PHYS 6210: Electrodynamics and Classical Field Theory

Syllabus Spring 2017

Teacher: Dr. Harald W. Griesshammer, Staughton 216, 202-994-3849, hgrie@gwu.edu.

Lectures: **Tuesday/Thursday 12:20 to 14:00 in Staughton 103** (100 min each, for 4 credits).
"Snow Days" (possible slots for rescheduled lectures): **Thu 17:00 to 18:40 in Staughton 103 or Wed 16:00 to 17:40 in Staughton 103**.

Homework Due: Wednesdays at 16:00 sharp
Surgery hours: Thursdays at 14:00 in Staughton 103 to discuss the problem sheets and for questions, discussions and suggestions; duration: till all questions are answered.
More office hours by appointment weekdays after 15:00 in my office. Best email what and when to discuss to make sure I have time and am prepared.

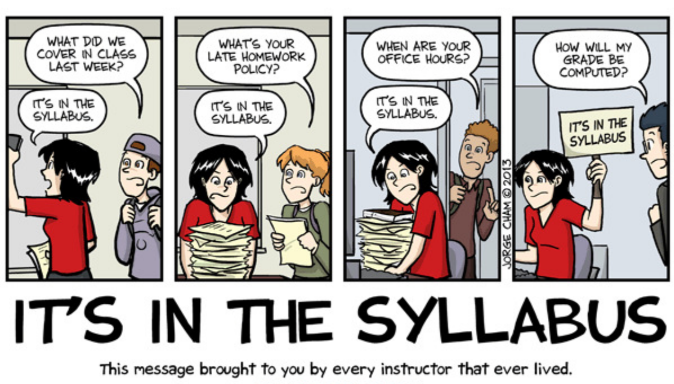
Mid-Term Exam: Wednesday, 22 March at 08:30 in Staughton 103, 2.0 hours.
Final Exam: Tuesday, 16 May at 09:30 in Staughton 103, 2.5 hours.
This Final Exam also serves as Part of the Physics PhD General Examination.
The General Examination Committee assesses Pass/Fail of this General Examination Part independently of your course grade. See the Procedures for details, or ask the Graduate Advisor.

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

Web-site: http://home.gwu.edu/~hgrie/lectures/edyn17/edyn17.html for up-to-date course information, .pdf-files of Problem Sheets, a manuscript, suggested reading, corrections, etc.

Prerequisites: Undergraduate Electrodynamics on the level of Griffith: *Introduction to Electrodynamics*, Chaps. 1-6; advanced undergraduate mathematical methods; undergraduate Quantum Mechanics.
The graduate courses in Autumn, in particular *PHYS 6110: Mathematical Methods of Theoretical Physics* and the chapters on Lagrangean Mechanics and on Relativity in *PHYS 6120: Classical Mechanics*, are indispensable. See the first two paragraphs in the *Questions to Check Your Progress*.
Coordinated with *PHYS 6220: Quantum Mechanics I* (Haberzettl).
Co-requisite: *PHYS 6230: Computational Physics II* (Haberzettl/Griesshammer).

Goals/Learning Objectives: Introduction to the theoretical concepts and mathematical methods of Classical Electrodynamics as example of a relativistic Field Theory, with many examples and applications. Focus on skill-building, symmetry principles, controlled approximations, and concepts at the fore-front of research. Students will demonstrate proficiency with fundamental methods of Electrodynamics; apply their knowledge to solve a wide range of problems in modern Physics, with focus on Nuclear and Condensed-Matter Physics, and with special relevance to parallel and future lectures of the graduate curriculum; compare and evaluate problem solving strategies, interpreting their respective value and limitations; be able to study and create more advanced and specialised techniques on their own and as their research will necessitate. See also the separate *Questions to Check Your Progress*.



Outline of Contents in thematic order only; duration is estimated only.

