ITMO University

"Mega-Science" Class Setups in Russia and Abroad

Course Workload		Assessment form (examination/ graded test/ ungraded test)
ECTS	Hours	
3	108	Ungraded test

Mega-Science facilities for fundamental and applied research are located all over the globe: from the foothills of the Alps in the center of Europe and the desert in the mountains of Chile to the depths of Lake Baikal and even the ice of Antarctica. At the same time, many of them are not completely artificial devices, but are organically built into the natural ecosystem. Such "non-accelerator" installations are becoming increasingly important, since they do not require huge costs. This course will give an overview of such facilities as cyclic and linear accelerators used both for fundamental research in particle physics, atomic and nuclear physics, and for a number of applied problems in chemistry, physics of materials, biology, and medicine. Many of these accelerators are used as sources of powerful synchrotron radiation, an important class of which are free electron lasers. We will talk incl. about the generation of the Higgs boson at the Large Hadron Collider, about applied research at the XFEL X-ray laser, and about the generation of hadron matter at the NICA collider. Another important class of installations for our course will be nuclear reactors and the ongoing research on neutron optics and neutrino physics (despite the similarity of the name, they are completely different things!) We will also talk about super-powerful lasers being built in Russia and Europe and how physicists are going to make the vacuum boil. We will study the fundamentals of interferometers used to detect gravitational waves and discuss how physicists use squeezed light to increase their sensitivity. Finally, we will also discuss how physicists catch very rare and faint flashes of light from neutrinos in the thickness of the crystal clear ice of Antarctica and under the water layer of Lake Baikal, which can shed light on how the Universe was born. The aim of the course is to introduce students to a number of advanced experimental facilities of the Mega-Science class, both existing and being designed. As a result of studying the course, students will significantly expand their knowledge of the world's cutting-edge research, primarily in particle physics with an emphasis on the use of optical systems, and will be able to form a clearer idea of trends in modern physics.

Course structure:

1. Circular accelerators: main elements of the setup, applications in fundamental and applied research, types

1.1. An introduction to particle physics. Typical distances, times and energies from the optical range to nuclear and below.
1.2. Qualitative and semi-quantitative estimates of expected effects in atomic physics, particle physics and nuclear physics.
1.3. Typical cross-sections of processes.
1.4. The need for accelerators. Luminosity of processes on accelerators

2. Synchrotron radiation sources: application in fundamental and applied research, review of the most important facilities: ESRF (Grenoble), PETRA III (DESY), Spring-8 (Japan), SSRC (Novosibirsk), USSR project, etc

2.1. Cyclic accelerators
2.2. Sources of synchrotron radiation
2.3. Linear accelerators
2.4. Free electron lasers
2.5. Heavy ion accelerators: RHIC, FAIR, NICA, etc.
2.6. Future accelerator projects: CLIC, ILC, HL-LHC, photon colliders, muon colliders, wake-field accelerators.

3. Linear accelerators: the main elements of the device, application in fundamental and applied research, an overview of the most important installations: SLAC, the AWAKE plasma accelerator project, etc

3.1. Linear accelerators: the main elements of the device
3.2. SLAC, the AWAKE plasma accelerator project, etc

4. Free electron lasers: the main elements of the device, application in fundamental and applied research, an overview of the most important installations: European XFEL, LCLS, SLAC, Swiss FEL, Novosibirsk THz FEL, etc.

4.1. Free electron lasers: the main elements of the device
4.2. European XFEL, LCLS, SLAC, Swiss FEL, Novosibirsk THz FEL, etc

5. Heavy ion accelerators: RHIC, FAIR, NICA, etc. Projects for future accelerators: CLIC, ILC, HL-LHC, photon colliders, muon colliders, wake-field accelerators

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6. Gravitational wave detectors

6.1. Principles of gravitational wave detection: interfermeters, shot noise and the use of squeezed light
6.2. LIGO, Virgo experiments and their achievements, IndIGO projects, etc.

7. Physics of neutrinos

7.1. Mass and flavor neutrinos, oscillations, PMNS mixing matrix,

types: reactor, atmospheric, solar, geo-neutrinos, etc.
7.2. Reactor neutrinos, JUNO experiments, Daya Bay, Kalini NPP, etc.
7.3. Neutrino telescopes: Ice Cube and Baikal-GVD
7.4. Other experiments and projects: Super-Kamiokande, BOREXINO, etc

8. Powerful lasers

8.1. Quantum physics in superpowerful electromagnetic fields
8.2. Extreme Light Infrastructure (Europe): application in fundamental and applied research
8.3. Project XCELS (Nizhny Novgorod), etc