Syllabus PHYS 6610: Nuclear and Particle Physics Part I

Teacher: Dr. Harald W. Griesshammer, Corcoran Hall 306, 202-994-3849, hgrie@gwu.edu .

Lectures: ***Tuesday/Thursday 14:00 to 15:30 in Corcoran Hall 309*** (formally 75 min each, but more realistically 90 minutes, for 3 credits).

"Snow Dates" (possible slots for rescheduled lectures): **Fridays 12:30 to 14:00 in Corcoran 309**, and "Surgery" is bumped to the same day at 16:00.

Homework Due: Thursdays at 12:00 sharp

Surgery hours: ***Fridays at 12:30 in Corcoran 309*** (when "Snow Date", then Surgery at 16:00) to discuss the problem sheets and for questions, discussions and suggestions; lasts till all questions are answered.

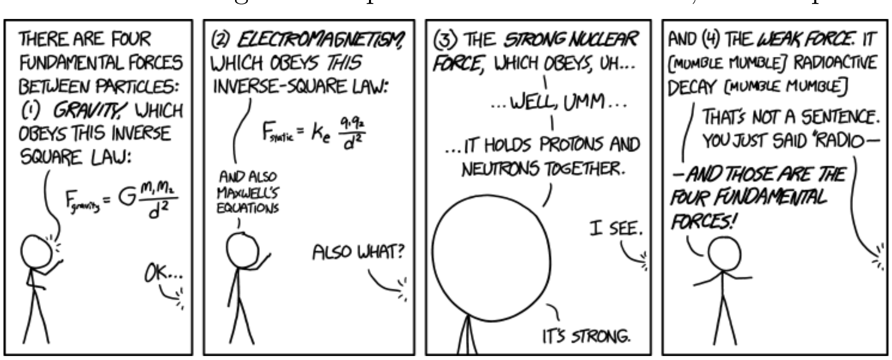
More office hours by appointment weekdays after 3pm in my office.

Mid-Term Exam: tentatively Wednesday 21 March, location and time t.b.a., 2.0 hours
Final Exam as Presentation: At the end of the semester, each student will give a 30-minute presentation, followed by questions, about a topic approved by the instructor. Presentation Day is **1 or 2 or 3 May**. You must perform a "dress-rehearsal" with me at least 1 week before.

Web-site: http://home.gwu.edu/~hgrie/lectures/nupa-18I/nupa-18I.html for up-to-date course information, .pdf-files of Problem Sheets, suggested reading, corrections, etc.

Prerequisites: The core lectures; in particular: The many facets of scattering; special relativity, relativistic classical and quantum field theory (tree-level QED, Feynman rules, etc.). Especially useful to refresh your memory is Dr. Haberzettl's Quantum Mechanics script, whose contents will be taken for granted.

Goals/Learning Objectives: Introduction to theory and experiment of the standard model of elementary particle physics of strong and electro-weak interactions and survey of Nuclear and Particle Physics from very low energies to its frontiers: Review of experimental and theoretical tools; observed phenomena and evidence for particles, symmetries and interactions; summary of present theoretical understanding in scale-appropriate descriptions. Embedded into the overview, the course addresses topics relevant to research at GW. Focus on skill-building, symmetry principles, controlled approximations and concepts at the fore-front of research. This course will *not* detail all of Nuclear and Particle Physics but survey the field's breadth such that those interested can delve in more details at their own discretion.
Students will demonstrate proficiency with fundamental methods, concepts and terminology of Nuclear and Particle Physics; learn to which extend current physical theory explains particle and nuclear phenomenology; be able to describe the basic physical principles behind theoretical, phenomenological and experimental approaches commonly used in research; be familiar with commonly used assumptions and methods in the field; be able to calculate simple observables in the standard model using Feynman techniques; apply their knowledge to solve a wide range of problems, with special relevance to research conducted in the department; compare and evaluate problem solving strategies, interpreting their respective value and limitations; know which important open questions remain; identify common tools and patterns in Nuclear and Particle Physics; understand the context of ongoing research in the department and be able to formulate research plans; be able to study more advanced experimental and theoretical techniques on their own and as their research will necessitate; understand the background of present research seminars, workshops and conferences.