1. The Fundamental Equations of Electrodynamics (1 lecture)

   Recap: vector analysis (incl. Gauß', Stokes', Helmholtz' theorems), fields, interpretation of Maxwell's equations

2. Electrodynamics as Relativistic Field Theory (3+1 lectures)

   Recap Special Relativity and action for point particles – Lagrange mechanics of continua, fields and Electrodynamics – gauge fields and gauges – conserved currents – energy, momentum and stress

3. Electrostatics (2 lectures)

   Poisson equation – Recap Green's functions, boundary value problems, spherical harmonics and other complete orthonormal sets of functions – Cartesian and spherical multipole moments

4. Magnetostatics (1 lecture)

   Law of Biot-Savart – magnetic dipole – Larmor precession and hyperfine splitting

5. Radiation and Radiating Systems (7 lectures)

   Wave equation – plain waves – polarisation – retarded potentials — antennae and radiation multipoles – radiation from a moving charge – Bremsstrahlung – synchrotron radiation – radiation loss and Larmor's formula

6. Scattering Theory (2+1 lectures)

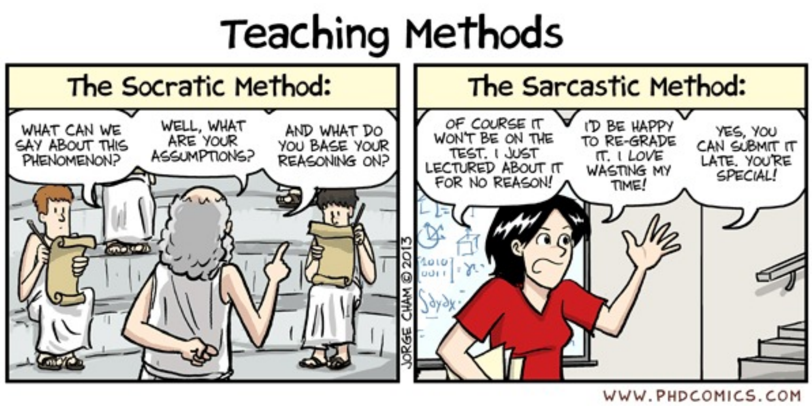
   boundary conditions – cross-sections – polarisabilities – Lorentz oscillator model and its limits – emergence of geometrical optics

7. Electrodynamics in Matter (8 or 9 lectures)

   Maxwell's equations in media – linear electric and magnetic response – energy-dependent dielectric constant and magnetic susceptibility – free fields in matter – electro-magnetic properties of condensed matter – reflection and refraction – dispersion relations

8. Advanced Topics (time permitting)

   Quantum Mechanics with the classical electromagnetic field – superconductivity and topology – non-perturbative phenomena in classical field theory – solitons



Style: ***"Commenting lecture with strong 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.* Most important is the link to a manuscript of the lecture in my (illegible) hand-writing, see p. 4. Read over the manuscript before class and grasp the essential points. *I will assume that you have read this material before each lecture and that you will familiarise yourself with its formal aspects after each lecture.* The better prepared you are, the more we can focus on

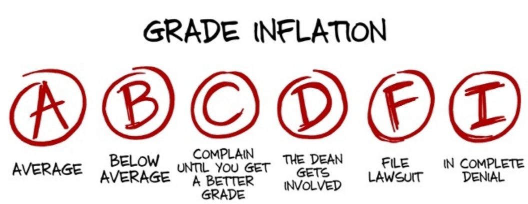
discussing your questions, problems, observations. The class becomes more interactive and thus more fun – and therefore you learn more. Study details of the manuscript after the lecture, as starting point for your own literature research using good books like those recommended for particular subjects in the "Suggested Reading" column below. Some people prefer to have a print-out of the manuscript in class, so that they do not have to write down all details but can highlight and annotate important points.
We will *not* repeat in class the contents of textbooks, but add different perspectives and seek a deeper understanding of the underlying concepts. I present you not the entirety of Electrodynamics – 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. From time to time, we will only briefly review the concepts and concentrate on solving as a group a problem which has been distributed to you in advance. You are strongly encouraged to think about the problem before class.
The "lectures" are only a first guide to study Electrodynamics in books, e.g. in those listed below. You should ask yourselves the type of questions that lead to developing and understanding the key physical 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.

