The newest Standard Model Chart from the Contemporary Physics Education Project

Gordon J. Aubrecht, II
Department of Physics, Ohio State University, Columbus 43210 and Marion 43302, Ohio USA

E-mail: aubrecht.1@osu.edu

(Recibibo el 26 de mayo de 2016 , aceptado el 2 de octobre de 2016)

Abstract

The Contemporary Physics Education Project (CPEP) is a nonprofit organization founded almost 25 years ago to produce charts and other materials exhibiting areas of ongoing physics research in colorful fashion. The charts are field tested extensively before their release. The current chart, written support materials, and internet-based support materials are discussed. The Standard Model Chart of Fundamental Interactions and Particle Physics was the first chart from CPEP, and the one that has seen the greatest number of changes over the intervening years. We discuss how this chart can be used not only to bring interest to the classroom but also how it can be used to teach particle physics.

Keywords: Contemporary Physics Education Project,

Resumen

El Contemporary Physics Education Project (CPEP) es una organización sin fines de lucro fundada hace casi 25 años para producir gráficos y otros materiales de las áreas de investigación de la física en curso, en coloridas exposiciones. Los gráficos son ampliamente probados en el campo antes de su liberación. El gráfico actual, material de apoyo escrito, y se discuten materiales sup-portuarias basados en internet. El gráfico Modelo Estándar de las Interacciones Fundamentales y Física de Partículas fue el primer gráfico de CPEP, y el que ha visto el mayor número de cambios durante los años intermedios. Se discute cómo este gráfico se puede utilizar para traer interés en el aula, y también la forma en que se puede utilizar para enseñar la física de partículas.

PACS: 11.30.-j, 12.10.Dm, 95.10.-a **ISSN 1870-9095**

I. INTRODUCTION

The edges of understanding are the active areas of research, and the researchers have the most understanding about their lack of complete knowledge. People can best appreciate how little we really know about the world, when they know what is known and can think about those unknown "dark continents" in our minds.

The members of the Contemporary Physics Education Project (CPEP) decided CPEP should bring the edges of our knowledge to the attention of those who we might consider becoming scientists, especially physicists, and in general try to communicate the excitement of the unknown, where our knowledge of nature is incomplete, to a broad public. It is in this spirit that the CPEP created all of its charts and ancillary materials.

II. THEORETICAL FRAMEWORK AND BRIEF REVIEW OF THE RELEVANT LITERATURE

I like to quote Walter Michels, who in his 1964 Oersted Lecture [1] noted that "we seem to be engaged in a conspiracy to prevent elementary students from learning that imagination, inventiveness, and intuition play any part in the growth of physics, or from suspecting that anything in the physical universe is not yet fully understood".

Many school teachers who know little of science even as they are assigned to teach it, have and transmit the impression that all that can be known is already known. What is known can be learned by rote, and is boring. As scientists, we know how wrong this view is.

The students of today still commonly see no physics beyond 1912 until they are in college, often in their second year (or sometimes even third) as physics undergraduates, as I have argued long ago [2].

Most high school and college students are not planning to become scientists (Earth still needs physics majors!), and never experience (even vicariously) the exploratory spirit characterizing research at the edges of knowledge. They may even be convinced by their teachers that, physics is unchanging, totally determined, and –again, the kiss of death– boring.

CPEP's focus on unanswered questions distinguished it from the beginning from other charts. As is discussed more thoroughly below, CPEP also generated teacher and student support materials that focused on these sorts of questions to catch the interest of possible future scientists.

II. CPEP'S ROLE IN PHYSICS EDUCATION

Fred Priebe, a high school teacher from Palmyra, Pennsylvania had the inspiration for and was the driving force behind the development of the wall chart [3]. He wanted such a chart to use in his teaching, and, having none, he worked to create a group that could create one. Fred's idea was that the chart be useful at both introductory college and high school levels.

