New Frontiers in Physics

NUCLEAR THEORIST'S WORK PAVES WAY TO BETTER UNDERSTANDING OF NUCLEONS

BY ELIZABETH O. COOPER

Growing up in the former Soviet Republic of Kyrgyzstan, Anatoly V. Radyushkin was fascinated with geography and dreamed of one day exploring remote, uninhabited islands. Then his uncle set him on the path that would eventually become his career and gain him international recognition.

"I was reading books about sea adventures and remote countries," recalls Radyushkin, eminent professor of physics at Old Dominion and senior scientist at the Thomas Jefferson National Accelerator Facility. "My uncle came from Moscow to visit our family and looked at my maps. He told me that all those islands were already discovered, so if I wanted to discover something new, I should go into physics."

To further encourage his nephew, Radyushkin's uncle sent him a set of advanced physics books for children. Radyushkin was hooked. "Since the age of 12, I knew I wanted to be a theoretical physicist," he says, adding that children in the former Soviet Union were required to study physics beginning in the sixth grade.

Entering Moscow University at the age of 17, he received his master's and doctoral degrees in physics. During his final year at the university in 1974, Radyushkin was working on his thesis at the Joint Institute for Nuclear Research when his adviser, Anatoly Efremov, introduced him to quantum chromodynamics (QCD), a theory that would lead him to cutting-edge research and to the United States. QCD is a fundamental theory that addresses the core structure of nucleons –the protons and neutrons that comprise the nucleus of the atom - according to their more elementary components. Nucleons are made up of quarks and gluons, which are elementary particles known as partons.

"The theory of quantum chromodynamics was proposed as an alternate explanation of strong interactions," Radyushkin recalls. "We were all excited about the new theory. We were exposed to new ideas and developments and began to work with quarks. When something is already established, it is not easy for students to participate in it, but when something starts, there are many new directions in which to go."

Breaking New Ground with Generalized Parton Distributions

Thirty years after he first delved into quantum chromodynamics, Radyushkin is an internationally recognized nuclear theorist and a pioneer in the development of generalized parton distributions (GPDs). GPDs are a set of mathematical functions describing how quarks are distributed and move inside the nucleon. Radyushkin's research allows physicists for the first time to obtain a 3-dimensional snapshot of the inner structure of the particles comprising the nucleus of the atom. Physicists can use GPDs to plot the location and momentum of the quarks and gluons inside a nucleon.

"These guys are always moving," Radyushkin says of the quarks. "GPDs describe the velocity with which quarks are moving."

The mathematical functions of GPDs are being studied with data obtained from electron-neutron collisions in which physicists use an accelerator to propel a beam of electrons to speeds approaching that of light. When the electrons hit a target, many of them collide with particles in the nuclei of atoms, scattering the particles. GPDs can be applied to those collisions that result in a scattered electron, proton and a photon, known as "deeply virtual Compton scattering." This application provides information about the structure of the nucleon before the collision.

Radyushkin's interest in GPDs started in 1996 after he heard Xiangdong Ji of the University of Maryland discuss GPDs at a conference. Ji contended that "deeply virtual Compton scattering" was the best tool for a more detailed study of the structure of nucleons. Charles E. Hyde-Wright, professor of physics at Old Dominion and a member of the university's experimental nuclear physics group, Bogdan Wojsekhowski of Jefferson Lab, and Alan Nathan of the University of Illinois-Urbana-Champaign, were planning to investigate Compton scattering, and Hyde-Wright urged Radyushkin to apply quantum chromodynamics to study the phenomenon.

"He was very enthusiastic about it," Radyushkin recalls. "He attracted my attention to Compton scattering a few years before 1996, but I had no idea how to proceed. Then I heard Ji's talk and realized that quantum chromodynamics can be applied to Compton scattering." Radyushkin and other theorists derived a set of formulas for GPDs to predict possible outcomes depending on how quarks composed the nucleon structure. The lab's accelerator is testing his hypothesis. The accelerator's high-energy electron beam identifies quarks and isolates them to determine how they cause protons and neutrons to spin.

"Our accelerator hits nucleons in bulk matter," Radyushkin explains. "The nucleon gets energy from the electron and releases energy in the form of one photon. Normal microscopes use light, i.e. only photons, to look deep inside the matter. Electron microscopes study the matter by scattering electron beams, i.e. they use electrons only. The virtual Compton scattering is a combination of an electron microscope and a conventional microscope because both electrons and photons are detected in the final state. This combines the strengths of two ways of study. We observe the structure of the nucleon using two tools to decipher the internal structure of the nucleon."