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. If you have no questions, I will assume that you get bored, encouraging me to speed up. 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 (20% of total): weekly, see below for details;
- Mid-Term Exam (40% of total);
- Final Exam (40% of total.

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, the exams are closed-book. A sheet with some possibly relevant mathematical formulae will be provided by me, several days before the exam. I will assume that you have memorised the most fundamental Physics formulae, like Maxwell's equations. If you have understood the Physics contents of formulae and practised enough examples, you will not even bother to consciously memorise anything.



Exercises/Homework: available online Wednesdays on the web, **due the following Wednesday at 16:00 noon** in my pigeon-hole for paper-submissions or by fax (202-994-3001) 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. 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. The course website contains Mathematica files used in the lecture, but they are not as well documented as I expect yours to be. 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 Wednesday**. Typically, problem sheets contain a mix of detailed and only outlined questions, with up to 30 points per sheet. Some problems require numerics or graphics programmes (Maple, Mathematica, Fortran, Assembler, C(++), etc.). I may also outline some solutions or give hints to solving a problem during the lectures.
Some projects of *PHYS 6230: Computational Physics II* will be chosen from this course's material, and hence need some "real" programming. These do not impact your grade in Electrodynamics; see announcement of *PHYS 6230: Computational Physics II* (Haberzettl/Griesshammer).
It is a fact of life that if you score more than 60% of the homework points, you will most likely perform well in exams and the qualifying. Some exam questions will almost certainly be based on homework solutions.
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, submit in .pdf format only and work with a good drawing programme like xfig or gimp (freeware) for sketches. Electronic submission is no excuse for leaving out sketches or figures.
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 or the manu-script. 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.

Lecture Manuscript

A scanned version of a chapter-by-chapter manuscript can be found by following the links of chapter headings in the Class Schedule and Contents Sections on the web-site. The files are in .djvu-format, at present the most condensed way of storing scanned images: 50 scanned pages translate into 1.2 Gbytes of bitmap, or 50 MBytes .pdf or 4.7 MBytes of .djvu. The freeware djvu reader "djvulibre" for all operating systems is available at http://djvu.sourceforge.net/, or as add-on to every decent Linux distribution.

Historical note: The manuscript was originally designed for a 2-semester, 150-minutes-per-week course in graduate curriculum year 1. This made it necessary to include some material now covered in Mathematical Methods and Classical Mechanics. In its present form, such topics are now course pre-requisites. Some other topics covered in the manuscript may not be course material. For more, read p. 3 of the script.
Caveat: Warning and Disclaimer These are my notes for preparing the class, in my handwriting. While considerable effort has been invested to ensure the accuracy of the Physics presented, this manuscript bears only witness of my limited understanding of the subject. I am most grateful to every reader who can point out typos, errors, omissions or misconceptions. Maybe over the years, with lots of student participation, this can grow into something remotely useful.
The manuscript only intends to ease the pain of preparing and following the lecture. It does not replace the thorough study of textbooks (see note on the Style of the Lecture, p. 2). The manuscript is not intended to be comprehensible, comprehensive – or even useful. It is certainly not legible. Your mileage will vary.
This manuscript is not useful or relevant for exams of any kind.

Some Suggested Reading

There is *no required reading* for this course. You will not be able to find all aspects of the lecture explained well in only one textbook. Moreover, it is an essential part of the learning process to view the same topic from different angles, i.e. using different textbooks. As [Nea 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. I suggest to wait with buying for a while before you decide which book suits your style best. Advanced graduate students are an excellent source for recommendations as well. *The web-site lists recommended readings for each lecture.* An asterisk * indicates titles on Course Reserve we have on semi-permanent loan in the Graduate Office Staughton 1XX, from Gelman Library. Be social.

