

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D714 DEP]

[Text] A description is given of an instrument for measuring static magnetic fields that are used in an 8-mm range EPR spectrometer. The operating principle of the instrument is based on the NMR phenomenon (resonance of protons in castor oil). The NMR signal detector is Robinson's autodyne circuit, which makes possible a signal-to-noise ratio of not less than 50. The magnetometer makes possible direct reading of the magnetic field on the digital

signal panel of a Ch3-34 electron counting frequency meter and recording of the NMR line on the graph paper of the EPR spectrometer's chart recorder. The instrument has an automatic mode in which scanning and tuning are carried out and the magnitude of the field to be measured is traced. The magnetometer's measurement range is 3 to 14 kOe. The maximum tracking rate is 20 Oe/s. References 4.
[146-8831]

USSR UDC 535.343.2

INTRINSIC AND EXTRINSIC DEFECT CENTERS IN CRYSTALS OF GARNET AND ORTHOALUMINATE

Tashkent RADIATSIONNO-STIMULIRUYUSHCHIYE YAVLENIYA V KISLORODSODERZHAYUSHCHIKH KRISTALLAKH I STEKLAKH [Radiation Stimulating Phenomena in Oxygen Containing Crystals and Glasses] in Russian 1978 pp 80-87

VAKHIDOV, SH. A., YESEMURATOV, B., IBRAGIMOVA, E. I. and RAKOV, A. F.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D465 summary]

[Text] A study is made of the optical characteristics of crystals of yttrium aluminum garnets and of yttrium orthoaluminates subjected to oxidative heat treatment and the effect of neutron, proton and gamma radiation. The nature of color and luminescence centers induced by radiation is discussed. Possible mechanisms are discussed for the formation of internal flaws and for their interaction with impurity centers.
[146-8831]

USSR UDC 535.343.2

SOME OPTICAL PROPERTIES OF SINGLE CRYSTALS OF SODALITE

Tashkent RADIATSIONNO-STIMULIRUYUSHCHIYE YAVLENIYA V KISLORODSODERZHAYUSHCHIKH KRISTALLAKH I STEKLAKH [Radiation Stimulating Phenomena in Oxygen-Containing Crystals and Glasses] in Russian 1978 pp 128-130

VARDOSANIDZE, Z. V., LOBACHEV, A. N., MUMLADZE, V. V., TRIODINA, N. S. and TSOTSKHALISHVILI, N. V.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D466 summary]

[Text] A study was made of the optical and sensitometric properties of single crystals of hydrosodalite, $Na_8Al_6Si_6O_{24}(OH)\cdot H_2O$, of the kinetics of coloring and decolorizing, of deep decolorization (thermal relaxation), and of the distribution of the absorption coefficient over the depth of the crystal. An examination is made of the way that diffraction efficiency of a simple hologram depends on exposure time for the case of two departing light beams (λ = 0.48 µm).
[146-8831]

USSR UDC 537.635:537.611.43:539.124;543.422.27

ELECTRON PARAMAGNETIC RESONANCE SPECTROMETER FOR THE EIGHT-MILLIMETER BAND

Leningrad SPEKTROMETR ELEKTRONNOGO PARAMAGNITNOGO REZONANSA 8-mm DIAPAZONA in Russian 1978 manuscript deposited at VINITI 2 Jan 79, No 46-79 Dep, 9 pp

SOBOLEVSKIY, V. K. and SHTEL'MAKH, K. F., Leningrad Polytechnical Institute

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D709 DEP]

[Text] A description is given of a spectrometer for studying EPR at a frequency of 28 GHz. This instrument is designed with a straight amplification circuit and employs synchronous detection. Used in the spectrometer are HF modulation (100 kHz) and a dielectric metalized resonator. Employed in the instrument is a standard AFC - microwave-oscillation-source system for the frequency of the operating resonator. The spectrometer can register both the first derivative of the absorption signal and the second derivative (when employing double 100 kHz and 30 Hz modulation). The temperature of the specimen studied can vary from 300 to 100 K. The spectrometer described possesses the following parameters: integral sensitivity--$6\cdot 10^{10}$ spins/gauss; concentration sensitivity--10^{14} spins/cm^3. Most of the components in the device are ready-made commercial items. References 3.
[146-8831]

USSR UDC 535.343.2

ANISOTROPIC JAHN-TELLER IMPURITY CENTERS IN CUBIC CRYSTALS

Leningrad SPEKTROSKOPIYA KRISTALLOV [Spectroscopy of Crystals] in Russian 1978 pp 11-27

PERLIN, YU. YE., TSUKERBLAT, B. S. and SINGKH DOD, T.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D467 by the authors]

[Text] A study is made of phenomena of latent optical anisotropy in broad (many-phonon) impurity light absorption bands. The method of moments is generalized to the case of anisotropic Jahn-Teller centers in cubic crystals and a study is made of its application to an analysis of electrical and pressure absorption, as well as magnetic circular dichroism.
[146-8831]

USSR UDC 535.343.2

SPECTRA AND SPACE STRUCTURE OF IMPURITY CENTERS IN MeF_2-TR CRYSTALS

Leningrad SPEKTROSKOPIYA KRISTALLOV [Spectroscopy of Crystals] in Russian 1978 pp 27-39

DAVYDOVA, M. P., MALKIN, B. Z. and STOLOV, A. L.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D468 by the authors]

[Text] The existence of centers with different symmetry in MeF_2-TR^{3+} crystals is associated with a difference in the type of local, as well as nonlocal, charge compensation in substitution of a doubly charged cation with a triply charged rare earth ion. A study is made of methods of isolating the spectra of these centers and microscopic models of them are discussed. References 61.
[146-8831]

