This week in the physics course

- **Lectures** will cover *Chapter 20 (Electric Charge)* and start *Chapter 22 (Electric Potential)*
- Please note: **lecture slides** and **scans of the textbook chapters** are available on Blackboard
- **Tutorial class** will practise problems from last week's lectures on *Chapter 16 (Temperature and Heat)*
- Physics help available in **MASH centre** (Chris Blake, Tues 10.30-12.30 and Wayne Rowlands Thurs 2.30-4.30)
- Don't hesitate to get in touch with any questions – cblake@swin.edu.au

Chapter 20 : Electric charge, force, field

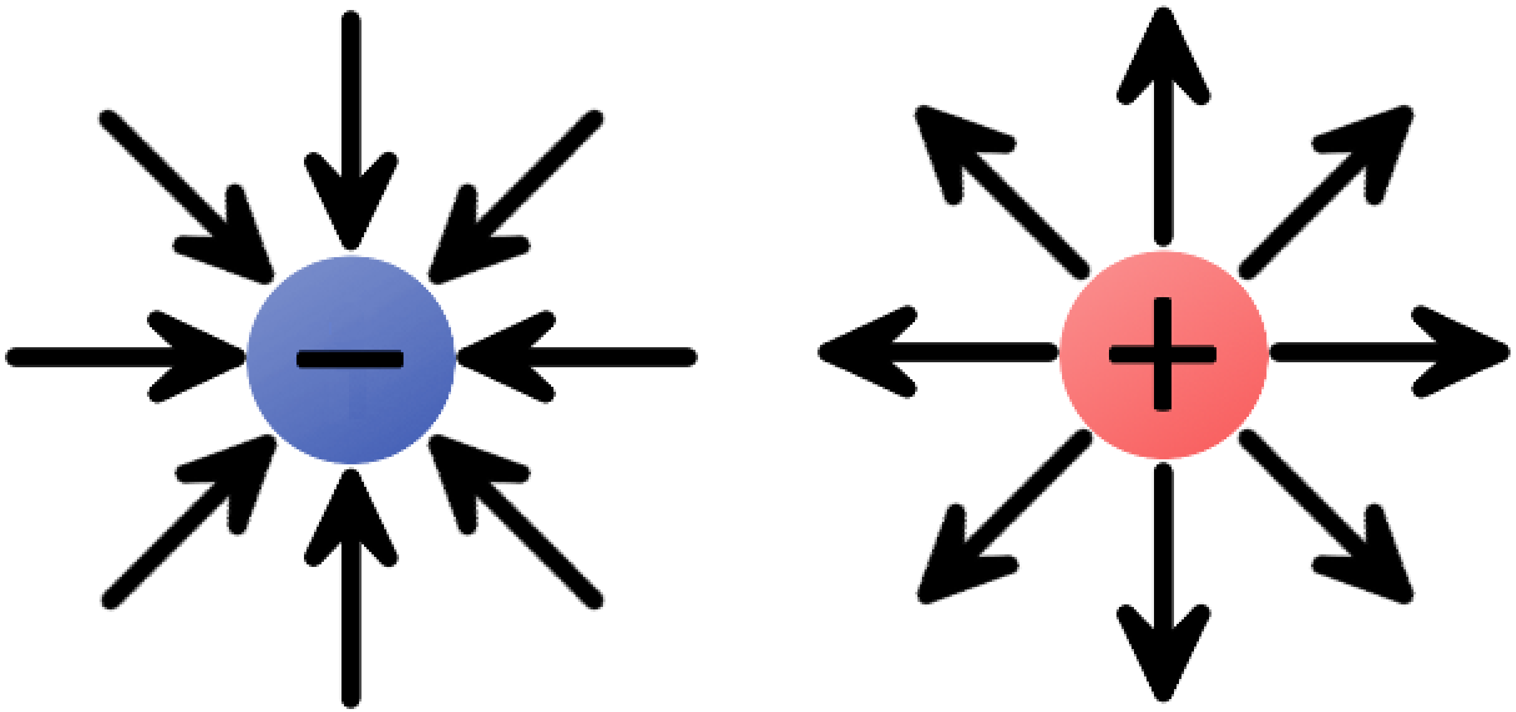
- What is electric charge and how do we measure it?
- Coulomb's Force Law between charges
- How an electric field can be used to describe electrostatic forces
- Some simple applications of these principles

Electric charge

- Intrinsic property of the particles that make up matter

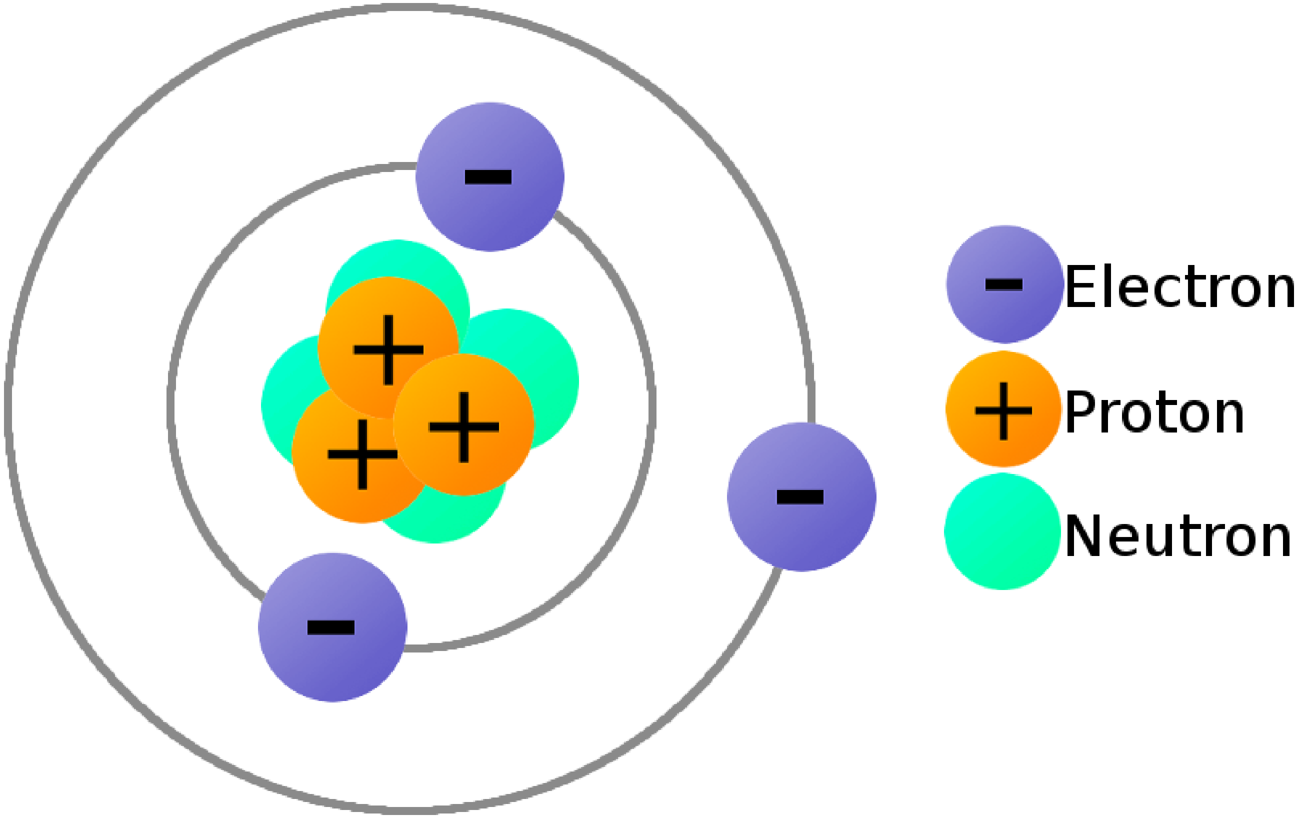
Electric charge

- Charge can be positive or negative



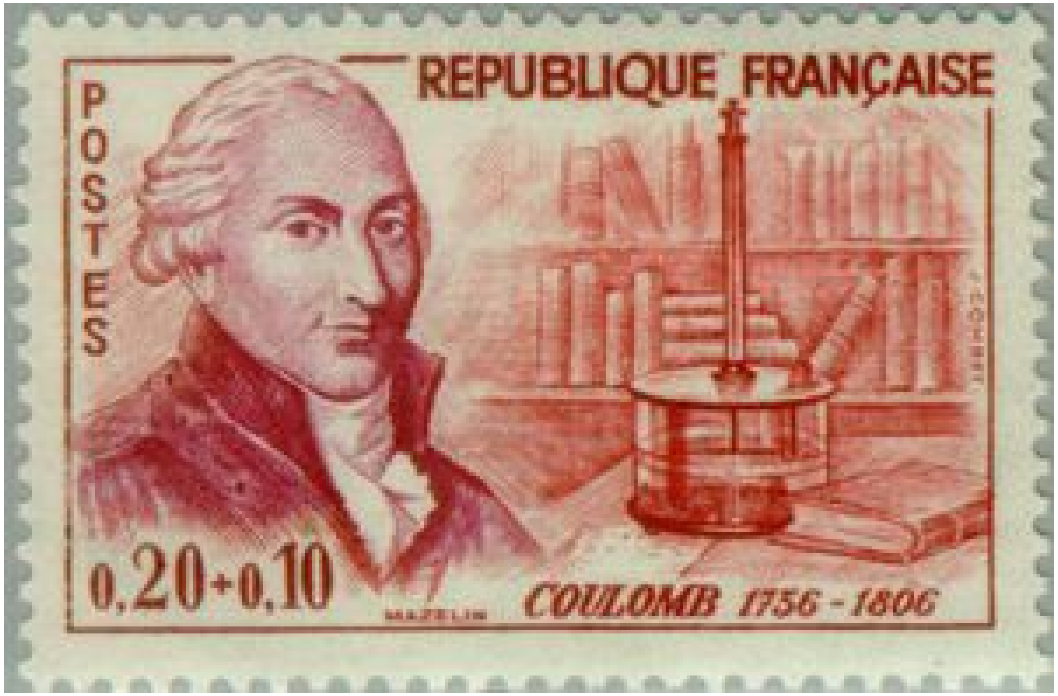
Electric charge

- Atoms are composed of negatively-charged electrons and positively-charged protons



Electric charge

- Charge is measured in Coulombs [unit: C]

