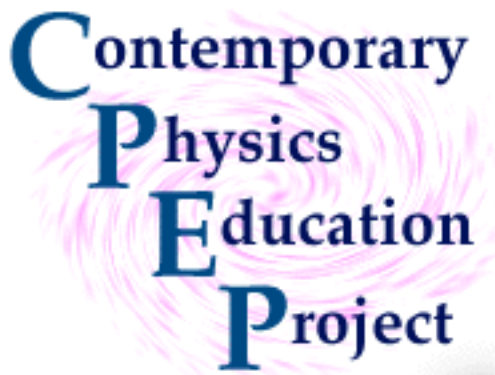


The Contemporary Physics Education Project: Classroom support for teaching about energy issues



Gordon J. Aubrecht, II, Department of Physics, Ohio State University,
Marion, OH 43302-5695 and Columbus, OH 43210-1106 Address: 1465 Mt.
Vernon Ave., Marion, OH 43302-5695 Phone: 740-389-6786, ext 6250 Fax:
614-292-5817 Email: aubrecht@mps.ohio-state.edu

Teachers wishing to have some support available for helping them teach about energy-related issues should consider ways to use materials available from the Contemporary Physics Education Project (CPEP). Both web-based and paper-based materials are available in addition to the CPEP charts that can help teachers design their own presentations and/or be used with students. Some such materials are available from CPEP, some from other sources.

The only hope for the future of all countries in the world economy lies in a better education for students now in school. They will be the world citizens of tomorrow, and they need to learn why science and technology go hand in hand. They need to see how topics relating to energy fit together and the importance of energy to the world (and world economy). It means restructuring of curricula, and introduction of new ideas from the research labs into the classroom. This also means there must be better materials for teachers to use in their classes.

This is where these CPEP charts can be useful. The physics described contains a lot that's new. It is important that students learn how exciting science is, that it is not a study of "dead," dry facts but rather of a continuing process of scientific investigation. We should not treat physics as a set of facts to be absorbed, but as a growing body of experimental science.

In the words of Richard Sutton at the AAPT Carleton Conference in 1956, we should be *uncovering physics rather than covering it.*

The charts provide a colorful way to “uncover” physics. The charts may also expose some talented students to the wonders of science by showing the liveliness and wonder of what we call contemporary physics.

Perhaps the most important use of the charts is to help both high school and college physics teachers learn about the fundamental ideas of modern physics, so they can feel the excitement of the chase and pass on their excitement to their students.

While there are now four charts available from CPEP, two are particularly useful for matters relating to energy: the fusion/plasma physics chart and the nuclear science chart.

Energy
Processes cover the sun and other stars, in fusion reactors, chemical power systems, or fission reactors. They involve the conversion of mass into energy. The sun produces about 3.8 x 10²⁶ W of energy. It is estimated by Einstein's formula, E = mc². In the sun, a sequence of fusion reactions converts protons into helium and produces the energy that powers the sun and other stars. The sun's energy is produced by nuclear fusion. The energy is carried away from the sun by radiation and convection.

Fusion

Physics of a Fundamental Energy Source

To make fusion requires on the order of 10⁸ K. To the high temperatures, the ions must be confined for a long enough time to allow fusion to occur. This is the condition for a fusion reactor. The sun's energy is produced by nuclear fusion.

ENERGY SOURCES & CONVERSIONS

AN OVERVIEW OF ENERGY CONVERSION PROCESSES

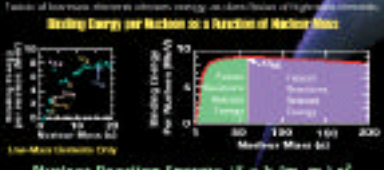
Energy conversion processes, and various processes, convert one form into another. While most energy conversion processes, these processes produce various forms of energy.

Source	Conversion	Useful Energy
Chemical	Combustion	~30-40%
Nuclear	Radioactive decay	~30-40%
Solar	Photovoltaic	~15-20%

Physical Parameters of Energy-Releasing Reactions

Reaction Type	Chemical	Fission	Fusion
Sample Reaction	C + O ₂ → CO ₂	²³⁵ U + n → ¹⁴¹ Ba + ⁹² Kr + 2n	D + T → ⁴ He + n
Typical Inputs (to Power Plant)	Coal and Air	UO ₂ (90-95%) and H ₂ O (5-10%)	Deuterium and Tritium
Typical Temp. (K)	1000	1000	100,000,000
Energy Released per kg Fuel (J/kg)	3.0 x 10 ⁷	8.0 x 10 ¹³	3.4 x 10 ¹⁴

HOW FUSION REACTIONS WORK



Essential Nuclear Masses

Label	Symbol	Mass (u)
Electron	m _e	0.00054858
Proton	m _p	1.007276467
Neutron	m _n	1.008664915
Deuteron	m _D	2.014101778
Triton	m _T	3.0160492
Helium-3	m _{He3}	3.016989
Helium-4	m _{He4}	4.002603254

Fusion Rate Coefficients

Plasma Fusion Reaction Rate Density = R = n₁ n₂

n₁ n₂ = density of reacting species (ions/m³), R = fusion coefficient (per m³ s). Multiply by ΔE to get the fusion power density.



