INTRODUCTION TO PARTICLE PHYSICS
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Announce:
- colloq
- DIS TIME

TODAY: LOGISTICS
REVIEW: KINEMATICS + SPECIAL RELATIVITY
[BREAK]
QED

Logistics

→ tanedo.github.io/Physics165-2018/

→ course syllabus online.
KEY POINTS

- philosophy: "start in the middle"
  w/ Feynman diagrams
  then build up theory & applications
  eg. WE WILL START BY ASSUMING ∃ ELECTRIC CHARGE & THAT IT IS CONSERVED
  - WE WILL USE THIS & FIGURE OUT CONSEQUENCES
  - LATER ON, WE WILL DEVELOP TOOLS TO SEE WHY ELECTRIC CHARGE EXISTS.
- No perfect textbook — we will be pulling in many different FREE references → PP6
  ↳ KNOW HOW TO USE VPN
- Goal of class: PREP FOR RESEARCH
  ↳ how to read plots, papers
  → how to use monte carlo tools
- HW, EXAMS, GRADING
  ↑
  2 PSET WK! not meant to be boong...

UNITS

In this class (& in my life)

$\boxed{\hbar = c = 1}$

PDG p.4: $c = 3 \times 10^8$ m/s

$\hbar = 6.6 \times 10^{-22}$ MeV s

↑ mega electron volt

What does this mean?

$c = 1$ is a conversion factor that turns units of length into units of time.

$1 = 3 \times 10^8 \frac{\text{meters}}{\text{sec}} \Rightarrow \boxed{1 \text{ sec} = 3 \times 10^8 \text{ meters}}$

we call this a "light second" HOW FAR SOMETHING TRAVELING @ SPEED OF LIGHT will go in one second.

Why we can do this: NATURE (or S.R.) gives us a fundamental constant, c, THAT LETS US UNAMBIGUOUSLY CONVERT BETWEEN UNITS.

eg: WHAT IS $\boxed{12 \text{ parsecs}}$ (HAN SOLO) in units of (seconds)?

p.6 of PDG: 3×10^{16} m

$12 \text{ pc} = 12 \times 3 \times 10^{16} \text{ m} \times \left(\frac{1}{c}\right)$

TRICK: MULTIPLY BY "ONE"

$= 4 \times 10^{17} \text{ m} \times \left(\frac{1}{3 \times 10^8 \text{ m/s}}\right)$

$= \boxed{1 \times 10^9 \text{ sec}}$

↑ "light seconds"

$[c] = \frac{\text{LENGTH}}{\text{TIME}}$

↑ "DIMENSION OF c"

so $c = 1$ converts LENGTH ↔ TIME.

$[\hbar] =$ ENERGY · TIME ← meas. of "quantum-ness"

↑ units of angular momentum

$[E] =$ MASS · (LEN/TIME)^2

$[L] =$ MASS (LEN/TIME) · LEN

so $\hbar = 1$ converts ENERGY ↔ TIME

↑ mnemonic: $\Delta E \, \Delta t \sim \hbar$ (Heisenberg)

↑

We will measure m * eV

↑ eg MeV GeV TeV

OUR BEST MICROSCOPE ↓

eg. Large Hadron Collider: $E_{cm} \sim 10$ TeV

naively: what length scale?

$$10 \text{ TeV} \cdot \left(\frac{1}{7\times10^{-22} \text{ MeV s}}\right) \cdot \left(\frac{1}{3\times10^{8} \text{ m/s}}\right)$$

↑ 10^6 MeV; ↑ $1 = 1/\hbar$; ↑ $1 = 1/c$

$$10^{7} \cdot 10^{21} \cdot 10^{-8} \frac{1}{m} = \boxed{\frac{1}{10^{-20} \text{ m}}}$$

← INVERSE: ↑E → ↓ len.

$\mathring{A} = 0.1 \text{ nm} = 10^{-10} \text{ m}$ ← scale of an atom

(NB → this is too naive... in this class, you'll learn why.

KINEMATICS

Review: special relativity & particle kinematics

RULE: Energy is conserved
RULE: Momentum is conserved

nb: these are kind of the same once you assume special relativity

nb: where does it come from?