Use of the chart both in high school and college would provide physics students with a sense of continuity reminiscent of the Periodic Table of the Elements, which is studied first in high school and, at a more sophisticated level, in college.

Over the years, many changes have occurred, both in physics and in the presentation of the particles chart. The original version of the chart is shown in Fig. 1. The current version of the particles chart is shown in Fig. 2, and a proposed version in Fig. 3. The three diagrams at the bottom were replaced with more contemporary questions being investigated as research continues, neutrino mass limits were added, and the Higgs boson was added to the gauge boson list. In addition, the constituent quark list for fermionic hadrons and mesons was removed from the newer versions

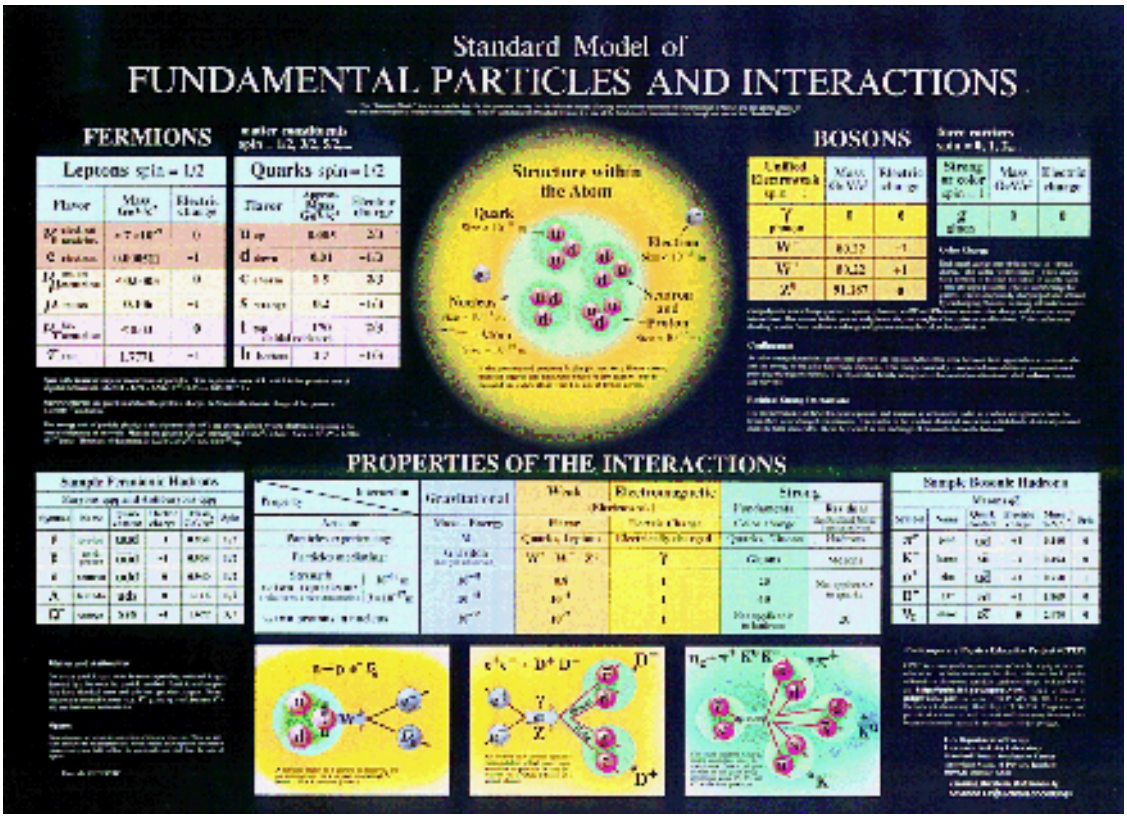

FIGURE 1. The original version of the particles and interactions chart.

