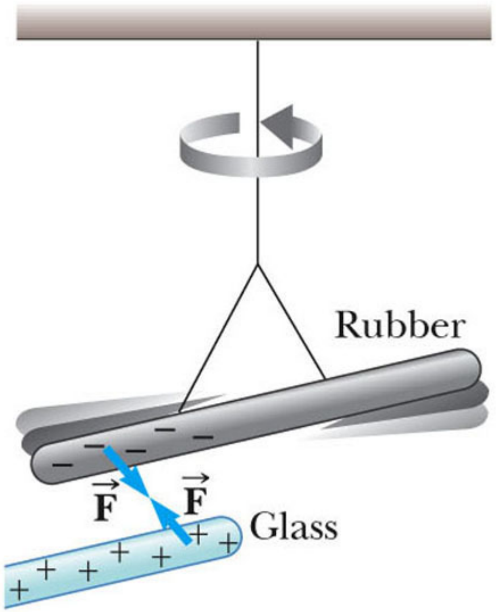
Electric Charge

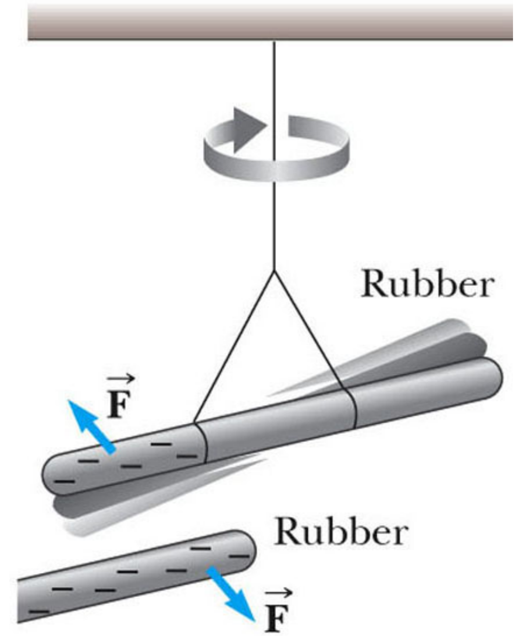
1. Electric charge.
2. Coulomb's Law about force between two point charges.
3. Application of Coulomb's Law.

Electric Charges

- There are two kinds of electric charges
  - Negative charges are the type possessed by electrons
  - Positive charges are the type possessed by protons
  - For example, a hydrogen atom has a proton and an electron. The force between them bound them into an atom.
- There are forces between electric charges:
  - Like-sign charges repel one another.
  - Unlike-sign charges attract one another.

One Way to “Generate” Electric Charge





- The rubber rod is negatively charged
- The glass rod is positively charged
- The two rods attract

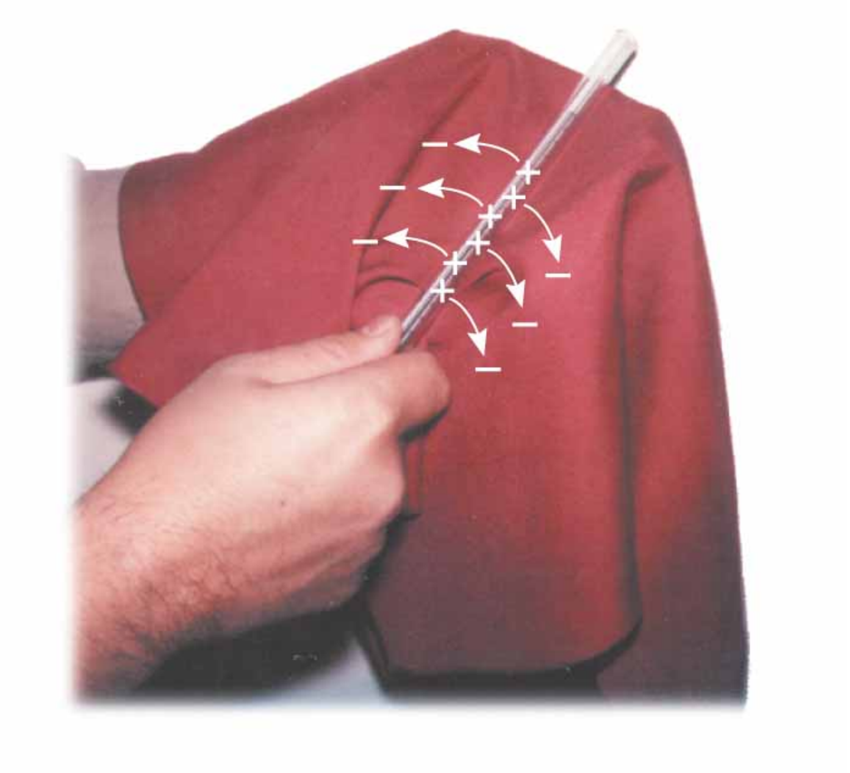
- The rubber rod is negatively charged
- The second rubber rod is also negatively charged
- The two rods repel