Outline of Contents, in thematic order only; durations are estimated and Extremely *likely to change.*

1. Tools (ca. 10 lectures)

   Overview: conventions, building blocks, interactions,. . . – accelerators, targets, detectors – experimental facts and statistical fiction – review QFT – scattering and decay – analysis tool electron scattering

2. Phenomena (ca. 6 lectures)

   Geometric shape and masses of nuclei – structure of hadrons – hadron resonances, isospin, mass multiplets – deep inelastic scattering, parton model – e^+e^- annihilation

3. Descriptions (ca. 12 lectures)

   Perturbative QCD: non-Abelian gauge principle, baryons, running coupling – non-perturbative QCD: lattice QFT, confinement – weak phenomenology of interactions – electro-weak unification, Higgs-Kibble-Englert mechanism – Effective Field Theories – the pion-nucleon and nucleon-nucleon interaction – Goldstone mechanism – low-energy Nuclear Physics – further topics as time permits

Style: "Commenting lecture with student participation", i.e. focus on central points to guide and assist you in exploring relevant literature. *The home-page lists strongly suggested reading to efficiently prepare and in particular follow-up on course material. I will assume you have read this material before each lecture, and will familiarise yourself with its formal aspects after each lecture.* I will add my notes and slides to the website as we progress. The better prepared you are, the more we can focus on discussing your questions, problems, observations. The class becomes more interactive and thus more fun – and you learn more.
We will *not* repeat in class the contents of textbooks, but add different perspectives and seek to understand the underlying concepts. I present not all you will ever need – that would be impossible –, but provide an introductory overview with a personal selection of topics which are frequently used in modern research.
Some topics are *not covered thoroughly enough* in class, some may be hard to find in textbooks (see notes on the bibliography), and others are only addressed in the homework. The "lectures" are only a first guide to study the material outlined more rigorously in books, e.g. in those listed below. You should ask yourselves the type of questions that lead to developing and understanding the key concepts and the skills of scientific reasoning. I as teacher can assist, guide, motivate, trigger and speed up your studies, but learning is an active process which takes place within you more than in the lecture hall. Its difference to research is mostly that when doing research, you learn what is not yet found in textbooks.
By the end of the 2-part lecture, you should be able to follow and both ask and answer critical questions in our seminars, in workshops and in conferences.

I encourage you strongly to ask questions and initiate discussions in class and during Surgery hours at all times. Think of lectures rather as "tutorial" or "studio" than a fixed set of hours in which I talk and you listen. If I cannot give you a satisfactory answer right away, I will come back to you, and you should continue asking until you are satisfied. As this is a course at the fore-front of research, this is pretty likely to happen. If you find discussion in class or Surgery hard to follow, see me instantly!

Grading policy: In order to foster collaboration and cooperation among you, the course will be graded on an absolute scale. The final grade is a sum of:

- Exercises/Homework (40% of total): weekly, see below for details;
- Mid-Term Exam (30% of total);
- Presentation as Final Exam (30% of total) – see above.

In order to pass, you need at least 60% of all points *and* at least 50% of the points available in each of the three components *separately.* In particular, you need at least 50% of all points in all Problem sheets together (not per sheet!). 80% is an excellent score, and 90% has not been achieved yet. I do not post scores on the web. If you have questions or comments on your grade or your overall score, please see me.

For your protection, exams are closed-book. A sheet with some possibly relevant mathematical formulae will be provided by me, several days before the exam. If you have understood the concepts and practised enough examples, you will not even bother to consciously memorise anything.

