

# 8.701

Introduction to Nuclear  
and Particle Physics

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1. Fermions, bosons, and  
fields

1.3 Ranges of Forces



# Ranges of Forces

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

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.

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

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

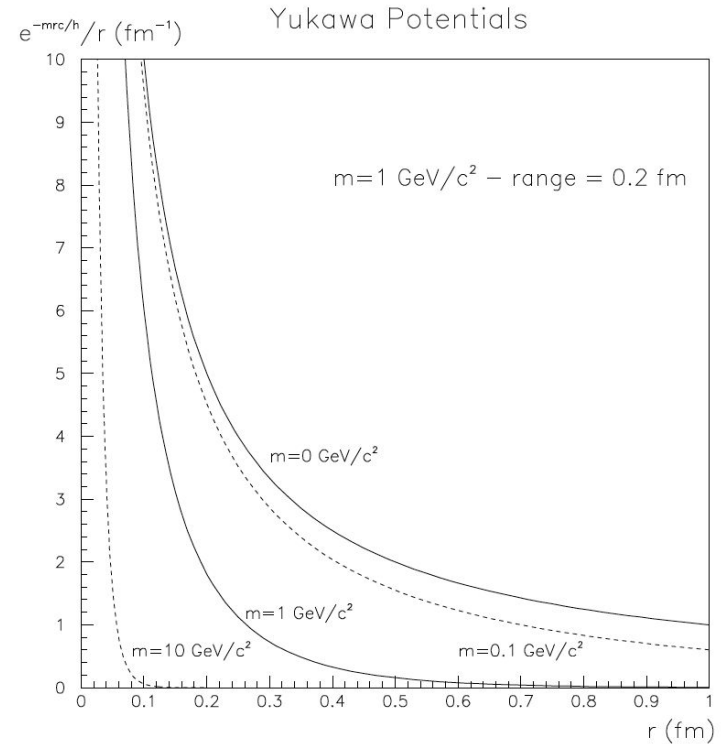
$$\frac{1}{c^2} \frac{\partial^2 \phi}{\partial t^2} - \nabla^2 \phi + \frac{m^2 c^2}{\hbar^2} \phi = 0$$

# Ranges of Forces

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Solution

$$\phi = \frac{Q}{4\pi\epsilon_0 r} e^{-m_\gamma cr/\hbar}$$

	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	$\infty$	$\infty$	$10^{-18}$	$\leq 10^{-15}$
source	mass	electric charge	'weak charge'	'colour charge'
coupling constant	$\frac{G_N M^2}{4\pi\hbar c}$ $= 5 \times 10^{-40}$	$\alpha = \frac{e^2}{4\pi\hbar c}$ $= \frac{1}{137}$	$\frac{G(Mc^2)^2}{(\hbar c)^3}$ $= 1.17 \times 10^{-5}$	$\alpha_s \leq 1$



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