

# THE STANDARD MODEL OF FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model is a quantum theory that summarizes our current knowledge of the physics of elementary particles and their interactions. Experimental predictions are confirmed by theory and by direct tests of particle collisions.

## FERMIONS

matter constituents  
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass (GeV) <sup>†</sup>	Electric charge	Flavor	Approx. Mass (GeV) <sup>†</sup>	Electric charge
$\nu_e$ electron neutrino	$0 - 0.09 \times 10^{-6}$	0	$u$ up	0.0022	2/3
$e$ electron	0.000511	-1	$d$ down	0.0047	-1/3
$\nu_\mu$ muon neutrino	$0.000 - 0.01 \times 10^{-6}$	0	$c$ charm	1.27	2/3
$\mu$ muon	0.1057	-1	$b$ strange	0.0034	-1/3
$\nu_\tau$ tauon neutrino	$0.00 - 0.01 \times 10^{-6}$	0	$t$ top	172.7	2/3
$\tau$ tau	1.777	-1	$b$ bottom	4.18	-1/3

<sup>†</sup> See the website for more details.

Mass is the intrinsic energy contribution of particles. Spin is given in units of  $\hbar$ , which is the quantum unit of angular momentum where  $\hbar = 1.054 \times 10^{-34}$  J s and  $\hbar = 1.054 \times 10^{-27}$  eV s.

Electric charge is given in units of the proton's charge,  $e$ . It is zero for electric charge of the proton is  $1.602 \times 10^{-19}$  coulombs.

The energy unit of particle physics is the electronvolt (eV). The energy gained by one electron in one volt average difference of potential. Masses are given in GeV<sup>†</sup>, where  $1 \text{ GeV} = 10^9 \text{ eV} = 1.602 \times 10^{-10}$  joules. The mass of the proton is 0.938 GeV<sup>†</sup> or  $1.672 \times 10^{-27}$  kg.

### Keynotes

Theories are produced in the past, experimental results, astronomical evidence, and many other processes, they produced theories can be described as any of these theories have been.  $\nu_e$ ,  $\nu_\mu$ ,  $\nu_\tau$  number by the type of charged lepton associated with its production. Each is a different quantum number of the three different mass lepton  $\nu_e$ ,  $\nu_\mu$ , and  $\nu_\tau$  are small numbers, showed these signs are shown in the table. Further knowledge of the properties of particles like  $\nu_e$  and  $\nu_\mu$  can be gained from their interactions with the production of mass and galaxy structure.

### Matter and Antimatter

For every particle there exists a corresponding antiparticle, also, known by a few names, the particle created (antimatter) (e.g., electron to positron). Particles and antiparticles have identical mass and spin but opposite charge. Some elementary fermions (such as  $\nu_e$ ,  $\nu_\mu$ , and  $\nu_\tau$ ) and  $\nu_e$  and  $\nu_\mu$  can be their own antiparticles.

## Particle Processes

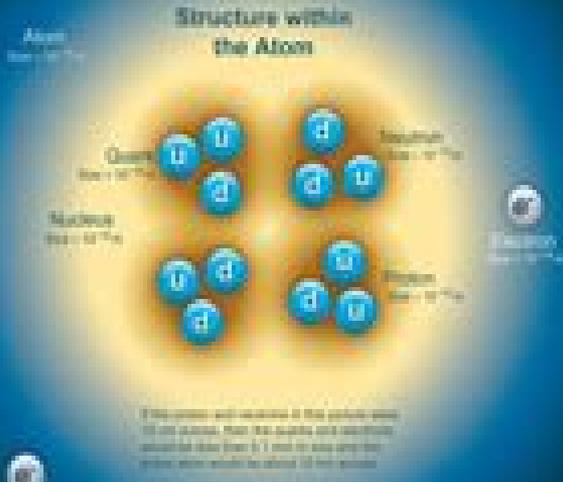
These diagrams are an artist's conception. Charge (red) and mass (green) are conserved.

