

STUDYING PHYSICS AT MOSCOW STATE UNIVERSITY

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This master's-degree program combines general instruction with specialized research experience. It is a tough course, and the graduates are in great demand.

students admitted to our physics department come directly from school and are 16-18, we can nevertheless take quite a large number from higher age groups. This section, as a rule, represents the group that, having finished high school, immediately took a job in a factory or office. They have a right to be admitted to any higher-educational institution provided, of course, that they qualify at the entrance examinations.

The examinations include a paper in mathematics. Generally five questions are given, to be solved in four hours; they include algebra, geometry and trigonometry. A knowledge of mathematics to the extent taught in the secondary schools is sufficient to tackle these problems. For an example, look at a few questions given in the 1967 entrance examinations (box on page 36). If a candidate obtains at least "satisfactory" grades in this written examination he qualifies for the "viva voce" (oral examination) in mathematics. In the oral examination, too, the questions cover the secondary-school curriculum.

Physics written and oral examinations are conducted after the mathematics tests are completed. The box on page 37 illustrates the contents of a physics paper from the 1968 examination; it contains five questions on different branches of elementary physics. The last examination is an essay on Russian literature (the student chooses from a few given topics).

The final selection of candidates is made on the basis of aggregate marks obtained in the four examinations

(written and oral in physics and mathematics), of those candidates who obtained at least a "satisfactory" grade for their essay. Those who complete their high-school education with a gold or a silver medal are given one more additional mark. Only those who obtain a certain minimal number of marks, the "qualifying grade," are admitted to the university. The qualifying grade is determined by the number of candidates appearing in the entrance examinations—a number that exceeds by a few times the number of available places. Thus in 1968 the ratio was about seven to one, and only 500 physics students were admitted. About 80% of these students will finish the stiff 5-6 year course.

Most of the students, about 60-70%, receive a state stipend, which is granted on two basic criteria. They are his progress (that he should obtain at least "good" grades) and his financial status. If the student is married and progress is "good," the stipend is granted regardless of the income of other family members. Students who make "excellent" grades are given higher stipends, and the top students are awarded special scholarships named after eminent scientists.

Groups and sections

Studies start on 1 Sept. at Moscow State University. The new students are formed into groups of 30-40. These groups are, in a sense, created for the convenience of the academic work; the size of each group is determined by such considerations as: Is it possible to conduct effective semi-

IN HIS FIVE AND A HALF YEARS at Moscow State University, a physics student takes three or four years of general courses followed by one or two years of specialized training in some field of research. During the first stage he receives a broad and rigorous education in general physics and mathematics, reaching modern physics by his third year. If he is successful in the examinations that test his progress regularly, he can continue into the second stage: specialization. He chooses his field of physics and is assigned to work in a nearby laboratory, perhaps one in the university itself. After about a year he is ready to write a dissertation, rather like a small PhD thesis, on his research work. When the student successfully defends this dissertation before his examining committee he finally becomes a graduate of the university and is eagerly sought by prospective employers.

Entrance requirements

The physics student at Moscow State University starts his educational career with the entrance examinations, generally conducted in July. Only those applicants who have completed their secondary-school education are allowed to take these entrance examinations.

Although a large number of the



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nars in which the teacher can observe each student individually and stimulate his interest towards his studies? The composition of the group is retained until its members graduate, and each group has its own teachers, who conduct seminars and laboratory practicals.

These groups are fused into two "sections" of 200-250 students each, for the purpose of attending lectures, which are delivered separately to each section.

Course philosophy

The general teaching practice in our department has been developed over

a long period and, in that sense, is traditional. However, some finer points are considered every year and undergo modifications. Changes are introduced in the syllabus of some subjects, new courses are added, the number of lecture hours are changed, one type of examination is replaced by another. Similarly, laboratory practicals undergo changes, and the regulations governing the rights and duties of students are reexamined every year.

With our entire educational process we try to train young specialists with the following characteristics:

- a broad and sufficiently deep knowledge of the fundamentals of

RUSSIAN STUDENTS at Moscow State University (far left) and Zhdanov University in Leningrad (left). Moscow State accepts about 500 new physics majors each year out of seven times that number of applicants.

modern physics and mathematical analysis (including the methods of mathematical physics)

- specialization in one of the branches of modern physics, chosen by the student himself. This training should be such that the student can undertake independent research in his special subject immediately after graduation.

