

8.02X Electricity and Magnetism

~~Problem Set 1 and Experiment Problem MI~~

~~Issued: Wed, Feb 2~~

~~Due: Problem set: Fri, Feb 11, 4PM in 4-337~~

~~MI experiment check off: Fri, Feb 11, 3PM in 4-355~~

~~Please note that in general both students for each partnership must submit an experiment write-up, answering the questions regarding the experiment. For experiment MI however, no write-up is necessary. You should be able to demonstrate the answers to the questions during experiment check-off!~~

~~Reading suggestions (from Young + Freedman, *University Physics*, 11th edition)~~

~~Fri: Electric Charge, Electric Induction 21-1, 21-2~~

~~Mon: Coulomb's Law: 21-3~~

~~Wed: Electric Field: 21-4, 21-6~~

~~Fri: Electric Field cntd, Dipoles: 21-5, 21-7~~

Homework Problems (30 points)

Problem 1 (5 Points) : Consider an electron and a proton in a hydrogen atom.

- (a) What is the ratio of the electric force to the gravitational force between them?
- (b) If we move the electron and proton either closer together or farther apart, can we find a configuration at which the gravitational force is bigger than the electric force? Explain your answer in one or two sentences.
- (c) Given your answer to (a) and (b), why does gravity dominate for astronomical distances?

~~**Problem 2 (5 Points):** Suppose the charge of an electron was $10^{-9}\%$ smaller than it is in nature (i.e. multiplied by a factor $(1 - 10^{-11})$), while the charge of the proton was the same.~~

- ~~(a) Under these circumstances, what would be the ratio of the electrostatic force between Earth and Moon to the gravitational force between them?~~
- ~~(b) Would they still form a stable system?~~

8.02x – Problem Set 1 Solutions

Problem 1 (5 points)

a) The ratio of the electric force to the gravitational force for an electron and a proton in a hydrogen atom is

$$\begin{aligned} \left| \frac{F_e}{F_g} \right| &= \frac{k \frac{e^2}{r^2}}{G \frac{m_e m_p}{r^2}} = \frac{k}{G} \frac{e^2}{m_e m_p} = \\ &= \frac{9.0 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2}{6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2 / \text{kg}^2} \frac{(1.6 \times 10^{-19} \text{ C})^2}{(9.1 \times 10^{-31} \text{ kg})(1.67 \times 10^{-27} \text{ kg})} \approx 2 \times 10^{39}. \end{aligned} \quad (1)$$

b) In a), we have seen that the ratio of the forces does not depend on the distance, because both Newton's gravitational law and Coulomb's law have r^{-2} dependence. Therefore, the ratio F_e/F_g doesn't change with distance.

c) The universe is charge neutral on large scales. Therefore, there is no net electromagnetic force on astronomical distances. However, gravitational mass adds up, and gravitation is only an attractive (and long-distance) force, it dominates.

~~Problem 2 (5 points)~~

~~a) The ratio of the forces would be~~

$$\left| \frac{F_e}{F_g} \right| = \frac{k Q_E Q_M}{G M_E M_M}. \quad (2)$$

~~We need to estimate the number of protons (and electrons) in Earth and in the Moon. We assume protons contribute to roughly half the mass (neutrons are the other part, and electrons are 1000 times lighter). Therefore, the Earth has approximately $N_E \approx (M_E/m_p)/2$ protons. On the other hand, the Moon has approximately $N_M \approx (M_M/m_p)/2$ protons. Assuming the electrons' charge is $(1 - 10^{-11})$ times the proton charge, the Earth would carry a charge $Q_E \approx e N_E \times 10^{-11}$, and the moon would have charge $Q_M \approx e N_M \times 10^{-11}$. The ratio of the forces would then be~~

$$\begin{aligned} \left| \frac{F_e}{F_g} \right| &= \frac{k \left(\frac{M_E}{2m_p} e \times 10^{-11} \right) \left(\frac{M_M}{2m_p} e \times 10^{-11} \right)}{G M_E M_M} = \frac{k e^2}{G 4m_p^2} \times 10^{-22} = \\ &= \frac{9.0 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2}{6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2 / \text{kg}^2} \frac{(1.6 \times 10^{-19} \text{ C})^2}{(1.67 \times 10^{-27} \text{ kg})^2} \times 10^{-22} \approx 1 \times 10^{14}. \end{aligned} \quad (3)$$