$e^- \rightarrow \mu^- + \nu_e + \bar{\nu}_\mu$

A free neutron (not shown) can decay by a similar process, and an antineutrino, as a result, producing  $\bar{\nu}_\mu$  neutrino. This is a reaction of beta decay.

$e^+ e^- \rightarrow \mu^+ \mu^-$

An electron and positron annihilation, creating a high-energy pair consisting of particles  $\mu^+$  and  $\mu^-$  instead of a usual  $e^+$  and  $e^-$  pair in a virtual photon.



## Properties of the Interactions

The strength of the interaction,  $G$ , varies, as shown, from the strength of the electromagnetic force to the strength associated with the unified interaction.

Property	Gravitational Interaction	Weak Interaction (electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on	Mass + Energy	Flavor	Electric Charge	Color Charge
Particles participating	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating	Graviton (not yet observed)	$W^+$ , $W^-$ , $Z^0$	$\gamma$	Gluons
Strength at $r = 10^{-16}$ m	$10^{-38}$	0.1	1	10
Strength at $r = 10^{-10}$ m	$10^{-47}$	$10^{-5}$	1	10

## BOSONS

force carriers  
spin = 0, 1, 2, ...

Unified Electroweak spin = 1			Strong (color) spin = 1		
Name	Mass (GeV) <sup>†</sup>	Electric charge	Name	Mass (GeV) <sup>†</sup>	Electric charge
$\gamma$ photon	0	0	$g$ gluon	0	0
$W^-$ $W$ bosons	80.36	-1	<b>Higgs Boson spin = 0</b>		
$W^+$ $W$ bosons	80.36	+1	Name	Mass (GeV) <sup>†</sup>	Electric charge
$Z^0$ $Z$ boson	91.188	0	<b>H</b> Higgs	125.20	0

### Higgs Boson

The Higgs boson is a crucial component of the Standard Model. The associated Higgs field provides the mechanism by which fundamental particles get mass. Particles that interact more strongly with the Higgs field are more massive.

### Color Charge

Strongly interacting particles carry "strong charge" (also called "color charge") and not these strong interactions that occur between these forms of color charge. These charges have nothing to do with the color of visible light, and are completely unrelated to anything resembling photons. In strong interactions, color-charged particles, except for antiquarks, quarks.

### Quarks Confined in Mesons and Baryons

Quarks and gluons combine to form hadrons. They are confined in color-neutral particles called hadrons. The confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. An exchange of gluons between quarks and gluons, however, the energy in the interaction field between them increases. The energy eventually is converted into additional quark-antiquark pairs. The quarks and antiquarks then combine into hadrons. There are the particles seen in nature.

The types of hadrons that have been observed in nature consist of all baryons and mesons. Among the many types of baryons observed are the proton (uud), antiproton ( $\bar{u}\bar{u}\bar{d}$ ), and neutron (udd). Quarks charge are in units of  $e$  so to make the proton have charge  $+1$  and the neutron charge  $0$ . Among the many types of mesons are the pion ( $u\bar{d}$ ), kaon ( $u\bar{s}$ ), and  $K^0$  ( $d\bar{s}$ ).

Learn more at [ParticleAdventure.org](http://ParticleAdventure.org)

## Unsolved Mysteries

Drawn by two scientists in our understanding of the physical world, particle physicists are following paths to new theories and starting theories. Experiments may reveal the more dimensions of space, time, and the existence of string theory.

### Why is the Universe Accelerating?

The expansion of the universe appears to be accelerating. Is this due to Einstein's cosmological constant? Or, are our assumptions about a few forms of matter or some other physical dimensions of space?

### Why No Antimatter?

Matter and antimatter were created in the Big Bang. Why do we see only matter today? Is the tiny amount of antimatter that we make in the lab and observe in cosmic rays?

### What is Dark Matter?

Visible forms of matter make up much of the mass observed in galaxies and clusters of galaxies. But the dark matter makes up the rest of the mass. How much? Why create an invisible matter?

### Are there Extra Dimensions?

All attempts to unify dimensions that are the standard model of physics combined with the other three fundamental forces, gravity, also show that a small region can act as a center for concentrating Earth's gravity.