The entire course of educational training, which must be completed in about five and a half years, is divided into two stages—general training and specialization. The first stage takes about 3-4 years, and the second about 1-2 years. However, these stages partially overlap each other, because the special subject is formally assigned at the second semester of the third year, and some general teaching continues up to the end of the fifth year.

We believe that the process of studying the sciences should repeat the history of their development. For this reason we start with arithmetic in the schools and move on to algebra and geometry—so following the steps by which mathematics developed.

With this approach, our 18-year-old students begin their serious studies with mathematical analysis and then make contact with classical physics. In practice this means that, during the first two years, a student will study the fundamentals of the physics of macroscopic objects in lectures, seminars and laboratory experiments without going into details of their theoretical structure. During this short period he will acquire the necessary training in differential and integral calculus and

will also take a course in theoretical mechanics.

Modern physics and research

The student first encounters modern physics in his third year. He listens to lectures on the experimental foundations of atomic and nuclear physics and carries out experiments in the appropriate laboratory. This work completes his general course on experimental physics. However, the lectures on atomic and nuclear physics are only a small part of this, the most difficult, part of the course. A major part of the third-year course is devoted to theoretical disciplines such as electrodynamics, quantum mechanics, thermodynamics and statistical physics. Moreover, much time in the third year is allotted to methods of mathematical physics. In his last two years at the university, the student is taught to be more and more independent in his work.

The student chooses his specialization from one of the following subjects: nuclear physics, radiation physics, physical electronics, physics of semiconductors, optics, low-temperature physics, and others. He makes his choice with the consent of the section of the physics department that conducts the appropriate subject. From that time on, the student is under the direction of the specialized section. The syllabus, and content of lectures, seminars and laboratory practicals in special disciplines, are more flexible than those of the general

Table 1. First-Year Course 1967-68

	Total number of hours in academic year	Lectures	Seminars	Practicals
Mathematics	340	204	136	
General physics	168	100	68	
Practical physics	170			170
Drawing and machine-shop practice	136			136
Other subjects (foreign language, physical training, sports, etc.)	374			

Plus 18 examinations and tests during the year

course in experimental and theoretical physics and mathematical analysis.

This specialized training is designed to allow the student to undertake independent research immediately after he graduates. He should receive enough scientific knowledge that he can perceive the development and trends in his specialization; he should acquire the necessary skills in handling apparatus (if he is an experimentalist). Of course, a proper balance should be maintained among the various elements of his training, the basic object being independent work in a research laboratory at the end of his university course.

The first year

Now let us return to our original topic and examine the training in detail.

Teaching is conducted strictly in conformity with the syllabus, which is drafted every year and defines the subjects to be taught, number of hours al-

lotted to each subject, seminars, laboratory and machine-shop practicals. The syllabus drafted for the first-year course in the 1967-68 academic year is shown in table 1.

The academic load on the first-year student is 35 academic lecture hours per week (one "lecture hour" consists of 45 minutes of work and a 15-minute break). A student attends 204 hours of lectures on mathematics and spends 136 hours in mathematics seminars, in which he is basically engaged in solving problems to assimilate the knowledge gained in lectures.

In the first year the student studies the fundamentals of differential and integral calculus (with the elements of the modern theory of functions of a complex variable), analytical geometry and linear algebra. In the general course in physics (100 hours of lectures and 68 hours of seminars) he studies the fundamentals of mechanics, physical properties of gases, liq-



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ENTRANCE EXAMINATION (mathematics)

1 Solve

$$\frac{(\log_{0.5} x - 81)^{1/2} + 2}{\log_{0.5} x - 1} < 1$$

2 For every real value of a , find all the real solutions to the equation

$$\sin x + \sqrt{2} \sin(a - x) = 1$$

3 Point C is located between A and B, where $AC = 17$ km and $BC = 3$ km. A car starts from A towards B, and, having covered no more than two kilometers, stops. It starts again towards B some time later. At this instant a pedestrian and a cyclist start from C towards B with constant speed. Each of them, on reaching B, immediately turns back towards C.