↳ INVARIANCE (symmetry) of our model of nature w/r/t
- TIME TRANSLATIONS
- SPACE TRANSLATIONS

RULE: $\boxed{E^2 = m^2 + p^2}$

↑ this is the correct version of $E = mc^2$
you will redefine $E = mc^2$ in your HW.

4-VECTORS: convenient to package energy & momentum into 4-vectors.

$$P_\mu = (E, p_x, p_y, p_z) \leftarrow \text{in unit-units } (E/c, p)$$

↑ $\mu = 0, 1, 2, 3$ (INDEX)

similarly,

$$x^\mu = (t, x, y, z) \leftarrow \text{SPACETIME} \quad (ct, x)$$

THIS IS A 4D VECTOR SPACE W/ INNER PRODUCT

$$x^\mu y_\mu = x \cdot y = x^0 y^0 - x^1 y^1 - x^2 y^2 - x^3 y^3$$

... we will go into this more as class progresses
... pls try to review!

SR summary (for now)

in any interaction between particles:

→ TOTAL ENERGY & TOTAL MOMENTUM MUST BE CONSERVED

↑ 4 constraint equations on the KINEMATIC variables

→ only physical particle satisfies

$$\boxed{E^2 = m^2 + p^2}$$

↑ 1 constr. eq per "physical particle"

PHYSICAL PARTICLE ↔ "ON SHELL"

↑ defines this term.

In contrast: a particle that is not on-shell is virtual ↪ $E^2 \neq m^2 + p^2$

VIRTUAL PARTICLES ARE QUANTUM MECHANICAL

↳ intermediate states

never in-states or out-states of any process.

We'll come to understand what this means as we go on.

this is a good time for a 7 minute BREAK.

↑ ~ 5:40 - 5:50 pm

OVER THIS BREAK: note cards

1. name
2. what should I know about you?
3. why are you taking this course?
4. QM ? GR BACKGROUND

PARTICLE PHYSICS

the endpoint of reductionist science.

BREAK EVERYTHING UP INTO SMALLER & MORE FUNDAMENTAL.

A THEORY (or model) of PARTICLE PHYSICS BOILS DOWN TO A LIST OF

PARTICLES ← FORCE PARTICLES & MATTER PARTICLES

&

INTERACTIONS BETWEEN THEM

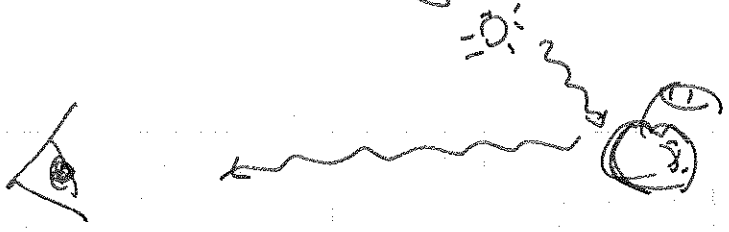
there are more elegant ways to say this ... usually invoking the idea of symmetry ...

We'll get to this — BUT IT ALL BOILS DOWN TO THESE INGREDIENTS.

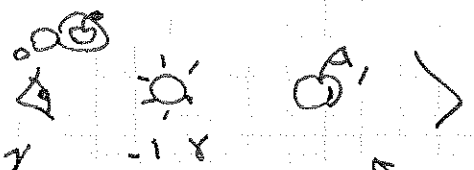
We don't really "pick up & look @" particles. We learn about them when they do something → usually involving other particles.

This is kind of a deep statement:

IF I look @ something, I'm really part of a scattering process:



initial state: $|$  $\rangle$

final state: $|$  $\rangle$

observer notices apple

sun w/ slightly less energy

apple w/ some small change

So we want to understand how a theory of particles

$\leftrightarrow$ | observable processes | ← USUALLY SCATTERING OR DECAY.

Here's a theory called QUANTUM ELECTRODYNAMICS

all of our theories are QUANTUM
WHAT DOES THIS MEAN?

Maxwell

@ A POP-PHYS LEVEL:
- discrete ... like energy levels
- superpositions, probabilities

wavefunction ← PROBABILITY vs. AMPLITUDES ← "sum over paths"

particle vs wave?