Electric charge is always conserved in an isolated system:

Charge is not created in the process of rubbing two objects together. The electrification is due to a transfer of charge from one object to another

Conservation of Electric Charges

- A glass rod is rubbed with silk
- Electrons are transferred from the glass to the silk
- Each electron adds a negative charge to the silk
- An equal positive charge is left on the rod



How electrical charges are measured?

How do the electrical charges move?

Quantization of Electric Charges

- The electric charge, q, is said to be quantized.

  (Which experiment first demonstrated this fact in history?)

  - q is the standard symbol used for charge as a variable
  - Electric charge exists as discrete packets
  - $q = \pm Ne$
    - N is an integer
    - e is the fundamental unit of charge
    - $|e|$ = 1.6 x 10^{-19} C (C, or Coulomb, is the unit of electrical charge in the SI unit system)
    - Electron: $q = -e$
    - Proton: $q = +e$

How do the electrical charges move?

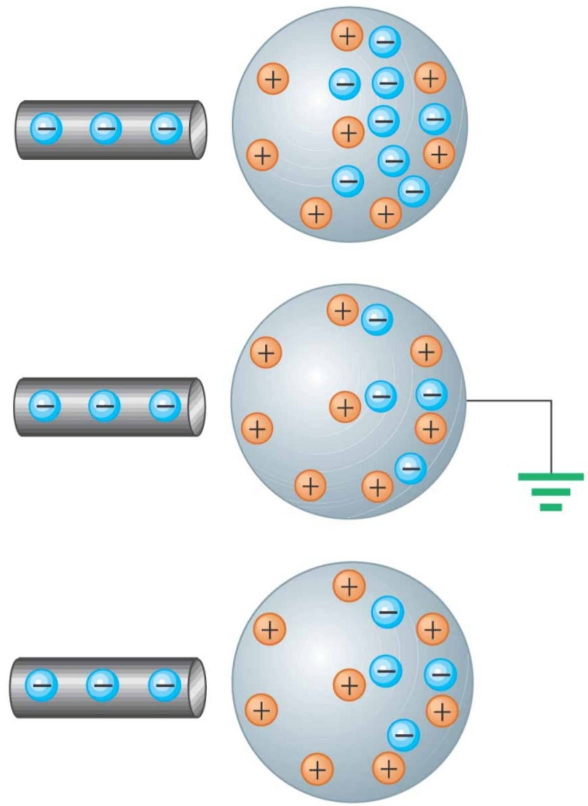
Conductors and Insulators

- Electrical conductors are materials in which some of the electrons are free electrons
  - These electrons can move relatively freely through the material
  - Examples of good conductors include copper, aluminum and silver
  - When a good conductor is charged in a small region, the charge readily distributes itself over the entire surface of the material
- Electrical insulators are materials in which all of the electrons are bound to atoms
  - These electrons can not move relatively freely through the material
  - Examples of good insulators include glass, rubber and wood
  - When a good insulator is charged in a small region, the charge is unable to move to other regions of the material

- The electrical properties of semiconductors are somewhere between those of insulators and conductors
- Examples of semiconductor materials include silicon and germanium

Induction. Another way to generate charge

- Charging by induction requires no contact with the object inducing the charge.
- Instead we make use of the forces between charges to obtain charged object.