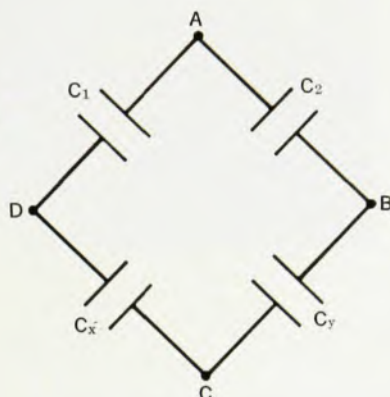
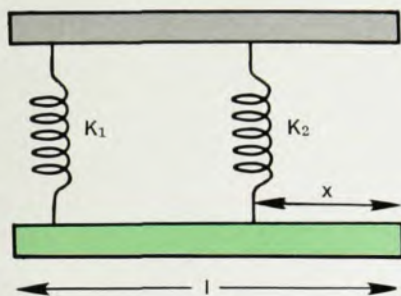
Who will meet the car first, if the speed of the car is four times greater than that of the cyclist and eight times greater than that of the pedestrian?

4 A circle is inscribed in an acute-angled triangle ABC, such that its diameter lies on the side AB, and an arc touches the sides AC and BC. Find the radius of the circle, length of the arc and sides AC and BC, if $AC = b$ and $BC = a$, angle $ABC = \alpha$.

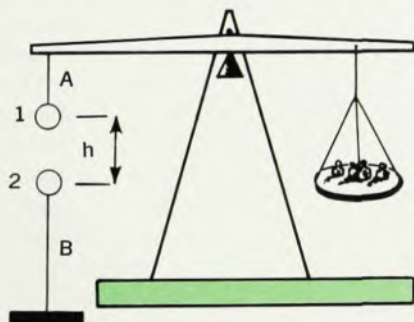
5 A sphere touches the slant edges of a right regular hexagonal prism, whose base lies outside the sphere. Find the ratio of the area of the sides of the prism enclosed by the sphere to the area of the sphere outside the prism.

ENTRANCE EXAMINATION (physics)

- 1 A uniform rod of length $L = 0.4$ m is suspended from the ceiling with two springs, as shown in the figure. They have identical lengths when unextended, and their coefficients of elasticity are related by the equation $2K_1 = K_2$. The spring with coefficient K_1 is fixed to one end of the rod. Find the distance x from the other end at which the spring with coefficient K_2 should be fixed if the rod is to remain in a horizontal position.



- 2 Four capacitors are interconnected as shown in the figure. The positive terminal of a battery can be joined to A and C, or to D and B. We are given $C_1 = 2 \mu\text{F}$ and $C_2 = 5 \mu\text{F}$. Find the capacities of C_x and C_y so that the charges on all capacitor plates will be equal in absolute value, irrespective of whether the positive emf is joined to A and C or B and D.
- 3 A thin thermally insulating and easily movable piston is enclosed inside a cylinder, which is horizontal, cylindrical, thermally insulating and closed at both ends. Oxygen at a constant temperature $t_1 = 127^\circ\text{C}$ fills the cylinder on one side of the piston, while hydrogen at a constant temperature $t_2 = 27^\circ\text{C}$ fills it on the other side. The masses of the two gases are equal. Find the position of the piston under these conditions if the length of the cylinder is 65 cm.
- 4 A point source of light is placed at the focus of a convex lens, with focal length 6 cm. A flat screen is placed 12 cm from the lens. A circular light patch is seen on the screen. In which direction and to what distance should the light source be moved from the lens (along the optical axis) so that the radius of the circular light patch on the screen is doubled?
- 5 A metal ball of radius $r_1 = 1$ cm is attached to the beam of a balance with a dielectric rod A. The balance is brought into equilibrium by placing weights in the pan. A charged sphere 2 of radius $r_2 = 2$ cm is placed below sphere 1. The distance between the centers of the spheres is $h = 20$



cm. The spheres were joined with a wire and subsequently disconnected. Then it was found that a weight $p = 4$ mg had to be removed from the pan to set the balance in equilibrium. Find the potential ϕ of the sphere 2 before it was joined to sphere 1.

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ENTRANCE EXAM JITTERS at MSU.

uids and solids, acoustics, molecular physics and heat (elementary thermodynamics). In this first course, the student should carry out at least 24 experiments and acquire some skills in handling mechanical and electrical apparatus.