Exercises/Homework: distributed Thursdays on the web, **due the following Thursday at 12:00 sharp** in my pigeon-hole for paper-submissions or electronically to my email (.pdf-file only). ***Late homework is graded as zero points, unless you notify me before the due date with reproducibly legitimate reasons (e.g. illness).***

Handwritten solutions must be on 5x5 quadrille ruled paper; electronic solutions must be in .pdf format. Use of a "lab-book" or "journal" for homework is strongly encouraged and may become mandatory if homework presentations are overly untidy to the point to become indecipherable.
You may use a symbolic programming language like Mathematica, but do not dependent on it. It is useful for some things (like plots), but you will work with pen and paper in exams and the real world. If you use it for part or all of your assignment, you *must* submit a paper printout or .pdf file of the code you used, with all results, and with all your documentation or comments. You can supplement your code by a write-up (.pdf or quadrille paper), and vice versa.

Graded solutions are **returned and discussed during Surgery hour on Friday**. Typically, problem sheets contain a mix of detailed and only outlined questions, with up to 20 points per sheet. Some problems require numerics or graphics programmes (Maple, Mathematica, Fortran, Assembler, C(++), etc.). Some short "quiz-like" questions to gauge your understanding will most likely be included as well.
While it is necessary to have the correct answer for full credit, it is not sufficient. Indeed, it may serve you only one point. What you hand in should be a tidy and efficiently short presentation of your results and how they come about, which can be understood and reproduced by your peers. Imagine it is not homework, but a research problem whose solution you are asked to explain to your peers. I neither encourage nor discourage you to submit solutions electronically. But if you do so, work with a good drawing programme like xfig or gimp (freeware) for sketches. Electronic submission is no excuse for leaving out sketches.
I reserve the right to award zero points for any illegible, chaotic or irreproducible section of your homework.
Homework serves several purposes, e.g.: expand and solidify your math "tool-chest", deepen your understanding by applying what you learned, and cover topics of relevance which are not discussed in the lecture.
To preclude a common mis-conception: A substantial portion of the problems addresses questions in which you have to expand on what was covered in class. A good book can help you to get inspired, but make sure that the solution is yours alone. "Practise-problems" are in the minority, so you should practise additional problems on your own, e.g. using a good book.
I encourage you to form study groups to discuss the reading and attack problem sheets as team. Nothing helps you understand better than interacting with your peers. However, practise additional problems alone to make sure that you do not become dependent on the others.
You can best study and check your progress if you present results and problems with selected exercises in the seminar-style Surgery hours. Your discussion of solutions, problems and comments shape them. As integral part of the lecture, I encourage you to attend them regularly. There is no better preparation for the exams. Surgery is my prime tool to gauge our progress and revisit material which is not fully digested yet.

Typical workload: 10 to 12 hours per week, in addition to lectures and surgery hours – minimum 8 hours.

Some Suggested Reading

Nuclear and Particle Physics is a vibrant research field. You will not find all aspects of the lecture explained well in only one textbook; indeed, some aspects will not be found in *any* textbook. Moreover, it is an essential part of the learning process to view the same topic from different angles, i.e. to use different textbooks. As [J. Nearing: Mathematical Tools for Physics, p. vii] writes: "It is always useful to get a second viewpoint because it's commonly the second one that makes sense – in whichever order you read them." Here is a list of those which I found most useful. If you discover others, tell me. I will bring most of the books listed to the first lecture. *The web-site lists recommended readings for each lecture.*

Compulsory Reading

[PDG] Particle Data Group: *Review of Particle Properties*, over 1500pp. The consolidated reliable up-to-date information of hadron, lepton and gauge boson properties (nearly no nuclei). At least as useful but often overlooked are the reviews with collections of useful formulae, plots, figures, and guide to further literature. You need it to complement any textbook with present-time information in an ever-changing field. Present print edition 2018; present online edition is 2017, reviews updated to 2017. Updated online every Summer, new print edition in the Summer of every even year. Order hardcopy for *free* from `pdg.lbl.gov` (order the free "Particle Physics Booklet" as well – it does actually fit into a pocket); online edition: `pdgLive.lbl.gov`.