Repel and attract forces re-arrange charges in sphere.

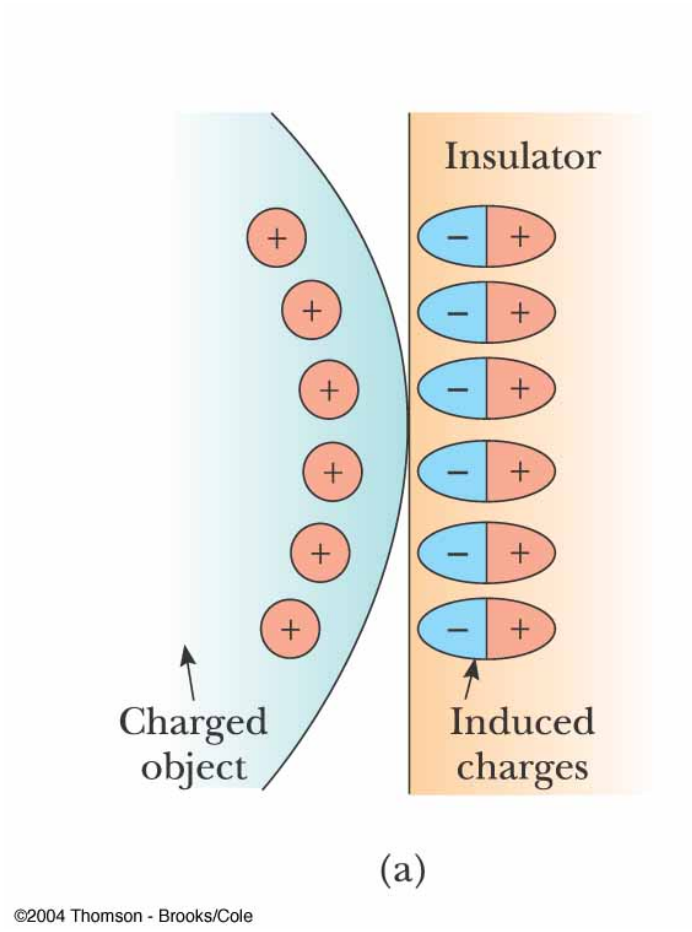
Ground to remove negative charge.

Remove the grounding wire. The sphere is left with an excess of positive charge.

Can you charging an insulator by the same process?

Charge Rearrangement in Insulators

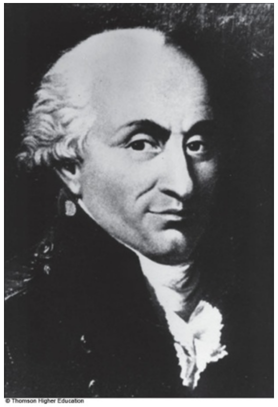
- A process similar to induction can take place in insulators.
- The charges within the molecules of the material are rearranged.
- But you cannot remove charges from the insulator to have it charged up.



The force between charges cause induction in conductor and polarization (charge re-arrangement) in insulator. How is this force quantified?

The Force Between Two Point Charges Follows Coulomb's Law

- The electrical force between two point charges is given by Coulomb's Law.
- The magnitude of the force is proportional to the product of the charges, q_1 and q_2; and inversely proportional to the square of the separation r between them.
- The direction of the force is along the line joining the two points:
  - The force is attractive if the charges are of opposite sign
  - The force is repulsive if the charges are of like sign
- The force is a conservative force.