As one of the first physicists to study GPDs, Radyushkin says he was "preparing for this business starting from the time I was a graduate student." One of his first research papers on quarks, written in 1977, delineated some important ingredients necessary for developing GPDs. "At the time, there were no accelerators which could really approach the full content of GPDs," he notes. "There were some studies on limiting cases where we studied the simpler functions of quarks. I was lucky enough that the mathematical tools necessary for the development with GPDs were very similar to what I started to use in 1977."

Virginia Outstanding Scientist of the Year

Radyushkin's work with GPDs earned him recognition as the Virginia Outstanding Scientist of 2004. The award honors scientists who recently contributed to basic scientific research that extends the boundaries of a field of science. Radyushkin is the third Old Dominion faculty member to receive this award, following in the footsteps of Cynthia Jones, professor of biological sciences (2003), and Daniel Sonenshine, professor emeritus of biological sciences 1994.

Despite his own efforts to advance GPDs, Radyushkin emphasizes that the Outstanding Scientist Award is not exactly a personal honor. "Many people from the university and the lab participate in this reward," he says. "This award is not only for me, but also for my collaborators and friends. This is a result of the combined efforts of Old Dominion, other local universities and the Jefferson Lab to build the theory group. It would be impossible without important decisions by Old Dominion to make a major contribution to develop the theory group at Jefferson Lab." Old Dominion is a member of the Southeastern Universities Research Association, a consortium of more than 60 universities which operates Jefferson Lab on behalf of the U.S. Department of Energy.

Old Dominion's Partnership with Jefferson Lab

The groundwork for Radyushkin's relationship with Old Dominion and Jefferson Lab was laid in 1984 when he met Franz Gross at a conference in Georgia, then a republic of the former Soviet Union. Gross was the key theorist forming the scientific program for the Continuous Electron Beam Accelerator Facility (CEBAF), the name Jefferson Lab used when it first opened. Six years later, Radyushkin was in the

United States to speak at an international conference in Cambridge, Mass. Gross suggested he give a seminar at CEBAF, where he met Nathan Isgur, CEBAF's first nuclear particle theory group leader. Isgur, who later became the chief scientist at Jefferson Lab, was especially interested in Radyushkin's work in quantum chromodynamics and realized that the lab's accelerator was the perfect venue in which to test his ideas. In 1992, Radyushkin accepted a joint position at Old Dominion and the lab.

Today, in addition to Radyushkin, there are four other nuclear theorists at Jefferson Lab who hold joint positions with Old Dominion: Ian Balitsky, associate professor of physics; Winston Roberts, professor of physics; Rocco Schiavilla, professor of physics; and J. Wallace Van Orden, professor and eminent scholar of physics. Radyushkin and Balitsky focus their research efforts on GPDs.

"There's been a big effort on the part of Old Dominion University to create a nuclear theory and experimental group which is one of the largest in the country. Together, we are a rather diversified group, and this is very important," Radyushkin says. "When you do something new, you never know if it's correct or wrong. You should try it on somebody who would criticize you. That's a good characteristic of a theorist. If somebody always agrees with you, he should not be trusted."