USSR UDC 535.343.2

INTERCONFIGURATIONAL TRANSITIONS IN IMPURITY CENTERS OF CRYSTALS

Leningrad SPEKTROSKOPIYA KRISTALLOV [Spectroscopy of Crystals] in Russian 1978 pp 39-45

YEREMIN, M. V.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D469 by the author]

[Text] A survey is given of data accumulated up to the present time on the investigation of interconfigurational transitions in crystals activated by ions with unfilled 4f and 3d shells. References 54.
[146-8831]

USSR UDC 535.343.2

SPECTROSCOPIC INVESTIGATIONS OF STRUCTURAL DISORDERING OF CRYSTALS OF GARNETS WITH A RARE EARTH ELEMENT IMPURITY

Leningrad SPEKTROSKOPIYA KRISTALLOV [Spectroscopy of Crystals] in Russian 1978 pp 71-83

ASHUROV, M. KH., VORON'KO, YU. K., OSIKO, V. V. and SOBOL', A. A.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D470 by the authors]

[Text] Methods are discussed of investigating disturbance of the stoichiometry of crystals of aluminum and gallium garnets from the spectra of rare earth ion tracer impurities. It is demonstrated that all crystals of garnets obtained from a melt have a non-stoichiometric composition on account of the addition of a portion of rare earth ions in place of octahedral Al^{3+} or Ca^{3+}. References 24.
[146-8831]

USSR UDC 535.343.2

INHOMOGENEOUS STRUCTURE OF SPECTRA OF GLASSES ACTIVATED BY RARE EARTH IONS

Leningrad SPEKTROSKOPIYA KRISTALLOV [Spectroscopy of Crystals] in Russian 1978 pp 96-108

PRZHEVUSKIY, A. K.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D471 by the author]

[Text] Methods are discussed which make it possible to investigate the spectra of individual groups of non-equivalent optical centers in a glass by means of isolating them according to a specific feature. Selection can be accomplished in exciting luminescence with monochromatic and polarized light and with pumping pulses of different length, by sensitization with a specific activator, as well as by means of selection according to spectrum and polarization and during the period of recorded luminescence. References 25.

[146-8831]

USSR UDC 535.343.2

MICROWAVE RADIATION TRANSMISSION SPECTRUM IN A SINGLE CRYSTAL OF $Dy(ReO_4)_3\cdot 4H_2O$ AT 4.2 K

Moscow TRUDY MOSKOVSKOGO FIZIKO-TEKHNICHESKOGO INSTITUTA, SERIYA OBSHCHAYA I MOLEKULYARNAYA FIZIKA [Transactions of Moscow Physics and Engineering Institute, General and Molecular Physics Series] in Russian 1978 No 10, pp 11-14

KIR'YANOV, A. P.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D473 by V.S.Z.]

[Text] A measurement is made of the transmission of microwave radiation with frequencies of from 5 to 40 cm^{-1} in a single crystal of the tetrahydrate of dysprosium perrhenate, $Dy(ReO_4)_3\cdot 4H_2O$, at 4.2 K. It is demonstrated that at low frequencies of $\nu < 13$ cm^{-1} the transmission coefficient is practically constant and equals 0.84 ± 0.02. At high frequencies heavy resonance absorption takes place with maxima at 16.6, 17.5, 21.8, 27.8 and 31.6 cm^{-1}. The increase in absorption observed in the direction of high frequencies is ascribed to the excitation of phonons in the lattice of the compound. The

frequencies of electronic transitions of the Dy^{3+} ion in this crystal are compared with the frequencies of transitions of dysprosium orthovanadate. [146-8831]

USSR UDC 539.143.43;543.422.25

NUCLEAR MAGNETIC RESONANCE SPECTRA IN THE STRONG BOND REGION

Moscow VESTNIK MGU, FIZIKA, ASTRONOMIYA [Moscow State University Newsletter, Physics, Astronomy] in Russian Vol 19 No 6, 1978 pp 49-56

TUMANOV, V. S.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D567 summary]

[Text] A procedure is described for the calculation of high-resolution NMR spectra in the region of strong spin-spin bonds. It is demonstrated that it is generally possible to determine the number of spectrum lines and the intensities of these lines. The kinds of spectra are determined for which a calculation can be made in analytical form. A_aB_b and ABC spectra are discussed as examples.
[146-8831]

APPROVED FOR RELEASE: 2007/02/08: CIA-RDP82-00850R000100100013-5

Lasers and Masers

USSR UDC 535.33:621.375.8;535:530.182;778.38

FREQUENCY SYNCHRONIZATION OF TWO LASERS AND FLUCTUATIONS IN THEIR DIFFERENCE VIBRATION

Minsk CHASTOTNAYA SINKHRONIZATSIYA DVUKH OKG I FLUKTUATSII IKH RAZNOSTNOGO KOLEBANIYA in Russian 1979 manuscript deposited at VINITI 2 Jan 79 No 41-79 Dep, 10 pp

MAKAROV, YU. P. and CHERNYAVSKIY, A. F., editorial board of VESTNIK BELO-RUSSKOGO UNIVERSITETA, SER. MAT., FIZ., MEKH.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D1227 DEP by the authors]

[Text] A description is given of a system making it possible to produce a stable mode for external synchronization of the frequency of a laser with the frequency of a second laser, with a relative root-mean-square error of about 10^{-11} without special temperature and mechanical stabilization. An important advantage of this system is the two-channel principle of compensating frequency drifts, making it possible to handle long-term and short-term fluctuations in the difference frequency of the two lasers. References 6.
[146-8831]

USSR UDC 535.33:621.375.8;535:530.182;778.38

A STUDY OF THE CHARACTERISTICS OF PULSED PERIODIC CO_2 LASERS

Moscow ISSLEDOVANIYE KHARAKTERISTIK IMPUL'SNYKH CO_2-LAZEROV PERIODICHESKOGO DEYSTVIYA in Russian, Preprint No 2996, Institute of Atomic Energy 1978 20 pp

BARANOV, V. YU., KAZAKOV, S. A., MALYUTA, D. D., MEZHEVOV, V. S., NIZ'YEV, V. G., PIGUL'SKIY, S. V. and STARODUBTSEV, A. I.

