

# Standard Model of FUNDAMENTAL PARTICLES AND INTERACTIONS

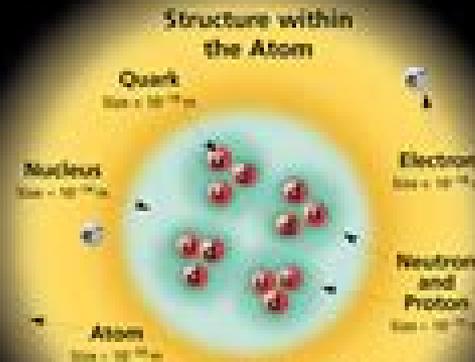
The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (Quantum Chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (Electroweak). Gravity is included on the chart because it is one of the fundamental interactions even though not part of the "Standard Model".

## FERMIONS

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

Leptons spin = 1/2		
Flavor	Mass GeV/c <sup>2</sup>	Electric charge
$\nu_e$ electron neutrino	$< 10^{-9}$	0
$e^-$ electron	0.000511	-1
$\nu_\mu$ muon neutrino	$< 0.0001$	0
$\mu^-$ muon	0.106	-1
$\nu_\tau$ tau neutrino	$< 0.02$	0
$\tau^-$ tau	1.7771	-1

Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c <sup>2</sup>	Electric charge
$u$ up	0.002	2/3
$d$ down	0.006	-1/3
$c$ charm	1.3	2/3
$s$ strange	0.1	-1/3
$t$ top	173	2/3
$b$ bottom	4.3	-1/3



If the proton and neutron are made of quarks, the size of the atom is determined by the distance between the quarks. The size of the quark is much smaller than the size of the atom.

## BOSONS

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

Unified Electroweak spin = 1		
Name	Mass GeV/c <sup>2</sup>	Electric charge
$\gamma$ photon	0	0
$W^\pm$	80.4	-1
$W^\pm$	80.4	+1
$Z^0$	91.187	0

Strong (color) spin = 1		
Name	Mass GeV/c <sup>2</sup>	Electric charge
$g$ gluon	0	0

**Color Charge**  
Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons, just as there are three possible types of electric charge for electrons.

Color-charged particles interact by exchanging photons. In strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and  $W$  and  $Z$  bosons have no strong interactions and hence no color charge.

**Quarks Confined in Mesons and Baryons**  
One cannot isolate quarks and gluons; they are confined to color-neutral particles called hadrons. The confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. In color-charged particles (quarks and gluons) there are six quarks and six antiquarks and three color charges. The strong interaction is considered into with the color-charged particles (quarks and gluons). The quarks and antiquarks that combine into hadrons have no net color charge, and the gluons have no net color charge. The first hadrons have been observed in nature: mesons ( $q\bar{q}$ ) and baryons ( $qqq$ ).

**Unified Strong Interaction**  
The strong binding of color-charged particles and quarks to form hadrons is due to confined strong interactions between them. It is similar to the binding of strong interactions between quarks and gluons. The quarks and gluons that combine into hadrons have no net color charge, and the gluons have no net color charge. The first hadrons have been observed in nature: mesons ( $q\bar{q}$ ) and baryons ( $qqq$ ).

Spin is the intrinsic angular momentum of particles. Spin is given in units of  $\hbar$ , which is the quantum unit of angular momentum, where  $\hbar$ 's size is  $1.0545718 \times 10^{-34}$  J s.

Electric charges are given in units of the proton's charge in  $e$  units. The electric charge of the proton is  $1.6021766 \times 10^{-19}$  coulombs.

The energy unit of particle physics is the electronvolt (eV), the energy gained by one electron moving through a potential difference of one volt. Masses are given in units of GeV/c<sup>2</sup>.  $1 \text{ GeV} = 10^9 \text{ eV}$ , where  $1 \text{ GeV} = 10^9 \times 1.6021766 \times 10^{-19}$  joules. The mass of the proton is  $0.938 \text{ GeV}/c^2 = 1.6726 \times 10^{-27}$  kg.