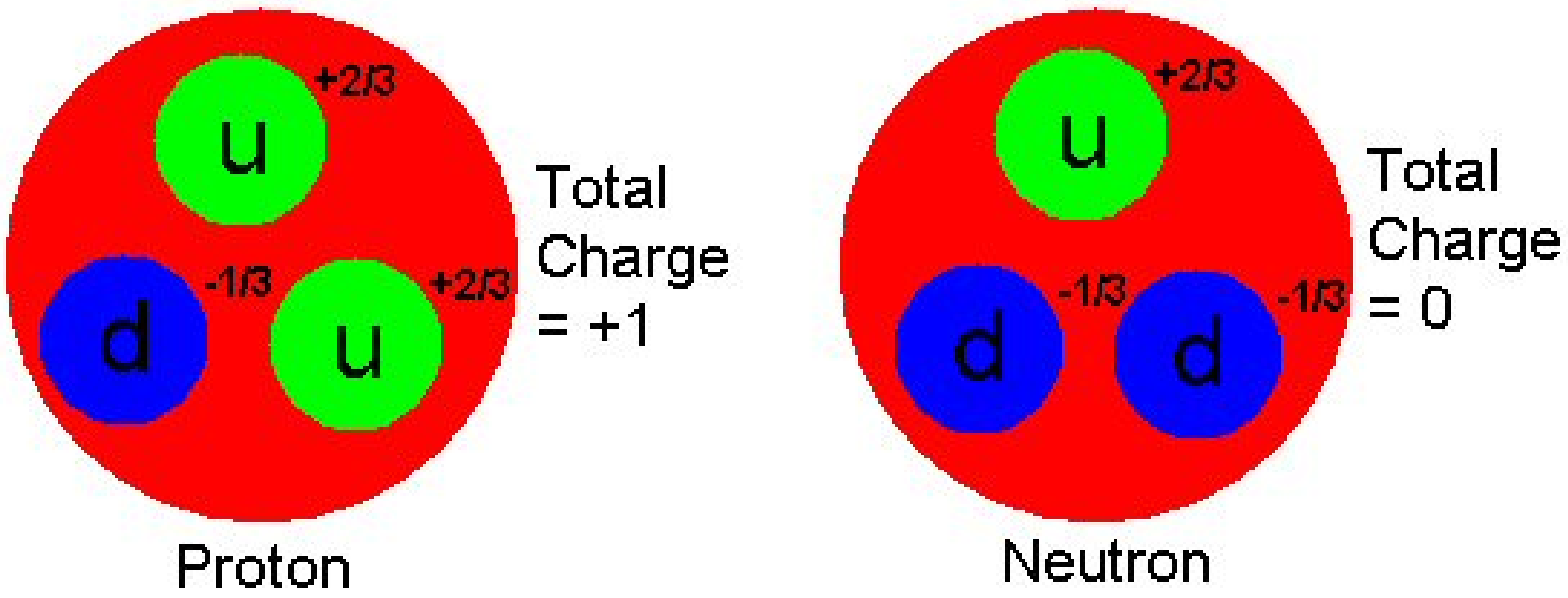


Electric charge

- Charge is measured in Coulombs [unit: C]
- Proton and electron have equal and opposite elementary charge = 1.6×10^{-19} C
- Charge on proton = $+1.6 \times 10^{-19}$ C
- Charge on electron = -1.6×10^{-19} C

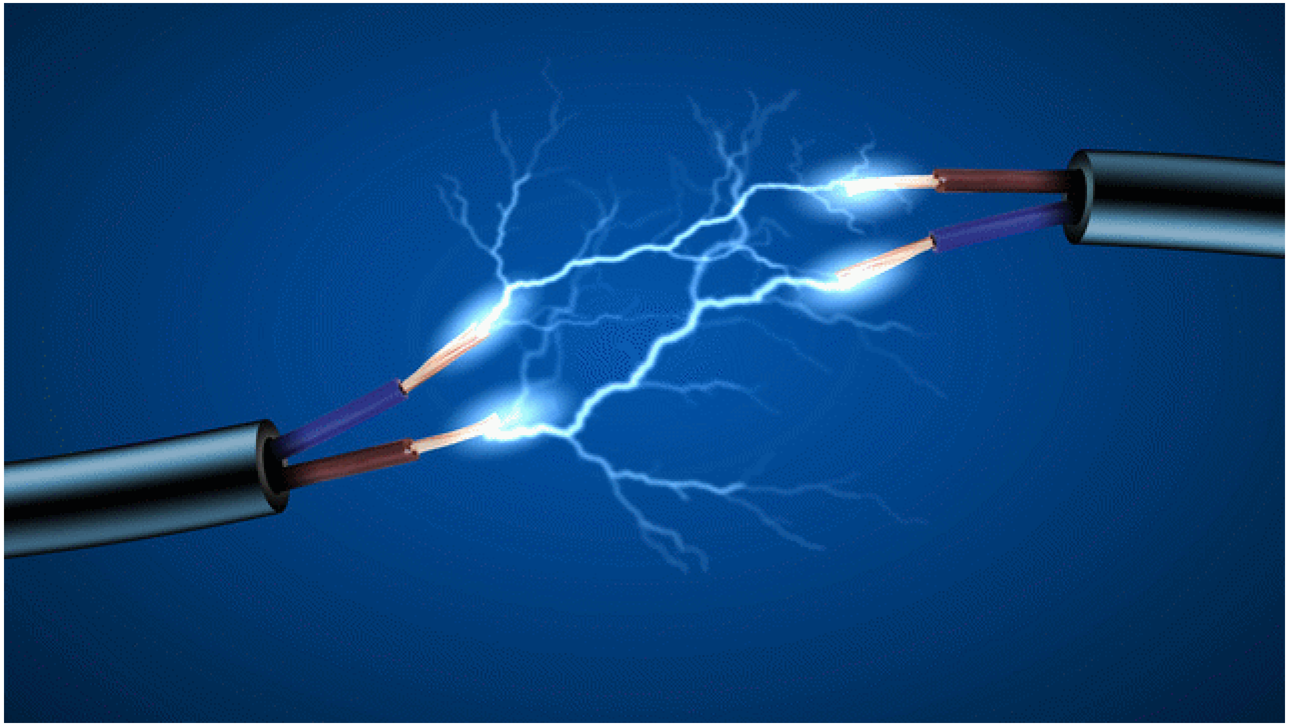
Electric charge

- We now know that protons and neutrons are made up of quarks with 2/3 and -1/3 charges (electrons are still fundamental)



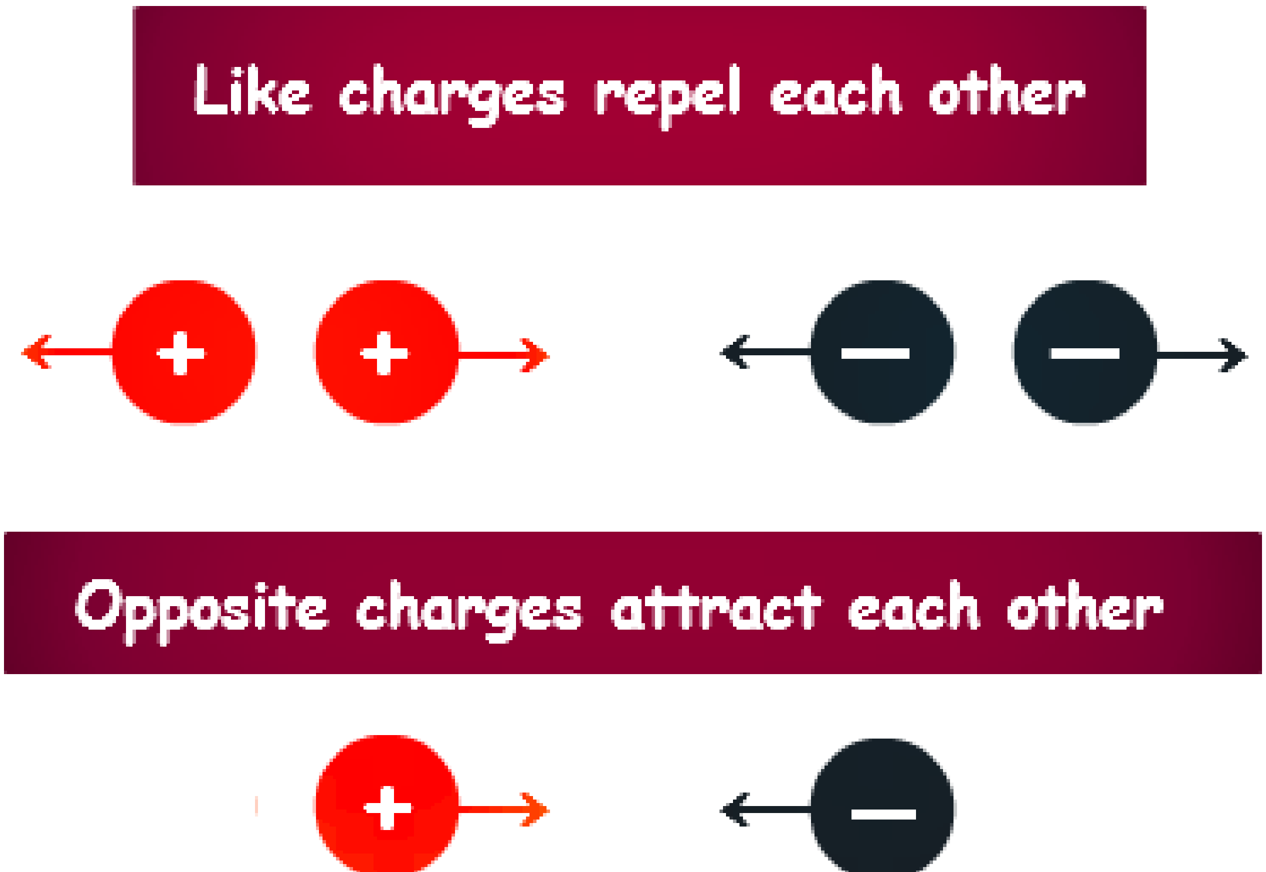
Electric charge

- Charge cannot be created or destroyed (it is conserved) but it can be moved around



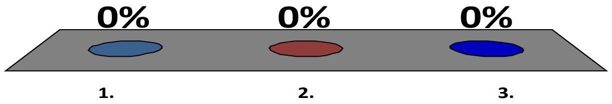
Electric charge

- Charges feel electrostatic forces



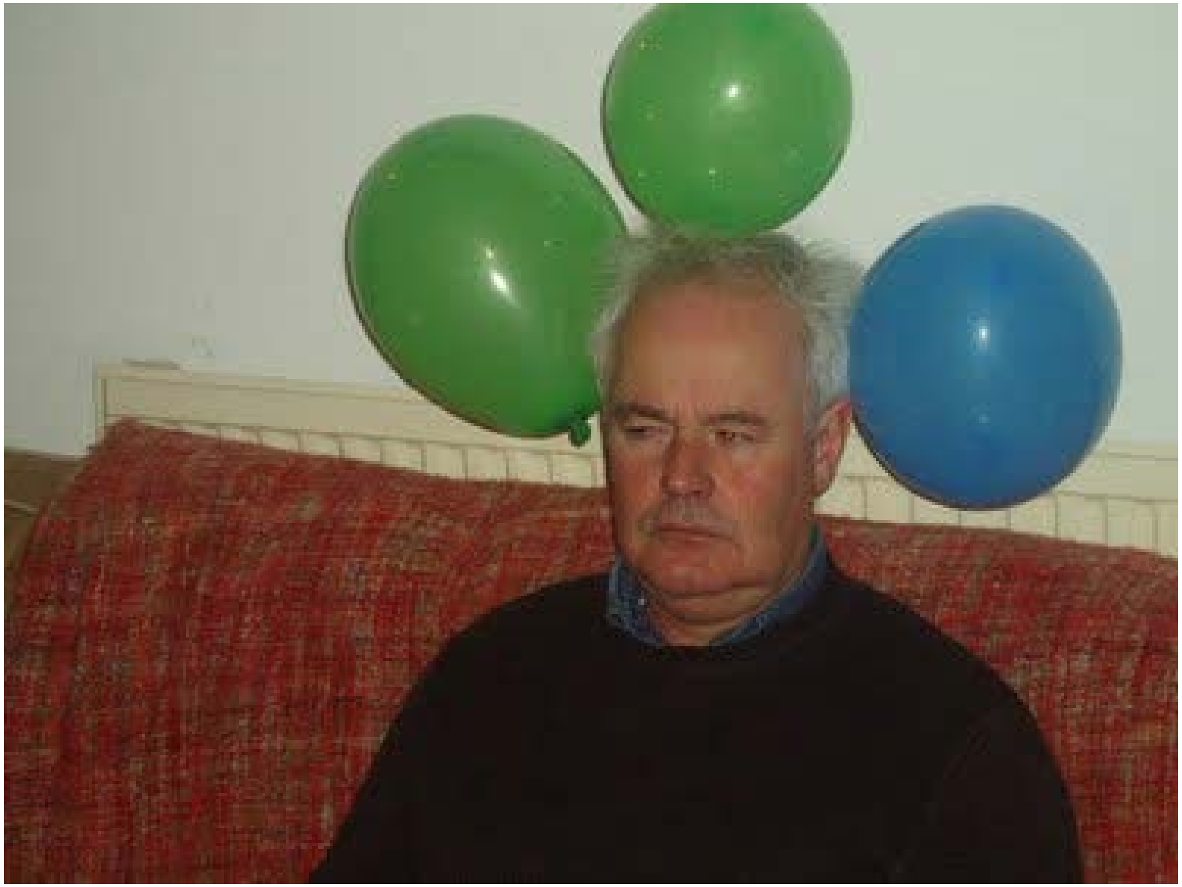
A balloon is rubbed against a nylon jumper, and it is then found to cause a force of attraction to human hair. From this experiment it can be determined that the electrostatic charge on the balloon is

1. **positive**
2. **negative**
3. **Impossible to determine**



Electric charge

- Rub a balloon on your hair and it will stick to things! Why??

