Particle Physics

$\Psi(x)$ - single particle wavefunction (normalized)

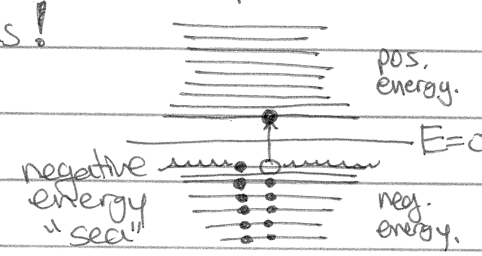
$\Psi(x_1, x_2)$ - 2-particle wavefunction (normalized, symmetrized)

$\Psi(x_1, \ldots x_N)$ - N-particle wavefunction " "

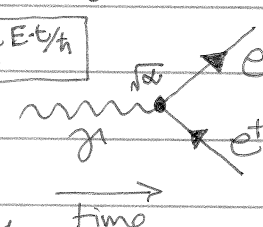
* what if N is unknown or changes, or $N<0$!!?
* what about relativistic particles?

Schrödinger Equation		Klein-Gordon Equation
$\left(\hat{T}=\frac{\hat{p}^2}{2m}\right)+\hat{V}=\hat{E}$	$\Rightarrow$	$(\hat{p}c)^2+(mc^2)^2=\hat{E}^2$
$-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\Psi + V(x)\Psi = i\hbar\frac{\partial}{\partial t}\Psi$		$-\hbar^2c^2\frac{\partial^2}{\partial x^2}\Psi + m^2c^4\Psi = -\hbar^2\frac{\partial^2}{\partial t^2}\Psi$

* solution by Dirac using a linearized version w/ matrices
  - wavefunctions have spin $E = \pm\sqrt{(pc)^2+(mc^2)^2}$
  - also negative energy solutions!



* interpreted as all (−) states occupied, per Fermi exclusion.
  - (−) states excited → holes "antiparticles"
  - ~~particles running backwards in time~~ $\boxed{e^{iE\cdot t/\hbar}}$
* discovered by C. Anderson (1932)



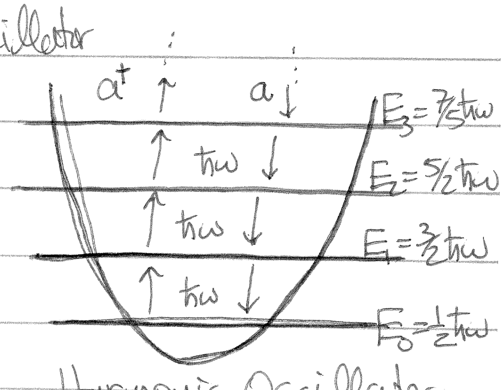
* ideas above formalized in "<u>Quantum Field Theory</u>"
  - "second quantization"
  - quantize fields (like Electric field, light waves → photons) instead of just particles.
  - borrows heavily from harmonic oscillator

    all states separated by $\hbar\omega$ = "energy quantum"

    Planck: $E = n\cdot\hbar\omega$
  - vacuum state $\boxed{\Psi_0}$

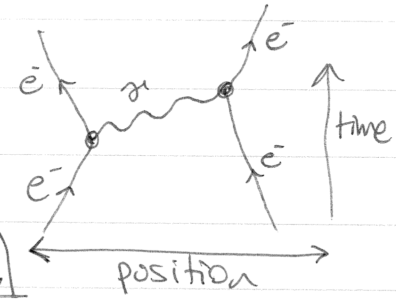
    "creation operators" $\Psi_1 = a^\dagger\Psi_0$

    "annihilation operators" $\Psi_0 = a\,\Psi_1$



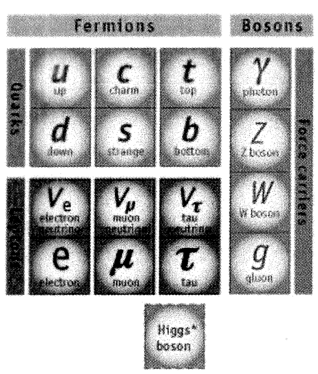
Harmonic Oscillator

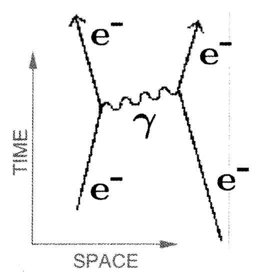
* Feynman diagrams — method to visualize multiparticle fields
  - interations by the exchange of particles
  - used to calculate "invariant amplitude" $\mathcal{M}$
  - cross-sections or decay rates = kinematic factors $\times |\mathcal{M}|^2$



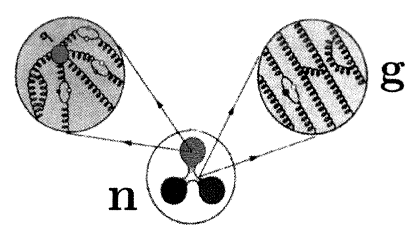
* QED - "Quantum Electrodynamics"
  - charged particles interact through quantized electrodynamic field (photons).
  - most precisely tested theory in physics 11-12 sig. figures.
  - expanded to include weak force, $\gamma \to W^{\pm}, Z$ (explains nuclear decays)

* QCD - "Quantum Chromodynamics"
  - "quarks" interact through exchange of "gluons"
  - 3 color charges $\left(\begin{smallmatrix} r & b & g \\ \bar{r} & \bar{b} & \bar{g} \end{smallmatrix}\right)$ instead of $(\pm)$
  - hadrons = (quarks (q) [$u, d, \ldots$], mesons ($q\bar{q}$) [$\pi = u\bar{u}$], baryons (qqq) [$p = uud$] [$n = udd$])

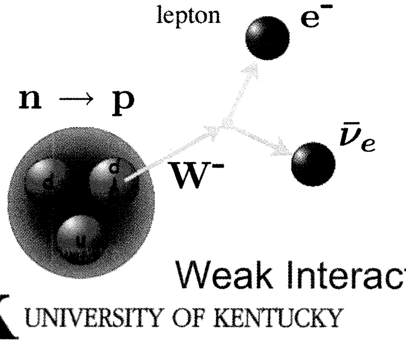




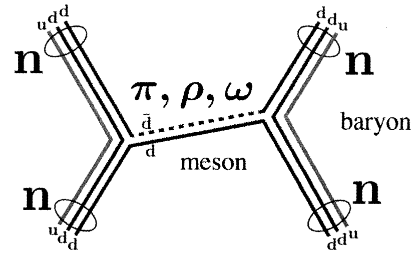
E&M Interaction



Strong Interaction



Weak Interaction



Hadronic Interaction
(residual nuclear force)

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