[From REFERATIVNYY ZHURNAL, FIZIKA, No 3 (I), Mar 79 Abstract No 3D1052]

[Text] Questions of frequency limitations and the average power in pulsed periodic CO_2 lasers are treated. Experimental results are given for the influence of gas dynamic perturbations on laser parameters. Results are also given for studies of the characteristics of the radiation in the laser with subsonic and supersonic pump-through of the mixture. Parameters are given for the "Dyatel" pulsed periodic laser which is designed for separating the isotopes of various elements.
[138-8225]

USSR UDC 535.33:621.375.8;535:530.182;778.38

AN INVESTIGATION OF THE AMPLIFICATION IN SUPPLEMENTAL BAND LINES IN CO_2 LASERS WITH SEMI-SELF-MAINTAINED DISCHARGE

Mogilev ISSLEDOVANIYE USILENIYA NA LINIYAKH DOPOLNITEL'NYKH POLOS V CO_2-LAZERAKH S NESAMOSTOYATEL'NYM RAZRYADOM in Russian, Preprint No 156, Physics Institute of the Academy of Sciences BSSR, 1978 18 pp

POPONIN, V. P., KUNTSEVICH, B. F., TRUSHIN, S. A. and CHURAKOV, V. V.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D1049]

[Text] The amplification in supplemental band lines in CO_2 lasers was studied theoretically. The laws governing the change in the small signal gain were analyzed as a function of the composition of the active mixture and the pumping power under conditions of semi-self-maintained discharge. [138-8225]

USSR UDC 535.33:621.375.8;535:530.182;778.38

MEASUREMENTS OF THE POLARIZATION PARAMETERS OF CO_2 LASER RADIATION

Moscow METROLOGICHESKOYE OBESPECHENIYE FAZOVYKH I POLYARIZATSIONNYKH IZMERENIY V KOGERENTNOY OPTIKE [Metrological Support of Phase and Polarization Measurements in Coherent Optics] in Russian 1978 pp 19-27

VARSHEVSKIY, M. YA., GRIGOR'YEV, I. F. and KUKHTEVICH, V. I.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D1118 by S.L.]

[Text] The major factors influencing the precision of the measurement of the polarization parameters of CO_2 laser radiation are analyzed for the case of studies of the optical properties of various objects by means of these lasers. It is shown that the main error in the manual measurement of polarization parameters using the MLR-1 polarizer and IMO-2 or IOM power meters is related to the timewise instability of the laser power and the characteristics of the radiation detector. An automated polarization parameter meter is briefly described which has measurement times of the polarization plane of about 70 microseconds and of the level of the polarization of about 3 seconds. The automated polarization parameter measurement circuitry substantially boosts the precision in determining the position of the polarization plane; however, the precision in the measurement of the level of polarization is lower than in the case of manual measurements because of the considerable influence of the quality of the adjustment of the device with respect to the beam of radiation being studied.
[138-8225]

USSR UDC 535.33:621.375.8;535:530.182;778.38

A FLASH-PUMPED PHOTODISSOCIATION LASER WITH IMPROVED CHARACTERISTICS

Leningrad OPTIKO-MEKHANICHESKAYA PROMYSHLENNOST' in Russian No 10, 1978 pp 23-26

BELOUSOVA, I. M., DANILOV, O. B., ZHEVLAKOV, A. P. and KISELEV, V. M.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D1075]

[Text] A photodissociation, flash-pumped laser using p-C_3F_7I and having a radiation energy of 330 J for one spectral component 0.05 Å wide with an efficiency of 0.4% is described. The possibility of spatial stabilization of the operating range of such a laser is shown.
[138-8225]

USSR UDC 535.33:621.375.8;535:530.182;778.38

ESTIMATION OF AVERAGED ENERGY CHARACTERISTICS OF GAS LASERS

Minsk OTSENKA USREDNENNYKH ENERGETICHESKIKH KHARAKTERISTIK GAZOVYKH LAZEROV in Russian 1979 manuscript deposited at VINITI 15 Jan 79 No 153-79 Dep, 15 pp

DORONIN, V. G. and SUKHANOVA, V. P., editorial board of Belorussian SSR Academy of Sciences ZHURNAL PRIKLADNOY SPEKTROSKOPII

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D1195 by the authors]

[Text] The sufficient conditions of applicability are found for the gain and emission density factor, averaged for the length of the cavity, for the generation of a gas communications laser, and for the recurrent dependence of these values at a certain point within the cavity. This relationship makes it possible to determine the average lasing emission density as a function of the parameters of the medium and of losses in the cavity and to estimate the output power of the laser. An estimate is made for a two-level model of an active medium, taking into account the influence of processes of particle distribution in terms of velocity, and for a three-level laser with optical pumping with a slight influence of these processes. Here it was assumed that the radiation has a narrow range and that there were no restrictions on the character of broadening of the substance's spectrum lines. The inequalities derived are convenient by virtue of their generality and demonstrate that the precision of an estimate of the energy characteristics of a gas laser in this approximation is fairly high in many cases. References 6.
[146-8831]

USSR UDC 535.33:621.375.8;535:530.182;778.38

A DEVICE FOR INCREASING THE PRECISION OF ELECTRICAL POWER SUPPLIES FOR LASERS

Moscow PRIBORY I TEKHNIKA EKSPERIMENTA in Russian No 5, 1978 pp 178-179

KUTSAROV, S. I. and MITEV, S. I.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D1135]

[Text] A device is described for charging a capacitor bank up to a preset voltage of 800--1,600 volts with a precision of $\pm 0.2\%$. The device is designed around K1UT531B integrated circuits.
[138-8225]

USSR UDC 535.33:621.375.8;535:530.182;778.38

A COMPACT SINGLE MODE CO_2 LASER

Moscow PRIBORY I TEKHNIKA EKSPERIMENTA in Russian No 5, 1978 p 205

BURMASOV, V. S.