1736 – 1806
French physicist

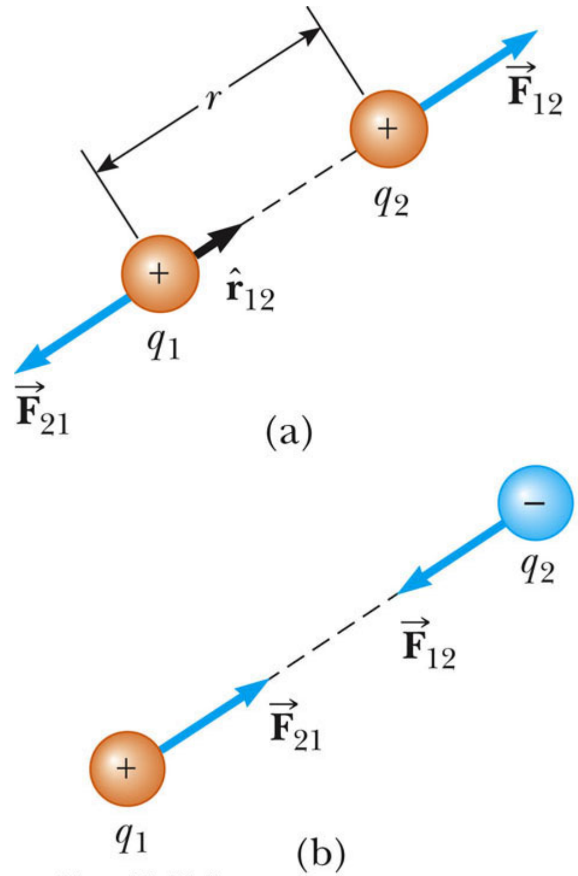
What is a conservative force? Have you met such a type of force in Mechanics?

Coulomb's Law, Equation

- Mathematically:

$$F_e = K_e \frac{|q_1||q_2|}{r^2} \quad \text{or} \quad \vec{F}_e = K_e \frac{q_1 q_2}{r^2} \hat{r}_{12}$$

- The SI unit of charge is the **coulomb** (C)
- k_e is called the **Coulomb constant**
  - k_e = 8.9876 x 10^9 N·m²/C² = $1/(4\pi\varepsilon_o)$
  - ε_o is the **permittivity of free space**
  - ε_o = 8.8542 x 10^{-12} C^2 / N·m²



Anyone remembers Newton's Law of gravitational force between two point masses?

How to get the order of magnitude right?

- How positive and negative charges I have in my body?