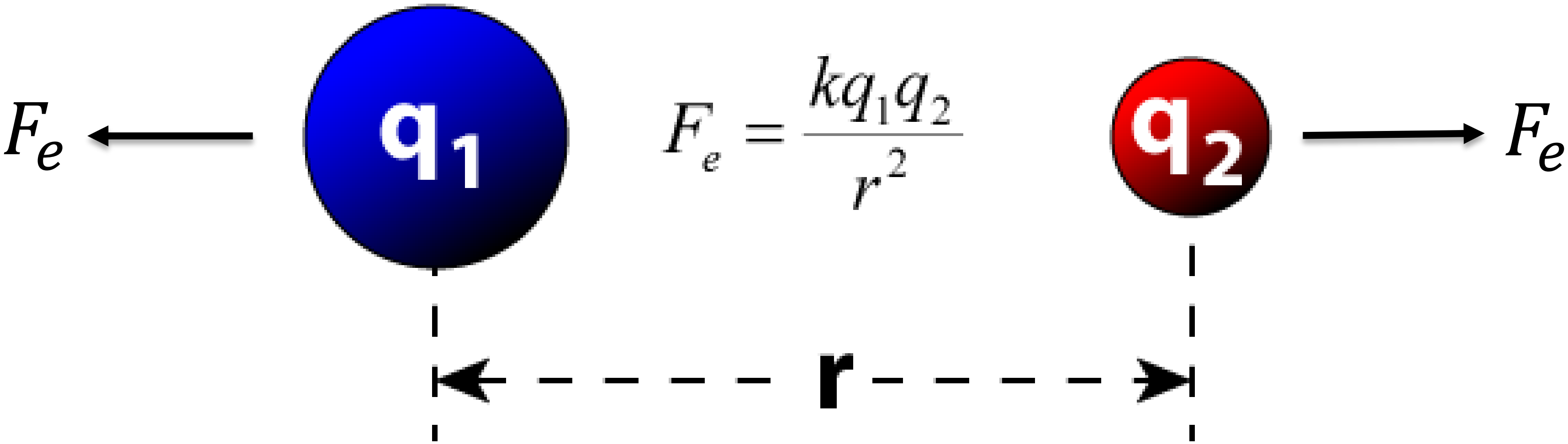


Electric charge

- Rub a balloon on your hair and it will stick to things! Why??
- Friction moves electrons from your hair to the balloon
- The balloon therefore becomes negatively charged, so your hair becomes positively charged (charge conservation)
- Your hair will stand on end (like charges repel), and the balloon will stick to your hair (opposite charges attract)
- Now move the balloon near a wall. The wall's electrons are repelled, so the wall becomes positively charged.
- The balloon will stick to the wall! (opposite charges attract)

Electrostatic force

- The strength of the electrostatic force between two charges q_1 and q_2 is given by Coulomb's law



$$k = 9 \times 10^9 \; N \, m^2 \, C^{-2}$$

- The direction of the force is along the joining line

Electrostatic force

- The electrostatic force is a vector, written $\vec{F}$
- Vectors have a magnitude and a direction. This may be indicated by components $\vec{F} = (F_x, F_y, F_z)$
- The magnitude is sometimes written as $\left|\vec{F}\right|$. It can be evaluated as $|\vec{F}| = \sqrt{{F_x}^2 + {F_y}^2 + {F_z}^2}$
- The direction can be indicated by a unit vector

Electrostatic force

<u>Example</u>

Two 0.5 kg spheres are placed 25 cm apart. Each sphere has a charge of 100 μC, one of them positive and the other negative. Calculate the electrostatic force between them, and compare it to their weight.

Coulomb's Law: $|F| = \frac{k\,|q_1|\,|q_2|}{r^2}$ $\quad k = 9 \times 10^9\ N\ m^2\ C^{-2}$

$$|q_1| = |q_2| = 100\ \mu C = 100 \times 10^{-6}\ C = 10^{-4}\ C$$

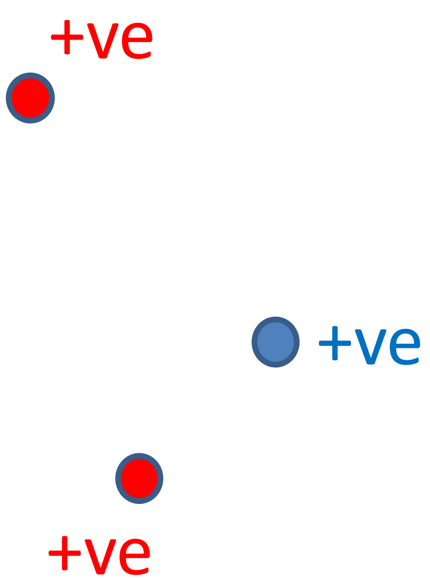
$$r = 25\ cm = 0.25\ m$$

$$F_{electrostatic} = \frac{9 \times 10^9 \times 10^{-4} \times 10^{-4}}{0.25^2} = 1440\ N$$

$$F_{weight} = mg = 0.5 \times 9.8 = 4.9\ N$$

Electrostatic force

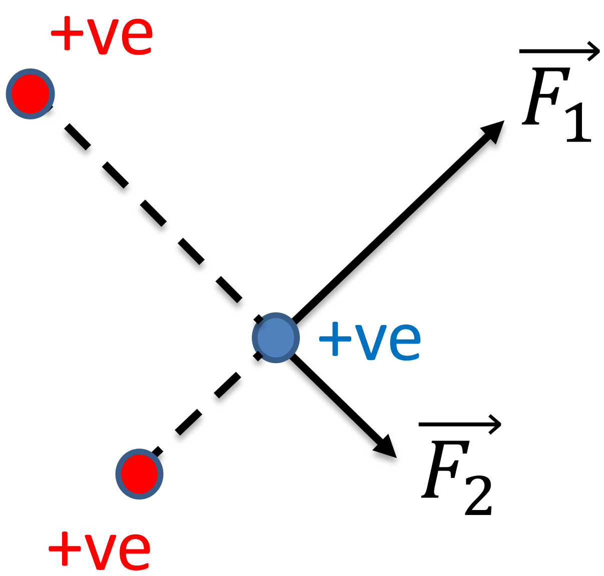
- Where multiple charges are present, the forces sum as vectors ("principle of superposition")



What is the combined force on the blue charge from the two red charges?

Electrostatic force

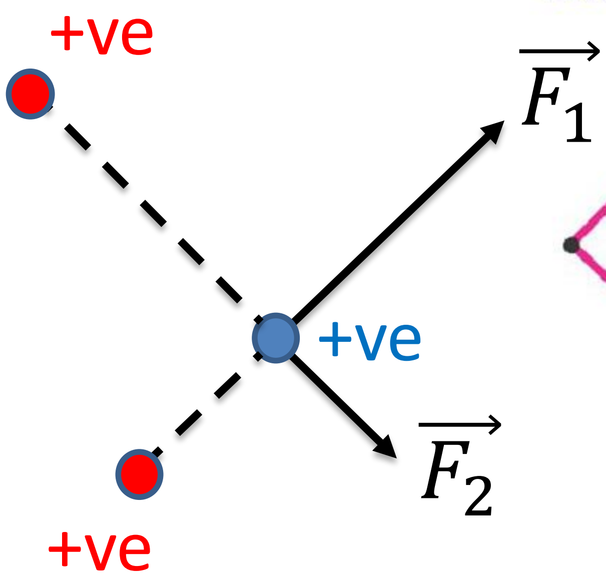
- Where multiple charges are present, the forces sum as vectors ("principle of superposition")

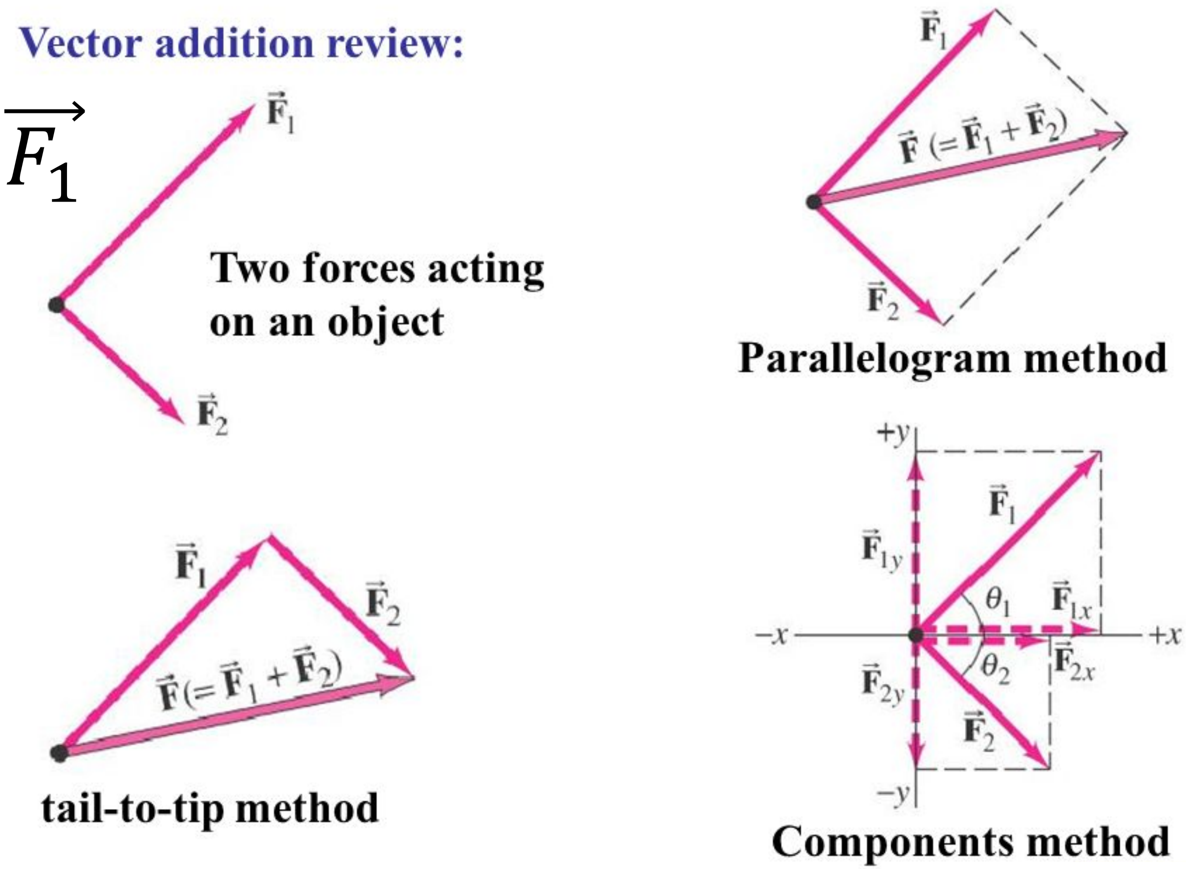


$$\overrightarrow{F_{total}} = \overrightarrow{F_1} + \overrightarrow{F_2}$$

Electrostatic force

- Where multiple charges are present, the forces sum as vectors ("principle of superposition")