Each academic year consists of two semesters. The first ends with winter examinations, conducted from about 25 Dec. to 25 Jan. For the first-year students this is the first examination after their admission.

Only those students who have obtained satisfactory gradings in seminars, laboratory and machine-shop practicals are permitted to take this examination. In addition, during the first semester, tests in physics and mathematics are conducted two or three times in the seminars. In these tests the students have to answer three or four questions in a limited time. A few typical examples of the physics questions set last fall are shown in the box on page 38. The laboratory practicals designed for the first-year course are standard (the box on page 39 shows examples). A few of the topics covered in the first examination in physics after the 1968-69 winter semester is shown in the box at the bottom of page 39.

Having taken the examination, the student spends two weeks, generally in February, as his well earned winter vacation, followed by three and a half months of intensive study. Then come more examinations in June just like those in the winter. Only those students who have done the minimal number of practicals (10-12 more experiments) and obtained satisfactory grades in the seminars on physics and mathematics are allowed to take this



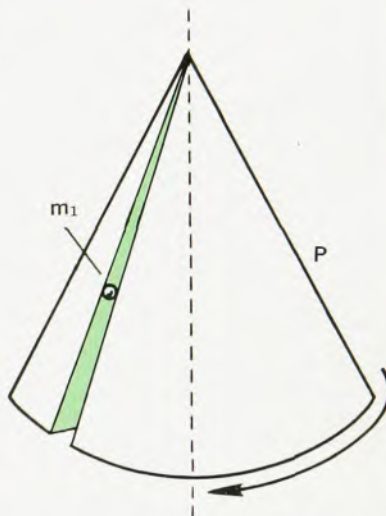
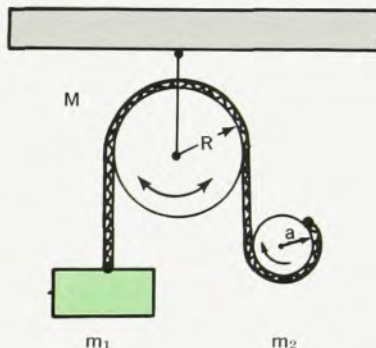
ASST. PROFESSOR DOBROV lectures on computing techniques in seminar room at Moscow State University (above).

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FIRST-YEAR SEMINARS (class test)

- 1 A mechanical system consists of a load (mass m_1), a suspended pulley (mass M , radius R), a free pulley (mass m_2 , radius a) made of uniform material and an inextensible wire. The suspended pulley can rotate freely about its axis. The system is arranged as shown in the figure. Find the accelerations of m_1 and m_2 (assuming that the wire does not slip over the pulleys).



- 2 A thin and shallow groove is cut on the inclined surface of a cone that can rotate freely about the vertical axis, which is also its geometrical axis. The cone is set in motion with an angular velocity and at the same time a ball is allowed to slide along the groove from the top. Find the angular velocity of the cone when the ball leaves it. Masses of the ball and cone are M_1 and P respectively.
- 3 Rotation of the earth deflects a falling body towards the east. Find the deflection x on the earth's surface for a body falling from a height h towards the equator. Solve this problem in three different ways:
 - 1) in a coordinate system fixed with respect to the earth.
 - 2) in a coordinate system fixed with respect to the stars, applying the laws of dynamics to the falling body.
 - 3) in a coordinate system fixed with respect to the stars, applying the law of conservation of momentum.

examination. Similarly each student must attain a minimal standard in physical training and sports. The summer examinations show the general progress achieved in the first year of study. Then the university closes, for the summer vacation, until 1 Sept.

Second and third years

Table 2 shows the distribution of lecture hours allotted to different disciplines taught in the second year. General (experimental) physics and mathematical analysis are continued. At this stage we start lectures on theoretical mechanics.

High-frequency techniques, which have gained immense importance lately, are also included in the syllabus. We give a special course of radiation physics, consisting of 48 lecture hours. The general academic load is maintained at about the same level as in the first year (33 hours in the first semester and 36 hours in the second, per week). *The Feynman Lectures on Physics*, by R. P. Feynman, R. B. Leighton and M. L. Sands, is one of the most popular texts for students at this stage.