[M] G.B. Arfken and H.J. Weber: Mathematical Methods for Physicists; 7th ed., Academic Press, ca. 110$. While not optimal (see last semester), it is a reasonable tool to refresh and study the necessary math.

[Brau] * Ch.A. Brau: Modern Problems in Classical Electrodynamics; Oxford University Press; ca. 98$. I find this a good compromise between [Jack] and [Lan2/8], arguing beautiful Physics. While most closely reflecting the philosophy of the lecture, some topics are not or insufficiently covered. May be too weak on explaining mathematical details. Watch the errata webpage!

[Lan2] * L.D. Landau and E.M. Lifshitz: The Classical Theory of Fields [Course of Theoretical Physics Series, Vol. 2]; 4th ed., Butterworth-Heinemann; ca. 45$. Indispensable for theorists, concise, dismissing mathematical details as trivial, and hence maybe sometimes hard to swallow. Includes General Relativity; Electrodynamics in matter is found in [Lan8].

[Lan8] * L.D. Landau, E.M. Lifshitz and L.P. Pitaevskii: Electrodynamics of Continuous Media [Course of Theoretical Physics Series, Vol. 8]; 2nd ed., Butterworth-Heinemann; ca. 45$. Good presentation, but slightly outdated, very detailed and maybe sometimes hard to swallow. Covers what [Lan2] leaves out.

[Jack] * J.D. Jackson: Classical Electrodynamics; 3rd ed., John Wiley, ca. 100$. The classic text/bible of researchers. Covers all aspects, but too focused on mathematical details. Chaotic treatment of media. A book most people love to hate, with a reputation which is not entirely undeserved.

[Grif] D.J. Griffith: Introduction to Electrodynamics; 3rd ed., Prentice Hall; ca. 102$. Undergraduate text.

[Schwa] M. Schwartz: Principles of Electrodynamics; Dover; ca. 12$. Undergraduate text.

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", "Teruji Cho", "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.

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.

Some Hints for a Successful Graduate Life

This is by no means a complete list, but it helps me in my teaching and research. Use your own judgement!

Follow simple tricks to check that your homework solutions are focused, understandable and correct. You do not have to type your homework for this course using LaTeX, but Dr. Haberzettl collected some simple but highly efficient tricks how to structure your solution, how to avoid errors and which cross-checks are very valuable. Citation with minor modifications:

- **Indicate each problem number and the parts according to the original questions** in your solutions. Follow them in sequence. If you do not have an answer for any part, write "no answer" or leave blank. Do not repeat the question.
- **Structure your document by paragraphs**; do *not* run all parts together in one big amorphous narrative. Be concise. When necessary for cross-referencing, number the equations. Clearly identify your answers to the specific questions of the problem.
- **Clearly explain your notation, what you are doing, and why you are doing it.** Otherwise, a teacher needs to guess and you have no recourse if that guess is wrong. "But it's obvious that I meant..." is not a valid excuse. Even a Professor of Physics is not psychic, and what is obvious to you may not be obvious to me.
- **Equations that mix incompatible mathematical entities are wrong!** For example, clearly distinguish between vectors and scalars. "$\vec{F} = ma$" is wrong because it equates a vector to a scalar.
- **Always check whether your results have the right units**. This is a very simple, but extremely effective, method to avoid many mistakes. If you make a habit of it, it becomes subconscious. For example, "[kg]=[N m^3]" must be wrong.

Attack your homework early. Don't postpone it to the last few days or even minutes.

Get a first impression. Explain to you (or, better, your peers) in your own words what the problem is about and what you are asked to determine. Avoid using formulae, focus on a "story". Sketch a figure explaining the physical situation.