## PROPERTIES OF THE INTERACTIONS

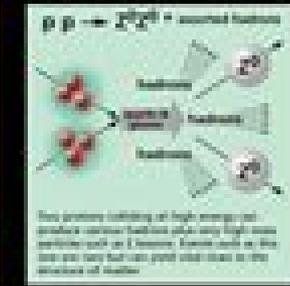
Baryons (qqq) and Antibaryons (q̄q̄q̄)					
Baryons are fermions (fermions). There are about 10 <sup>3</sup> types of baryons.					
Symbol	Quarks	Quark content	Electric charge	Mass (GeV/c <sup>2</sup> )	Spin
$p$	uuu	uud	+	0.938	1/2
$\bar{p}$	ūūū	ūūd̄	-	0.938	1/2
$n$	udd	udd	0	0.938	1/2
$\bar{n}$	ūd̄d̄	ūd̄d̄	0	0.938	1/2
$\Lambda$	uds	uds	0	1.116	1/2
$\bar{\Lambda}$	ūd̄s̄	ūd̄s̄	-	1.116	1/2

Property	Interaction	Fundamental			
		Gravitational	Weak	Electromagnetic	Strong
Acts on		Mass + Energy	Flavor	Electric Charge	Color Charge
Particles participating		All	Quarks, Leptons	Electrically charged	Quarks, Gluons
Particles mediating		Graviton (not yet observed)	$W^\pm, W^\pm, Z^0$	$\gamma$	Gluons
Strength increases/decreases as		$1/r^2$	0	1	1
Range		$1/r^2$	$10^{-16}$	1	1
Is it applicable to quarks?		$1/r^2$	$10^{-16}$	1	1
Is it applicable to leptons?		$1/r^2$	$10^{-16}$	1	1

Mesons (qq̄)					
Mesons are bosons (bosons). There are about 10 <sup>3</sup> types of mesons.					
Symbol	Quarks	Quark content	Electric charge	Mass (GeV/c <sup>2</sup> )	Spin
$\pi^+$	u $\bar{d}$	u $\bar{d}$	+	0.140	0
$\pi^0$	$\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$	$\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$	0	0.135	0
$\pi^-$	d $\bar{u}$	d $\bar{u}$	-	0.140	0
$\rho^+$	u $\bar{d}$	u $\bar{d}$	+	0.770	1
$\rho^0$	$\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$	$\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$	0	0.770	1
$\rho^-$	d $\bar{u}$	d $\bar{u}$	-	0.770	1

**Matter and Antimatter**  
For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (lepton or quark) or charge (photon). Particle and antiparticle have identical mass and spin but opposite charges. Some elementary neutral bosons (e.g.,  $Z^0$ ,  $\gamma$ , and  $g$ ), or  $\pi^0$ , but not  $\pi^\pm$ , are their own antiparticles.

**Figures**  
These diagrams are an artistic representation of physical processes. They are not exact and have no measurement scale. Green shaded areas represent the cloud of gluons in the gluon field, and red lines the quark paths.



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# Nuclear And Particle Physics

**W. E. Burcham, Melvyn Jobs**



## **Nuclear And Particle Physics:**

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

**Foundations of Nuclear and Particle Physics** T. William Donnelly, Joseph A. Formaggio, Barry R. Holstein, Richard G. Milner, Bernd Surrow, 2017-02-01 This textbook brings together nuclear and particle physics presenting a balanced overview of both fields as well as the interplay between the two The theoretical as well as the experimental foundations are covered providing students with a deep understanding of the subject In chapter exercises ranging from basic experimental to sophisticated theoretical questions provide an important tool for students to solidify their knowledge Suitable for upper undergraduate courses in nuclear and particle physics as well as more advanced courses the book includes road maps guiding instructors on tailoring the content to their course Online resources including color figures tables and a solutions manual complete the teaching package This textbook will be essential for students preparing for further study or a career in the field who require a solid grasp of both nuclear and particle physics