TWO IMPORTANT FUSION PROCESSES

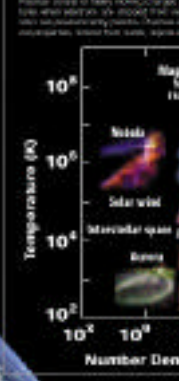


CREATING THE CONDITIONS FOR FUSION

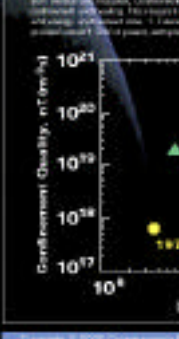
PLASMA CONFINEMENT AND HEATING

Confinement	Gravity	Magnetic Fields	Inertial
Fusion requires high temperature. Rare physical conditions being sought at high density to release appreciable energy.	Star Fusion by Gravity	Star Fusion by Magnetic Fields	Star Fusion by Inertial Confinement
Typical Scales: 10 ¹⁴ W per cubic meter Power Density, 10 ¹¹ s, 10 ¹¹ s	10 ¹⁴ W per cubic meter Power Density, 10 ¹¹ s, 10 ¹¹ s	10 ¹⁴ W per cubic meter Power Density, 10 ¹¹ s, 10 ¹¹ s	10 ¹⁴ W per cubic meter Power Density, 10 ¹¹ s, 10 ¹¹ s
Heating Mechanisms: • Ohmic heating • Fusion Product Energy	• Ohmic heating • Fusion Product Energy	• Ohmic heating • Fusion Product Energy	• Ohmic heating • Fusion Product Energy

PLASMAS - THE 4th STATE OF MATTER



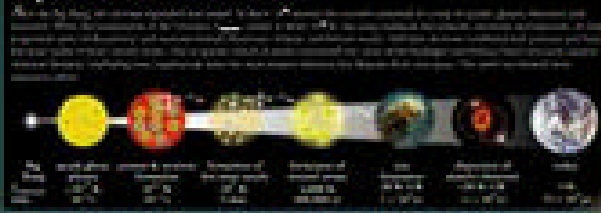
ACHIEVING FUSION



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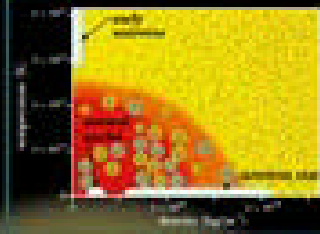
Nuclear Science

Expansion of the Universe



Nuclear Science is the study of the nucleus, composed of protons and neutrons, and the forces that hold it together. It includes the study of nuclear reactions and the development of nuclear energy. The field is interdisciplinary, involving physics, chemistry, and engineering. The research community is composed of scientists, engineers, and technicians working in laboratories and industry.

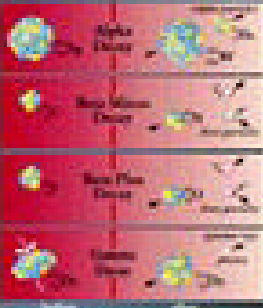
Energy is the capacity to do work. It is a scalar quantity, measured in joules (J) or kilowatt-hours (kWh). Energy can be converted from one form to another, but it cannot be created or destroyed.



Phases of Nuclear Matter

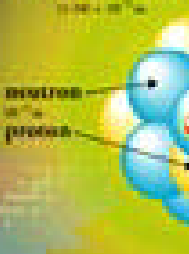
Nuclear matter can exist in several phases, depending on the temperature and density. The phases are: normal nuclear matter, nuclear pasta, quark-gluon plasma, and color superconducting quark matter.

Radioactivity



Radioactivity is the process by which an unstable atomic nucleus loses energy by emitting ionizing radiation. This radiation can be in the form of alpha particles, beta particles, or gamma rays. The rate at which a radioactive substance decays is characterized by its half-life.

The Nucleus



The nucleus is the central part of an atom, composed of protons and neutrons. It is held together by the strong force, which is one of the four fundamental forces of nature. The electromagnetic force acts between protons, and the weak force is responsible for beta decay.

Nuclear

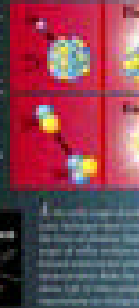


Chart of the Nuclides



Applications

- Radioactive Tracing:** Used in medicine and industry to track the movement of substances.
- Medical Applications:** Used in cancer treatment and diagnostic imaging.
- Power Generation:** Nuclear reactors generate electricity through nuclear fission.
- Space Exploration:** Radioisotope thermoelectric generators (RTGs) provide power for spacecraft.
- Archaeology:** Radiocarbon dating is used to determine the age of ancient artifacts.
- Industry:** Nuclear techniques are used in agriculture, food processing, and materials science.

The fusion/plasma physics chart

Energy sources & conversions gives a lot of information on the differences among generation of energy from fossil fuel, fission, and fusion. For those who want to emphasize the difference between fission and fusion the curve of the binding energy vs. mass number under *How fusion reactions work* gives the opportunity.

The central figures emphasize how almost all energy on Earth comes from the sun, and all energy from the sun comes from fusion, primarily p - p fusion.

Obviously, there are many other ways this chart and the others can be used to promote student understanding of the issues related to energy.

The nuclear science chart

Nuclear energy gives more information on the way the sun provides energy to Earth.

The section *Radioactivity* will be needed in any detailed discussion of fission energy, and the diagonal theme, the *chart of the nuclides* also conveys information useful to teachers and students on nuclear energy.

The section *Applications* in the lower left gives ways nuclear physics is used in devices students commonly see.

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org/

As Chair of CPEP, I am grateful for the dedication of the many physicists and physics teachers, members of CPEP, who give so much of their time in the significant volunteer effort required for the success of all our endeavors.