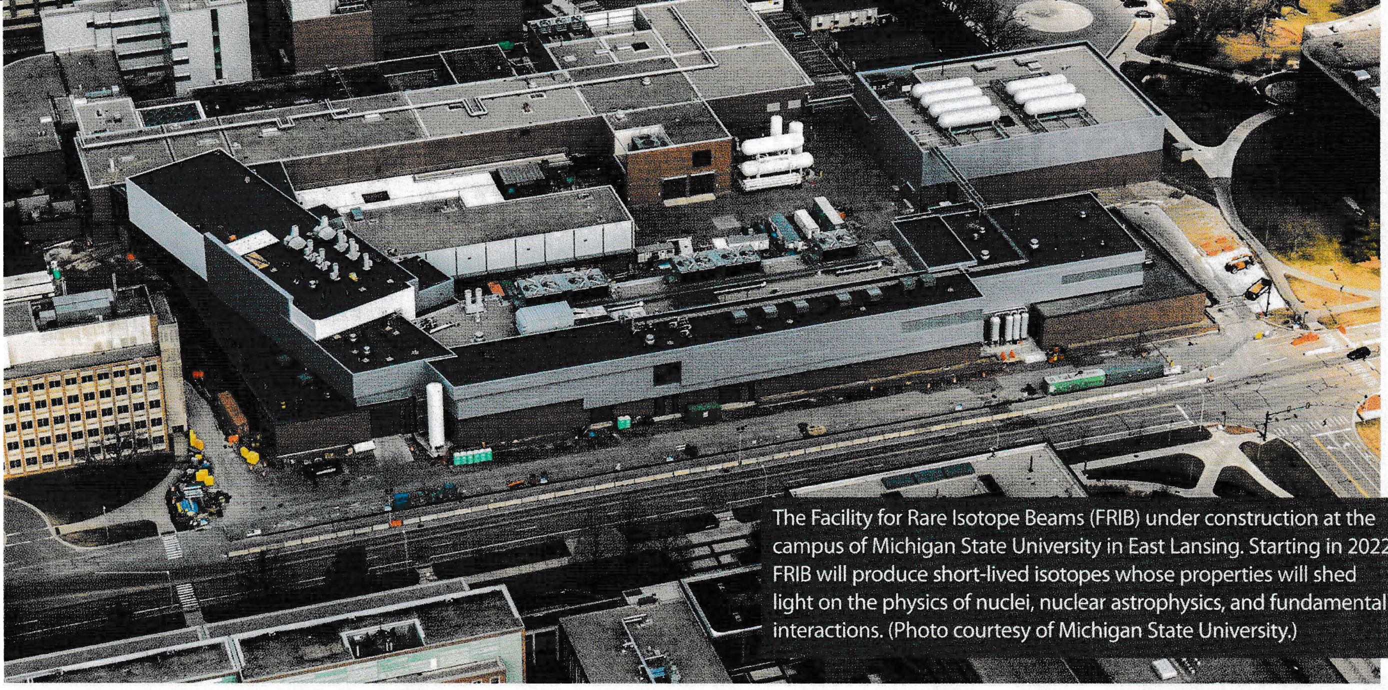

The Facility for Rare Isotope Beams (FRIB) under construction at the campus of Michigan State University in East Lansing. Starting in 2022 FRIB will produce short-lived isotopes whose properties will shed light on the physics of nuclei, nuclear astrophysics, and fundamental interactions. (Photo courtesy of Michigan State University.)

Nuclear physics in *Reviews of Modern Physics*

Throughout its 90-year history, the journal has elucidated all the major advances in the science of the densest phases of matter.

George Bertsch, Witold Nazarewicz, and Achim Richter

In 1932, shortly after the founding of *Reviews of Modern Physics* (*RMP*), nuclear physics became a scientific discipline with the discovery of the neutron. In the ensuing five years, the field had grown to an extent that justified the 450-page, monumental three-part review in *RMP* by Hans Bethe and his collaborators.[1] Nicknamed Bethe's Bible, it covered not only the new phenomena revealed by nuclear reactions and beta decay, but also a theory of nuclear forces, which would later explain nuclear shells, and various experimental findings.

Compared with that early review, the scope of nuclear physics today is enormous. The field deals with the structure of hadrons and nuclei, nuclear matter at extreme densities, nuclear astrophysics, and symmetry tests involving all the fundamental forces of nature.[2] As illustrated by selected examples below, articles in *RMP* have played a uniquely important role in shaping the agenda of nuclear physics research and in seeding new topics.