**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

**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

*Nuclear Physics* R Prasad, 2014 Nuclear Physics provides a clear and concise introduction to the subject Fundamentals aside the book reviews the evolution of the subject from its emergence to its present day advancements and critically examines the future directions of nuclear and particle physics The book brings together the essence of nuclear particle and cosmic ray physics serving as an ideal text for undergraduate students

**Experimental Techniques in Nuclear and Particle Physics** Stefaan Tavernier, 2010-02-06 I have been teaching courses on experimental techniques in nuclear and particle physics to master students in physics and in engineering for many years This book grew out of the lecture notes I made for these students The physics and engineering students have rather different expectations of what such a course should be like I hope that I have nevertheless managed to write a book that can satisfy the needs of these different target audiences The lectures themselves of course need to be adapted to the needs of each group of students An engineering student will not question a statement like the velocity of the electrons in atoms is 1% of the velocity of light a physics student will Regarding units I have written factors  $h$  and  $c$  explicitly in all equations throughout the book For physics students it would be preferable to use the convention that is common in physics and omit these constants in the equations but that would probably be confusing for the engineering students Physics students tend to be more interested in theoretical physics courses However physics is an experimental science and physics students should understand how experiments work and be able to make experiments work This is an open access book

**Nuclear and Particle Physics** Wolfgang Demtröder, 2023-01-23 This introduction to nuclear physics and particle physics provides an accessible and clear treatment of the fundamentals Starting with the structure of nuclei and explaining instability of nuclei this textbook enables the reader to understand all basics in nuclear physics The text is written from the experimental physics

point of view giving numerous real life examples and applications of nuclear forces in modern technology This highly motivating presentation deepens the reader s knowledge in a very accessible way The second part of the text gives a concise introduction to elementary particle physics again together with applications and instrumentation Nuclear fusion fission radionuclides in medicine and particle accelerators are amongst the many examples explained in detail Numerous problems with solutions are perfect for self study

Particles and Nuclei Bogdan Povh,2004 This introductory textbook gives a uniform presentation of nuclear and particle physics The first part Analysis is devoted to disentangling the substructure of matter This part shows that experiments designed to uncover the substructures of nuclei and nucleons have a similar conceptual basis and lead to the present picture of all matter being built out of a small number of elementary building blocks and a small number of fundamental interactions The second part Synthesis shows how the elementary particles may be combined to build hadrons and nuclei The fundamental interactions responsible for the forces in all systems become less and less evident in increasingly complex systems Such systems are in fact dominated by many body phenomena A section on neutrino oscillations and one on nuclear matter at high temperatures bridge the field of nuclear and particle physics and modern astrophysics and cosmology The fourth edition includes new developments in particular a new section on the double beta decay including a discussion of the possibility of a neutrinoless decay and its implications for the standard model This concise text translated into many languages has become a standard reference for advanced and undergraduate courses

Nuclear and Particle Physics W. E. Burcham,Melvyn Jobes,1995 A textbook for 2nd 3rd and 4th year undergraduates and postgraduates studying physics and theoretical physics and a reference for nuclear and particle physicists in government and industry It combines coverage of both nuclear and particle physics to present a detailed exposition of the behavior of the fundamental particles of nature It examines the interaction between these particles and the symmetries that appear to govern them as well as the intrinsic properties of the particles themselves Annotation copyright by Book News Inc Portland OR

**Problems and Solutions on Atomic, Nuclear and Particle Physics** Yung-kuo Lim,2000 Atomic and Molecular Physics Atomic Physics 1001 1122 Molecular Physics 1123 1142 Nuclear Physics Basic Nuclear Properties 2001 2023 Nuclear Binding Energy Fission and Fusion 2024 2047 The Deuteron and Nuclear forces 2048 2058 Nuclear Models 2059 2075 Nuclear Decays 2076 2107 Nuclear Reactions 2108 2120 Particle Physics Interactions and Symmetries 3001 3037 Weak and Electroweak Interactions Grand Unification Theories 3038 3071 Structure of Hadros and the Quark Model 3072 3090 Experimental Methods and Miscellaneous Topics Kinematics of High Energy Particles 4001 4061 Interactions between Radiation and Matter 4062 4085 Detection Techniques and Experimental Methods 4086 4105 Error Estimation and Statistics 4106 4118 Particle Beams and Accelerators 4119 4131