In the third year the student is given a glimpse of the vast expanses of modern physics. He encounters electrodynamics, quantum mechanics, atomic and nuclear physics. Lest he should be overcome by the lofty heights he has climbed, he is fed a weighty course in the methods of mathematical physics. The program of the third year—an arduous period

FIRST-YEAR LABORATORY PRACTICALS (first semester)

12 experiments must be completed in the first semester

- 1 Exact weighing
- 2 Pendulum
- 3 Reversible pendulum
- 4 Determination of moment of inertia
- 5 Determination of Young's modulus by linear expansion and beam-bending methods
- 6 Torsional vibrations
- 7 Oscillations of a spring pendulum
- 8 Determination of viscosity of liquid by Poiseuille's and Stoke's methods
- 9 Determination of mechanical equivalent of heat
- 10 Determination of C_p/C_v for air and other gases

plus 30 more experiments

in the physics course—is shown in table 3. The academic load, as usual, is heavy—about 33–36 hours per week. There are two examination sessions. To give a rough idea of the program, let me illustrate with topics from a few question papers in different courses: atomic physics and electrodynamics appear in the boxes on page 40. The box on page 40 contains some of the experiments that a student should carry out in his practicals on atomic physics.

During the first three years of study the student learns the basic foundations of mathematics. He takes 812

lecture hours, reinforced by 326 seminar hours, and is given six periodic examinations (of course, there are many class tests). This basic foundation in mathematics is needed so that the fundamentals of theoretical physics can be taught in the fourth or fifth courses on a sufficiently high level.

Fourth year—specialization begins

The course in general topics of physics is completed with lectures and seminars on quantum mechanics, thermodynamics and statistical physics. Special disciplines occupy an important position in the syllabus of this fourth-

year course, and a student's syllabus is drafted with reference to the specializations. Thus, for example, the fourth-year students opting for nuclear physics take lectures on nuclear theory, reactors, neutron physics, electronics in nuclear physics, ionizing radiations, cosmic rays and other topics—a total of 232 hours. In addition they must carry out a large number of experiments in the nuclear laboratory. Some of these experiments are shown in the box on page 40.

The aim of our university education is to train scientists who could subsequently make use of their acquired knowledge with maximal activity and independence. These two qualities—activity and independence—develop along with the experience gained in direct research work in the laboratory. Acquiring skills in research methods is the main content of the final stages of our program. By the end of the fourth, or the beginning of the fifth, year of study the students are assigned to different research laboratories in Moscow and its suburbs (including the laboratory of the physics department of Moscow State University). We find that the personal contact between scientific personnel and students plays a very significant role in this work.

Soon after the student is introduced to research work he is allocated an independent topic that eventually forms the subject of his master's-degree dissertation. It is a small research project carried out by the student under the guidance of one of the scientific staff of the laboratory. Generally, one year is spent on it. Some dissertation topics of students specializing in atomic and electron physics in 1967–68 are shown in the box on page 40. In essence, the dissertation is a miniature PhD thesis.

In many cases the dissertation contains results valuable enough for jour-

Table 2. Second-Year Course 1967–68

	Total number of hours in academic year	Lectures	Seminars	Practicals
Mathematics	292	188	104	
General physics	204	136	68	
Practical physics	170			170
Radio physics	48	48		
Theoretical mechanics	64	32	32	
Other subjects	358			

Plus 18 examinations and tests during the year

Table 3. Third-Year Course 1967–68

	Total number of hours in academic year	Lectures	Seminars	Practicals
Methods of mathematical physics	206	120	86	
Atomic physics	54	54		
Nuclear physics	48	48		
Theoretical mechanics	90	54	36	
Electrodynamics	120	86	34	
Quantum mechanics	64	48	16	
Optional subject	64	64		
Practical physics	150			150
Other subjects	294			

Plus 18 examinations and tests during the year

FIRST-YEAR EXAMINATION PAPER (general physics)

Winter semester, 1968–69

- 1 Laws of dynamics in moving system of axes. Centrifugal force of inertia and Coriolis force
- 2 Gyroscope. Precession
- 3 Law of conservation of energy. Law of change of momentum of a moving point

THIRD-YEAR EXAMINATION PAPER (atomic physics)