GW Lecture Notes

Material is prerequisite for this course, but you may know other/better sources.

[Hab] H. Haberzettl: *Quantum Mechanics with Introduction to Quantum Field Theory – Lecture Notes*; version May 2015. Available upon request from the author.

[MM] H. W. Grießhammer: *A Manuscript of the Graduate Lecture on Mathematical Methods of Theoretical Physics*; version December 2015. Online at home.gwu.edu/~hgrie/.

[Edyn] H. W. Grießhammer: *A Manuscript of the Graduate Lecture on Electrodynamics and Classical Field Theory*; version May 2012. Online at home.gwu.edu/~hgrie/.

Books on which the course is (mostly) based: Phenomenology

Select at least one; insufficient theoretical concepts for a graduate course.

[PRSZ] B. Povh, K. Rith, C. Scholz, F. Zetsche, W. Rodejohann: *Particles and Nuclei – An Introduction to the Physical Concepts*; 7th ed., Springer 2015, ca. US$80. "Standard text" for this kind of course, between graduate and undergraduate level. At times, formulae used are presented without proper motivation. Large enough to cover all aspects but small enough that one does not get lost completely.

[HG] E. M. Henley, A. Garcia: *Subatomic Physics*; 3rd ed., World Scientific 2007, ca. US$70. The "other standard text" for this kind of course. More detailed than [PRSZ] and more for undergraduates.

[DFHMS] T. W. Donnelly, J. A. Formaggio, B. R. Holstein, R. G. Milner, B. Surrow: *Foundations of Nuclear and Particle Physics*; Cambridge University Press 2017, ca. US$75. New Kid on the Block, with very many cutting-edge topics of research; definitely more detailed that [PRSZ] or [HG], but maybe sometimes a bit more "describing" than "motivating" results. Nothing about experimental methods. Let me know what you think of it!

Books on which the course is (mostly) based: Theory

Select at least one; insufficient experimental concepts for a graduate course.

[HM] F. Halzen, A. D. Martin: *Quarks and Leptons: An Introductory Course in Modern Particle Physics*; Wiley 1984, ca. US$70. Although its experimental portions are slim and outdated by now, its presentation of the theory going with them is very good. You learn to do simple Feynman diagram calculations, cross sections, etc. Well suited for experimentalists, and for theorists who studied this long ago and need to be reminded. May be difficult to get new.

[CL] T.-P. Cheng, L.-F. Li: *Gauge Theories of Elementary Particle Physics*; Clarendon Press 1988, ca. US$80. Thorough reader of the theory side of the Standard Model. Nothing about Nuclear Physics.

Further books useful for this course: Theory and Phenomenology

[Per] D. H. Perkins: *Introduction to High Energy Physics*; 4th ed., Cambridge University Press 2000, ca. US$70. An instant classic. Nothing about Nuclear Physics.

[Tho] M. Thomson: *Modern Particle Physics*; Cambridge University Press 2013, ca. US$75. More tuned to upper-level undergraduates without QFT knowledge, and for my taste at times somewhat convoluted, but very nice figures and up-to-date. Nothing about Nuclear Physics.

[Ber] C. Bertulani: *Nuclear Physics in a Nutshell*; Princeton University Press 2007, ca. US$75. The only halfway decent and acceptably modern book on Nuclear Physics I found (entirely my bias). The biggest problem is that Nuclear Physics books in general quickly sketch a bit about the few-nucleon system and then turn to the heavy nuclei for the remaining 90%. This one is a rare exception, but still does not cover adequately the modern developments, especially of Effective Field Theory. The reason for that may well be that this is cutting-edge research where much will be outdated in 5 or 10 years, so it is difficult to condense into textbooks.

[EW] T. Ericson, W. Weise: *Pions and Nuclei*; Oxford University Press 1988, only used or in libraries. While ignorant of any modern development, this is a very nice source especially of the more traditional treatment of the pion-nucleon interaction. For the specialised reader.