CPEP's unique blend of high school and college physics teachers and particle physicists produced the chart and other materials discussed in this paper. The group was originally structured to achieve a balance among individuals directly involved in particle physics and those involved in introductory physics instruction at the high school and undergraduate levels. The original so-called Fundamental Particles and Interactions Chart Committee was soon re-formed to become the Contemporary Physics Education Project, a nonprofit organization. This balance has been maintained even as CPEP has branched into support of other areas of contemporary physics [4].

CPEP recognized very early that support for teachers and students was essential. The original particles and interactions chart was accompanied by an attempt at a teacher resource book [5]. It soon became apparent that the material in Ref. 5 was too advanced for most teachers and students. Members of CPEP rewrote many times ad published a book that worked better for this purpose: *The charm of strange quarks* [6]. The chart is also complemented by the Particle Adventure, a web-based encyclopedia of particle physics that is accessible in many languages [7].

Meanwhile, CPEP added charts and ancillary materials.

Fusion makes the stars glow and the H-bomb. What is it that causes fusion in the Sun and makes it so hard to get fusion on Earth? The Fusion and Plasma Physics Chart from the CPEP helps students find some answers. FusEdWeb is based on the web and is accessible in several languages.

The Nuclear Science chart from CPEP helps students find some answers about the chart of the nuclides and radioactive decay. It also presents them with cutting-edge nuclear physics, such an investigation of quark-gluon plasmas.

, .

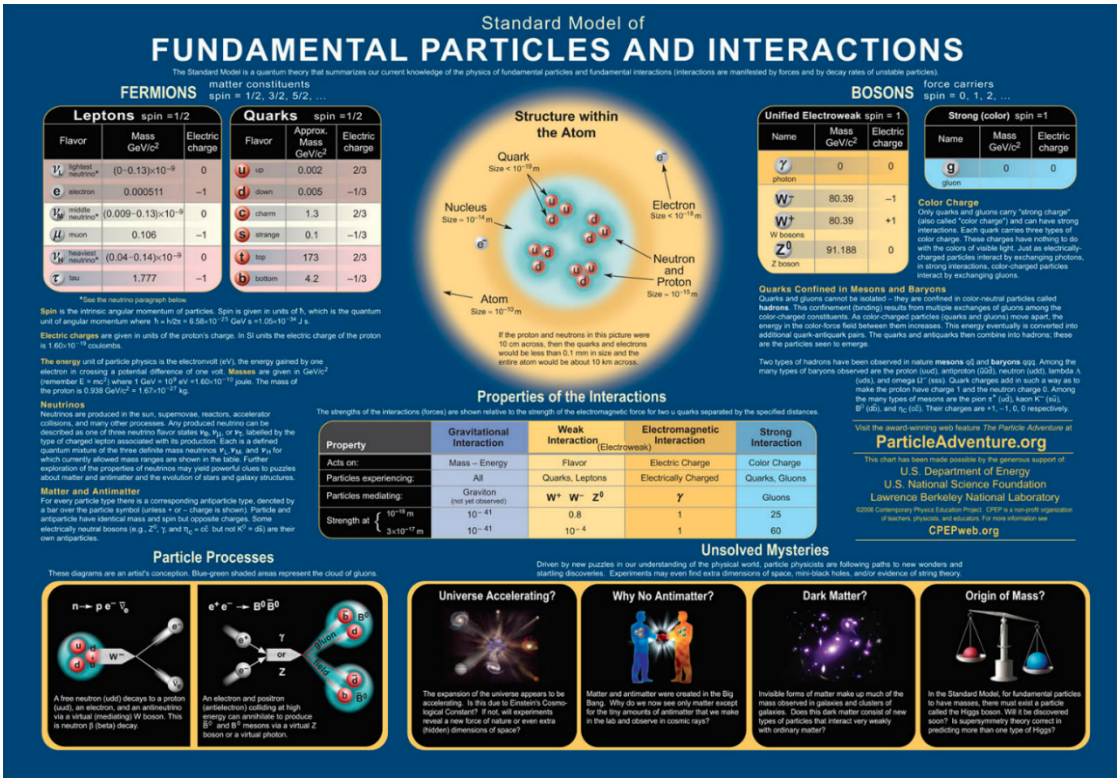

FIGURE 2. The current version of the particles and interactions chart.

