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Science Day 2005 Poster Abstracts: Nuclear Physics

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Fusion and Fission: Converting Mass to Energy (or as Einstein Would Say: $E = mc^2$)

Jeffery Latkowski

Einstein's famous equation, $E = mc^2$, indicates the equivalency of mass and energy. It is this relationship that lets us understand the power source of the universe, thermonuclear fusion. It explains not just fusion, but also the basis of nuclear fission and fission power plants that already supply a significant fraction of electric energy (~20% in the US and more than 75% in France). In practice, we use Einstein's equation to determine the energy release from nuclear reactions by comparing the mass of the initial nuclei to the mass of the resultant nuclei. In the most common fusion reaction being studied around the world today, two isotopes of hydrogen, deuterium and tritium, undergo fusion to form a helium nucleus (also known as an alpha particle) and a free neutron. The sum of the mass of the alpha and neutron is less then the sum of the mass of the deuterium (D) and tritium (T) by 0.019 atomic mass units (amu). This loss of mass results in a release of 17.6 MeV in the form of kinetic energy of the alpha and neutron. The conversion from mass to energy is at the rate of ~931 MeV/amu. Likewise, if we compare the mass of the fission products to the reactants, in this case a neutron and a fissile isotope of uranium or plutonium, we find a loss of nuclear mass and conversion to kinetic energy of the fission products, about 220 MeV per fission reaction. To appreciate the magnitude of the energy released in fusion and fission reactions following Einstein's law, consider that the burning of 1 kg of D and T in fusion reactions releases the same energy as burning ~10 million kg of coal, and the fission of 1 kg of uranium releases the equivalent of burning 12,000 barrels of oil. These nuclear reactions also have the benefit of not releasing any greenhouse gases, thus providing an attractive option for supplying the growing energy needs of our world.

Studies of Inertial Confinement Fusion Targets with HYDRA

Marty Marinak

This poster describes various physics issues important in inertial confinement fusion targets and shows examples of how these are modeled with the 3-D multiphysics code, HYDRA. Simulations performed on Livermore's massively parallel computers study the performance of ignition targets for the National Ignition Facility. HYDRA can simulate the entire ignition target, including the hohlraum, capsule and all significant features. Simulations model intrinsic asymmetries that result from the ideal laser illumination pattern and those that result from effects of irregularities in laser pointing and power balance. High-resolution simulations study the evolution of hydrodynamic instabilities that occur when the capsule implodes. HYDRA calculates all of the radiation, electron, ion and charged-particle transport, and the hydrodynamics from first principles, i.e., no adjustments are made to the modeling parameters.

Prospects for Demonstrating Ignition on the National Ignition Facility in 2010 with Noncryogenic Double-Shell Targets

Peter Amendt

According to Einstein's mass–energy relationship, a nuclear reaction, which is exothermic, releases energy proportional to the mass difference between the initial and final nuclear states. We exploit this relationship to consider fusing deuterium and tritium into helium and a 14.1 MeV neutron with aid of the expected high-energy density of the NIF laser in 2010. The double-shell ignition target design is one of several paths to demonstrating controlled thermonuclear ignition by potentially harnessing the energy of the 14.1-MeV neutrons that are liberated in the fusion reaction. A significant advantage of the double-shell target is the potential for fielding at room temperature, thereby avoiding the need for costly and challenging cryogenic preparation. This poster will highlight the advantages and challenges of demonstrating double-shell ignition on the NIF in 2010, while offering a balanced assessment of the prospects for success.

Exploring the Fast-Ignition Approach to Fusion Energy

Richard Town

Probably the most famous equation in physics is Einstein's $E = mc^2$, which was contained within his fifth and final paper published in 1905. The fusion process exploits this relationship between energy (E) and mass (m) to generate energy. When two isotopes of hydrogen [normally deuterium (D) and tritium (T)] fuse, they form an atom of helium and a neutron. In this process, some of the mass of the hydrogen is converted into energy. In the fast-ignition approach to fusion, a large driver (such as the NIF laser) is used to compress the DT fuel to extremely high densities, which is then "sparked" by a high-intensity, short-pulse laser. Understanding the transport of this short-pulse laser energy to the DT fuel is the critical issue explored in this poster.

Simulating the National Ignition Facility with Arbitrary Lagrangian Eulerian Methods and Adaptive Grids

Alice Koniges

Advanced 3-D computer simulations are enabling the design and operation of the National Ignition Facility (NIF). Experiments on NIF exemplify two of Einstein's 1905 ideas—the quantization of light allows production of a laser that will drive a fusion ($E = mc^2$) reaction. However, the reality of these regimes (in 2005 and beyond) produced by the high-energy facility requires state-of-the-art simulations to predict the effect of the laser-vaporized and -fragmented material on the target chamber. The poster discusses the use of arbitrary Lagrangian Eulerian (ALE) methods alone and ALE combined with adaptive mesh refinement to create a powerful simulation technique. LLNL's highly parallel computing facilities enable these compute-intensive calculations.