[From REFERATIVNYY ZHURNAL, FIZIKA, SVODNYY TOM (A-D) No 3 (I), Mar 79 Abstract No 3D1054]

[Text] A compact single mode CO_2 laser of simple design is described. The laser is 1 m long and 4 cm in diameter. The single mode power of the laser amounts to about 1 watt.
[138-8225]

USSR UDC 535.33:621.375.8;535:530.182;778.38

A SYSTEM FOR FREQUENCY STABILIZATION OF A HIGH POWER LASER USING A REFERENCE LASER

Moscow PRIBORY I TEKHNIKA EKSPERIMENTA in Russian No 5, 1978 pp 206-207

KOLOSOVSKIY, O. A., SEMENOVSKAYA, N. A., TKACHENKO, V. S., FERTIK, N. S. and CHUPRAKOV, A. V.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D1107]

[Text] A system for stabilizing the radiation frequency of a high power laser based on a stabilized master laser is described, where the master contains an active RC filter with frequency dependent feedback and makes it possible to obtain a regulation factor of 30--50 in a bandwidth of 70 Hz. [138-8225]

USSR UDC 535.33:621.375.8;535:530.182;778.38

A CONTROLLED PHOTOTROPIC SHUTTER WITH INCREASED PRECISION OF SINGLE PULSE SYNCHRONIZATION OF A RUBY LASER

Moscow PRIBORY I TEKHNIKA EKSPERIMENTA in Russian No 5, 1978 pp 208-209

BALENKO, V. G., KAGNA, V. Z. and PODGAYETSKAYA, V. M.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D1140]

[Text] The design of a controlled phototropic shutter with an auxiliary exciter lamp is described, which provides for high synchronization precision of single pulse lasing, where the pulse attains tenths of microseconds. [138-8225]

USSR UDC 535.33:621.375.8;535:530.182;778.38

A DURABLE MINIATURE He-Ne LASER

Moscow PRIBORY I TEKHNIKA EKSPERIMENTA in Russian No 5, 1978 p 261

GUGA, Z. P., KALAGURSKIY, B. M., SAYCHUK, YA. D. and SENYUKOV, A. I.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D1030 by S.L.]

[Text] The brief technical characteristics of the portable LG-78 He-Ne laser (633 nm) are given. The output power of the laser attains mW in multimode operation and the average service life is 5,000 hours.
[138-8225]

USSR UDC 535.33:621.375.8;535:530.182;778.38

WIDEBAND INTERFERENCE REFLECTORS FOR ORGANIC DYE LASERS

Moscow SBORNIK NAUCHNYKH TRUDOV. MOSKOVSKIY INSTITUT ELEKTRONNOY TEKHNIKI [Collected Scientific Papers. Moscow Institute of Electronic Technology] in Russian No 35, 1977 pp 166-171

BALAGUROV, A. YA., PETROV, V. N. and SIMONOV, B. M.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D1137]

[Text] A method of monitoring the thicknesses of the layers of wideband dielectric mirrors is described which is distinguished by increased precision. Spectral characteristics are given for the resulting mirrors with reflection factors of 50 and 99% in the visible region of the spectrum; the values of the optical durability of a number of the coatings obtained were measured.
[138-8225]

USSR UDC 535.33:621.375.8;535:530.182;778.38

AN AUTOMATIC FREQUENCY CONTROL CIRCUIT FOR A He-Ne LASER USING THE LAMB SHIFT

Moscow SKHEMA AVTOPODSTROYKI CHASTOTY IZLUCHENIYA He-Ne LAZERA PO PROVALU LEMBA in Russian VINITI manuscript No 3879-78, 21 Dec 78 19 pp

KHANOV, V. A., Editorial staff of "Pribory i Tekhnika Eksperimenta" USSR Academy of Sciences

[From REFERATIVNYY ZHURNAL, FIZIKA, SVODNYY TOM (A-D) No 3 (I), Mar 79 Abstract No 3D1108DEP]

[Text] A He-Ne laser automatic frequency control circuit based on the Lamb shift is described, which maintains the precision characteristics of the radiation without monitoring on the part of the operator during an extended cycle of measurements and under conditions of a wide variation in air parameters and an increased level of vibration. A procedure is given for calculating the AFC parameters, as well as results of its experimental investigations and production tests.
[138-8225]

USSR UDC 535.33:621.375.8;535:530.182;778.38

THERMAL GAS DYNAMIC LASERS UTILIZING A $CO-CS_2-He$ MIXTURE

Moscow TEPLOVYYE GAZODINAMICHESKIYE LAZERY (TGDL) NA SMESI $CO-CS_2-He$ in Russian, Preprint No 235 Physics Institute, Academy of Sciences USSR, 27 pp

ORAYEVSKIY, A. N., RODIONOV, N. B. and SHCHEGLOV, V. A.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D1192]

[No text]

[146-8831]

USSR UDC 535.33:621.375.8;535:530.182;778.38

ON THE QUESTION OF VARIATION IN THE SPATIAL DISTRIBUTION OF THE GAIN OF LASER MEDIA

Moscow TRUDY MOSKOVSKOGO FIZIKO-TEKHNICHESKOGO INSTITUTA. SERIYA OBSHCHAYA I MOLEKULYARNAYA FIZIKA [Proceedings of Moscow Physicotechnical Institute. General and Molecular Physics Series] in Russian No 10, 1978 pp 52-55