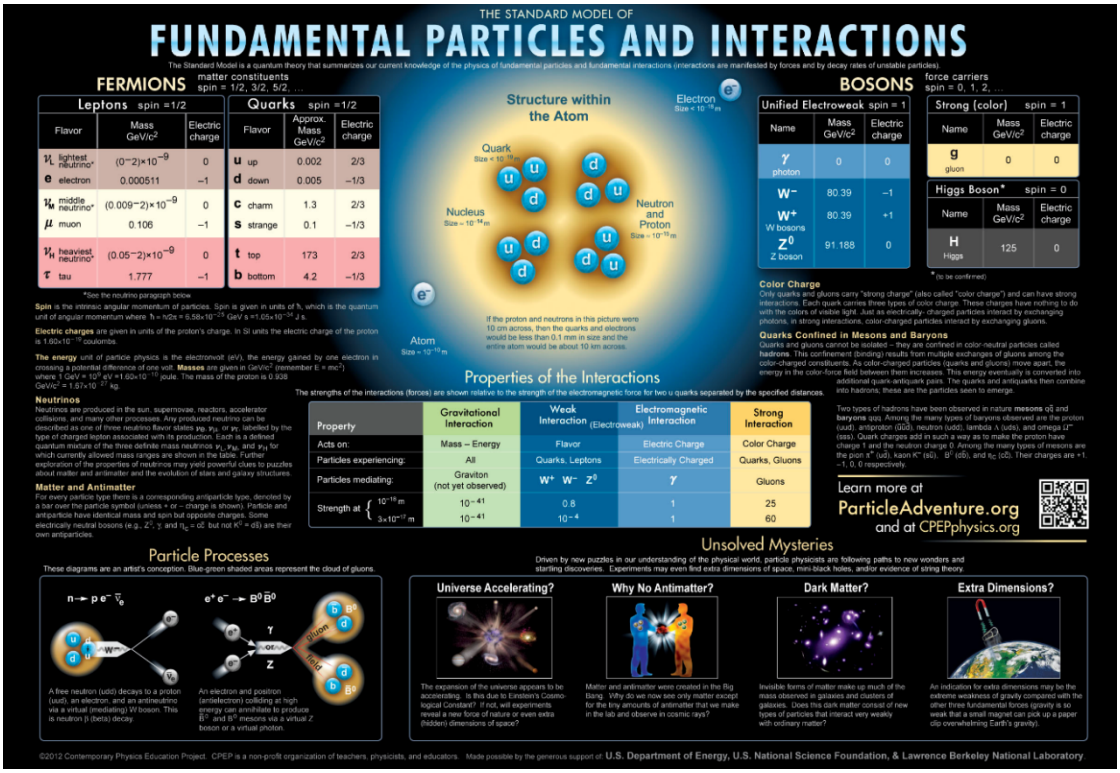

FIGURE 3. The proposed version of the particles and interactions chart.

The chart is complemented by ABCs of Nuclear Science, which is based on the web.

The History and Fate of the Universe chart from CPEP helps students find some answers to the questions we have about where we've been and where we're going [8].

The cosmology chart is complemented by The Universe Adventure [9], which is based on the web and accessible in several languages.

We discuss how these charts can be used not only to bring interest to the classroom but also how they can be used to teach elements of the content.

VI. CONCLUSIONS

The open questions that occupy many particle physicists include:

Is there just a single Higgs particle? How will we see the physics beyond the Standard Model? Why is the universe accelerating? What happened to the original (assumed equal) amount of antimatter in the universe? What is the origin of mass? How will quantum mechanics and gravitation finally be reconciled? How can we be certain of the origin of dark matter? Why does the range of masses in the universe span from 10^{-31} kg to 10^{35} kg? Are the additional dimensions in Kaluza-Klein-type theories physically realizable? Are there really no magnetic monopoles in the universe? How does neutrino mass arise?

