Physics 165: Lecture 2 (outside day)

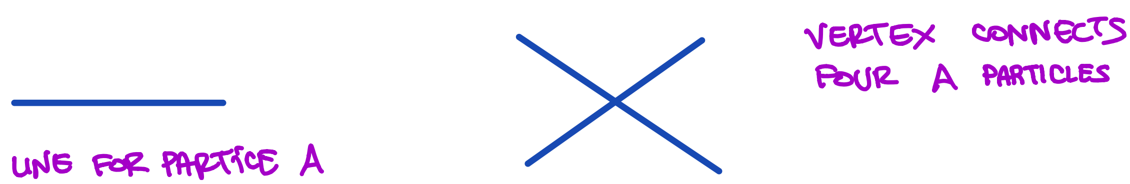
9 January 2020 Prof. Flip Tanedo

The Rules (Feynman Rules)

You have a **list of lines** (particles) and a **list of vertices** (interactions) that you're allowed to use. You can use as many copies of these "rules" as you need to.

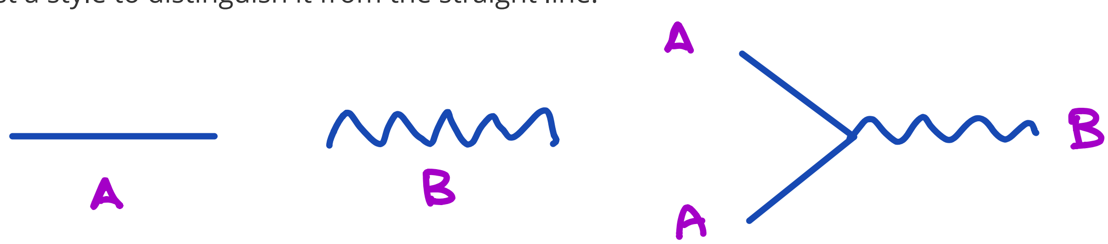
Theory A

For example, here are the rules for **theory A**:



Theory B

Here's a slightly more complicated theory, **theory B**. We denote the B particle with a wiggly line. This is just a style to distinguish it from the straight line.



Properties of The Rules

You can move or rotate the lines however you want.

Lines may "pass over," but they can only **intersect** through an allowed vertex.

The Game (physical process)

The goal of the game is to draw a *physical process*.

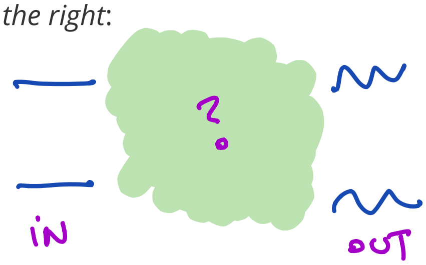
Initial and Final States

A **physical process** connects some specified **initial state** ("in state") to some specified **final state** ("out state").

States are endpoints of lines; they specify the particles that you start with and the particles that you end with. Examples of states are

- 3 particles of type A
- 2 A particles and a B particle

A physical process is a set of diagrams. Each diagram has the *initial state on the left* and the *final state on the right*:

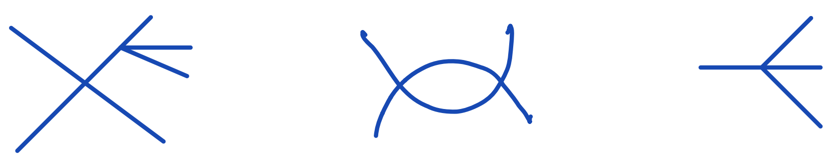


← 2 A PARTICLES GO IN
2 B PARTICLES COME OUT

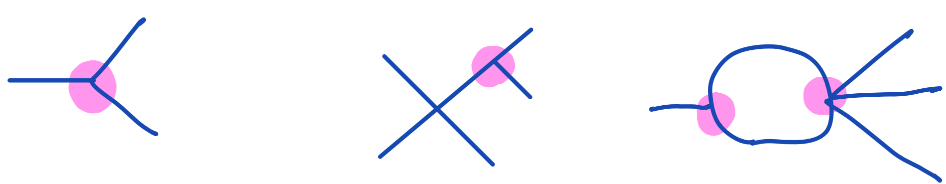
The Challenge

Use The Rules to draw a *graph*, or **Feynman Diagram**, that connects the *initial states* to the *final state*. A graph (Feynman Diagram) is any number of lines connected by vertices.