BRODOV, M. YE., KAMENENTS, F. F., KOROBKIN, V. V. and SEROV, R. V.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D969 by G. Ye. Nikolayev]

[Text] The distribution of the gain over the cross-section of the active medium of a laser is studied theoretically. A relationship is found between the measured and the true values of the gain, which takes into account the size and shape of the cross-section of the probing beam.
[138-8225]

Magnetohydrodynamics

USSR UDC 533.92:621.039.61

EVOLUTION OF THE EQUILIBRIUM OF A TOROIDAL PLASMA COLUMN IN A SHELL OF COMPLEX SHAPE

Moscow EVOLYUTSIYA RAVNOVESIYA TOROIDAL'NOGO PLAZMENNOGO SHNURA V KOZHUKHE SLOZHNOY FORMY in Russian, Preprint No 119, Institute of Applied Mathematics 1978 36 pp

BABISHCHEVICH, P. N., DEGTYAREV, L. M., PISTUNOVICH, V. I., POSHEKHONOV, YU. YU. and SHAFRANOV, V. D.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4G119]

[No text]

[146-8831]

USSR UDC 537.52

A HIGH CURRENT ARC IN AN UNBOUNDED GAS FLOW

Frunze VOPROSY ATOMNOGO SPEKTRAL'NOGO ANALIZA I RASCHETOV NIZKOTEMPERATURNOY PLAZMY [Problems of Atomic Spectral Analysis and Calculations of Low-Temperature Plasma] in Russian No 1, 1977 pp 64-74

ZHAYNAKOV, A., LELYEVKIN, V. M. and ENGEL'SHT, Z. S.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3G242 by V. N. Soshnikov]

[Text] A steady-state high current electrical arc in a longitudinal gas flow is characterized by equations of motion which take into account viscosity and the intrinsic (radial) magnetic field, Ohm's law, Maxwell's equations with a longitudinal electrical field and the energy conservation equation. The forces of gravity, viscous dissipation, the work of expansion, joule heat emission in a radial direction, etc., are neglected. A boundary layer approximation is employed (the axial temperature and velocity gradients are small as compared to the radial ones). A system of partial differential two-dimensional equations is solved by making a transition to a finite difference network using a sweep method employing itterative procedures. Results are given for the numerical calculation of an arc in argon at a current of 200 amps, a nozzle radius of 1.5 mm, a cold ambient gas pressure of 1 atm, a temperature at infinity of 1,000 K, a mass rate of flow of 0.02 g/s and velocities of 0, 10 and 25 m/s.
[138-8225]

USSR UDC 537.52

MAGNETIC GAS DYNAMIC EQUATIONS FOR A HIGH CURRENT ARC DISCHARGE

Frunze VOPROSY ATOMNOGO SPEKTRAL'NOGO ANALIZA I RASCHETOV NIZKOTEMPERATURNOY PLAZMY [Problems of Atomic Spectral Analysis and Calculations of Low-Temperature Plasma] in Russian No 1, 1977 pp 75-93

SLOBODYANYUK, V. S. and ENGEL'SHT, V. S.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3G240 by V. N. Soshnikov]

[Text] A general system of gas dynamic equations taking convection, radiation and electromagnetic forces into account), as well as Maxwell's equations and Ohm's law is specifically applied to the conditions of an open high current arc (currents greater than 100 A at atmospheric pressure). The difficulties related to specifying the boundary conditions in a steady-state open arc are noted. The differential equations are simplified in a so-called approximation of a laminar boundary layer (the axial temperature gradients and velocity are small as compared to the radial ones). An integral form of writing the motion, continuity and energy balance equations is also given, from which equations for the arc are derived as a special case in a laminar boundary layer approximation in integral form.
[138-8225]

Nuclear Physics

USSR UDC 533.9(201)

ANALYZER OF SINGLE RADIATION PULSES

Moscow EKSPERIMENTAL'NYYE METODY YADERNOY FIZIKI [Experimental Methods of Nuclear Physics] in Russian No 4, 1978 pp 89-105

BEGLYAKOV, N. N., KIRILLOV-UGRYUMOV, M. V., PRORVICH, V. A. and SARTORI, A. V.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4G235 by Ye. P. Potanin]

[Text] The possible methods are discussed of designing analyzers of the electrical signals of detection systems for single radiation pulses and a description is given of functional circuits of a developed analyzer and of its individual components. The following key requirements are formulated for electronic analyzing equipment: a) multi-channel design; b) wide dynamic range of signal amplitudes ($\sim 10^3$); c) measurement error of less than one percent; d) time for processing signals and outputting information shorter than the radiation pulse repetition rate; e) general-purpose application; f) ability to connect analyzing system on-line with a computer. The results are given of tests of the analyzer developed.
[146-8831]

USSR UDC 535.33:621.375.8;535:530.182;778.38

THE OBSERVATION AND INVESTIGATION OF THE PROCESS OF TWO-ELECTRON MANY-PHOTON IONIZATION OF ATOMS

Moscow NABLYUDENIYE I ISSLEDOVANIYE PROTSESSA DVUKHELEKTRONNOY MNOGOFOTONNOY IONIZATSII ATOMOV in Russian, Preprint No 172, Physics Institute of the Academy of Sciences USSR 1978 19 pp

ALEKSAKHIN, I. S., DELONE, N. B., ZALESOCHNYY, I. P. and SURAN, V. V.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D925]

[Text] The process of the formation of doubly charged ions during many-photon ionization of a series of atoms (Sr, Ba, Sm) is revealed, where these have two optical electrons, and the process occurs in a strong laser radiation light field. It was determined that the ions are formed as a result of a two-electron process of resonant many-photon ionization of the atoms.
[138-8225]

USSR UDC 535.33:621.375.8;535:530.182;778.38

THE RADIATION OF A RELATIVISTIC CHARGED PARTICLE IN AN ALTERNATING ELECTRICAL FIELD

Moscow PROBLEMY STATISTICHESKOY I KVANTOVOY FIZIKI [Problems of Statistical and Quantum Physics] in Russian 1978 pp 87-90

GUTSUNAYEV, TS. I. and KAZACHKOV, V. D.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D980 by V. Kh.]