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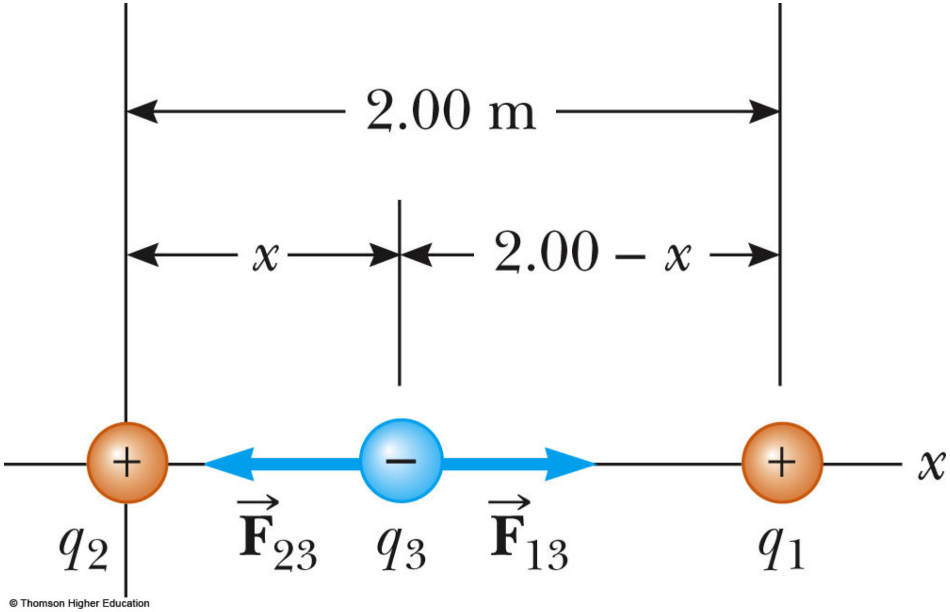
- How positive and negative charges I have in my body?
  - Assumptions: I weigh 170 lb and my body is made of water (H_2O).
  - The molar mass of H_2O is 18.015 g/mol. 170 lb = 77273 grams and 4289.4 mol.
  - 1 mole = 6.022×10^{23} molecules (the Avogadro's number).
  - My body has $4289.4 \times (2 + 8) \times 6.022 \times 10^{23} = 2.574 \times 10^{28}$ electrons or $2.574 \times 10^{28} \times 1.60212 \times 10^{-19}$ C = 4.12×10^{9} C of negative charge and the same amount of positive charge.
- If I concentrate all the electrons in my body to the top of my head, and all the nuclei to my feet, what would be the Coulomb force from my head to my feet? Compare this with the gravitational force of the matter and what kind of conclusion you can draw from this estimate?

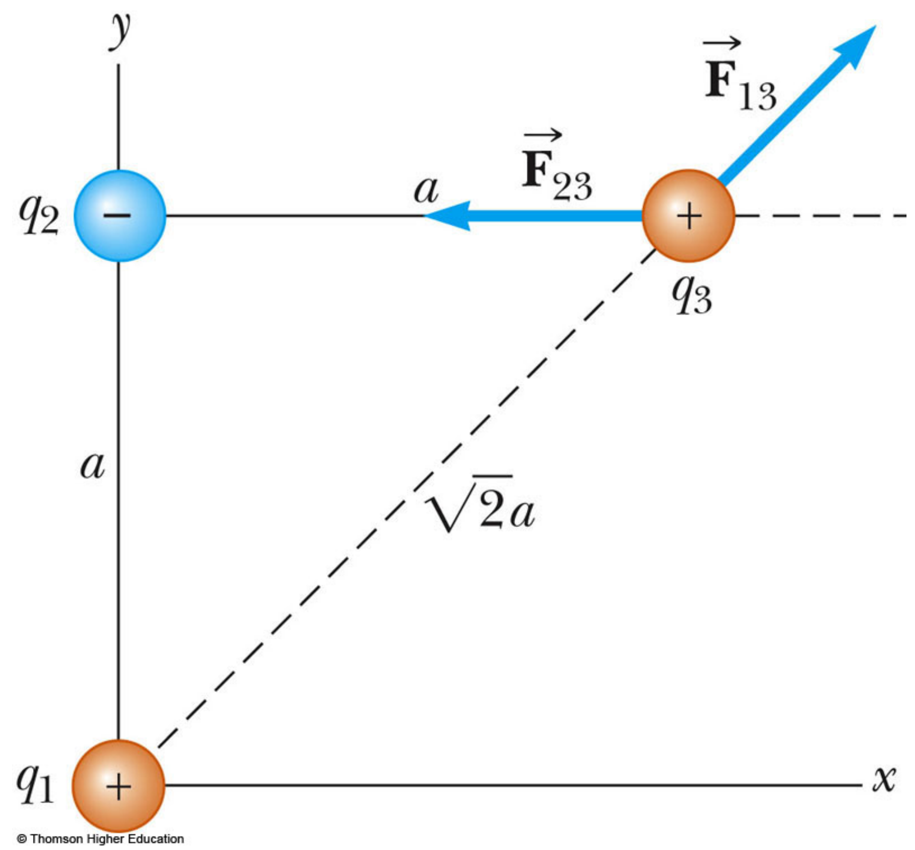
where to place q_3 so the force on it is zero?