- 1a Fundamental equations of geometric electron optics for an electrostatic field
- b Lamb's experiment on hyperfine splitting of hydrogen levels
- 2a Principle of operation and construction of betatron
- b Compton effect
- 3a Focusing of paraxial beams with a magnetic lens
- b Measurement of the magnetic moment of atoms and atomic nuclei
- 4a Rutherford scattering formula
- b Characteristic x-ray emission and absorption spectra

THIRD-YEAR EXAMINATION PAPER (electrodynamics—selected questions)

- 1a Motion of a conducting medium in magnetic field
- b To find the force acting on a small dielectric ball enclosed in the Coulomb field of a point charge q
- 5a Potential at remote points of a charge system at rest; electric dipole; quadrupole
- b Uniform electromagnetic field; $\mathbf{E}$, $\mathbf{H}$ exists in a coordinate system—find the coordinate system in which $\mathbf{E}$ is parallel to $\mathbf{H}$. Does the solution always exist? Is it unique?
- 18a Relativistic law of frequency transformation and wave vector; Doppler effect
- b A conducting sphere ($\mu = 1$) is enclosed in an external uniform variable magnetic field—find the resulting field if the skin layer is much thinner compared to the radius of the sphere.
- 21a Lagrange function for a relativistic charged particle in an external field; the nonrelativistic limit
- b Find the energy of a dipole placed close to the plane boundary of a conductor. Find the force and its moment acting on the dipole.

nal publication, and such publication is then recommended. However, we generally find that this work reflects the knowledge and capabilities of its author more than it contains any new information on scientific phenomena.

The student completes his education at the end of the sixth year, after submitting his completed dissertation in November or December. He must then defend it before a special committee, and, finally, pass an examination in philosophy.

At this stage the student's future is assured, because the graduates of our physics department are absorbed immediately by one of the research institutes.

Comparisons

I have often discussed the effectiveness of different systems of education—in particular, the training given at the

Moscow State University compared with the systems adopted elsewhere. Such a comparison is possible, because a large number of Polish, German, Czechoslovakian and Hungarian students have graduated from our department since World War II. Today they are working in their respective countries with their colleagues trained in other West European countries. The results of such a comparison, it appears to me, are in our favor. Our students undergo a more difficult course and receive a much more general scientific training. No other higher-educational institute gives its students such a mass of scientific knowledge and takes so much care to ensure that they assimilate it.

In these days of widespread student unrest, it is interesting that our students in the physics department are kept so busy that they hardly have

time to go to the cinema, let alone demonstrate!

During the course at Moscow State University each student listens to 15–20 professors and is under the strict control of a great many assistants. We have a joke that each professor must make it his duty to impart to each pupil at least 20% of his own knowledge. Then, even if we are only successful to half this extent, each student on graduation should excel any professor in terms of his knowledge! Of course, everyone knows that excessive knowledge gained in a short time is soon forgotten. However, the foundations of university education reinforced by years of continuous training will withstand the future trials.

* * *

This article is an adaptation of a talk given at Massachusetts Institute of Technology on 18 April 1969. □

THIRD-YEAR PRACTICALS (atomic physics—selected examples)

- 1 Compton effect
- 2 Magnetic lens
- 3 Zeeman effect (normal and anomalous)
- 4 Isotopic shift of anomalous levels
- 5 Optical absorption spectra
- 6 Chronotron (exact measurement of masses of isotopes)
- 7 Electron paramagnetic resonance (at low and room temperatures)
- 8 Laser (investigation of characteristics)

FOURTH-YEAR PRACTICALS (nuclear physics)

- 1 Determination of upper boundary to beta-ray spectra by ionization methods
 - 2 Determination of gamma-radiation energy
 - 3 Artificial radioactivity and determination of half life
 - 4 Nuclear-fission reactions with neutron beams
 - 5 Dosimetry and protection against ionizing radiations
 - 6 Nuclear-radiation counters
 - 7 Physical principles of registering nuclear radiations
- and 10–12 other experiments

SOME DISSERTATION TITLES SUBMITTED IN 1967–68

- 1 Studies in gaseous lasers with a nitrogen-helium mixture
- 2 Studies in the cell structure of swollen muscles
- 3 Studies in electron paramagnetic spectra of chalcogenic glass
- 4 Studies in the magnetic-field structure of stellarators
- 5 Some properties of counters used in measuring the stellarator parameters
- 6–10 Various theoretical topics on calculating different containment geometries