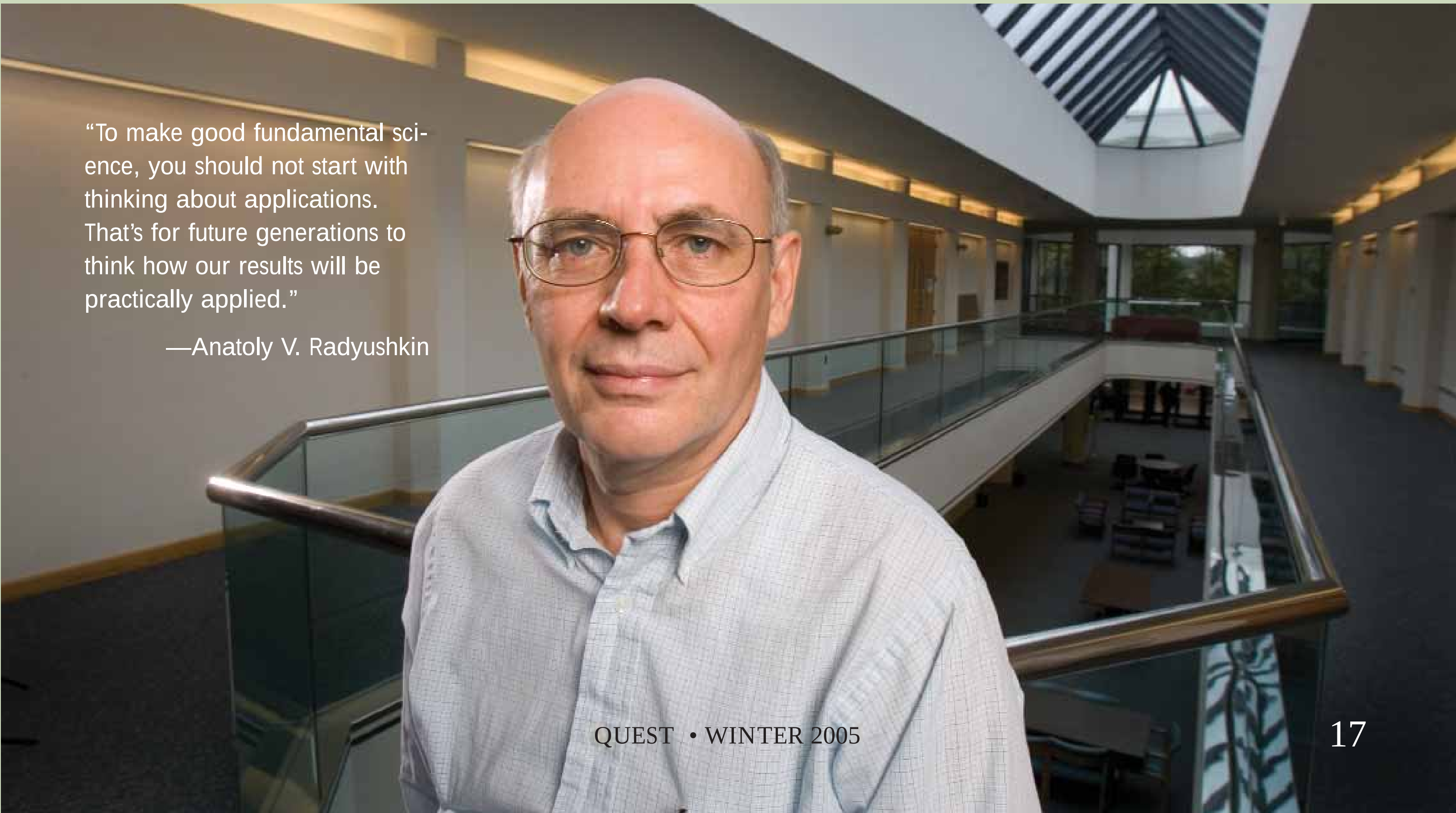
Jefferson Lab recently obtained support from the U.S. Department of Energy for a $225 million upgrade that will double the energy of its central electron accelerator from 6 billion to 12 billion electron volts and add a fourth experimental hall to the facility. Radyushkin says the upgrade will lead the lab in new directions: further study of GPDs, and advanced study of the physical confinement of quarks and how the "glue" holding them together works.

"You can't separate quarks from each other," he explains. "They are glued to each other. You can pull them, and the glue becomes a string that contains energy. If the string is long enough, it breaks, and the released energy generates pairs of quarks in the form of usual particles."

As for GPDs, Radyushkin says the facility upgrade would allow additional experiments. "What's easy to do theoretically is difficult to test with experiments. Every experiment requires big manpower preparations. There's a line of people that's like several years waiting to do experiments here. There are several proposed experiments at Jefferson Lab on GPDs, and that's one of the priorities for future studies at the lab."

The theory group at Jefferson Lab is all about fundamental science. "To make good fundamental science, you should not start with thinking about applications," Radyushkin says. "That's for future generations to think how our results will be practically applied. To be able to use something, you should know its structure. If you don't know the structure of a nucleon, how can you use it? We are on the frontier of nucleon study."

Even without the upgrade, Radyushkin asserts that Jefferson Lab is the top facility of its kind in the world, with no visible competitors. "You cannot build installations like that in one year. This was an opportunity for Old Dominion to be associated with an internationally prominent organization. Jefferson Lab understands the significance of support from Old Dominion University."



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