[TW] A. W. Thomas, W. Weise: *The Structure of the Nucleon*; Wiley-VCH 2001, ca US$140. Possibly the last book without a low-energy treatment based on EFT, this is nonetheless an excellent summary of all known about the nucleon, especially at medium energies. For the specialised reader.

[SS] S. Scherer, M. R. Schindler: *A Primer for Chiral Perturbation Theory*; Springer 2011, ca. US$70. The first book-form account of Chiral Effective Field Theory. Focus on the purely mesonic sector, but also some pion-nucleon interaction. Highly pedagogical, many not-too-difficult exercises with detailed solutions for self-study and future low-energy theorists. Schindler was postdoc in our EFT group.

[TALENT] R. Furnstahl, A. Schwenk: *2013 TALENT/INT Course on Nuclear Forces and Their Impact on Structure, Reactions and Astrophysics*, online. Pedagogical INT summer programme of the modern trends in Nuclear Physics. First half focuses on few-nucleon systems at low energies. Online videos, slides, manuscripts, exercises.

Further books useful for this course: Experimental Methods As experimentalist, you may prefer owning one of these.

[Leo] W. R. Leo: *Techniques for Nuclear and Particle Physics Experiments – A How-To Approach*; Springer 1987 , ca. US$100. Still on nearly every experimentalist's shelf.

[Tav] S. Tavernier: *Experimental Techniques in Nuclear and Particle Physics*; Springer 2010 , ca. US$55. Appears to be a very good update of [Leo].

[Kno] G. F. Knoll: *Radiation Detection and Measurement*, 4th ed.; Wiley 2010, ca. US$200. Just for looking, not for buying.

Further books useful for this course: Quantum Field Theory

Not central to the first semester, but to the second one. Theorists may prefer owning one of these.

[PS] M. E. Peskin, D. V. Schroeder: *An Introduction to Quantum Field Theory*; Perseus Books 1995, ca. US$75. A standard text for Quantum Field Theory. Nothing about Nuclear Physics.

[Ryd] L. H. Ryder: *Quantum Field Theory*; 2nd ed., Cambridge University Press 1996, ca. US$75. Another, slightly more modern standard text for Quantum Field Theory, covering material in less excruciating detail. Nothing about Nuclear Physics.

[LB] T. Lancaster, S. J. Blundell: *Quantum Field Theory for the Gifted Amateur*; Oxford University Press 2018, ca. US$45. The scope appears to be for people who want to understand and not go into gory details. Tell me how you like it.

Further (Online) Resources – Click on Link to Access

[arXiv] `arxiv.org`: the Physics preprint server.

[inspire] `inspirehep.net`: the High Energy Physics information system. Access to pretty much every article since 1980, including reviews, summer school proceedings and other pedagogical and up-to-date material.

[NN] `nn-online.org`: the Nijmegen Partial Wave database and analysis website, mostly for nucleon-nucleon scattering.

[DAC] `gwdac.phys.gwu.edu`: The Data Analysis Center at GW maintains the SAID Partial-Wave Analysis Facility as well as further analyses and databases for mesons, baryons and their interactions.

Further reading as needed and advertised.

A note on academic integrity: You like Physics, or you would not be here. Thus, it is trivial that you will abide by the GW Code of Academic Integrity in all graded work. An excerpt: "*Academic dishonesty is defined as cheating of any kind, including misrepresenting one's own work, taking credit for the work of others without crediting them and without appropriate authorization, and the fabrication of information.*" For the remainder of the code, see: http://studentconduct.gwu.edu/code-academic-integrity. I will deal with violations according to the Code.
A breach of academic integrity is a serious issue. The Scientific Method relies on the faith of the scientific community that the findings of its members are not fraudulent or forged. Reserachers may be wrong or sloppy, but we inherently trust they try their best to do a good job. Every researcher builds that reputation during a whole academic life – in graduate school, postdoctoral research, and thereafter. In recommendation letters, the department, your thesis advisor and collaborators all put their reputation at stake to endorse you. They all trust you. When that trust is broken, the Scientific Community feels violated and offended. It takes the only and strongest remedy: ostricisation, i.e. banishment from the scientific discourse; see e.g. wikipedia articles "Jan-Hendrik Schön", "Victor Ninov", "Andrew Wakefield".