# A Level Physics Nuclear Physics And Fundamental Particles

**N Colangelo**



## **A Level Physics Nuclear Physics And Fundamental Particles:**

**The Basics of Nuclear and Particle Physics** Alexander Belyaev, Douglas Ross, 2021-11-08 This undergraduate textbook breaks down the basics of Nuclear Structure and modern Particle Physics Based on a comprehensive set of course notes it covers all the introductory material and latest research developments required by third and fourth year physics students The textbook is divided into two parts Part I deals with Nuclear Structure while Part II delves into Particle Physics Each section contains the most recent science in the field including experimental data and research on the properties of the top quark and Higgs boson Detailed mathematical derivations are provided where necessary to help students grasp the physics at a deeper level Many of these have been conveniently placed in the Appendices and can be omitted if desired Each chapter ends with a brief summary and includes a number of practice problems the answers to which are also provided

**Nuclear Physics and Fundamental Particles** Roger Muncaster, 1995 Its large format allows for the clear presentation of topics Illustrations and charts are used wherever possible to convey information and enhance the text Student friendly language is used throughout Consolidation sections stress key points Definitions and fundamental points are highlighted Worked examples are included throughout Questions are included at relevant points in the text allowing students to test immediately their understanding of a topic In addition each chapter ends with a selection of questions the majority of which are taken from past examination papers

Introduction to Nuclear and Particle Physics Ashok Das, 2003 Annotation Readership Advanced undergraduates and researchers in nuclear and particle physics

*Cambridge International AS and A Level Physics Coursebook with CD-ROM* David Sang, Graham Jones, Gurinder Chadha, Richard Woodside, 2014-08-07 Fully revised and updated content matching the Cambridge International AS A Level Physics syllabus 9702 Endorsed by Cambridge International Examinations the Second edition of the AS A Level Physics Coursebook comprehensively covers all the knowledge and skills students need for AS A Level Physics 9702 first examination 2016 Written by renowned experts in Physics the text is written in an accessible style with international learners in mind The Coursebook is easy to navigate with colour coded sections to differentiate between AS and A Level content Self assessment questions allow learners to track their progression and exam style questions help learners to prepare thoroughly for their examinations Contemporary contexts are discussed throughout enhancing the relevance and interest for learners

**Atomic and Nuclear Physics** Thomas Albert Littlefield, 2012-12-06 After the death of Dr Littlefield it was decided that I should undertake the revision of the whole of Atomic and Nuclear Physics an Introduction for the third edition and it was soon apparent that major changes were necessary I am confident that these changes would have had Dr Littlefield's approval The prime consideration for the present edition has been to modernize at a minimum cost As much as possible of the second edition has therefore been retained but where changes have been made they have been fairly drastic Thus the chapters on fine structure wave mechanics the vector model of the atom Pauli's principle and the Zeeman effect have been completely restructured The chapters on nuclear models cosmic rays

fusion systems and fundamental particles have been brought up to date while a new chapter on charm and the latest ideas on quarks has been included It is hoped that the presentation of the last named will give readers a feeling that physics research can be full of adventure and surprises

**Nuclear Science Abstracts**, 1969 NSA is a comprehensive collection of international nuclear science and technology literature for the period 1948 through 1976 pre dating the prestigious INIS database which began in 1970 NSA existed as a printed product Volumes 1 33 initially created by DOE s predecessor the U S Atomic Energy Commission AEC NSA includes citations to scientific and technical reports from the AEC the U S Energy Research and Development Administration and its contractors plus other agencies and international organizations universities and industrial and research organizations References to books conference proceedings papers patents dissertations engineering drawings and journal articles from worldwide sources are also included Abstracts and full text are provided if available

Introduction to Nuclear Physics Harald A. Enge, 1966 The main parts of this book have been developed from lecture notes for a course in Introduction to Nuclear Physics that were given at Massachusetts Institute of Technology for a number of years