There are many other unanswered questions in other branches of physics. Where do ultraenergetic cosmic rays come from? What does a quark-gluon plasma look like? What is the exact nature of the strong nuclear interaction? Can room-temperature superconductors be developed? Can a quantum computer really be built? How can sonoluminescence be explained? Why is nature not time-reversal invariant? Why is the sun's corona at such a great temperature compared to the photosphere?

These questions will need dedicated work to elucidate, and the CPEP focus on the incomplete knowledge of nature we possess will, we hope, lead to more students appreciating the opportunities physics offers to slake human curiosity about the universe around us.

ACKNOWLEDGEMENTS

With its record of accomplishment, CPEP has been able to obtain support from Government, private, and nonprofit sources.

The development and publication of the chart and ancillary materials was made possible by support from the U.S. Department of Energy, Lawrence Berkeley Laboratory, Stanford Linear Accelerator Center, CERN-Microcosm, and the American Association of Physics Teachers, and by corporate support from IBM, Rockwell International, Martin Marietta Astronautics Group, Burle Electron Tubes, and Science Kit and Boreal Laboratories.

The work of CPEP would not have been possible without the dedicated volunteers over the years.

Many other founding members of FPICC and CPEP and the physicists who have come later have dedicated many hours of time and effort to making the project a success.

In particular, my colleagues Michael Barnett, Robert Beck Clark, Helen Quinn, and the late Andria Erzberger and Ted Zaleskiewicz have served in exemplary fashion to bring the particles chart to completion and updating.

Barnett has been instrumental in the translation and extension of Erzberger's HyperCard™ software to the web as the Particle Adventure (and Barnett also spearheaded creation of the Universe Adventure). The author is Chair Emeritus of the Contemporary Physics Education Project.

REFERENCES

[1] Michels, W. C., *Freedom, responsibility and barriers*, Am. J. Phys. **32**, 499-503 (1964).

[2] Aubrecht, G. J., *Redesigning courses and textbooks for the twenty-first century*, Am. J. Phys. **57**, 352-359 (1964).

[3] Priebe, F., In: Aubrecht, G. J., (Ed.), *Papers prepared for the Conference on Teaching of Modern Physics* (AAPT, College Park, 1986).

[4] Aubrecht, G. J., Making it easier to teach Contemporary Physics: The Contemporary Physics Education Project, In: Pintó, R. & Surinach, S., (Eds.), *International Conference Physics Teacher Education Beyond 2000. Selected Contributions* (Elsevier Editions, Paris, 2001). p. 721. ISBN 2-84299-312-8.

[5] Quinn, H. R., Dorfan, J., Barnett, R. M., Cahn, R. N. Goldhaber, G. & Aubrecht, G. J., *Teacher's resource book on fundamental particles and interactions*, (US Government, Berkeley, 1989). LBL-26669.

[6] Barnett, R. M., Mühry, H. Quinn, H. R. Aubrecht, G. J. Cahn, R. N., Dorfan, J., Dresden, M., Goldhaber, G., Jackson, J. D. & Olive, K., *The Charm of Strange Quarks* (New York, Springer-Verlag, 2001).

[7] Aubrecht, G. J., Web resources from the Contemporary Physics Education Project, In: R. Pintó & S. Surinach (Eds.), *International Conference Physics Teacher Education Beyond 2000. Selected Contributions* (Elsevier Editions, Paris, 2001). p. 725. ISBN 2-84299-312-8, <http://www.particleadventure.org>

[8] Aubrecht, G. J., *The new History and Fate of the Universe chart from the Contemporary Physics Education Project*, Latin American Journal of Physics Education **10**, 4302 (2016).

[9] *The universe adventure*, Available in <http://www.universeadventure.org>,