Here are some examples of Feynman Diagrams for Theory A:



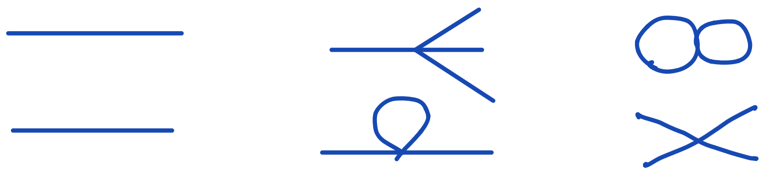
Here are some examples of *not allowed* Feynman diagrams for Theory A:



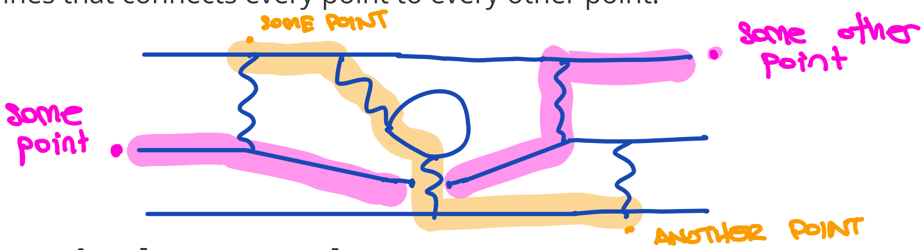
HIGHLIGHTED: NOT ALLOWED VERTEX!

Disconnected graphs

Sometimes you can draw graphs that are *disconnected*. For example:

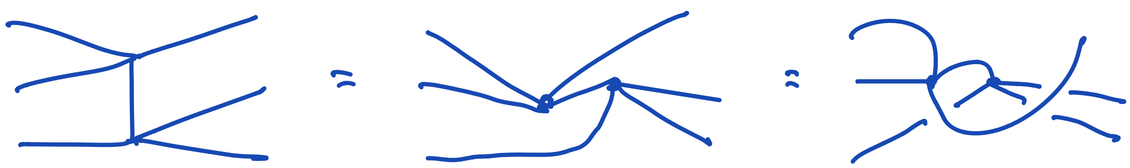


These graphs do not count. We only care about *connected* graphs where there is some sequence of lines that connects every point to every other point.

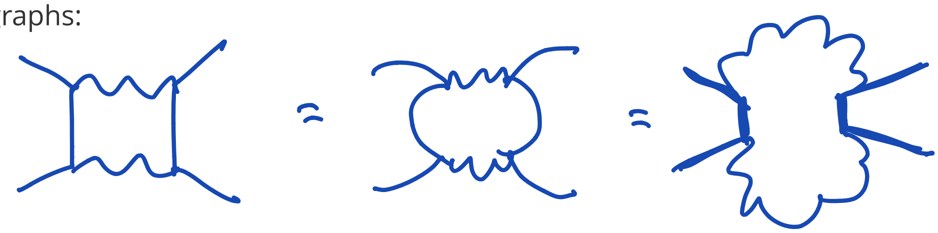


Equivalent graphs

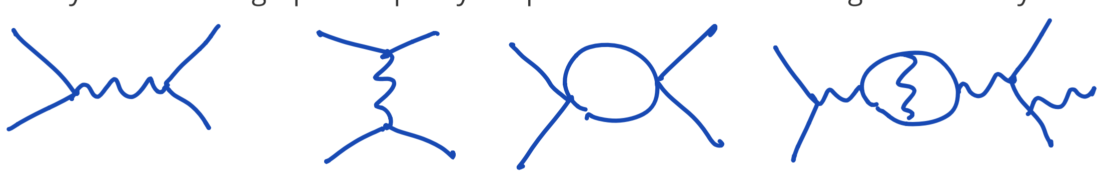
The initial and final states are fixed. This *pins down* the end points of the graph. Everything inside can be "pulled tight." The position of vertices does not matter; these are all equivalent graphs:



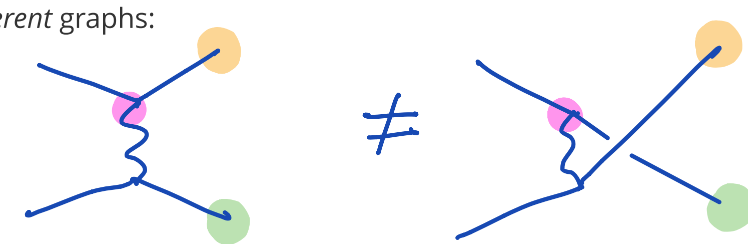
Internal lines can go in any direction or curve as needed to reach vertices. These are all equivalent graphs:



We try to make the graphs as "pretty" as possible. Make lines straight when they can be straight.



Note that you *cannot* move the initial or final states (endpoints). The following graphs in Theory B are two *different* graphs:



DOES PINK VERTEX CONNECT TO TOP LEFT TO
- TOP RIGHT OR
- BOT RIGHT ?

Observations

- For some initial and final states, there is *no physical process* allowed. You cannot draw a graph satisfying the rules.

  Usually we can come up with rules for when a process is allowed that doesn't require trying to draw graphs. Often we have to start by trying to draw graphs and seeing what causes us to fail.

- For some physical processes, there are *many* graphs you can draw. How many? (Is the number big or small?)

  If there are many graphs, maybe we should have some guidelines on which graphs to prioritize?

The Game, Part II

Let's make the game more precise.

1. Given an *initial state* and a *final state*, identify whether or not you can draw a graph that connects everything.

   If you cannot, try to come up with a rule for why you cannot.

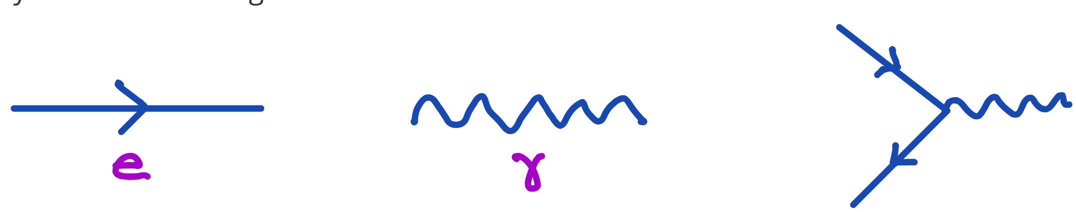
2. If you can, then you've drawn a *physical process*. You can probably draw more than one distinct graph.

   Your goal is to draw the **simplest** possible graphs. This means the graphs with the *fewest number of vertices*.

3. The last step is to decide if the *physical process* is **kinematically allowed**. This is something where we decide based in the initial state and final states alone. [We'll do this next lecture.]

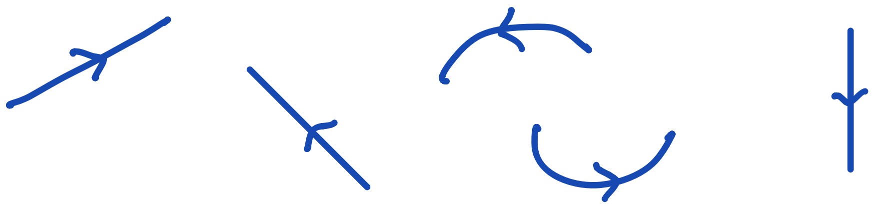
Quantum Electrodynamics: The Game

Here's our first "real" theory of particle physics. It is called **quantum electrodynamics**. For now, it's just a theory with the following rules:



Call the solid lines e and the wiggly lines γ.

Observe that there's something new here: the straight lines have an arrow. This means they have an *orientation*. You can distinguish a line going into a vertex versus a line coming out of the vertex. You can rotate the lines so you can have arrows that move "forward" or "backward":



The single vertex that we have always has an arrow coming in and an arrow coming out. The following are *not* rules:

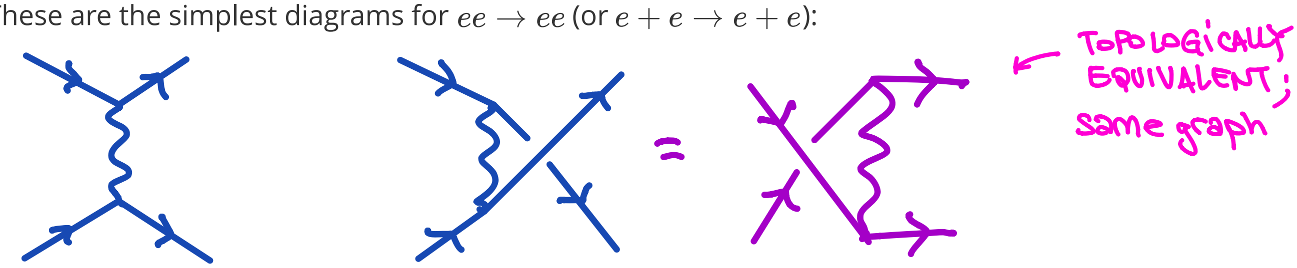
For initial and final states with solid lines, we have to specify the direction of the arrows. Here's our convention:

- Initial states with arrows going *into* the diagram (to the *right*) are labeled e. (Sometime these are called e^- for reasons you may guess.)
- Initial states with arrows going *out of* the diagram (to the *left*) are labeled $\bar{e}$. (Or $e^\dagger$ or e^* or e^+.)
- Final states with arrows going *into* the diagram (to the *left*) are labeled $\bar{e}$.
- Final states with arrows going *out of* the diagram (to the right*) are labeled e.

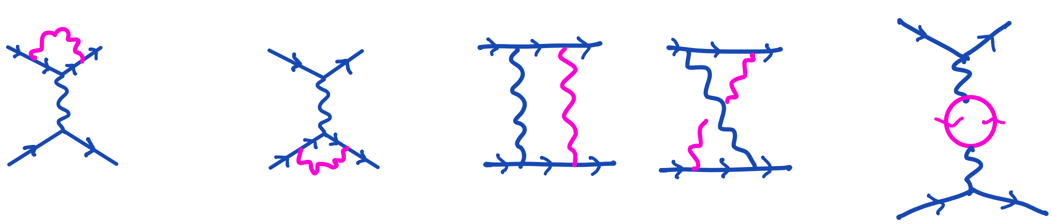
Simple Examples

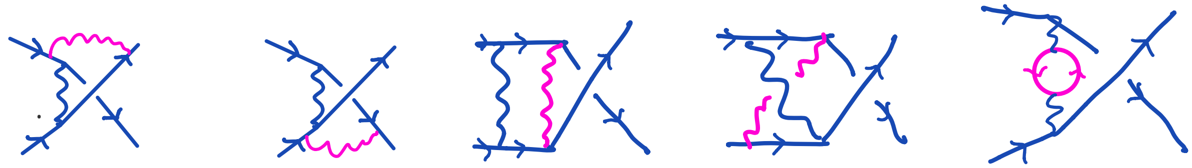
We specify the *in* and *out* states by asking for a physical process of the form: $\text{in} \to \text{out}$

1. These are the simplest diagrams for $ee \to ee$ (or $e + e \to e + e$):



Here are the next-simplest diagrams (requires more vertices) for $ee \to ee$. Because it's more complicated, we don't need them for now.





2. Here are the simplest diagrams for $e\bar{e} \to e\bar{e}$:

Challenges

1. What, if any, are the simplest diagrams for $e\gamma \to e\gamma$?
2. What is the next-simplest diagram for $e\bar{e} \to e\bar{e}$? (Example 2 above.)
3. What, if any, are the simplest diagrams for $ee \to \gamma\gamma$?
4. What, if any, are the simplest diagrams for $e\bar{e} \to \gamma\gamma$?
5. What, if any, are the simplest diagrams for $e\bar{e} \to \gamma\gamma\gamma$?
6. What, if any, are the simplest diagrams for $e \to e\bar{e}e$?
7. What, if any, are the simplest diagrams for $\gamma \to ee\bar{e}\bar{e}$?
8. Is $e\bar{e} \to 100\gamma$ possible? (One hundred γ in the final state)
9. Is $e\bar{e} \to 100e$ possible?
10. Is $e\bar{e} \to 100e + 100\bar{e}$ possible?
11. Can you deduce rules to determine whether a process is physical (you can draw a graph) based on the initial and final states alone?