**Nuclear and Particle Physics** Brian R. Martin, Graham Shaw, 2019-02-08 Updated and expanded edition of this well known Physics textbook provides an excellent Undergraduate introduction to the field This new edition of Nuclear and Particle Physics continues the standards established by its predecessors offering a comprehensive and highly readable overview of both the theoretical and experimental areas of these fields The updated and expanded text covers a very wide range of topics in particle and nuclear physics with an emphasis on the phenomenological approach to understanding experimental data It is one of the few publications currently available that gives equal treatment to both fields while remaining accessible to undergraduates Early chapters cover basic concepts of nuclear and particle physics before describing their respective phenomenologies and experimental methods Later chapters interpret data through models and theories such as the standard model of particle physics and the liquid drop and shell models of nuclear physics and also discuss many applications of both fields The concluding two chapters deal with practical applications and outstanding issues including extensions to the standard model implications for particle astrophysics improvements in medical imaging and prospects for power production There are a number of useful appendices Other notable features include New or expanded coverage of developments in relevant fields such as the discovery of the Higgs boson recent results in neutrino physics research to test theories beyond the standard model such as supersymmetry and important technical advances such as Penning traps used for high precision measurements of nuclear masses Practice problems at the end of chapters excluding the last chapter with solutions to selected problems provided in an appendix as well as an extensive list of references for further reading Companion website with solutions odd numbered problems for students all problems for instructors PowerPoint lecture slides and other resources As with previous editions the balanced coverage and additional resources provided makes Nuclear and Particle Physics an excellent foundation for advanced undergraduate courses or a valuable

general reference text for early graduate studies      Fundamentals in Nuclear Physics Jean-Louis Basdevant, James Rich, Michael Spiro, 2006-01-16 Nuclear physics began one century ago during the miraculous decade between 1895 and 1905 when the foundations of practically all modern physics were established The period started with two unexpected spinoffs of the Crookes vacuum tube Roentgen's X rays 1895 and Thomson's electron 1897 the first elementary particle to be discovered Lorentz and Zeemann developed the theory of the electron and the influence of magnetism on radiation Quantum phenomenology began in December 1900 with the appearance of Planck's constant followed by Einstein's 1905 proposal of what is now called the photon In 1905 Einstein also published the theories of relativity and of Brownian motion the ultimate triumph of Boltzmann's statistical theory a year before his tragic death For nuclear physics the critical discovery was that of radioactivity by Becquerel in 1896 By analyzing the history of science one can be convinced that there is some rationale in the fact that all of these discoveries came nearly simultaneously after the scientifically triumphant 19th century The exception is radioactivity an unexpected baby whose discovery could have happened several decades earlier Talented scientists the Curies Rutherford and many others took the observation of radioactivity and constructed the idea that is the subject of this book Of course the discovery of radioactivity and nuclear physics is of much broader importance It led directly to quantum mechanics via Rutherford's planetary atomic model and Bohr's interpretation of the hydrogen spectrum This in turn led to atomic physics solid state physics and material science      **Nuclei and Particles** Emilio Segrè, 1974      **Which Degree in Britain**, 1999 A comprehensive guide to full time degree courses institutions and towns in Britain      Technical Information Pilot, 1951      **Which Degree Guide**, 2001      Introduction to Nuclear and Particle Physics Ashok Das, Thomas Ferbel, 1994 Stresses the reasoning chain of experimental observation the development of physical principles and how to make math quantitative models Includes more modern material than its competitors Chapters on the techniques of the fields provide a unique perspective and connect the methodologies of nuclear and particle physics In addition explanations of the connection between formalism of theory and more classical concepts bring the theory down to a more understandable level      Biennial Catalog New Mexico Institute of Mining and Technology, New Mexico. Institute of Mining and Technology, 1893      **The Budget of the United States Government** United States, United States. Office of Management and Budget, 1995      Handbook on U.S. Study for Foreign Nationals Institute of International Education (New York, N.Y.), 1973      **Budget of the United States Government** United States. Office of Management and Budget, 1995      New Scientist, 1969      **Cornell University Courses of Study** Cornell University, 2003

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