[Text] The motion of a relativistic particle in a spatially homogeneous harmonic electrical field is computed. The trajectory of motion and the Lienard-Wiechert potentials of the electromagnetic field of the particle are derived. Expressions are given for the spectral and angular distribution of the particle radiation energy in the harmonic field under discussion. [138-8225]

USSR UDC 539.1.08

INTERFACING MINICOMPUTERS TO UNIFIED SYSTEM COMPUTERS BY MEANS OF A SMALL INTERFACE

UPRAVLYAYUSHCHIYE SISTEMY I MASHINY in Russian No 5, 1978 pp 87-90

ABADZHIDI, V. YE., IVANOV, V. A., ILLARIONOV, V. N., SMICHKUS, YE. A. and TIMASHOV, A. A.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3V728 by the authors]

[Text] The connection of a microprogram minicomputer having a 2K interface and limited memory volume directly to a YeS-1022 by means of a specially designed adapter, feeding out to a small interface of the unified series of computers is treated. The functions of simulating a tape transport mechanism are assigned to the minicomputer in this case. [138-8225]

USSR UDC 539.1.08

ON THE OPERATION OF THE LUE-300 ACCELERATOR DURING 1977

Khar'kov VOPROSY ATOMNOY NAUKI I TEKHNIKI. SERIYA TEKHNIKI FIZICHESKOGO EKSPERIMENTA [Problems of Nuclear Science and Engineering Series on Physics Experiment Techniques] in Russian No 1/1, 1978 pp 3-5

GONCHAR, V. P., IVANOV, G. M., MAKHNENKO, L. A., PONOMARENKO, B. A., PAKHOMOV, V. V., RYABKA, P. M. and SALIY, L. D.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract 3V516]

[Text] The basic data are given for the operation of the LUE-300 accelerator during 1977, and a comparative analysis is carried out for the operation of its systems over the last five years.
[138-8225]

USSR UDC 539.1.08

A MULTIPLE BEAM ACCELERATOR BASED ON THE LU-2 ACCELERATOR OF THE KHAR'KOV PHYSICS AND ENGINEERING INSTITUTE OF THE UKRAINIAN ACADEMY OF SCIENCES

Khar'kov VOPROSY ATOMNOY NAUK I TEKHNIKI. SERIYA TEKHNIKI FIZICHESKOGO EKSPERIMENTA [Problems of Nuclear Science and Engineering. Series on Physics Experiment Techniques] in Russian No 1/1, 1978 pp 6-8

ARTEMOV, V. I., DEM'YANENKO, G. K., MEL'NICHENKO, V. V. and PEYEV, F. A.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3V518]

[Text] A structural configuration is proposed for the accelerating and focusing channel of a multibeam accelerator designed around the LU-2 [linear accelerator] of the Khar'kov Physics and Engineering Institute of the Ukrainian Academy of Sciences, which provides experimenters with the capability of simultaneously working on two to four independent programs. The basic principles of accelerator control are determined. The characteristics of the beam shaping channel are determined on a computer by means of a mathematical model. Based on the specified initial parameters of the beams, their values are computed at the accelerator output.
[138-8225]

USSR UDC 539.1.08

A PICOSECOND LINEAR ELECTRON ACCELERATOR

Khar'kov VOPROSY ATOMNOY NAUKI I TEKHNIKI. SERIYA TEKHNIKI FIZICHESKOGO EKSPERIMENTA [Problems of Nuclear Science and Engineering. Series on Physics Experiment Techniques] in Russian No 1/1, 1978 pp 9-12

PAVLOV, YU. S.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3, Mar 79 Abstract No 3V517]

[Text] The paper describes a linear electron accelerator operating in the subnanosecond range by virtue of a device which employs subharmonic preliminary bunching of the beam. The operation of the individual accelerator components is analyzed: the deflecting system for generating the nanosecond pulses, the subharmonic resonator and the synchronization system. Experimental data are given for the operation of the accelerator in the pulsed mode with pulses having a half-height width of 0.2 ns.
[138-8225]

USSR UDC 539.1.08

ON THE POSSIBILITY OF ACCELERATING IONS WITH A MODULATED ELECTRON BEAM IN A PERIODIC MAGNETIC FIELD

Khar'kov VOPROSY ATOMNOY NAUKI I TEKHNIKI. SERIYA TEKHNIKI FIZICHESKOGO EKSPERIMENTA [Problems of Nuclear Science and Engineering. Series on Physics Experiment Techniques] in Russian No 1/1, 1978 pp 18-20

GAVRILOV, N. M. and NESTEROVICH, A. V.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3V501]

[Text] It is proposed that ions be accelerated in a system with a time modulated high current electron beam, injected into a corrugated magnetic field. Based on a calculated estimate of the electrical field, the possibilities and prospects for the realization of a method employing the effect of collective interaction in a resonance system are analyzed.
[138-8225]

USSR

UDC 539.1.08

A STUDY OF THE CHARACTERISTICS OF AN ELECTRON BEAM WITH MAGNETIC INSULATION

Khar'kov VOPROSY ATOMNOY NAUKI I TEKHNIKI. SERIYA TEKHNIKI FIZICHESKOGO EKSPERIMENTA [Problems of Nuclear Science and Engineering. Series on Physics Experiment Techniques] in Russian No 1/1, 1978 pp 21-24