**Nuclear and Particle Physics Source Book** Sybil P. Parker,1988 A spinoff volume derived entirely from the McGraw Hill Encyclopedia of Science Technology 6th edition 1987 with articles arranged by chapter within sections not alphabetically This book is one of the titles in our new Science

Reference Series a series designed to serve the educational professional needs of individuals who do not have access to the parent 20 volume set Nuclear physics the study of atomic nuclei their interactions its subset particle physics which deal with elementary particles concerns itself with the only natural system i e nucleus in which all known natural forces can be studied simultaneously It is therefore one of the most fundamental important areas of scientific research not only provides a rich range of phenomena to investigate but merges with the most applied topics The instrumentation itself has found broad applicability throughout science technology medicine Nuclear medicine nuclear engineering nuclear chemistry are important areas of specialization The information will be covered in approximately 125 articles

*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

*Subatomic Physics: An Introduction To Nuclear And Particle Physics, And Astrophysics* Ioannis John Demetrius Vergados, Charalampos Moustakidis, 2020-12-22 This book is intended for undergraduate or beginning graduate students The net outcome is material to cover one integrated course on Nuclear and Particle Physics as well as Astrophysics There are many advantages in teaching all these subjects together as they have become increasingly inseparable From a theoretical point of view understanding the similarities between atoms nuclei and other hadrons and applying analogs from one to the other have been very effective in research and they have led to the development of all these fields From an experimental point of view a high energy experimentalist must understand nuclear physics if he or she wants to construct new devices like detectors etc appropriate for observing new high energy phenomena Furthermore an understanding of certain areas of astrophysics and the physics of the cosmos demands a good grasp of both nuclear and particle physics This book is intended as a menu from which the reader can pick material according to his or her taste and interests The authors inserted proper cross references to make a specific selection by the reader from this menu as easily digestible as possible The authors supplied sets of problems with varying degree of complexity accompanied by hints or a sketch of the solution if needed in most chapters

**Nuclear and Particle Physics** R.J. Blin-Stoyle, 2013-03-08 This book is intended to give a clear and concise introductory account of the basic ideas underlying nuclear and elementary particle physics The attempt throughout is to convey a sound physical understanding of the structures and processes encountered It assumes some knowledge of elementary quantum mechanics particularly the treatment of angular momentum and the rudiments of special relativity In addition to standard calculations based on this knowledge frequent use is made of order of magnitude and dimensional arguments In this way it has been possible to give some discussion of quite advanced topics and recent developments Although reference is made from time to time to the apparatus of nuclear and particle physics no technical detail is given My basic hope is that students using this book will acquire a sound understanding of what nuclear and particle physics is about and will wish to learn more I am indebted to Dr David Bailin and various nameless referees for penetrating and helpful comments on parts of the text

*Introduction to Nuclear and Particle Physics* Ashok Das, Thomas Ferbel, 2003      Nuclear and Particle Physics, 1975

Nuclear and Particle Physics S. L. Kakani, Shubhra Kakani, 2008 This book examines the major developments in nuclear and particle physics that have taken place in the past few years and provides an up to date view of the field in a compact form The study of nuclei is placed in its proper relation with the subject of subatomic particles Relationships with the underlying quark substructure of nucleons and the fundamental interactions between the elementary building blocks of nuclei are emphasized providing an outstanding introduction to the field The text offers a concise coverage of nuclear and particle physics in a lucid yet uncomplicated manner Each chapter contains a wide range of worked out problems At the end of each chapter a number of review questions and exercises are provided so that the book may also be useful for upper level courses Nuclear properties decay structure and reactions are covered initially followed by discussions of nuclear forces B decay and elementary particles and their interactions      **Introduction to Nuclear and Particle Physics** V. K. Mittal, 2011

**Nuclear and Particle Physics** Hans Frauenfelder, 1975

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