The biggest breakthrough in nuclear physics after World War II and the Manhattan Project was the recognition of nuclear shells in 1949. The shell model not only explained the distinctive properties of nuclei with the closed-shell magic numbers; its wavefunctions also made it possible to describe nuclear structure in detail. For example, in their 1963 *RMP* article, Leonard Kisslinger and Raymond Sorensen showed how a simplified interaction between shell orbitals could quantitatively account for many features of nuclear spectra.[3] A crucial component of the model is an attractive interaction between like particles that produces a pairing condensate. The pairing has consequences that are qualitatively similar to those seen in superconductivity. Today, as Mark Alford and his coauthors pointed out in their 2008 *RMP* article, superconductivity is a ubiquitous nuclear phenomenon that arises not only in nuclei and nuclear matter but also in dense quark matter.[4]

The development of nuclear reaction theory beyond its prewar state has several important milestones recorded in *RMP*. Electron scattering, a basic experimental tool of nuclear physics since the early 1950s, was reviewed in 1956 by Robert Hofstadter.[5] When hadronic probes are used, reaction theory requires joining together two differ-

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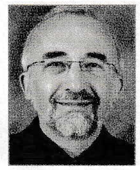

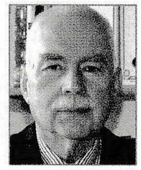

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ent kinds of wavefunctions, namely the continuum wave functions of the scattering particles and the discrete wavefunctions of the resonances and internal states of the nuclei formed. That difficult challenge can be handled by R-matrix theory, which Anthony Lane and Robert Thomas reviewed[6] in 1958.

Another important reaction for studying nuclear structure and the response of nuclei to external probes is Coulomb excitation by a heavy ion passing nearby. In their 1956 *RMP* article, Kurt Alder and his coauthors reviewed the required theory and the early results it yielded.[7] Another process, particle transfer from one nucleus to another, is also invaluable for elucidating the shell structure of nuclei, as Malcolm Macfarlane and Bruce French laid out in their 1960 *RMP* article.[8] Today, all those tools and their sophisticated variations are used to study nuclei and hadrons at modern low- and medium-energy nuclear facilities.

Nuclear fission is a complex process whose elucidation in *RMP* has brought many threads together. The explanation, presented in the ground-breaking 1972 paper by Matthias Brack and his coauthors,[9] arose from the same theory that describes nuclear shells and shape deformations. The paper showed that the path to fission has hills and valleys in the total energy surface that can trap the system before it gets to the point at which the nucleus breaks into fragments. That work was followed by Sven Bjørnholm and J. Eric Lynn's 1980 review of fission data.[10] Since the 1990s a microscopic description of fission has been given by nuclear density functional theory, which, as Michael Bender, Paul-Henri Heenen, and Paul-Gerhard Reinhard reviewed[11] in 2003, explains the presence of nuclear deformations in terms of symmetry-violating intrinsic states.

In more recent years, the domain of nuclear physics has expanded to include high energy densities and small length scales that are best understood within the framework of the standard model of particle physics with quantum chromodynamics (QCD). High energy densities can be produced in the laboratory only by smashing large nuclei together. A seminal review of the properties of highly excited hadronic matter, interpreted as a quark–gluon plasma, was published in *RMP* in 1981 by David Gross, Robert Pisarski, and Laurence Yaffe.[12] In QCD the underlying interactions mediated by gluons are largely hidden from experimental view. Instead, the observable dynamics are likely manifested by effective interactions—in particular, those characterized by the so-called instanton solutions to equations of motion. The 1981 review has guided the interpretation of experimental findings from relativistic heavy ion collisions. In their 1998 *RMP* paper, Thomas Schäfer and Edward Shuryak showed that the instanton could also be applied to a qualitative understanding of meson masses and other hadronic properties.[13] One of the main research directions in nuclear structure is to anchor the nuclear force, which binds protons and neutrons into nuclei, in QCD, as reviewed 10 years ago by Evgeny Epelbaum, Hans-Werner Hammer, and Ulf-G. Meißner.[14]

In this brief overview, we inevitably left out many topics in nuclear physics and its intersections having an impact on other branches of physics. Examples are the statistical theory of spectra in strongly interacting systems, as reviewed in 1981 by Tomás Brody and his coauthors;[15] solar fusion, as reviewed in 1998 by Eric Adelberger and his coauthors;[16] and double beta decay, as reviewed in 2008 by Frank Avignone, Steven Elliott, and Jonathan Engel.[17]

In 2013, one century after Ernest Rutherford discovered the atomic nucleus, the National Academy of Sciences published its fourth and most recent decadal survey of nuclear physics.[2] The survey's authors identified four overarching questions that are being addressed by nuclear physics: How did visible matter come into being and evolve? How does subatomic matter organize itself? Are the fundamental interactions that are basic to the structure of matter fully understood? How can the knowledge and technological progress provided by nuclear physics best be used to benefit society? Given that the questions remain open, we foresee a continuing presence of forefront nuclear reviews in the pages of *RMP*.

This article should have appeared in February's special issue, which celebrates the 90th anniversary of RMP. *PHYSICS TODAY apologizes to the authors and to readers for the error.*

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