- Where is the resultant force equal to zero?
  - The magnitudes of the individual forces will be equal
  - Directions will be opposite



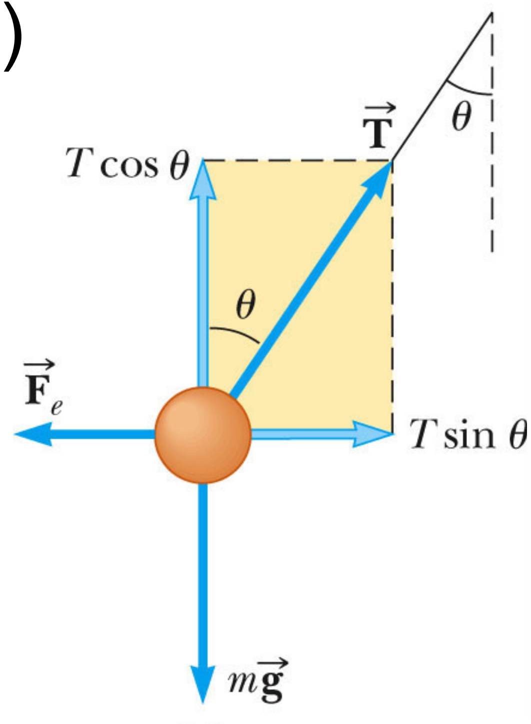
The force on q_3?

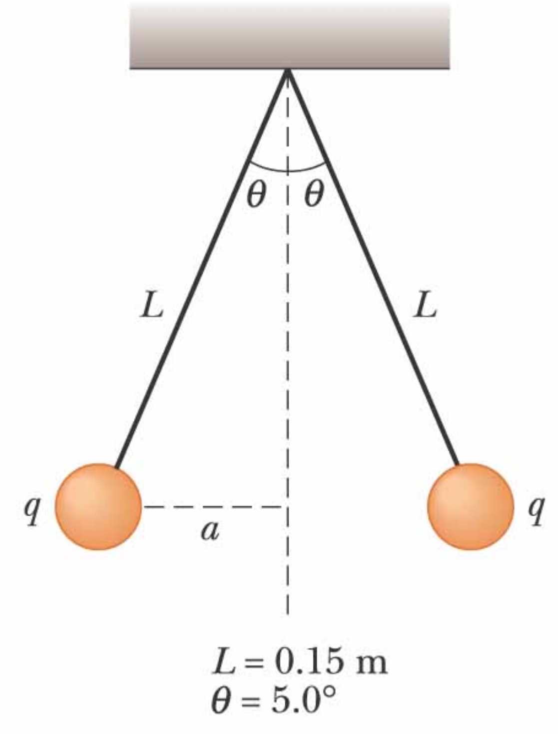
- The force exerted by q_1 on q_3 is $\vec{\mathbf{F}}_{13}$
- The force exerted by q_2 on q_3 is $\vec{\mathbf{F}}_{23}$
- The *resultant force* exerted on q_3 is the vector sum of $\vec{\mathbf{F}}_{13}$ and $\vec{\mathbf{F}}_{23}$



Electrical Force with Other Forces.

- The spheres (mass m) are in equilibrium. Find out the magnitude of the charge q.

