Part II Study Guide (otherwise known as the Written Exam)

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Abstract

The purpose of this study guide is to provide something close to comprehensive listing of topics that have been covered in the exams currently available on the MIT Physics-REFS website

(http://web.mit.edu/physics/refs/generals/index.html#examsII).

This list of topics presented below represents a condensation of the topics that I used to prepare for the exam over the course of the winter of 2014-2015.By no means is this the end all listing of topics you have to know in order to pass Part II, but rather use this as a place to identify topics that you need to work on in order have the best possible chance of passing Part II. In light of the recent departmental changes to the general exam structure, you may end up only studying one or two of the sections listed below. Also take the information listed below with a grain of salt, since everyone has their own opinions regarding the exam structure, difficultly, topics that need to be covered etc... If you find anything amiss with this guide, please email me at aleder@mit.edu and I will be sure to update this as needed.

1 Some tips regarding Part II

While studying for part II for the first time, remember that you only need to answer one of the two questions that are asked. Generally, but not always, each section has question that is less algebra but requires more insight while the second question is more straightforward but requires more algebra. If possible get a group of people together and try to study as a group, meeting once a week at first and increasing the frequency the closer you get to the test. Be aware that there are some mistakes in the solutions provided by the PhysREFS, so in cases where your answer does not match with the solution, do not always automatically assume you are in the wrong. In addition, time permitting, try out a few of the harder/end of chapter problems from your favorite undergraduate physics textbooks. For topics that come up with a high frequency, I suggest making a summary sheet of the formulae and concepts covered by that topic and then reviewing said summary sheets from time to time. The same strategy can also be employed with each exam, try to write a single or two page write-up of each exam that you go through, one of the main points of this exam making sure that you can remember in depth a wide array of topics from the major areas covered by various exams. Finally, do not forgo unit analysis simply because you are in graduate school now, it can provide you with a quick check on your answer (except for those of you who prefer Gaussian units for some reason) and can be a valuable tool for remembering formulae.

2 List of topics Statistical Mechanics/Thermodynamics

In particular in this section there are certain topics that come up quite frequently, while the list maybe be shorter, the depth to which you need to know some topics is higher. The topics are in no particular order:

- Debye/Phonon Heat Capacity
- Average energy of a system, variance of the energy in a system
- Isothermal Compressibility
- Adiabatic Processes
  - γ = adiabatic constant
  - Adiabatic compression/processes
- Fermi waveguides,Fermi number,Fermi Level, well really anything that has the name Fermi in front of it...
- Fermi verses Bose Statistics
- Classical limit in Statistical Mechanics
- Sterling's approximation
- Maxwellian Speed/Velocity Distribution
- Maxwell Relations and other general thermodynamic relations (relations such as $\frac{\partial E}{\partial S}|_v$ = T)
- Equilibrium processes in Statistical Mechanics - in particular pay attention to what parameters are held constant when certain thermodynamic potentials are in equilibrium
- Ideal Gas Partition Function (grand and not so grand versions)
- Thermal wavelength
- Clausius-Clapeyron Relation
- Density of States - very important be able to derive both the relativistic and non-relativistic versions of the density of states in both $\vec{k}$ and ϵ space (do not forget about spin degeneracies!)
- Bose-Einstein Condensation - this is a favorite topic of the Part II committee, be sure to know this topic very well
- Partition Function - this topic is particularly important as many of the problems you will encounter will require you to either calculate the partition function or derive some quantity based on the partition function of a system
  - Single verses Multiple Systems
  - Conversation from a discrete sum over k-states to an integral over k-volume (this is slightly more subtle than you might initially realize)
  - Partition function and their corresponding Thermodynamic potentials

3 Classical Mechanics

In light of the recent changes to the General exam, everyone has to take at least this section, therefore I suspect most of you will pay attention to this section. Again in no particular order the listing of topics covered:

- Relativistic Mechanics
  - Relativistic momentum
  - Lagranian/Hamiltonian Formalism in relativistic limit
  - Forces in relativistic limit
- Orbits in Central Force motion - this comes up quite frequently
- ~~Classical Scattering, in particular the formula for determining the change in the angle of a particle as a function of energy~~
- ~~Relation between potential and angular momentum~~ ?
- Coordinate transformation both in linear and rotational frames
- ~~Invariant quantities in collisions~~
- Euler-Lagrange formula
  - With and without constraints
  - Dealing with the constraint forces
- ~~Vibrational/Rotational Eigenmodes/Eigenfrequencies of some basic 2/3 body system (Example: coupled pendula)~~
- Spring damping
- Inertia Tensor and Euler Angles → rigid body
- ~~Conversation of Angular Momentum~~
- ~~Linear and Rotational Power~~
- ~~Rolling - basically understand when you can apply the rolling without slipping condition~~
- Virial Theorem - comes up a lot in other areas including the simple harmonic oscillator in Quantum Mechanics → 2-body problem
- Hamilton-Jacobi Formula
- Adiabatic invariants
- ~~Oscillations - both linear and rotational (epicyclic)~~
- Poisson Brackets - note similarity to Quantum Mechanical Commutation Relations