BELIKOV, V. V., LYMAR', A. G. and KHIZHNYAK, N. A.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3V502]

[Text] Expressions for the parameters of the electron beam as a function of the applied voltage, the beam geometry, the cathode material and the intensity of the magnetic field are derived for a diode beam with a field emission-plasma cathode and magnetic isolation between the cathode and anode. It is shown that in a strong magnetic field, along with the useful collector current, there also exists a significant leakage current at points unprotected by the magnetic field. This current causes the shorting of the high voltage electrode and thereby limits the pulse width. Electron beams were obtained with an energy of 200 KeV, a current of 600 A and a pulse width of 1 microsecond; the magnetic field was 2 T and the diameter of the electron beam was 8 mm.
[138-8225]

USSR

UDC 539.1.08

A DISK TYPE CASCADE GENERATOR

Khar'kov VOPROSY ATOMNOY NAUKI I TEKHNIKI. SERIYA TEKHNIKI FIZICHESKOGO EKSPERIMENTA [Problems of Nuclear Science and Engineering. Series on Physics Experiment Techniques] in Russian No 1/1, 1978 pp 27-29

VENEVTSEV, I. T., SKOROMNYY, G. M. and REVUTSKIY, YE. I.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3V504]

[Text] Questions of reducing the dimensions of cascade generators (KG) are analyzed. The small KG-300 cascade generator is described, which is designed around K15-4 capacitors and silicon rectifier columns of the D1004 type when driven by a voltage at a frequency of 500 Hz. The parameters of the KG-300 at frequencies of 500 Hz and 18 KHz are given. A schematic is shown for a thyristor frequency converter being designed to drive the KG-300. The anticipated output voltage is 350 kilovolts.
[138-8225]

USSR UDC 539.1.08

A HIGH VOLTAGE CASCADE GENERATOR USING SILICON DIODES

Khar'kov VOPROSY ATOMNOY NAUKI I TEKHNIKI. SERIYA TEKHNIKI FIZICHESKOGO EKSPERIMENTA [Problems of Nuclear Science and Engineering. Series on Physics Experiment Techniques] in Russian No 1/1, 1978 pp 30-31

VENEVTSEV, I. T., SKOROMNYY, G. M. and SHELETKO, V. P.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3V505]

[Text] The 150 kilovolt KG-150 high voltage cascade generator is described, in which silicon diodes with discharger protection (without shunting capacitors) and ceramic capacitors with a high specific capacitance per unit volume are employed. The specific features of the design calculations are shown. The divergence between the characteristics obtained by trial calculations and those based on a model of it are insignificant.
[138-8225]

USSR UDC 539.1.08

ON THE CALCULATIONS OF THE ELECTRICAL FIELDS EXCITED BY MAGNETIC MOMENT PRECESSION IN A FERRITE

Khar'kov VOPROSY ATOMNOY NAUKI I TEKHNIKI. SERIYA TEKHNIKI FIZICHESKOGO EKSPERIMENTA [Problems of Nuclear Science and Engineering. Series on Physics Experiment Techniques] in Russian No 1/1, 1978 pp 44-46

RAKITYANSKIY, A. A. and SHENDEROVICH, A. M.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3V500]

[Text] The authors consider the feasibility of using precession of the magnetic moment in a ferrite to set up electric eddy fields for electron beam acceleration. The electrical field is calculated in the case of an arbitrary precession amplitude for two cases: 1. The ferrite is placed in a metal waveguide; 2. There is no metal waveguide. It is shown that the precession period is almost independent of its amplitude. The maximum precession amplitude at which the results of the calculations for both of the cases considered practically coincide is computed.
[138-8225]

USSR UDC 539.1.08

A DEVICE FOR DETERMINING THE POSITION OF THE CENTER OF GRAVITY OF A BEAM OF CHARGED PARTICLES

USSR Author's Certificate No 500721 filed 4 Feb 74, published 9 Aug 77

OL'KHOVIKOV, L. V., GERASIMOV, V. T. and SKOSAREV, V. A.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3V546 by L.I.]

[Text] An improved device for determining the position of the center of gravity of a charged particle beam is proposed, which contains a dual winding sensor, amplifiers for the signals from the sensor windings, a differential amplifier and a summing amplifier, a division (normalization) circuit, a recording indicator and a test signal generator. For the purpose of preventing additive errors in the measurements, due to the action of induced noise on the sensor and the cables connecting the sensor to the equipment, each winding of the sensor is made as a dual section winding with a grounded center tap. The switching of the inputs and outputs of the blocks of the unit is described, which provides for the optimum operating mode of the device.
[138-8225]

USSR UDC 533.92:621.039.61

A THERMONUCLEAR FACILITY

USSR Author's Certificate No 529717 in Russian filed 17 Jan 75, published 17 Feb 77

BOL'SHAKOVA, M. M., IZOTOV, YE. I., SAMARIN, A. YE. and ODINTSOV, V. N.

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4G145 by Ye. P. Potanin]

[Text] A thermonuclear facility of the "Tokamak" type is known that contains a high-temperature discharge chamber located in the windings of a longitudinal magnetic field and surrounded by a cooled jacket pressurized along its equatorial meridian sections and separated from this jacket by a vacuum space in which are located local heat proofing shields. For the purpose of lowering the heat transfer coefficient and reducing energy costs for heating the chamber, it is suggested that the heat proofing be executed in the form of a multilayered toroid made out of reflecting segments arranged in tandem and forming multilayered poloidal sections offset relative to one another in the

vertical plane and mechanically connected to one another and the discharge chamber while preserving two degrees of freedom. Furthermore, all sections are electrically and thermally insulated from one another, and each segment is made with a two-sided coating of a dielectric material improving its reflecting properties.
[146-8831]

USSR UDC 539.1.08

A DEVICE FOR STUDYING NUCLEAR PARTICLE INTERACTION AND DECAY

USSR Author's Certificate No 554516 filed 16 Aug 74, published 14 Jun 77

OKONOV, E. O., Joint Nuclear Research Institute

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3V693P by L.I.]