We'll leave QM @ this pop level for now ... & will develop formalism as needed.

QED HAS 2 PARTICLES:

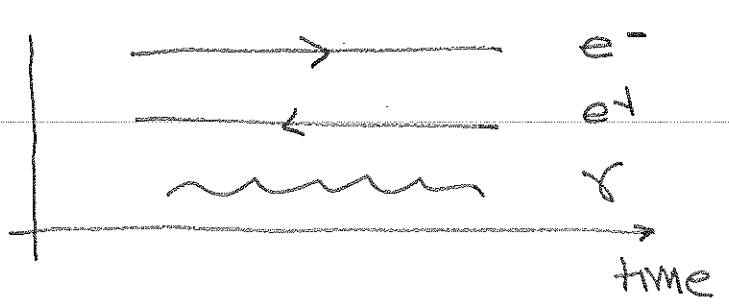
$e^{\pm}$ "electron"

(w/ anti-particle, positron ... AUTOMATIC!

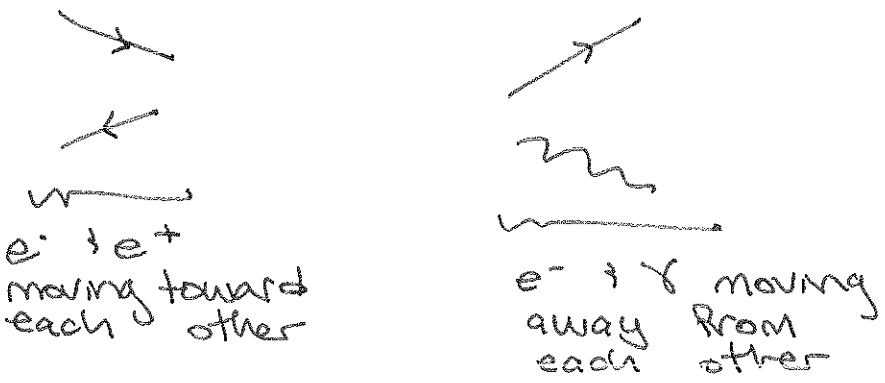
a quantum of light (EM wave) → photon: γ "FORCE PARTICLE"

(sketch

WE WILL DRAW THE TRAJECTORIES OF THESE PARTICLES ON A SPACETIME DIAGRAM

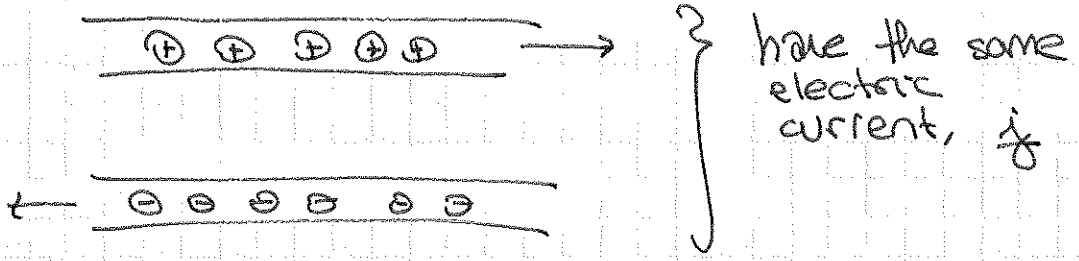


- we will drop the axes from now on



- hey... e^+ looks like e^- moving backward in time.

→ NOT A COINCIDENCE!

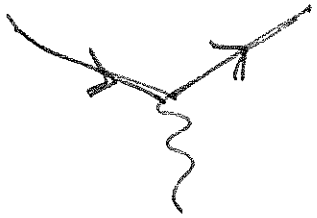


Related to idea that antiparticle & particle come from the same place.

We could say that there's <u>one</u> matter particle, →

& you can draw the arrow either way to denote charge flow.

