PHYS 3446 – Lecture #19

Wednesday, Nov. 9, 2016

Dr. Amir Farbin

- Elementary Particle Properties
  - Forces and their relative magnitudes
  - Elementary particles
  - Quantum Numbers
    - Strangeness
    - Isospin
  - Gell-Mann-Nishijima Relations
  - Production and Decay of Resonances

Announcements

- Reading assignments: 9.6 and 9.7

Reminder: Homework #9

1. End of chapter problems 9.1, 9.2 and 9.3
2. Due for these assignments is Monday, Nov. 14

Physics Department
The University of Texas at Arlington
COLLOQUIUM

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Solar Wind Induced Atmospheric Erosion at Mars

Dr. Yingjuan Ma
UCLA

Wednesday November 9, 2016
4:00 Room 100 Science Hall

Modern Mars atmosphere is thin, cold and dry. However, there is considerable evidence that Mars' climate has changed greatly during the planet's history. Solar wind induced atmospheric erosion is one candidate for causing the long-term variations of the Mars atmosphere. Mars has only localized crustal magnetic fields, so the solar wind plasma flow interacts directly with the Mars atmosphere/ionosphere system. Such an interaction generates induced current in the ionosphere, modifies the magnetic field environment around Mars and more importantly, causes the erosion of the Mars atmosphere. Here we use a 3D time-dependent multi-species single-fluid MHD model to study the plasma environment of Mars and quantify the ion loss rate. The effects of the crustal magnetic fields are discussed based on model results and their comparison with MGS (Mars Global Surveyor) magnetometer observations. Two event studies of MAVEN (Mars Atmosphere and Volatile Evolution) mission are also presented, one for quiet solar wind condition and the other for a strong ICME impact in March 2015. The ongoing MAVEN mission was designed to study the upper atmosphere, ionosphere, and magnetosphere of Mars, the response to solar and solar-wind input, and the ability of atmospheric molecules and atoms to escape to space. Through detailed comparisons between the model results and the relevant plasma observations from MAVEN, we find that the time-dependent global MHD model is able to reproduce the main features of the plasma environment around Mars for both quiet and disturbed solar wind conditions. Model results suggest that the total ion escape rate was enhanced by an order of magnitude during the ICME event. Given the likely prevalence of ICME-like conditions earlier in the solar system history, ion loss during solar events in ancient times could have contributed significantly to the long-term evolution of the Mars atmosphere.

Refreshments will be served at 3:30 p.m. in the Physics Library

Forewords

- What are the elementary particles?
  – Particles that make up matter in the universe
- What are the requirements for elementary particles?
  – Cannot be broken into smaller pieces
  – Cannot have sizes
- The notion of "elementary particles" have changed from 1930's through present
  – In the past, people thought protons, neutrons, pions, kaons, ρ-mesons, etc, as elementary particles
- Why?
  – Due to the increasing energies of accelerators that allows us to probe smaller distance scales
- What is the energy needed to probe 0.1–fm?
  – From de Broglie Wavelength, we obtain

$$P = \frac{\hbar}{\lambda} = \frac{\hbar c}{\lambda c} = \frac{197\text{fm} - MeV}{0.1\text{fm}\ c} \approx 2000 MeV / c$$

Forces and Their Relative Strengths

- Classical forces:
  - Gravitational: every particle is subject to this force, including massless ones
    - How do you know?
  - Electromagnetic: only those with electrical charges
  - What are the ranges of these forces?
    - Infinite!!
  - What does this tell you?
    - Their force carriers are massless!!
  - What are the force carriers of these forces?
    - Gravity: graviton (not seen but just a concept)
    - Electromagnetism: Photons

Forces and Their Relative Strengths

- What other forces?
  - Strong force
    - Where did we learn this force?
      - From nuclear phenomena
      - The interactions are far stronger and extremely short ranged
  - Weak force
    - How did we learn about this force?
      - From nuclear beta decay
  - What are their ranges?
    - Very short
  - What does this tell you?
    - Their force carriers are massive!
    - Not really for strong forces
- All four forces can act at the same time!!!

Forces' Relative Strengths

- The strengths can be obtained through potential, considering two protons separated by a distance r.
- Magnitude of Coulomb and gravitational potential are

$$V_{EM}(r) = \frac{e^2}{r} \xrightarrow{\text{Fourier x-form}} V_{EM}(r) = \frac{e^2}{q^2}$$

$$V_g(r) = \frac{G_N m^2}{r} \xrightarrow{\text{Fourier x-form}} V_g(r) = \frac{G_N m^2}{q^2}$$

  – q: magnitude of the momentum transfer
- What do you observe?
  – The absolute values of the potential E decreases quadratically with increasing momentum transfer
  – The relative strength is, though independent of momentum transfer

$$\frac{V_{EM}}{V_g} = \frac{e^2}{G_N m^2} = \left(\frac{e^2}{\hbar c}\right)\frac{1}{(mc^2)^2}\frac{\hbar c^5}{G_N} = \left(\frac{1}{137}\right)\frac{1}{1GeV^2}\frac{10^{39}\,GeV^2}{6.7} \sim 10^{36}$$