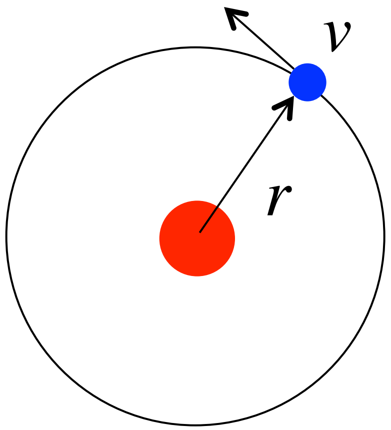




- Since they are like charges, they exert a repulsive force $\vec{F}_e$ on each other.
- Proceed as usual with equilibrium problems, noting one force is an electrical force

Another example on estimate

- What is the speed of an electron in a hydrogen atom in its ground state?
  - Assume classic mechanics
  - The atomic radius if a hydrogen atom is about 0.5 angstrom or 5×10^{-11} meter.



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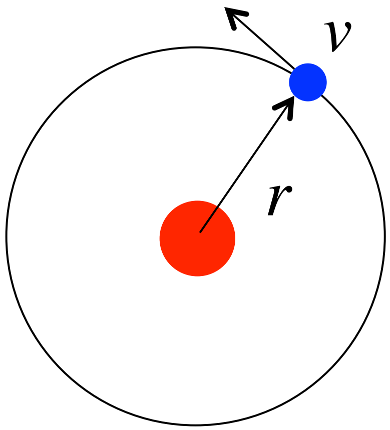


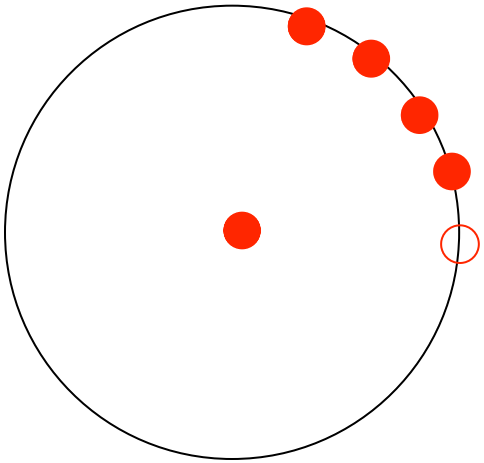
$$\vec{F}_e = k_e \frac{e^2}{r^2} = m_e \frac{v^2}{r}$$

$$v = \sqrt{\frac{k_e}{m_e r}}\,|e| = \sqrt{\frac{8.99\times10^{9}}{9.11\times10^{-31}\times5\times10^{-11}}}\,1.60\times10^{-19}\ \text{m/s}$$

$$v = 2.25\times10^{6}\, m/s$$

Think before act

- One proton is placed at the center of a ring with a radius of 1 meter. Seventy one protons are added to the ring at 5 degree intervals. What is the force the proton at the center experiences?



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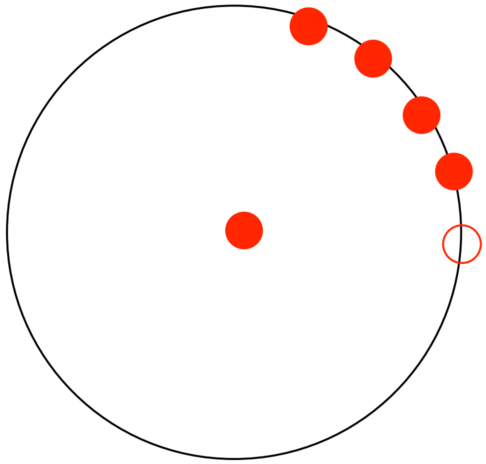

360/72 = 5, so 72 protons fill up one full circle at 5 degree intervals. Because of symmetry the force on the proton at the center will be 0 in this case.

Now take out one proton to match the condition described in the problem, the force from the proton that was taken out on the center proton was

$$F_e = k_e \frac{e^2}{r^2}$$

This force balanced the force of the 71 protons on this center proton. So it now experiences a net force of the same magnitude, but opposite in direction. That is, the center proton now experiences a force that points to the empty spot for the 72nd proton.

Reading material and Homework assignment

Please watch this video (48 minutes):
http://videolectures.net/mit802s02_lewin_lec01/

Please check wileyplus webpage for homework assignment.