4 Quantum Mechanics

Again in no particular order:

- Pauli Matrices - do not simply assume they will be given to you
- Probability current
- Spin
  - Commutation Relations
  - Ladder operator relations/eigenvalues
  - Degeneracies
  - Addition of spins
- Commutating Operator properties
- Canonical commutation relations
- Quantum Mechanical Scattering
  - Optical Theorem
  - Scattering State Solutions
  - Plane Wave Solutions
- WKB approximation (or JWKB if you happen to really like Jeffery)
  - Theory of Alpha Decay (see example in Griffth's QM)
  - Connection Formulas
  - WKB in spherical coordinates
- Perturbation Theory
  - Time Independent know both 1st order changes to wave function and energy and second order shift to energy
  - Time Dependent - evolution of 2-state system states
- Ehresfest's Theorem
- Translation operators in both x,p and E,t space
- Wavefunction evolution in x and p space
- Matter-Wave duality, remember $\vec{p} = \hbar\vec{k}$ and you can derive a surprising amount of results from that
- Heisenberg Equation of motion/ Time Evolution of Operators - This comes up time and time again, learn it well, also note connection between this and Poisson Brackets in Classical Mechanics
- Simple Harmonic Oscillator - know this backwards and forwards! This topic in particular comes up quite frequently and in various iterations on the various exams
- Quantum Mechanical Effective Potential
- A few useful relationships to know for any arbitrary function G
  - $[x, G(\vec{p})] = i\hbar\frac{\partial G}{\partial p}$

- $[p, G(\vec{x})] = -i\hbar \frac{\partial G}{\partial x}$ (note the negative)
- $\frac{\partial}{\partial x}^{\dagger} = -\frac{\partial}{\partial x}$

- Generalized Uncertainty Principal
- Aharonov - Bohm Effect
- S-matrix and scattering theory

5 Electromagnetism

Overall the impression I have gotten is that this section in particular covers a much wider range of topics than the other three. Also even the more insightful problems in this section can easily turn into a mess of algebra. When we had to take all four sections at once, this was the section that many people focused more of their time on. That being said certain members in my class opted to simply do a large percentage of the Griffith's EM problems in addition to reviewing the old exam problems. Up to you, again in no particular order.

- Fresnel Relations including phase shifts at boundaries
- Magnetic/Electric Fields of various basic geometries (loops,line,square of charge or current etc...)
- Dipoles! This is a favorite of the people who write the exams
  - Potential and Electric Field of static and oscillating cases
  - Magnetic Dipoles - solid disk and spinning sphere
  - Electric Dipole Radiation
- Maxwell Relations (note about unit systems, just pick one when you start studying and stick with it, I will not judge too much if you opt for Gaussian units...)
- Poisson's/Laplace's Equations and their corresponding solutions in spherical and cylindrical coordinates
- Ohms Law (both forms)
- Capacitance of various basic geometries (shell, parallel plates, coaxial etc...)
- Poynting vector - dimensional analysis is actually fairly useful in disentangling all the various derivations from the basic Poynting vector formula
- Energy/Momentum stored in fields - this comes up fairly frequently (personal note it also came up on my exam)
- Multipole Hierarchy/Expansion up to Octopole moment
- Method of Images - another favorite, be sure to practice calculating the induced charge in a system
- Maxwell Stress Tensor
- Pressure Energy Density relations
- Current Density and Vector Potential
- Momentum stored in fields verses momentum available to do work
- EM Lagrangian and canonical momentum
- EM boundary conditions - both at vacuum and media interfaces

- Plasma Oscillation Frequency
- Relativistic EM
  - Lorentz Transformations
  - Invariant quantity - $\vec{E}^2 - c\vec{B}^2$
  - Electromagnetic field tensor - work through a few examples
- Electric and Magnetic Fields in media
- Rectangular Waveguides
- EM wave guide in both vacuum and in media
- Magnetic Force

6 Other Topics/Math Methods

- Dirac Delta function (vector and functional forms)
- Series expansions of basic math functions
- Speed of sound in air
- Unit vector in various coordinate systems
- General Rotation matrix
- Binomial Expansion with fractional exponent
- Trigonometric Identities
- Solid Angle definition
- Conversion between SI and Gaussian units
- Vector Operations and Identities
- General form of Legendre Polynomials
- Commutation relations Identities - in particular those involving 3 operators

7 Closing Thoughts

I hope you found this guide useful. If you see anything missing or amiss or just want me to make you my famous carrot souffle feel free to email me at aleder@mit.edu. You will get through these exams, it can be scary, but just stay the course and you will get through them. PhysRefs and your fellow classmates are great resources when studying for these exams. Just keep at it, I myself had to take Part I three times and Part II twice and I know of people who had to take the oral in parts Parts I and II and they passed. Of course that means I get to call you all whippersnappers and wave my cane angrily at you while you study for the sole written exam. Best of luck students of the future!

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