QED HAS one fundamental interaction



this is a rule for how to connect lines

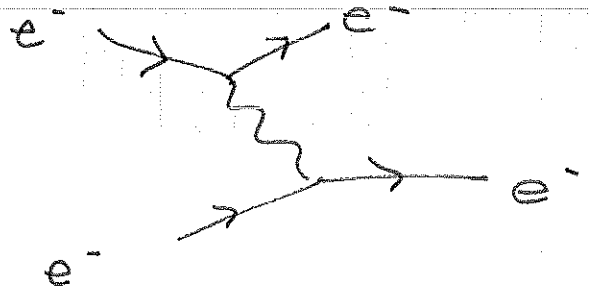
The direction of the arrows is very important.

BUT you can rotate this rule

↳ imagine lines are shoelaces

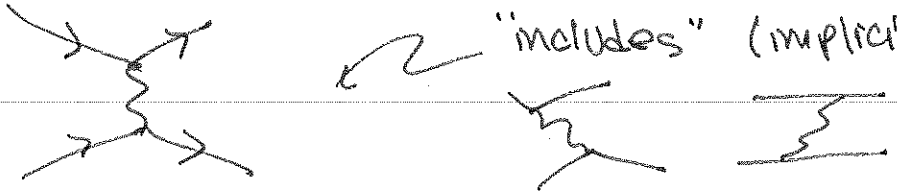
$e^+e^- \to \gamma$ $e^-\gamma \to e^-$ $e^+\gamma \to e^+$ $\gamma \to e^+e^-$ ...

Feynman diagram: representation of a process on a spacetime diagram



imagine two people throwing a ball on an ice rink

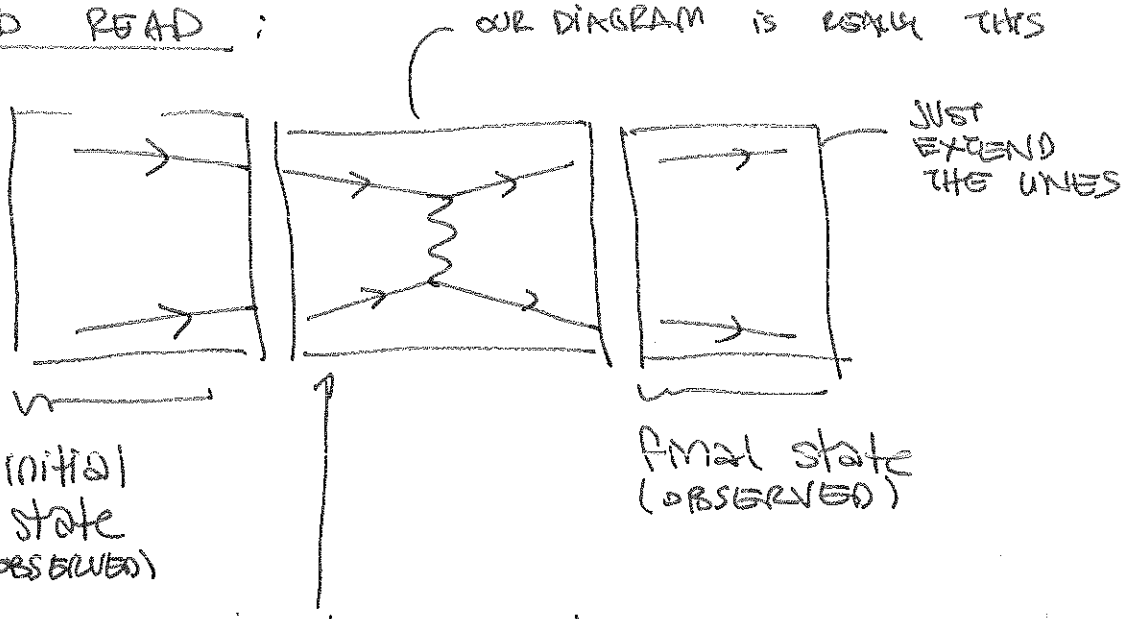
convention: "tighten" the diagram



"includes" (implicitly)

(DIFF ANGLES OF LINES, DIFF ORDERING OF INTERNAL POINTS)

HOW TO READ :



scattering : not observed

quantum mechanically, anything that can connect the in & out states does happen.

this diagram represents some of those possibilities.

in-state particles } are on-shell
out-state particles }

intermediate particles are virtual.

→ every line & vertex conserves momentum & E.