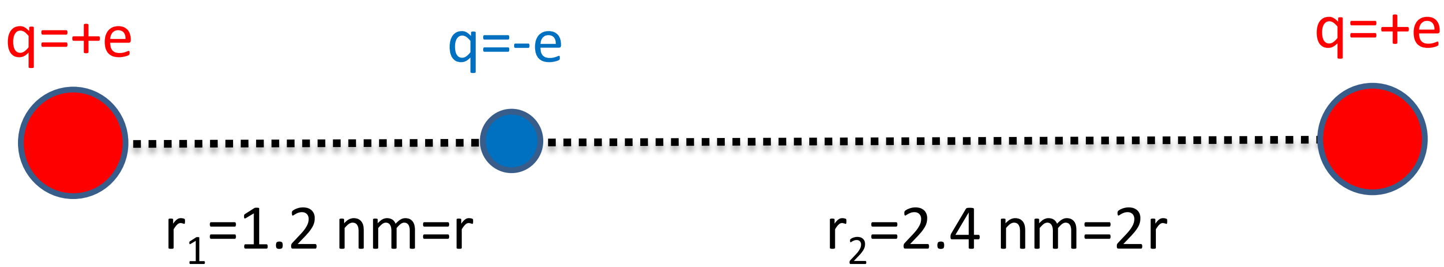




Electrostatic force

Example

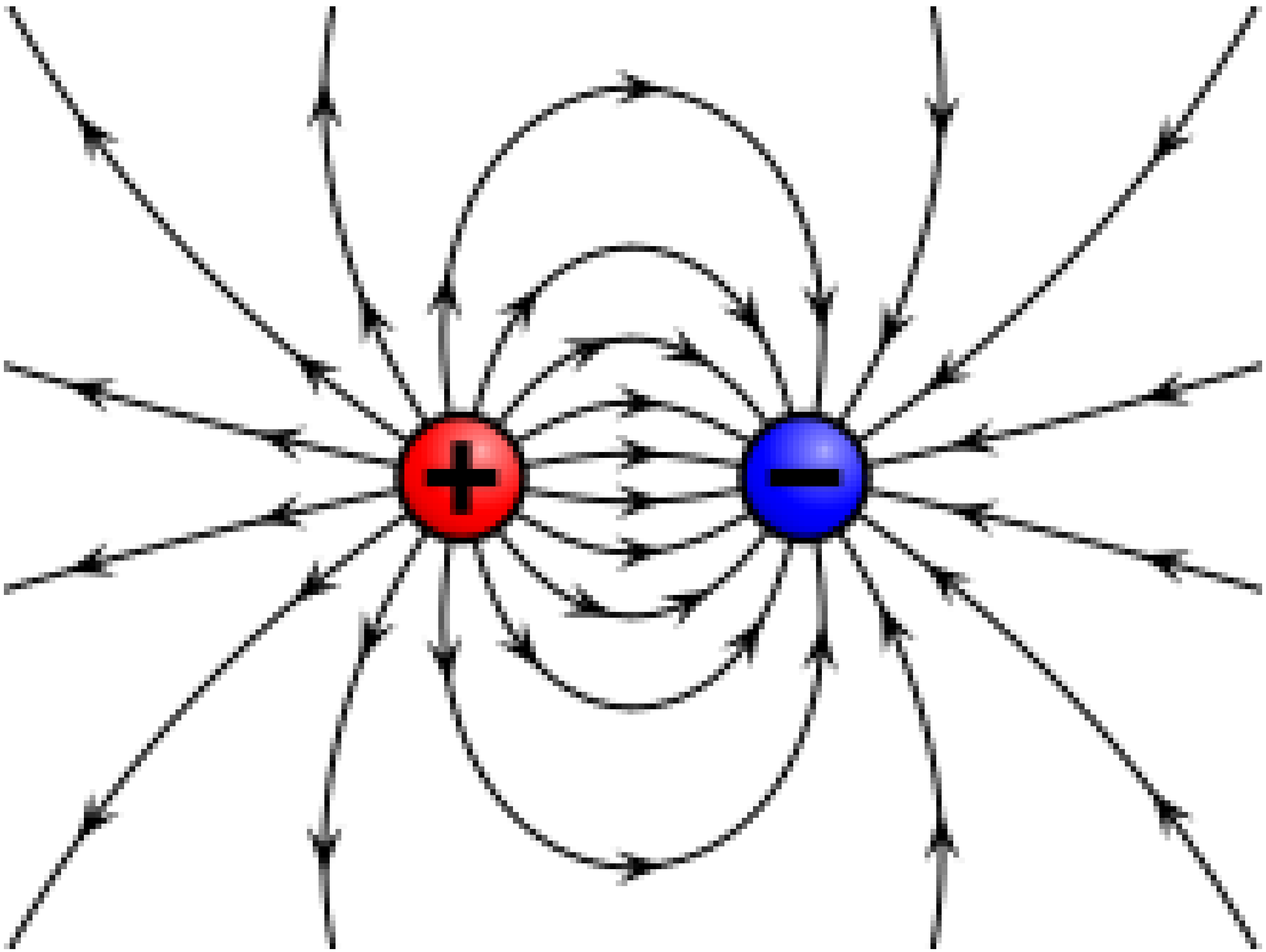
Two protons are 3.6 nm apart. What is the total force on an electron located on the line between them, 1.2 nm from one of the protons? (elementary charge $e=1.6 \times 10^{-19}$ C)



$$|F_1| = \frac{k\,|q_1||q_2|}{{r_1}^2} = \frac{k\,e^2}{r^2} \qquad |F_2| = \frac{k\,|q_1||q_2|}{{r_2}^2} = \frac{k\,e^2}{(2r)^2}$$

$$|F_1| - |F_2| = \frac{ke^2}{r^2} - \frac{ke^2}{4r^2} = \frac{3ke^2}{4r^2} = \frac{3 \times 9 \times 10^9 \times (1.6 \times 10^{-19})^2}{4 \times (1.2 \times 10^{-9})^2} = 0.12\,nN$$

Electric field



Electric field

- The electric field at a point is the force a unit charge (q = +1 C) would experience if placed there

$$\vec{E} = \frac{\vec{F}}{q} \qquad \vec{F} = q\,\vec{E}$$

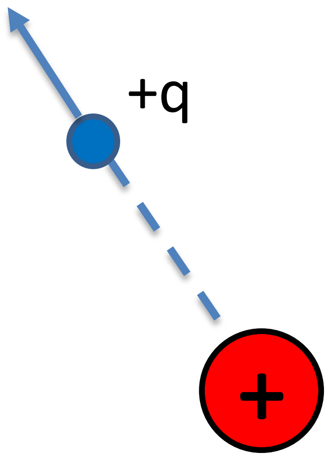
(Units of E are N/C)

- It is a vector and its direction can be represented by electric field lines

- Let’s look at some simple examples!

Electric field

- Electric field around a positive charge +Q



Test charge +q at separation r feels an outward force

$$|F| = \frac{k\ Q\ q}{r^2}$$

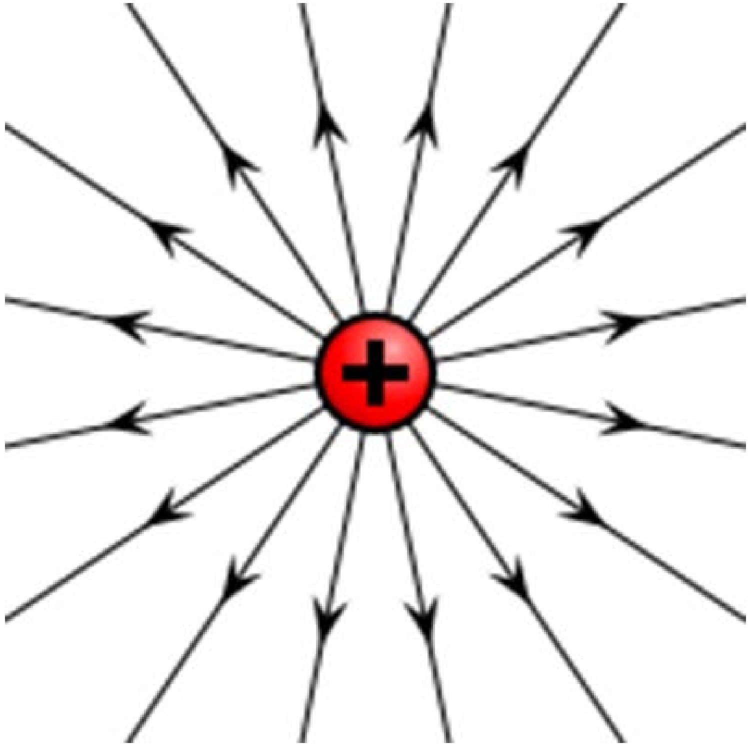
Electric field is also outward

$$|E| = \frac{|F|}{q} = \frac{k\ Q}{r^2}$$

Now imagine placing the test charge at many different places to map out the whole electric field

Electric field

- Electric field around a positive charge +Q



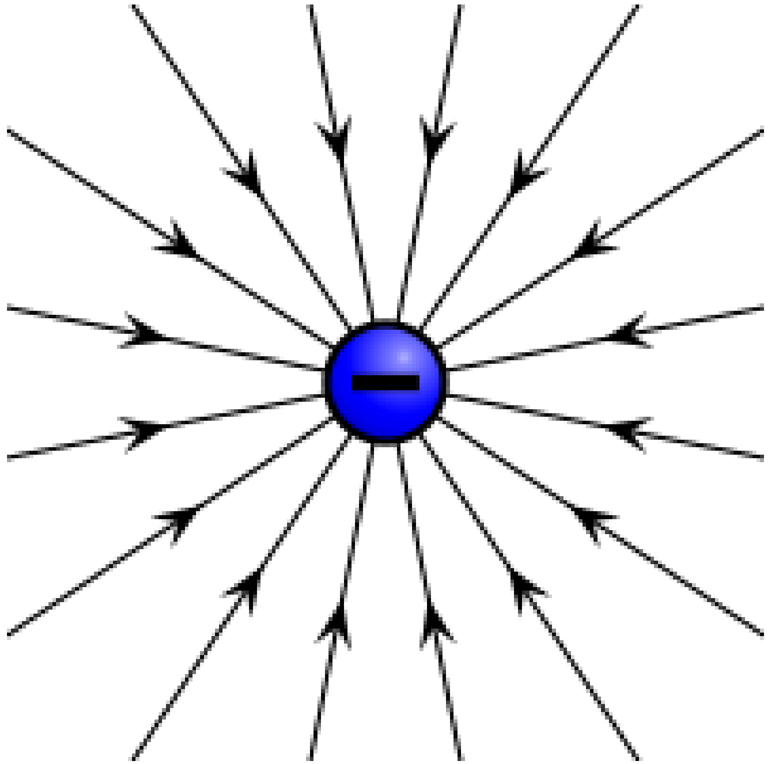
Magnitude of electric field at any point:

