MIT Course 8.033, Fall 2005, Study Guide

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MATH

- Be able to do basic calculations with matrices (add, multiply, transpose, *etc.*).
- Be able to solve variational calculus problems with the Euler-Lagrange equation.

SPECIAL RELATIVITY BASICS & KINEMATICS

Be able to solve problems that involve converting between different intertial frames. Key concepts:

- Invariance/symmetry under a transformation (translation, rotation, Galilean, Lorentz, etc.)
- Aether, Michaelson-Morley experiment
- The two postulates of special relativity
- Event, inertial frame
- Lorentz transformation, transforming a 4-vector
- c, β, γ
- 4-vectors: spacetime 4-vector, velocity 4-vector, wave 4-vector
- Time dilation, length contraction, relativity of simultaneity, spacetime
- Invariants: rest length, proper time interval
- Event separations: spacelike, timelike & null
- Velocity addition, aberration, Doppler shift
- Numerical value of speed of light.

Breadth

- Key experimental evidence for special relativity
- Galilieo, Newton, Maxwell, Michaelson & Morley, Lorentz, Emmy Noether, Einstein (if you can't remember their key achievement(s) discussed in class, Google them – same for the people listed below)

SPECIAL RELATIVITY DYNAMICS

Be able to solve problems that involve acceleration and force. Examples: Rocket problems, particle accelerators. Key concepts:

- Mass-energy unification
- 4-vectors: momentum 4-vector, acceleration 4-vector, force 4-vector
- Rest mass invariant

PARTICLE PHYSICS

Depth

Be able to solve particle physics problems (collisions *etc.*) using energy-momentum conservation and these key concepts:

- Conservation laws: energy-momentum, charge, lepton number, *etc.*
- Rest mass, rest energy, kinetic energy, total energy, binding energy

Breadth

Basic familiarity with this:

- Particles: electron, muon, proton, neutron, pion, neutrino, photon, graviton, nucleus, atom, hydrogen, deuterium, helium, carbon, iron, ion, molecule, alpha particle, gamma ray, the six quarks, the six leptons, baryon, fermion, boson, antiparticles
- Ballpark masses of electron, proton, neutron.
- Terminology: atomic number, atomic weight, isotope, mass excess,
- The four fundamental interactions, chemical reactions, nuclear reactions, elementary particle reactions
- Beta decay, Compton scattering, recoil, Mössbauer effect, Pound Rebka experiment
- Particle accelerators: linear accelerator, circular accelerator, fixed-target experiment vs. colliding beam experiment

- Fusion in stars, Eddington
- Qualitative knowledge of some key unsolved problems in particle physics

ELECTROMAGNETISM

Be able to solve problems involving the Lorentz force law and transforming the electric and magnetic fields between frames.

- Lorentz force law
- Lorentz transforming the electromagnetic field
- Current 4-vector
- Electromagnetic field from moving charge, retarded position
- Concept: What's meant by "**E** implies **B**"

GENERAL RELATIVITY BASICS

Be able to solve problems involving particle motion in various metrics (Minkowski, Newtonian, FRW and Schwarzschild).

Depth

- General concept of a metric, how to work with it.
- How a metric transforms when you change coordinates.
- For a spatial metric (2D, 3D), how to compute length of a given curve.
- For a spacetime metric (4D), definition of timelike, spacelike and null curves through spacetime.
- How to compute ageing along a timelike curve.
- How to compute proper length of a spacelike curve.
- Definition of geodesic.
- How do compute geodesics given a metric.
- How to compute the trajectory of a massive particle.
- How compute the trajectory of a photon.
- How to compute gravitational redshift.

Breadth

- Definition of weak and strong equivalence principle.
- Effects of spatial curvature (on angles, "parallel lines"). Effects of spacetime curvature (can't set up global inertial frame; no coordinate transformation gives Minkowski metric).
- Experimental evidence for general relativity.

COSMOLOGY

Depth

- The FRW metric
- Interpretation of FRW metric (spatial curvature, expansion, comoving objects, geodesics, cosmological redshift)
- The Friedmann equation, how its solution depends qualitatively on the cosmologigical parameters.
- How ρ depends on a for various de density components.
- Cosmological parameters: Ω_γ, $\Omega_{\rm m}$, $\Omega_{\rm k}$, Ω_Λ, Ω_b, Ω_d, h, their meaning
- Age of the Universe, qualitative dependence on cosmological parameters.

Breadth

- Evidence for Big Bang
- Rough timeline for the history of the Universe (planck time, inflation, nucleosynthesis, recombination, first stars, typical galaxy formation, formation of Earth, now, death of Sun, ultimate cosmic fate) and rough qualitative understanding of these stages.
- Rough values of key cosmic distance scales (size of Earth's orbit, size of solar system, distance to nearest star, size of Milky Way galaxy, distance to Andromeda galaxy, size of observable universe).
- Rough measured values of the above-mentioned cosmological parameters.
- Qualitative observational knowledge about the metric of our Universe from *Science* article (curvature, topology, expansion history, fluctuation growth, black holes).
- Qualitative knowledge of some key unsolved problems in Cosmology
- Friedmann, Gamow, Hubble, Penzias & Wilson

SCHWARZSCHILD METRIC & BLACK HOLES

Depth

Be able to solve problems using the Schwarzschild metric.

- The Schwarzschild metric
- Interpretation of the Schwarzschild metric (t-coordinate, r-coordinate, shell coordinates, gravitational redshift, event horizon, Schwarzschild radius, event horizon)
- Geodesics of the Schwarzschild metric: radial and angular, stable and unstable circular orbits, computing general geodesics using the effective potential, computing weak light deflection and Mercury perihelion shift, tidal forces
- Definition of a black hole
- Gravitational lensing, Einstein rings

Breadth

- Evidence that General Relativity is correct
- Evidence that black holes exist (both stellar mass and supermassive)
- How black holes probably form
- No-hair theorem: the three properties of a black hole
- Singularity
- Hawking radiation
- Falling into a black hole: what it feels like and what it looks like from afar
- River model of black holes, sense in which nothing special happens at the event horizon
- Time travel: possibilities for going forward and backward, wormholes
- Taylor-Hulse binary neutron star system
- Shapiro time delay
- The GPS satellite system
- Schwarzschild, Wheeler, Hawking
- Qualitative knowledge of some key unsolved problems in general relativity