1/5/15 Ken Intriligator's Phys 4D Lecture outline

⋆ Reading: Volume 2, chapter 18, of Feynman Lectures (see link on class website).

• In previous quarters, you learned about gravity, as described by Newton (1687), and about electricity and magnetism, as described by Maxwell (1862). As we'll discuss more, Maxwell's equations show that time varying electric fields can source magnetic fields, and time varying magnetic fields can source electric fields. So, even in empty space, they can flip-flop to create each other. This is an electric-magnetic wave, a.k.a. light.

• As far as we know, there are 4 basic forces: gravity, electromagnetism, and the strong and weak nuclear forces. They might all be unified into different manifestations of one force, there are theories, but so far no experimental hints of that. We won't discuss the nuclear forces any more, and we won't discuss quantum physics, which is needed to really understand them.

• At the classical level, Maxwell's equations are perfect, whereas Newton's law of gravity has a problem with unexplained action at a distance and causality (evidently, Newton himself was very bothered by this, but it would take over 225 years until it was resolved). Draw electric field likes of charge and gravitational field lines of mass. Explain what happens when a charge accelerates. Something similar should happen in gravity. This was eventually explained by Einstein's theory of gravity as spacetime curvature, called general relativity (1916). We will discuss this a tiny bit (the math is advanced geometry, so it's mostly learned in grad courses). We will discuss in great detail Einstein's special relativity (1905) framework. The names are kind of backwards. Special relativity is a general framework for how the world works – everything, as far as we know, is described by special relativity. General relativity, on the other hand, is the relativistic theory of gravity, which reduces to Newtonian gravity as an approximation.

• Stress causality: it takes some time between cause and effect. There is a fastest possible speed that interactions can travel. We call that speed c, or "the speed of light". But it's not unique to light. In quantum physics, light is made up of particles, called photons, which are massless (but nevertheless carry energy). Any massless particle travels at that same speed c. It's also (according to theory) the speed of gravity waves, or graviton particles. We can also just call c "the speed limit".

• Plan: (1) introduce some starting concepts from relativity as an appetizer, (2) discuss light in more detail, (3) return to relativity, (4) Optics.

• Spacetime diagrams. Points as being time-like, space-like, or light-like (a.k.a. null) separated. Causality: a cause can only lead to effects within the (forward) light cone.

• $ds^2 \equiv (cdt)^2 - d\vec{x}^2$, the "invariant interval". We'll understand later why it's invariant. $ds^2 > 0$ for timeline, $ds^2 < 0$ for spacelike, and $ds^2 = 0$ for light-like separated events.

• $dx^\mu = (cdt, d\vec{x})$ is an example of a 4-vector. Another example is $p^\mu = (E/c, \vec{p})$. Let $a^\mu = (a^0, \vec{a})$ and $b^\mu = (b^0, \vec{b})$ be two 4-vectors. We define their dot product as $a \cdot b \equiv a_\mu a^\mu \equiv a^0 b^0 - \vec{a} \cdot \vec{b}$. The notation is that if $a^\mu \equiv (a^0, \vec{a})$ then $a_\mu \equiv (a^0, -\vec{a})$. We will understand when we get more into relativity why this dot product is nice: observers in all inertial frames of reference will agree on its value. For now, this is just an appetizer. Note that $ds^2 = dx_\mu \cdot dx^\mu$ in this notation.

• Recall waves on strings, and the 1d wave equation. Traveling wave solutions, e.g. $\psi = A\cos(kx - \omega t)$, with $k = 2\pi/\lambda$, $\omega = 2\pi/T$, and $v = \omega/k = \lambda/T$.