$$|E| = \frac{|F|}{q} = \frac{k\ Q}{r^2}$$

Direction of electric field is radially outward

Electric field

- Electric field around a negative charge -Q



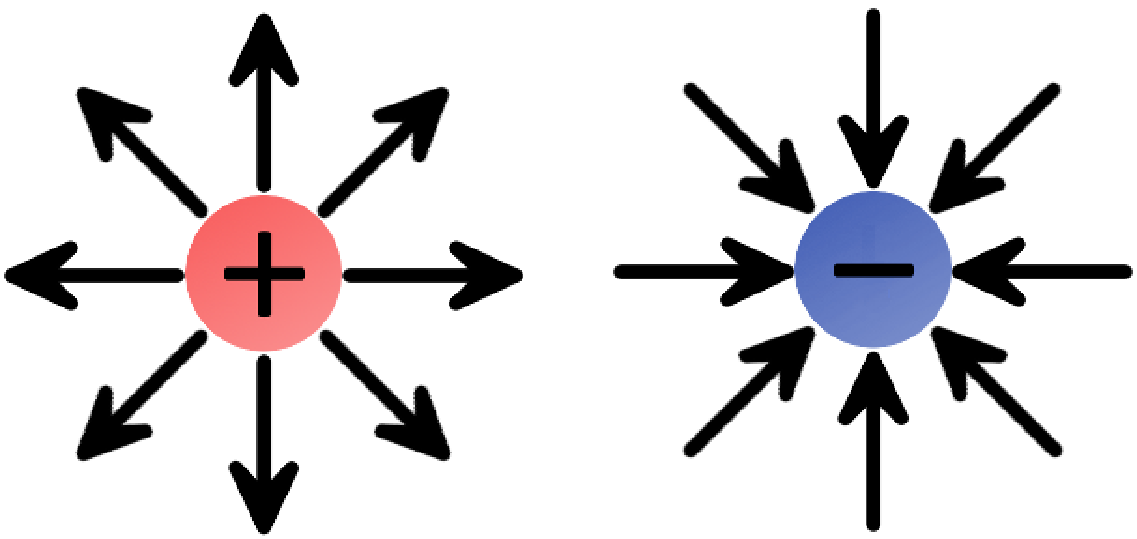
Magnitude of electric field at any point:

$$|E| = \frac{|F|}{q} = \frac{k\,Q}{r^2}$$

Direction of electric field is radially inward

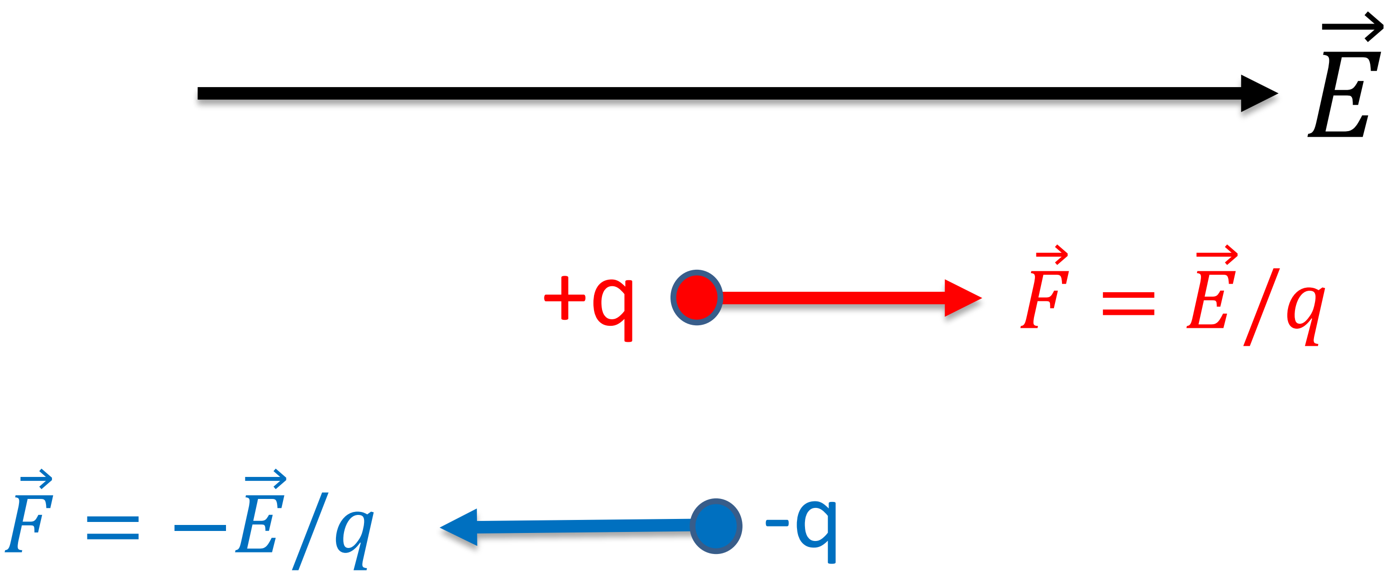
Electric field

- Electric field lines start on positive charges and end on negative charges
- The more closely spaced the field lines, the stronger the force



Electric field

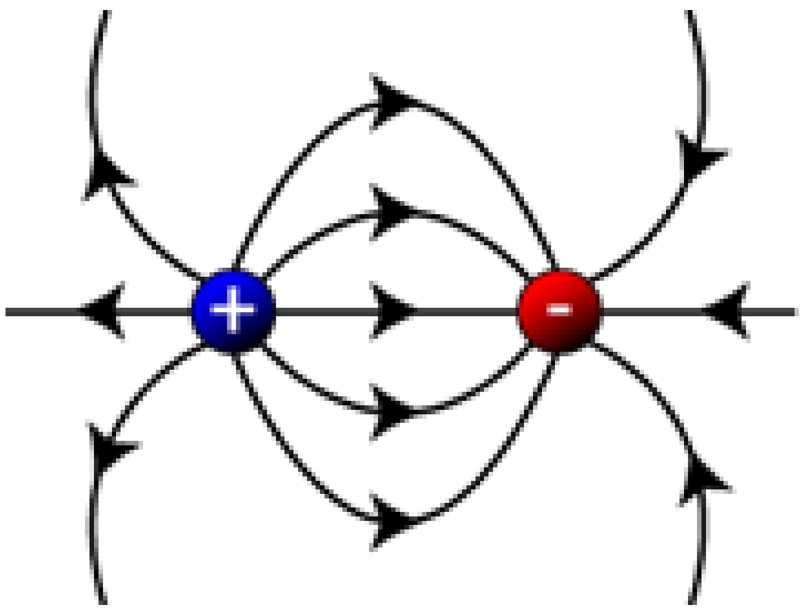
- The direction of the field lines show how a positive charge would move if placed at that point. A negative charge would move the opposite way.



