8.701

Introduction to Nuclear and Particle Physics

Markus Klute - MIT

1. Fermions, bosons, and fields

1.3 Ranges of Forces

Ranges of Forces

Force	Name	Symbol	Number	EM charge
Strong	Gluons	g	8	0
EM	Photon	γ	1	0
Weak	W and Z	$W^{\pm}$, Z^0	3	± 1, 0

Electromagnetic potential due to point charge as solution Maxwell's eq.

$$\phi = \frac{Q}{4\pi\epsilon_0 r} \qquad \nabla^2\phi = -\frac{\rho}{\epsilon_0}$$

Massless photon has infinite range.

How would this be modified if the photon were massive?

Ranges of Forces

Generalize by a) using the time-dependent Maxwell equation

$$\frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2} - \nabla^2\phi = 0$$

and b) adding a mass term.

$$E^2 = p^2c^2 + m^2c^4 \qquad \text{with} \qquad \hat{E} = i\hbar\partial/\partial t \quad \text{and} \quad \hat{\boldsymbol{p}} = -i\hbar\boldsymbol{\nabla}$$

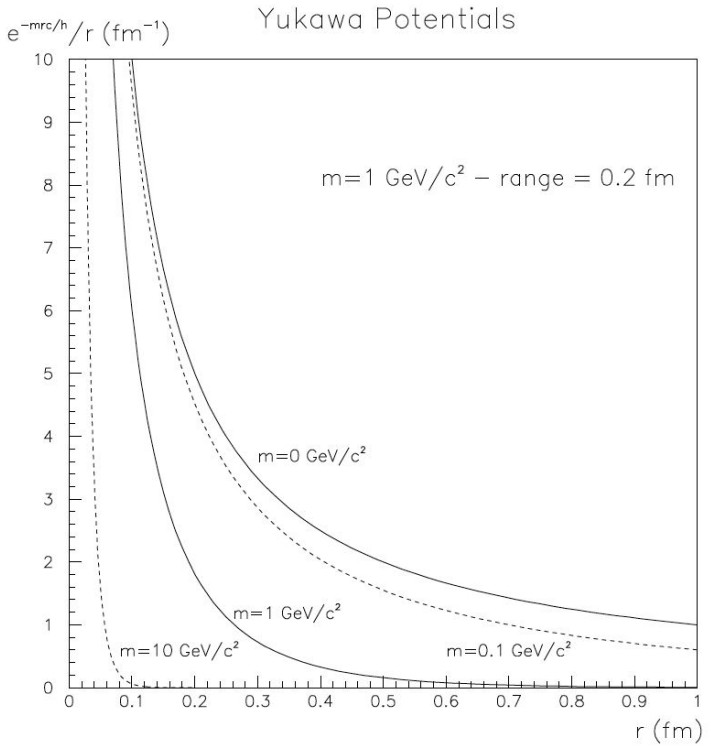
$$-\hbar^2\frac{\partial^2\phi}{\partial t^2} = -\hbar^2c^2\nabla^2\phi + m^2c^4\phi$$

$$\frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2} - \nabla^2\phi + \frac{m^2c^2}{\hbar^2}\phi = 0$$

Ranges of Forces

Solution $\phi = \dfrac{Q}{4\pi\epsilon_0 r} e^{-m_\gamma c r/\hbar}$

	Gravitational	Electromagnetic	Weak	Strong
field boson	graviton	photon	$W^{\pm}$, Z	gluon
spin-parity	2^+	1^-	1^-, 1^+	1^-
mass, GeV	0	0	$M_W = 80.2$ $M_Z = 91.2$	0
range, m	∞	∞	10^{-18}	$\leq 10^{-15}$
source	mass	electric charge	'weak charge'	'colour charge'
coupling constant	$\dfrac{G_N M^2}{4\pi\hbar c}$ $= 5 \times 10^{-40}$	$\alpha = \dfrac{e^2}{4\pi\hbar c}$ $= \frac{1}{137}$	$\dfrac{G(Mc^2)^2}{(\hbar c)^3}$ $= 1.17 \times 10^{-5}$	$\alpha_s \leq 1$



8.701 Introduction to Nuclear and Particle Physics
Fall 2020