Introduction to holography - Exam topics

Fall 2025

Dear students,

Here is a list of topics and concepts that you are expected to know for the exam. The stars indicate the level of detail you are expected to know this:

* : be able to state the concept and its implications/physical interpretation

** : be able to sketch the derivation and write down the necessary equations to start/finish it

*** : be able to perform a full calculation of the given quantity

The lecture notes are the main reference material. Below, we include some additional reading that you may find useful. We also include further, more advanced reading - cited with the prefix *adv.* - if you become particularly interested in given topic.

Advanced GR and hints of holography

1. Variational principle* and Gibbons-Hawking term** [Wald appendix E, Blau ch. 20.5]
2. Structure of GR Hamiltonian: constraints + boundary term* [adv: Blau ch. 21]
3. Energy as a boundary term: know at least one explicit formula that you can use in a computation*** [Brown-York quasilocal energy(notes & Hartman ch. 8)/ Blau eqn (21.191)]
4. Statement of singularity theorems and their applications* [Jacobson, adv: Witten 2019]
5. Raychaudhuri equation** [Blau sec. 12.2]
6. Statement of cosmic censorship* [wikipedia, Witten 2019 sec. 4.4]
7. Laws of Black Hole mechanics*** (0^{th}, 1^{st}, and 2^{nd}) [Jacobson, adv: Wald ch.10, Wald '01]
8. Definition of surface gravity and Hawking temperature** [Townsend sec. 2.3.5 & 2.3.6]
9. Unruh effect* [Carroll sec. 9.5, Mukhanov ch. 8, Hartman sec. 3]
10. 't Hooft argument for holography** ['t Hooft '93]
11. Large N 't Hooft limit in theories with matrix dof** [Hong Liu lectures 6 & 7]

The basics of string theory

Main references: Szabo, Tong, Green-Schwarz-Witten (GSW), adv: Polchinski

1. Nambu-Goto and Polyakov actions**[GSW sec. 2.1, Tong ch. 1, Szabo ch. 2, ...]
2. Spectrum and string states built from the oscillators** [GSW sec.2.2, Tong ch. 2, Szabo ch. 3, ...]
3. Low energy effective action of bosonic string theory * [Polchinski section 3.7, Tong ch. 7]
4. String perturbation theory (genus expansion)* [Tong chapter 6, GSW]
5. The $AdS_5 \leftrightarrow CFT_4$ correspondence (type IIB $AdS_5 \times S^5 \leftrightarrow \mathcal{N} = 4$ SYM) [MAGOO ch. 3]
   (a) D-branes* [Polchinski sec. 8.7, adv: Polchinski '96] and the decoupling argument** [MAGOO sec. 3.1]
   (b) Matching of parameters and discussion of the different regimes *** [MAGOO sec. 3.1]
   (c) UV-IR correspondence** [MAGOO sec. 3.3, Susskind-Witten '98]

Conformal Field Theory

Main references: João's notes, Simmons-Duffin

1. Conformal and Weyl transformations*** [João notes section 2.1, Di Francesco chapter 4]
2. Primary and descendant operators *** [João notes section 2.1]
3. Ward Identities ** [João notes section 2.1, Di Francesco chapter 4]
4. Correlation functions *** [João notes section 2.4, Di Francesco chapter 4]
5. Radial quantization ** [Rychkov notes section 3.1]
6. Unitarity bounds *** [João notes section 2.9]
7. Operator Product Expansion (OPE) * [Rychkov notes section 3.3]
8. Conformal anomaly (in $d = 2, 3, 4$) ** [João notes section 2.13]
9. Virasoro algebra from the anomaly ($d = 2$) ** [Homework 9 exercise 3]
10. The Cardy formula *** [Tong section 4.4.3]

Anti-de Sitter spacetime

1. Penrose diagrams ***
2. Global/Poincaré coordinates and their properties ** [MAGOO chapter 2.2]
3. Geodesics in AdS **

Symmetries in gauge theories

Main reference: lecture notes, adv: Compère

1. Noether current and conserved charges in theories with global vs gauge symmetries*
2. Isometries vs asymptotic symmetries**
3. Asymptotic symmetries of AdS_3 and computation of the central charge**

Correlation functions in AdS/CFT

More advanced: Skenderis notes

1. Basic dictionary** [MAGOO section 3.3]
2. Computing correlation functions ** and in particular the 2-point function *** [MAGOO sec. 3.3]
3. Witten diagrams ** [MAGOO section 3.3, Witten "AdS and Holography"]

Black holes in AdS**

Hartman ch. 16

Holographic entanglement*

Hartman ch 17-22 (esp. last two), van Raamsdonk, adv: "The entropy of Hawking radiation" 2006.06872

- know how to setup a simple holographic entanglement calculation**

Disclaimer

We have done our best to identify the topics in the course that you should know for the exam. If you find a topic in the lecture notes that is not mentioned here, and you are unsure whether it will be required, please ask.