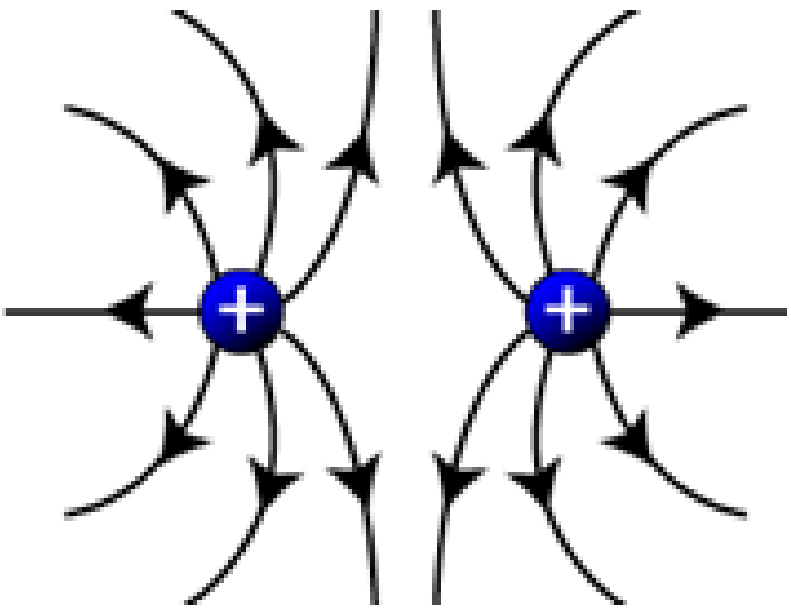
Electric field

- Electric field lines between two charges

Unlike charges

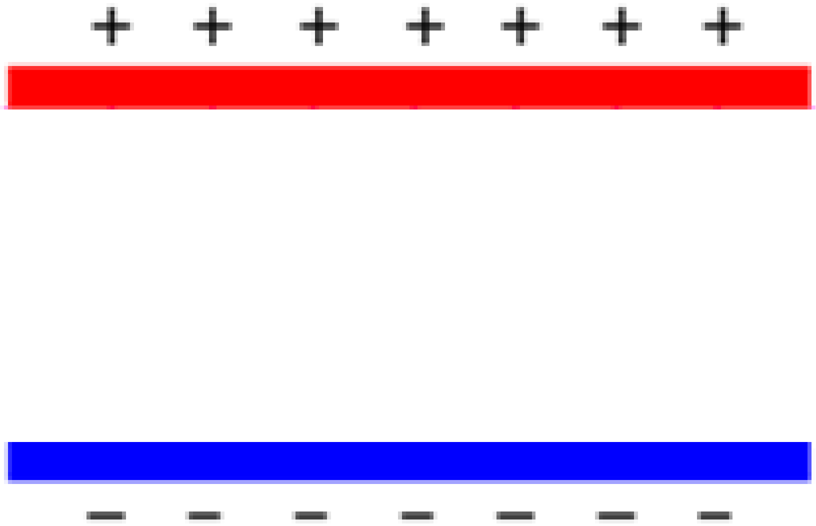


Like charges



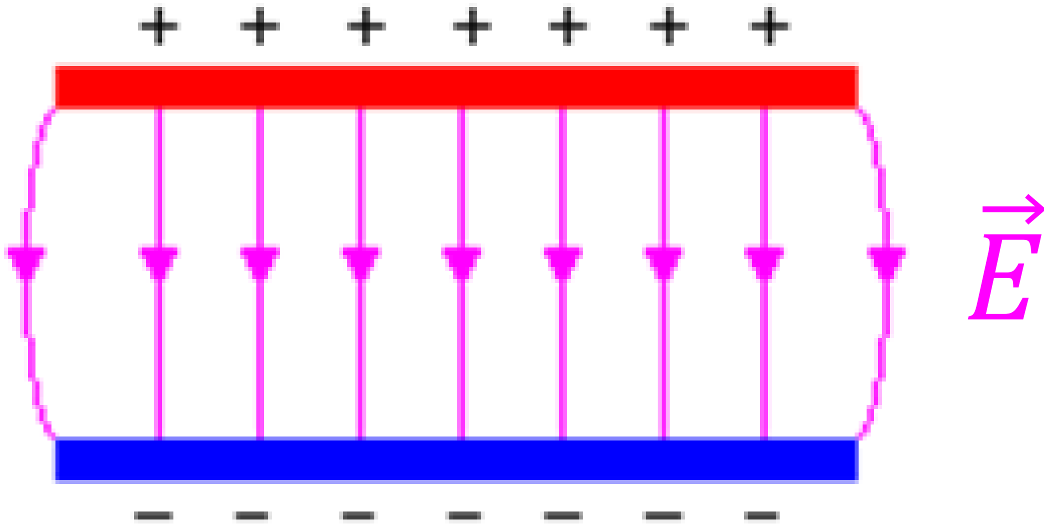
Electric field

- Electric field lines between charged plates



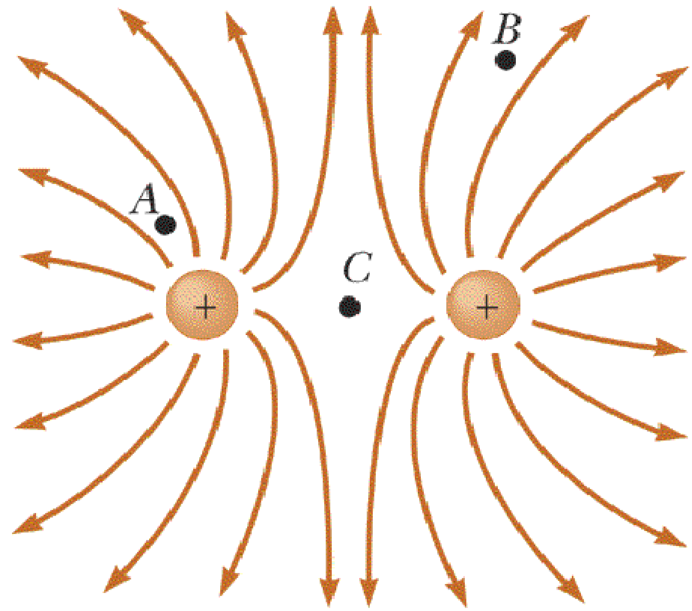
Electric field

- Electric field lines between charged plates

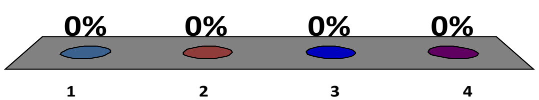


- A constant electric field is obtained (see later material on capacitors)

Consider an electron placed near a pair of identical positive charges, as in the field diagram. If the electron is at position “A” the direction of the force on it is best indicated by which of the following arrows?



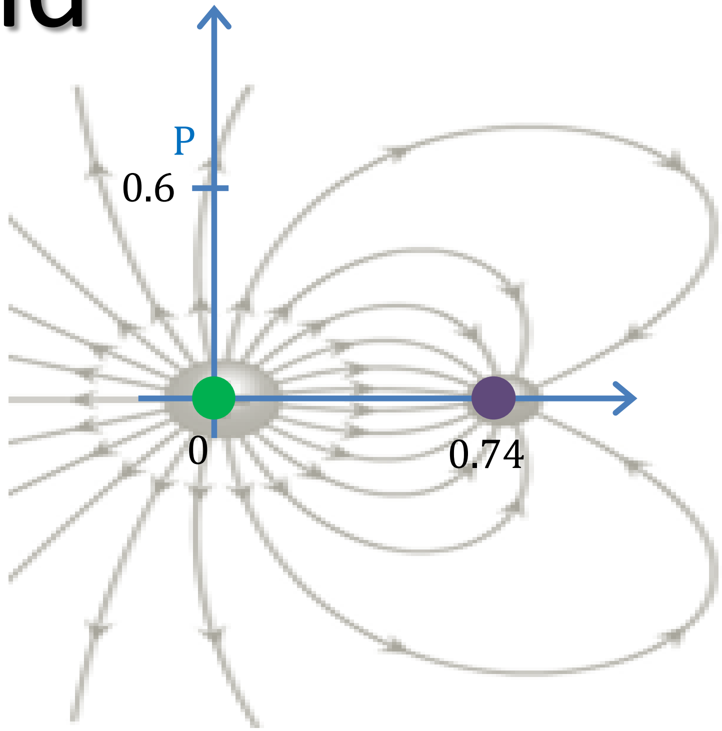
1. ↑
2. ↖
3. ↘
4. →



What is the force at location “C”?

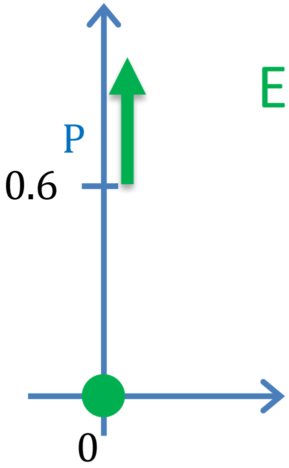
Electric field

Example A +5.0 μC charge is located at the origin, and a -2.0 μC charge is 0.74 m away on the x-axis. Calculate the electric field at point P, on the y-axis 0.6 m above the positive charge. If a +1.5 μC was placed at P, what force would it experience?



Electric field is superposition of 2 charges

$E = kq/r^2$ along joining line, $k=9x10^9$



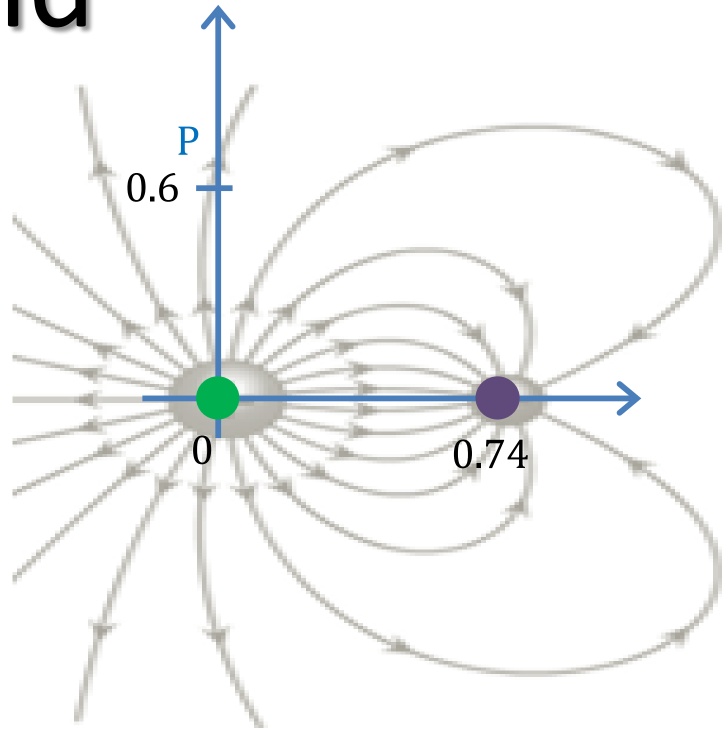
Electric field at P due to green charge q = $+5x10^{-6}$ C

$$E = \frac{k\,q}{r^2} = \frac{9\times 10^9 \times 5 \times 10^{-6}}{0.6^2} = 3.5 \times 10^5\ N/C$$

Direction is along y-axis: $(E_x, E_y) = (0, 3.5 \times 10^5)$

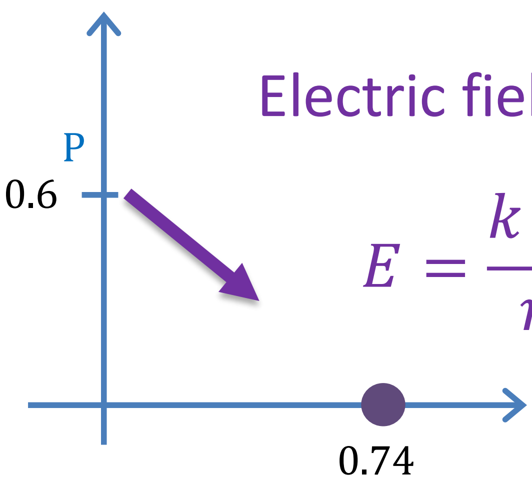
Electric field

Example A +5.0 μC charge is located at the origin, and a -2.0 μC charge is 0.74 m away on the x-axis. Calculate the electric field at point P, on the y-axis 0.6 m above the positive charge. If a +1.5 μC was placed at P, what force would it experience?



Electric field is superposition of 2 charges

E= kq/r^2 along joining line, $k=9x10^9$



Electric field at P due to purple charge q = $-2x10^{-6}$ C

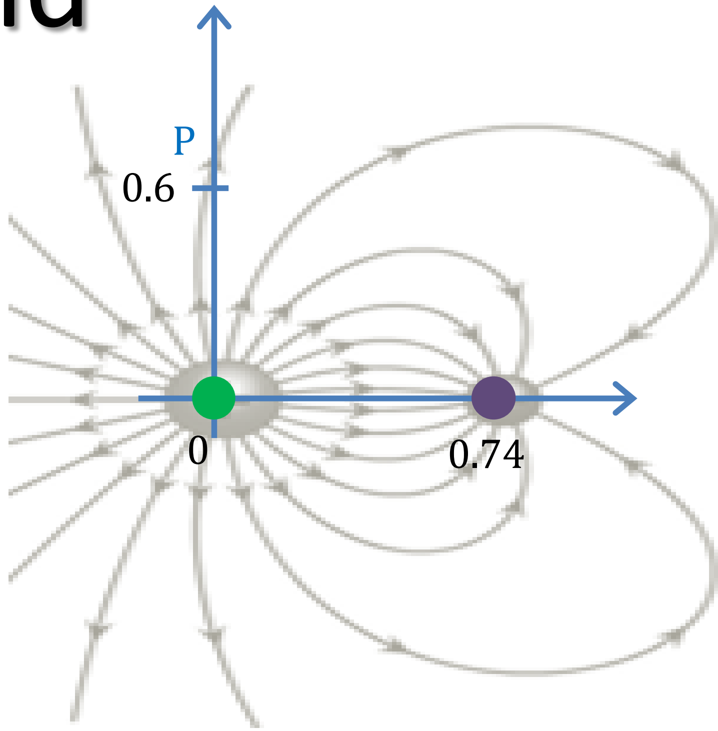
$$E = \frac{k\,|q|}{r^2}$$

Pythagoras: $r^2 = 0.6^2 + 0.74^2 = 0.91\ m^2$

$r = 0.95$ m

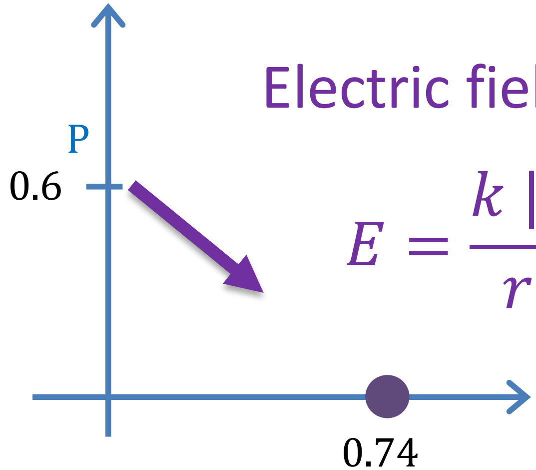
Electric field

Example A +5.0 μC charge is located at the origin, and a -2.0 μC charge is 0.74 m away on the x-axis. Calculate the electric field at point P, on the y-axis 0.6 m above the positive charge. If a +1.5 μC was placed at P, what force would it experience?