New Energy Sources: Extracting Energy from Radioisotope Materials

Jeff Morse

Are we tired of our cell-phone batteries dying while we're talking? These problems may be solved in the future by using nuclear-powered batteries that will exploit the energy stored in common radioisotope materials. Typically, this energy is emitted from radioisotopes as a range of energetic particles and photons. While many of these particles can be harmful to humans, a select group of radioisotopes are limited to particles called alphas, which are fairly benign and are readily absorbed over distances much less than the width of a human hair in most materials, including skin and clothes. We have embarked on a research effort to efficiently convert these energetic particles to useful electric power. Of the various energy conversion techniques, the poster reviews and presents results for thermal-to-electrical and direct alpha-voltaic energy-conversion approaches. Increasing the conversion efficiency for these approaches to levels by more than 20 % make them competitive with other power generation schemes at the microscale. So, while it may be years before we receive regulatory permission to use these power sources in consumer products, it is likely that they will be introduced for applications such as remote sensors and communications networks.

Production of Superheavy Elements

Ken Moody and Josh Patten

The search for superheavy elements explores the reaches of the Periodic Table and wouldn't be possible without a fundamental understanding of Einstein's work on inertia, energy, and special relativity. The production and separation of the heaviest elements is performed through the use of large particle accelerators and small-scale physical separation techniques. Understanding how particles interact when accelerated at one another and how matter is turned into energy is important to the design of the experiments that have successfully discovered several new elements of the Periodic Table. Understanding Einstein's special relativity has helped determine the chemistry of these heaviest elements and their place in the Periodic Table.

Nuclear Physics from Scratch: Ab-initio Description of Nuclei with Effective Interaction

Eric Ormand

How much does the nucleus weigh? Not surprisingly, the nucleus, consisting of protons and neutrons, weighs less than the sum of the mass of its constituents. This is due to the fact that protons and neutrons interact with one another via the strong interaction, and as a consequence are bound together. The energy required to bind this system of individual particles together, called the binding energy, reduces the total mass of the nucleus. This is a direct consequence of the Einstein mass–energy equivalence relation, $E = mc^2$. Perhaps the most important impact of nuclear binding is that some of this binding energy can be released in nuclear reactions, both fusion and fission.

After 50 years of intense study, the conceptually simple task of "building" complex nuclei from their constituent parts—protons and neutrons—has yet to be fully realized. The nucleus is a rich, complex quantum system whose constituents interact in ways that are extraordinarily complex and not yet fully understood. Here at LLNL, the Nuclear Theory and Modeling Group is pursuing this topic with the goal of achieving a fundamental understanding of these complex phenomena from a unified theoretical standpoint. Our primary goal is to indeed theoretically "build" nuclei from their constituents and the fundamental interactions between them, thus deriving nuclear structure from "scratch."

Finding Fission with Scintillator and a Stopwatch: Statistical Theory of Fission Chains

Neal Snyderman

Detailed information about fissioning materials can be extracted from the time of arrival of neutron and gamma ray counts. Analysis of the timing signal is based on a little-known theory first proposed by Feynman during the Manhattan project.

There are different numbers of neutrons and gamma rays emitted in each fission. Each of the created neutrons can induce a subsequent fission with some probability, establishing a chain of fissions that creates many neutrons and gamma rays starting from one neutron. The multiplication process amplifies the intrinsic fluctuations in the number of emitted particles from each induced fission. Any random emission process leads to a series of counts in a detector in time that is a special probability distribution, a Poisson distribution. Complete randomness is very special, arising fundamentally from the complete randomness of quantum mechanics. The large fluctuations in the number of neutrons and gamma rays emitted in time from fission chains creates a pattern of counts in time that stands out sharply relative to this random distribution.

Mass to Energy: How Einstein's Equation is Helping Homeland Security

Jason Pruet

Finding fissile material hidden in sea-going cargo containers is a major security challenge around the world because cargo containers are large and carry nearly every material found in modern commerce. However, recent experiments and calculations at LLNL indicate that the solution may be found in observing the conversion of mass to energy first predicted by Einstein's equations. This poster presents recent work on cargo interrogation techniques that rely on observing the energy released as heavy nuclei are ripped apart.

Nuclear Car Wash

Dennis Slaughter

A weak neutron beam is used to produce fission in special nuclear material that may be hidden in cargo. The subsequent delayed radiation produced by decaying fission products is very intense and distinct from background radiation so that even small quantities of illicit material can be detected. The beam is weak enough so that the cargo is not damaged and the dose to operating personnel or stowaways is well within government guidelines.

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