Forces' Relative Strengths

- Using Yukawa potential form, the magnitudes of strong and weak potential can be written as

$$V_S(r) = \frac{g_S^2}{r} e^{-\frac{m_\pi c^2 r}{\hbar c}} \xrightarrow{\text{Fourier x-form}} V_S(r) = \frac{g_S^2}{q^2 + m_\pi^2 c^2}$$

$$V_W(r) = \frac{g_W^2}{r} e^{-\frac{m_W c^2 r}{\hbar c}} \xrightarrow{\text{Fourier x-form}} V_W(r) = \frac{g_W^2}{q^2 + m_W^2 c^2}$$

  - g_W and g_s: coupling constants or effective charges
  - m_W and m_π: masses of force mediators
- The values of the coupling constants can be estimated from experiments

$$\frac{g_s^2}{\hbar c} \approx 15 \qquad \frac{g_W^2}{\hbar c} \approx 0.004$$

Forces' Relative Strengths

- We could think of π as the strong force mediator w/ $m_{\pi} \approx 140 MeV / c^2$
- From observations of beta decays, $m_W \approx 80 GeV / c^2$
- However there still is an explicit dependence on momentum transfer
  - Since we are considering two protons, we can replace the momentum transfer, q, with the mass of protons

$$q^2 c^2 = m_p^2 c^4 \approx 1 GeV$$

Forces' Relative Strengths

- The relative strength between EM and strong potentials is

$$\frac{V_S}{V_{EM}} = \frac{g_s^2}{\hbar c}\frac{\hbar c}{e^2}\frac{q^2}{q^2 + m_\pi^2 c^4} = \frac{g_s^2}{\hbar c}\frac{\hbar c}{e^2}\frac{m_p^2 c^4}{m_p^2 c^4 + m_\pi^2 c^4}$$

$$\approx 15 \times 137 \times 1 \approx 2 \times 10^3$$

- And that between weak and EM potentials is

$$\frac{V_{EM}}{V_W} = \frac{e^2}{\hbar c}\frac{\hbar c}{g_W^2}\frac{q^2 + m_W^2 c^4}{q^2} = \frac{e^2}{\hbar c}\frac{\hbar c}{g_W^2}\frac{m_p^2 c^4 + m_W^2 c^4}{m_p^2 c^4}$$

$$\approx \frac{1}{137} \times \frac{1}{0.004} \times 80^2 \approx 1.2 \times 10^4$$

Interaction Time

- The ranges of forces also affect interaction time
  - Typical time for Strong interaction ~10^{-24}sec
    - What is this?
    - A time that takes light to traverse the size of a proton (~1 fm)
  - Typical time for EM force ~10^{-20} – 10^{-16} sec
  - Typical time for Weak force ~10^{-13} – 10^{-6} sec
- In GeV ranges, the four forces are different
- These are used to classify elementary particles

Elementary Particles

- Before the quark concepts, all known elementary particles were grouped in four depending on the nature of their interactions

Particle	*Symbol*	*Range of Mass Values*
Photon	γ	$\lesssim 2 \times 10^{-16}\ \mathrm{eV}/c^2$
Leptons	$e^-, \mu^-, \tau^-, \nu_e, \nu_\mu, \nu_\tau$	$\lesssim 3\ \mathrm{eV}/c^2 - 1.777\ \mathrm{GeV}/c^2$
Mesons	$\pi^+, \pi^-, \pi^0, K^+, K^-, K^0,$	
	$\rho^+, \rho^-, \rho^0, \ldots$	$135\ \mathrm{MeV}/c^2$ – few GeV/c^2
Baryons	$p, n, \Lambda^0, \Sigma^+, \Sigma^-, \Sigma^0, \Delta^{++},$	
	$\Delta^0, N^{*0}, Y_1^{*+}, \Omega^-, \ldots$	$938\ \mathrm{MeV}/c^2$ – few GeV/c^2

Elementary Particles

- How do these particles interact??
  - All particles, including photons and neutrinos, participate in gravitational interactions
  - Photons can interact electromagnetically with any particles with electric charge
  - All charged leptons participate in both EM and weak interactions
  - Neutral leptons do not have EM couplings
  - All hadrons (Mesons and baryons) responds to the strong force and appears to participate in all the interactions

Elementary Particles: Bosons and Fermions

- All particles can be classified as bosons or fermions
  - Bosons follow Bose-Einstein statistics
    - Quantum mechanical wave function is symmetric under exchange of any pair of bosons

$$\Psi_B\left(x_1,x_2,x_3,\ldots x_i\ldots x_n\right)=\Psi_B\left(x_2,x_1,x_3,\ldots x_i\ldots x_n\right)$$

    - x_i: space-time coordinates and internal quantum numbers of particle i
  - Fermions obey Fermi-Dirac statistics
    - Quantum mechanical wave function is anti-symmetric under exchange of any pair of Fermions

$$\Psi_F\left(x_1,x_2,x_3,\ldots x_i\ldots x_n\right)=-\Psi_F\left(x_2,x_1,x_3,\ldots x_i\ldots x_n\right)$$

    - Pauli exclusion principle is built into the wave function
      - For $x_i=x_j$, $\Psi_F=-\Psi_F$