Electric field is superposition of 2 charges

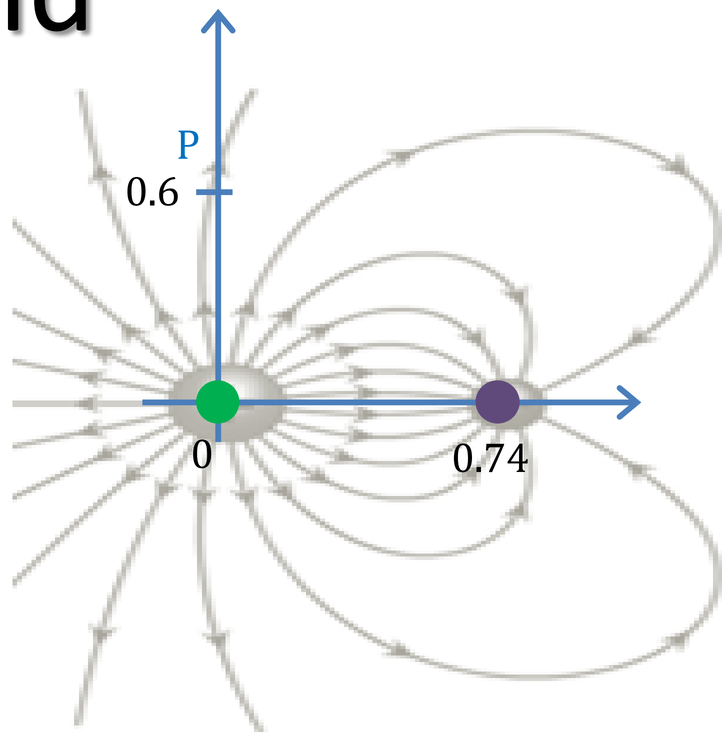
E= kq/r^2 along joining line, k=9x10^9



Electric field at P due to purple charge q = -2x10^{-6} C

$$E = \frac{k\,|q|}{r^2} = \frac{9 \times 10^9 \times 2 \times 10^{-6}}{0.95^2} = 0.20 \times 10^5\ N/C$$

Electric field

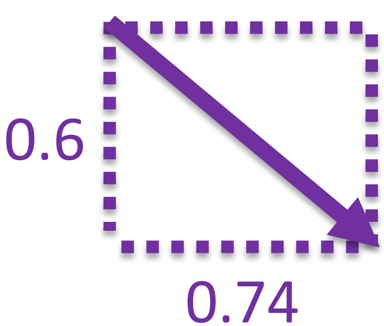


Example A +5.0 μC charge is located at the origin, and a -2.0 μC charge is 0.74 m away on the x-axis. Calculate the electric field at point P, on the y-axis 0.6 m above the positive charge. If a +1.5 μC was placed at P, what force would it experience?

Electric field is superposition of 2 charges

$E = kq/r^2$ along joining line, $k=9\times10^9$

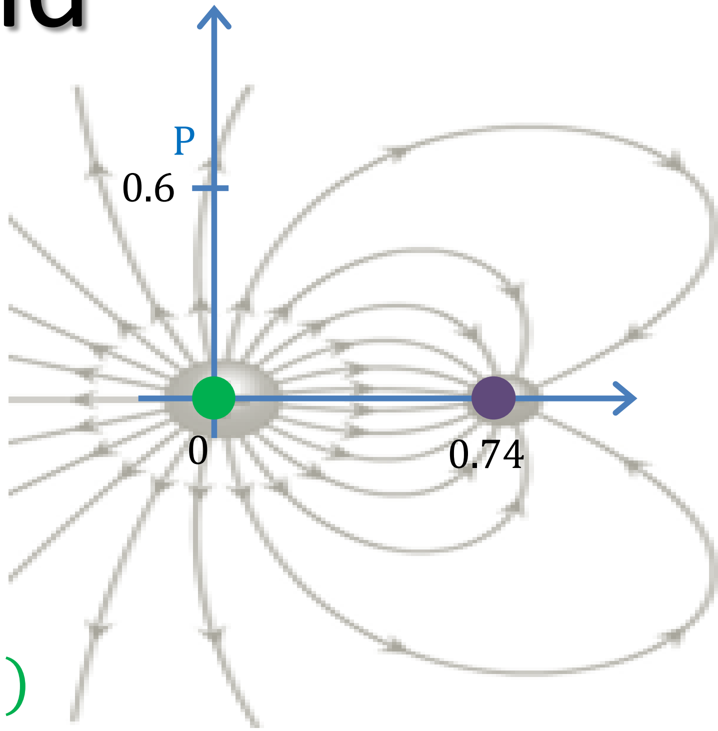
Electric field at P due to purple charge $q = -2\times10^{-6}$ C



$$E = \frac{k\,|q|}{r^2} = \frac{9\times10^9\times2\times10^{-6}}{0.95^2} = 0.20\times10^5\ N/C$$

$$(E_x, E_y) = (0.16\times10^5, -0.13\times10^5)$$

Electric field



Example A +5.0 μC charge is located at the origin, and a -2.0 μC charge is 0.74 m away on the x-axis. Calculate the electric field at point P, on the y-axis 0.6 m above the positive charge. If a +1.5 μC was placed at P, what force would it experience?

Electric field is superposition of 2 charges

Green charge: $\left(E_x, E_y\right) = (0, 3.5 \times 10^5)$

Purple charge: $\left(E_x, E_y\right) = (0.16 \times 10^5, -0.13 \times 10^5)$

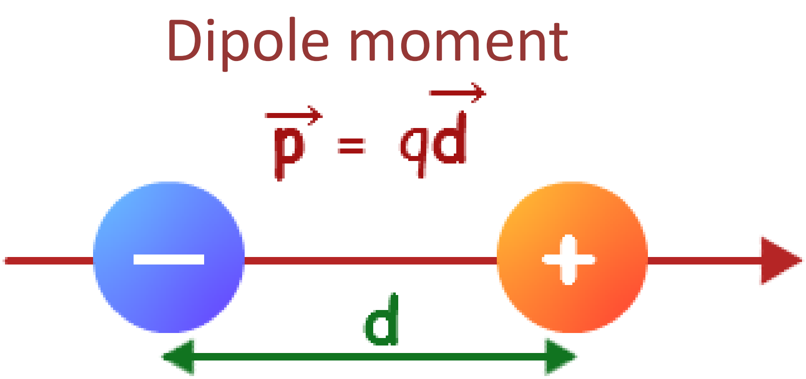
Total: $\left(E_x, E_y\right) = (0.16 \times 10^5, 3.37 \times 10^5)$

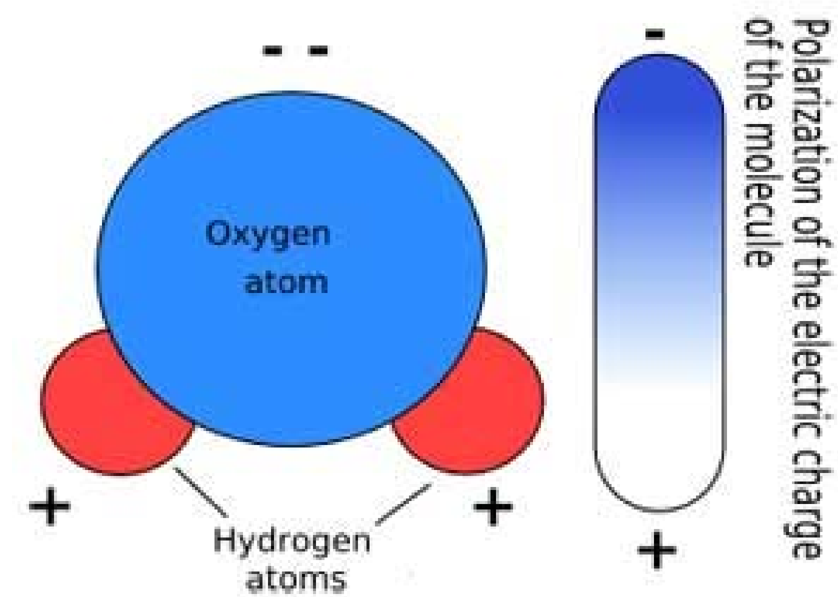
Electric field strength at P: $E = \sqrt{{E_x}^2 + {E_y}^2} = 3.38 \times 10^5\ N/C$

Force: $F = qE = 1.5 \times 10^{-6} \times 3.38 \times 10^5 = 0.51\ N$

Electric dipole

- A pair of positive and negative charges together form an electric dipole

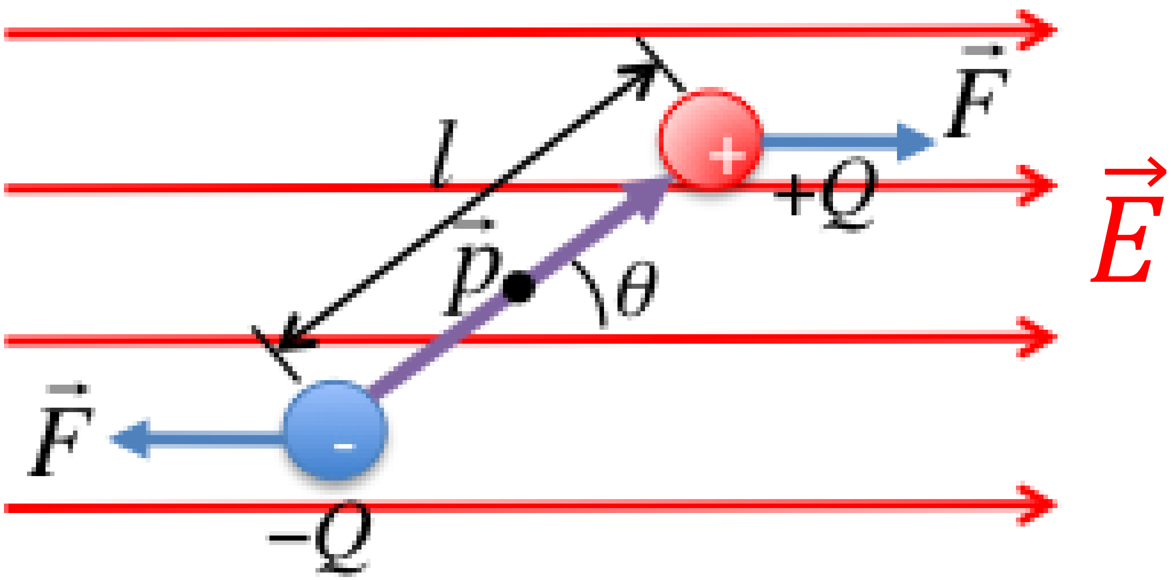




- An example in nature is the water molecule H_20

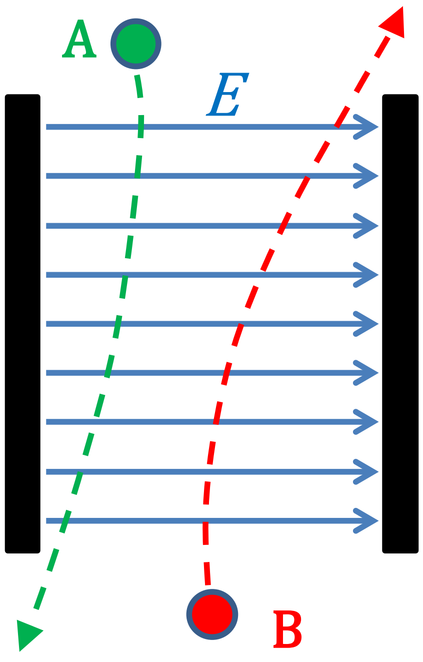
Electric dipole

- A dipole in an electric field will feel a torque but no net force

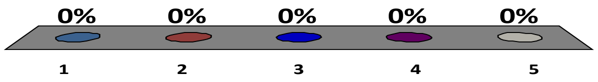


$$|\tau| = Fl\sin\theta = EQl\sin\theta \qquad \vec{\tau} = \vec{E} \times \vec{p}$$

Two particles move into the region between charged parallel plates, moving as shown in the diagram. Which of the following combinations is possible?