Academic integrity is at the heart of your credibility as scientist. It is your most valuable asset. Do not risk it.

You are encouraged to collaborate on your homework and even to be inspired by a good textbook, but make sure you have understood what you hand in as your solution. Do *not* offend your own (and my) intelligence by copying other people's work (especially without referencing). The web-site, all problems and solutions are for your personal use only. Do not pass solutions or problems on to any student who has not taken the course (yet). Do not accept or solicit solutions from students who have taken the course. Other examples of a breach of academic integrity include: to facilitate cheating or help others to cheat; to obtain information for homework, exams, presentations, etc., by means other than disclosed in your bibliography; to ask for or give any kind of factual information which is not in an exam but needed to solve the problem, no matter how insignificant it may seem, except if the examiner approves; etc.
Noncompliance with these rules is a breach of integrity and will be dealt with accordingly. If you have any questions about what constitutes academic dishonesty, ask.

Absences and Excuses follow standard GW policy. It is your own responsibility to make sure you fulfil the criteria for passing, in particular that you get at least 50% of all the points available in all Problem sheets together (not per sheet). The only way around this criterion is to submit in writing documentation that you were unable to perform homework for more than half the semester due to reasons out of your control, as outlined in the GW policy on absences and excuses.
There will be no make-up exams. A missed exam will be dealt with case-by-case. Bring any potential conflicts or difficulties to my attention *before* the exam. If you miss an exam for some unexpected reason, it is your responsibility to notify in writing *within 24 hours* of the missed exam, or the grade will be zero for the missed exam. Absence for medical reasons must have formal, written documentation from the medical office providing care. DC traffic is no excuse, and no additional time will be provided for late-comers.
If you see a conflict between religious observances and the class and exam schedule, you will bring them to my attention in advance, in the first week of the semester. It is University policy to extend to these students the courtesy of absence without penalty on such occasions, including permission to make up examinations.

Recording Taking written notes in lectures has been the practise for centuries and is of course permitted. Indeed, I encourage you to at least have the manuscript printed out and annotate it vigorously during class. Taking notes makes sure your brain processes and stays awake.
However, ***electric or electronic recording*** of the lecture or any discussion in any way, shape or form (audio, video with or without sound, camera, photography, shellack, casette, dictaphone etc.) ***needs my prior written permission***, as well as prior permission by all students. I consider failing to obtain permission as a breach of GW's Students Rights and Responsiblities and Academic Freedoms policies. It also infringes on my and GW's copyright. I will call GW police, refer violators to the appropriate authorities for sanctions, and advocate for the strongest-possible prosecution permitted by criminal and civil law.

Security In the case of an emergency, if at all possible, the class should shelter in place. If the building that the class is in is affected, follow the evacuation procedures for the building. After evacuation, seek shelter at a predetermined rendezvous location.

Disability Support Services (DSS): http://counselingcenter.gwu.edu/ Any student who feels that man accommodation may be needed based on the potential impact of a disability should contact me privately to discuss specific needs. Please also contact the Disability Support Services office at 202-994-8250 in Rome Hall, Suite 102, to establish eligibility and to coordinate reasonable accommodations. For additional information, please refer to: http://disabilitysupport.gwu.edu/.

GW's Mental Health Services (202-994-5300) offers 24/7 assistance and referrals to address students' personal, social, career, and study skill problems. Services for students include:
– **Crisis and Emergency Mental Helth Consultations 202-994-5300** 24 hours, not only for emergency.
– Confidential assessment, counseling (individual & small group), referrals.