[Text] A refinement of a streamer chamber is proposed which is placed in the field of an electromagnet, which permits increasing the effectiveness of recording particle interactions and decays, and prevents the merging of the streamers as well as breakdowns in the chamber. The electromagnet, the field intensity of which is chosen on the basis of the capture condition in a spiral (or circular) orbit of the particles being studied is equipped with either shims or additional windings which produce a gradient of the magnetic field along its major component. The particles are introduced into the chamber at an angle θ to the plane perpendicular to the major component of the magnetic field H so that in crossing into the region of increasing field, the particles form a trajectory of increasing curvature in the form of a contracting spiral. In this way the magnetic field gradient that twists the streamer track into a helix precludes the merging of the streamers of adjacent turns and prevents flashover along the electrical field.
[138-8225]

USSR UDC 539.1.08

A DEVICE FOR MONITORING AND MEASURING THE MEMORY TIME OF A STREAMER CHAMBER

USSR Author's Certificate No 566221 filed 24 Mar 76, published 10 Nov 77

VOLODIN, V. D., GLAGOLEVA, N. S., MATYUSHIN, A. T., MATYUSHIN, V. T., MUSUL'MANBEKOV, ZH. ZH. and NURGOZHIN, N., Joint Nuclear Research Institute

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3V699P by L.I.]

[Text] A device is designed for monitoring and measuring the memory time of a streamer chamber, which is distinguished by increased sensitivity and precision. The operational principle of the device is based on registration of gas escaping from the streamer chamber. The unit for registering the gas is made in the form of a spark chamber with a filmless device for registering the presence of a spark in the chamber and with an independent triggering unit, in which a variable delay block is incorporated. The spark chamber is equipped with scalers to measure the memory time of the streamer chamber based on spark chamber efficiency. The designed device permits continuous operational monitoring of the streamer chamber memory time in the course of an experiment and reduces the acceleration time losses by about 4%. [138-8225]

Optics and Spectroscopy

USSR UDC 535.33:621.375.8;535:530.182;778.38

AN EXPERIMENTAL STUDY OF LASER PHASE METER CHARACTERISTICS

Moscow METROLOGICHESKOYE OBESPECHENIYE FAZOVYKH I POLYARIZATSIONNYKH IZMERENIY V KOGERENTNOY OPTIKE [Metrological Support of Phase and Polarization Measurements in Coherent Optics] in Russian 1978 pp 10-18

ZHELKOBAYEV, ZH., KALENDIN, V. V. and KUKHTEVICH, V. I.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D1162 by A.D.]

[Text] A device is described for the precise measurement of the phase difference between interfering beams: a laser phase meter. The optical section of the instrument is designed around a Mach-Zehnder laser interferometer with photoelectric registration of the phase modulation signal. The operational modes and experimental characteristics of the device are described. The capability of achieving a relative phase sensitivity of 10^{-6}--10^{-7} and a measurement precision for small phase shifts of about 0.01 degree is shown. Questions of the practical application of the laser photometer are discussed. [138-8225]

USSR UDC 535.33:621.375.8;535:530.182;778.38

THE UTILIZATION OF A DIFFERENTIAL PRODETECTOR IN A COORDINATE SENSITIVE MODE

Moscow METROLOGICHESKOYE OBESPECHENIYE FAZOVYKH I POLYARIZATSIONNYKH IZMERENIY V KOGERENTNOY OPTIKE [Metrological Support of Phase and Polarization Measurements in Coherent Optics] in Russian 1978 pp 30-35

BARDYUKOV, A. M., BERG, M. E., KUKHTEVICH, V. I. and MOLDAVSKAYA, F. V.

[From REFERATIVNYY ZHURNAL, FIZIKA No 3 (I), Mar 79 Abstract No 3D1143 by V. Kh.]

[Text] A differential dual stage pyrodetector is described. The coordinate sensitive operational mode is analyzed, which is employed in determining the shape of the wave front of coherent radiation. The range of linearity of the device is determined (linear relationships between the device signal and the displacement of the light beam). A beam is analyzed, the intensity distribution in which is described by a Bessel function and is similar to the

distribution in a stopped down beam with plane wave diffraction at a circular opening.
[138-8225]

USSR UDC 535.8;53.082.5

UNIT FOR OBSERVING SPECTRAL CHARACTERISTICS OF THIN-FILM OPTICAL COATINGS IN THE PROCESS OF THEIR FABRICATION

Moscow USTROYSTVO DLYA NABLYUDENIYA SPEKTRAL'NYKH KHARAKTERISTIK TONKOSLOYNYKH OPTICHESKIKH POKRYTIY V PROTSESSE IKH IZGOTOVLENIYA in Russian 1978 manuscript deposited at VINITI 17 Jan 79 No 224-79 Dep, 12 pp

JEFREMOV, D. YE., Moscow Higher Technical School imeni N. E. Bauman

[From REFERATIVNYY ZHURNAL, FIZIKA No 4, 1979 Abstract No 4D1480 DEP by the author]

[Text] A description is given of an uncomplicated instrument for observing the spectral characteristics of thin-film optical coatings in the process of their fabrication. The instrument's operating principle is based on the separation of the light flux passing through a specimen with the coating being applied into individual light fluxes which, after passing through light filters, encounter photodetectors. A description is given of the operating procedure when applying different kinds of coatings. The unit is recommended for use in the fabrication of optical coatings under laboratory and industrial conditions. References 4.
[146-8831]

CSO: 1862

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