Make a plan of attack. First think what solution you expect from your physical intuition. This can include a sketch of the expected solution. Then ponder over a good way to find the solution. This can take even an hour. Then take a deep breath. Then think again about the problem. Then solve. The time spent on first thinking about the solution is much shorter than the time wasted with abandoned attempts when you instantly start scribbling. In particular in exams.

Form teams (see above). Nothing helps one to understand better than discussing homework and lectures with peers. But practise additional problems alone in order not to become dependent on others.

Rank craftsmanship over ingenuity. You will be outstanding soon enough, but for now, continuous, solid work is more reliable than occasional sparks of brilliance.

Don't get nailed-down. Nobody requires you to find the *best/most elegant/fastest* solution. *Any* solution will do for a start. Once you have one, you can always look for a better one – if you have the time. When stuck, discuss with your peers (and consult the lecture and books). If you get very stuck, do another problem first. It's no use to get no problem done because you wasted all your resources on the first one.

Practise sketching and plotting. Discussions, sketches and plots are a must! Not only because the homework is full of these words, and you will loose a lot of points if you do not discuss, sketch and plot. But human beings are visual beings: We understand and recollect much better when we see a figure.

Assess your answer. Does the result make sense? Compare to limits in which the problem simplifies or in which you know the solution. Does the answer match your expectations (see "first impression")? If not, why not? Check that you answered all questions in the problem description.

Scrutinise your homework when it is returned to you and reproduce a correct solution. Clean up your notes. What did you not understand? What did you miss? Was there a faster way? Where are your strengths and weaknesses? You should spend at least an hour on that, as soon as possible. It will help you with the next homework set.

Work through each lecture on the day it is delivered. If you miss that, you will have a very hard time to understand the next lecture. In that context, "Tomorrow will be another day" is a very bad motto.

"Fill in the gaps" of the lecture. Spell out the details of proofs, make sure the signs and factors are correct, etc. That already gives you a lot of free practise in math, and makes sure your thinking and notes are up-to-date and correct. And you have a set of notes you understand when you come back after weeks or months or years, for exams or research.

Consult books (plural!) after you have reviewed the lecture. It will clarify things further, show you new and different perspectives, and deepen your understanding. I usually excerpt information which I found interesting in a book, in addition to lecture notes.
"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." [Nearing: Mathematical Tools for Physics, p. vii]

Look at the Physics behind a formula. Does it make "sense" from your physical intuition? Do you understand what it means? What are its limits, i.e. regimes where it becomes particularly simple to understand? What are its limitations, i.e. where does it not work? Explain it and its underlying principle to a peer or to an undergraduate, using no math. You will believe your most beautiful mathematical proof only if you can also give a good intuitive argument why the formula should be right.

Ask yourself: What is the hidden agenda behind this topic in the lecture, homework, etc.? What can I learn that goes beyond the straightforward application? Is there a greater principle involved which I can use in different contexts? Why is e.g. a proof presented this way? In which other fields could I use similar techniques/reasoning?

Talk with your lecturers. We post out office hours not out of courtesy, and we don't bite. If you don't come to me with your problems, how can we help you? we – for one – love discussing. Have no fear to overburden us. We will tell you when we have had enough.

Have a life outside Physics.

The University Counseling Center (UCC) assists you in addressing personal, social, career, and study problems that can interfere with your academic progress and success.
Services for students include:
– **Crisis Consultations at 202-994-5300** open day and night, not only for emergency.
– Confidential assessment, counseling services (individual and small group), and referrals: http://counselingcenter.gwu.edu/counseling
– Academic Support and Peer Tutoring Services: http://gwired.gwu.edu/counsel/AcademicSupport
– Podcasts and Self-Help: http://gwired.gwu.edu/counsel/PodCast, http://gwired.gwu.edu/counsel/OutreachSelfHelp

They are also very good when you need to review your habits, like learning and exam strategies.

It's never too early to get help.