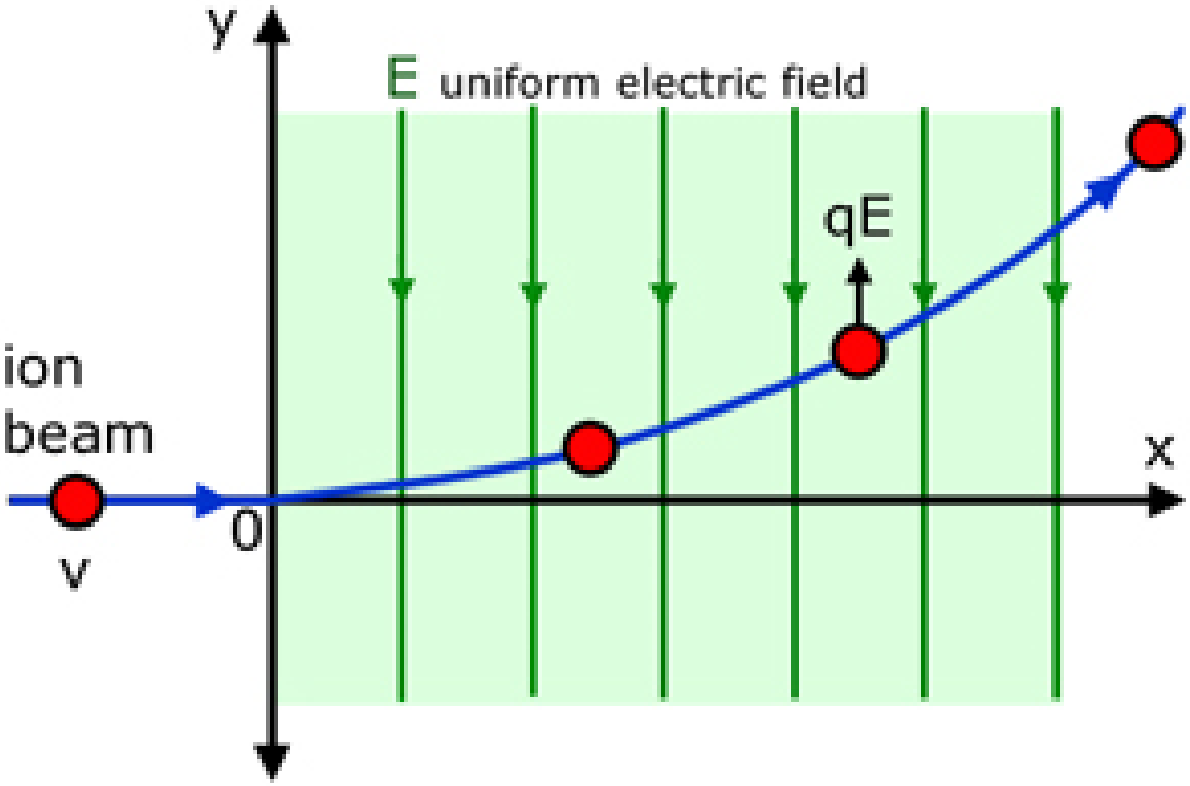


1. **A and B are both electrons**
2. **A and B are both protons**
3. **A is a proton, B an electron**
4. **A is an electron, B a proton**
5. **No way to determine**



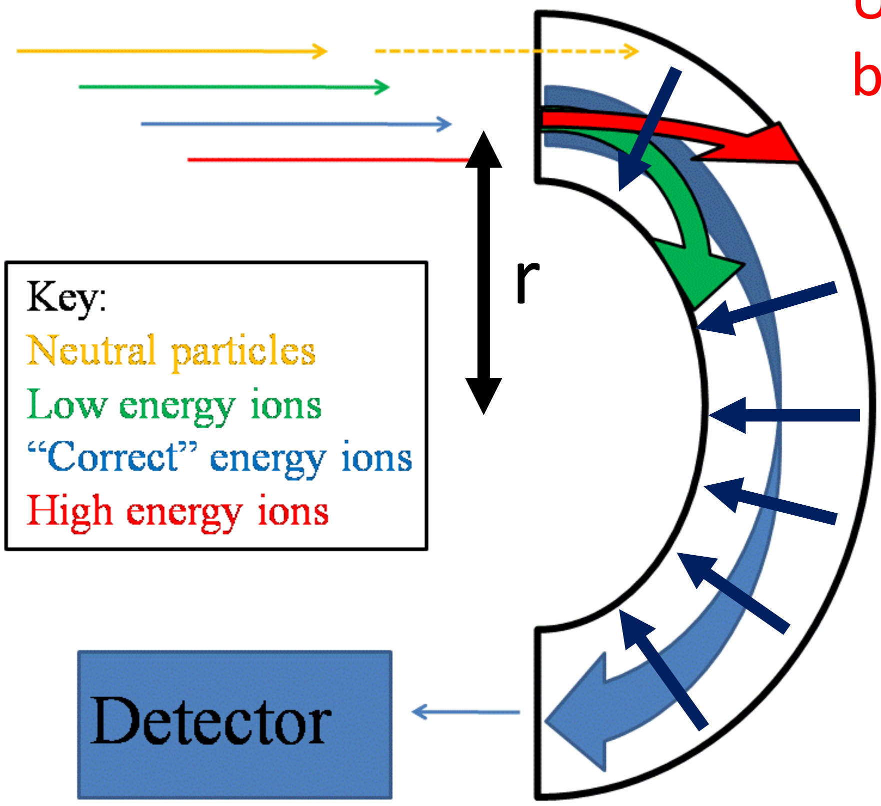
Electrostatic analyzer

- Charged particles will experience a force in an electric field F=qE, hence acceleration a=F/m=qE/m



Electrostatic analyzer

- An electrostatic analyzer selects velocities



Uniform electric field E applied between curved surfaces

Acceleration a is given by:

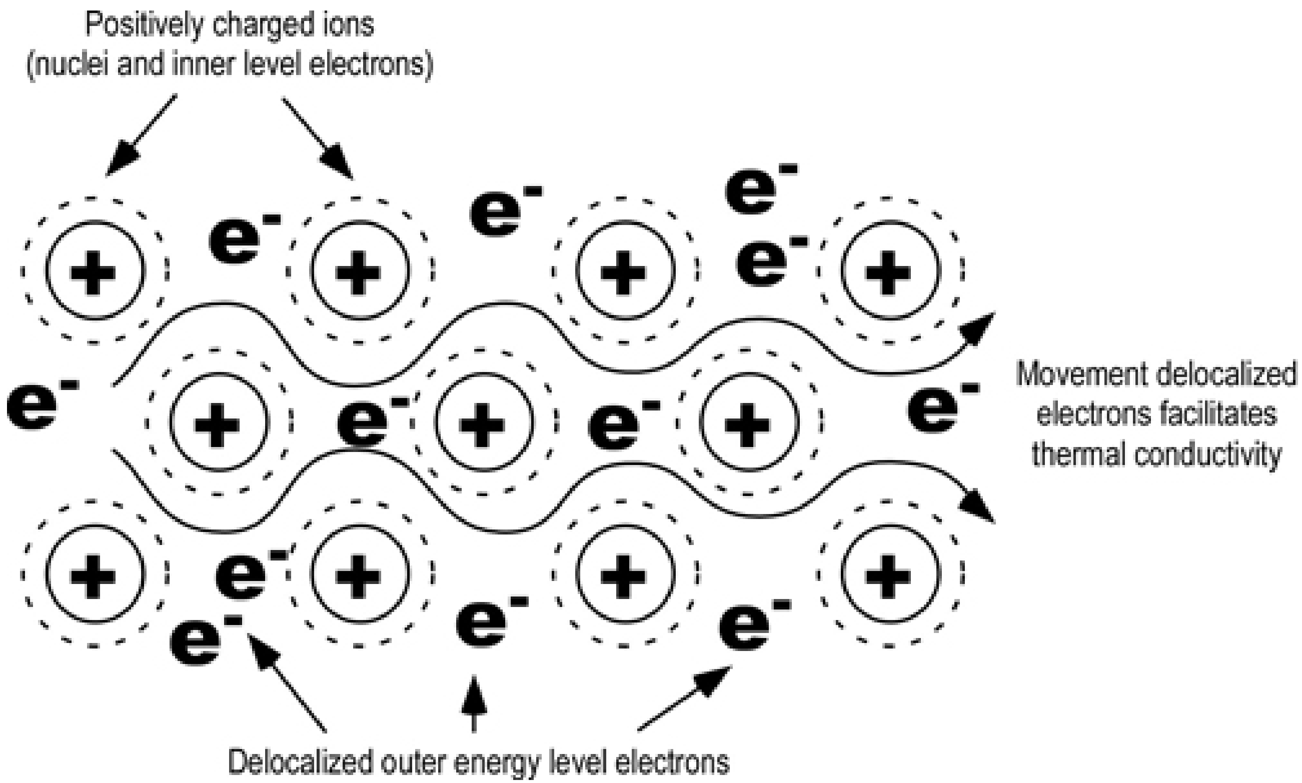
$$a = \frac{F}{m} = \frac{qE}{m}$$

$$a = \frac{v^2}{r}$$

$$\frac{v^2}{r} = \frac{qE}{m} \rightarrow v = \sqrt{\frac{qEr}{m}}$$

Conductors and Insulators

- In metals (e.g. copper, iron) some electrons are weakly held and can move freely through the metal, creating an electric current. Metals are good conductors of electricity.



Conductors and Insulators

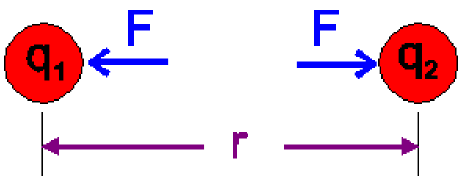
- In metals (e.g. copper, iron) some electrons are weakly held and can move freely through the metal, creating an electric current. Metals are good conductors of electricity.
- In non-metals (e.g. glass, rubber, plastic) electrons are strongly held and are not free to move. Non-metals are poor conductors of electricity, or insulators.
- Semi-conductors (e.g. germanium, silicon) are half-way between conductors and insulators.

Freely moving electrons make **metals** good conductors of **electricity** and **heat**

Chapter 20 : Summary

- Matter is made up of positive and negative charges. Electrons/protons carry the elementary charge 1.6 x 10^{-19} C

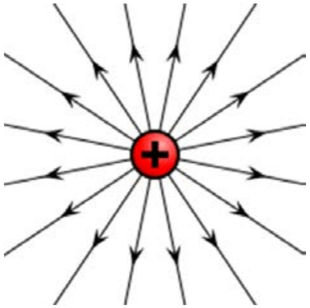
- Forces between charges are described by Coulomb's Law

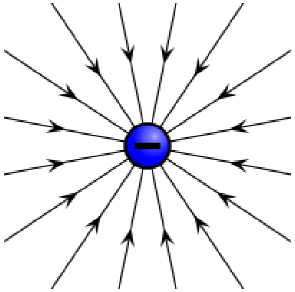


$$F = \frac{k\, q_1\, q_2}{r^2} \qquad k = 9 \times 10^9\ N\, m^2\, C^{-2}$$

- Forces from multiple charges sum as vectors

- Electric field describes the force-field around charges





$$\vec{E} = \frac{\vec{F}}{q} \qquad \vec{F} = q\, \vec{E}$$