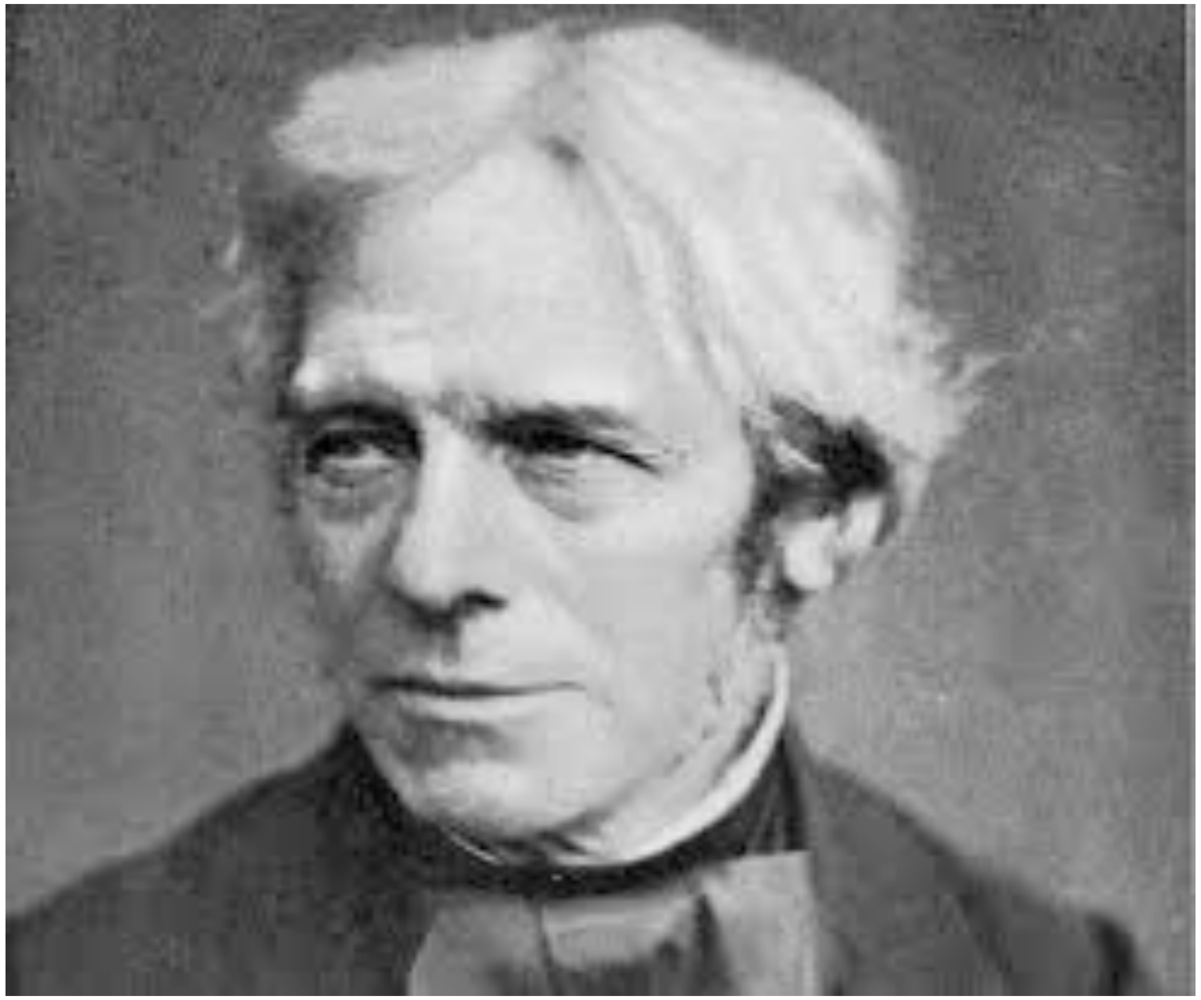
“Science is not for the very bright.

It is for the hard working!”

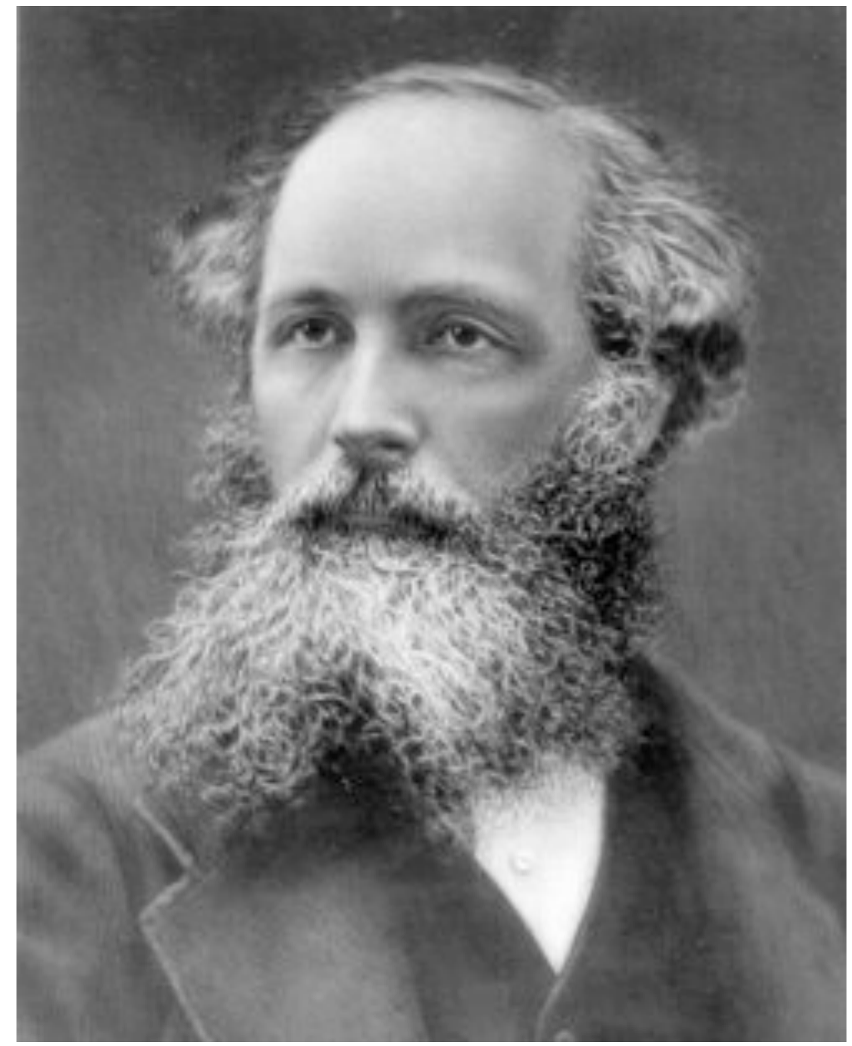
Nomzando, teacher in Khayalitsha



Michael Faraday

Young man
(portrait)

Old man
(photograph)



James Clerk Maxwell (1831 – 1879)

1. Frictional forces, such as rubbing, add something we choose to call *charge* to an object or remove it from an object. More vigorous rubbing produces a larger quantity of charge.

2. There are two kinds of forces, attractive and repulsive, hence we say that there are two kinds of charge which we call (for convenience) positive and negative.

3. Two objects with *like charge* (positive/positive or negative/negative) exert repulsive forces on each other. Two objects with *opposite charge* (positive/negative) exert attractive forces on each other. We call these electrical forces

4. The force between two charged objects is a long-range force. The magnitude of the force increases as the quantity of charge increases and decreases as the distance between the charges increases.

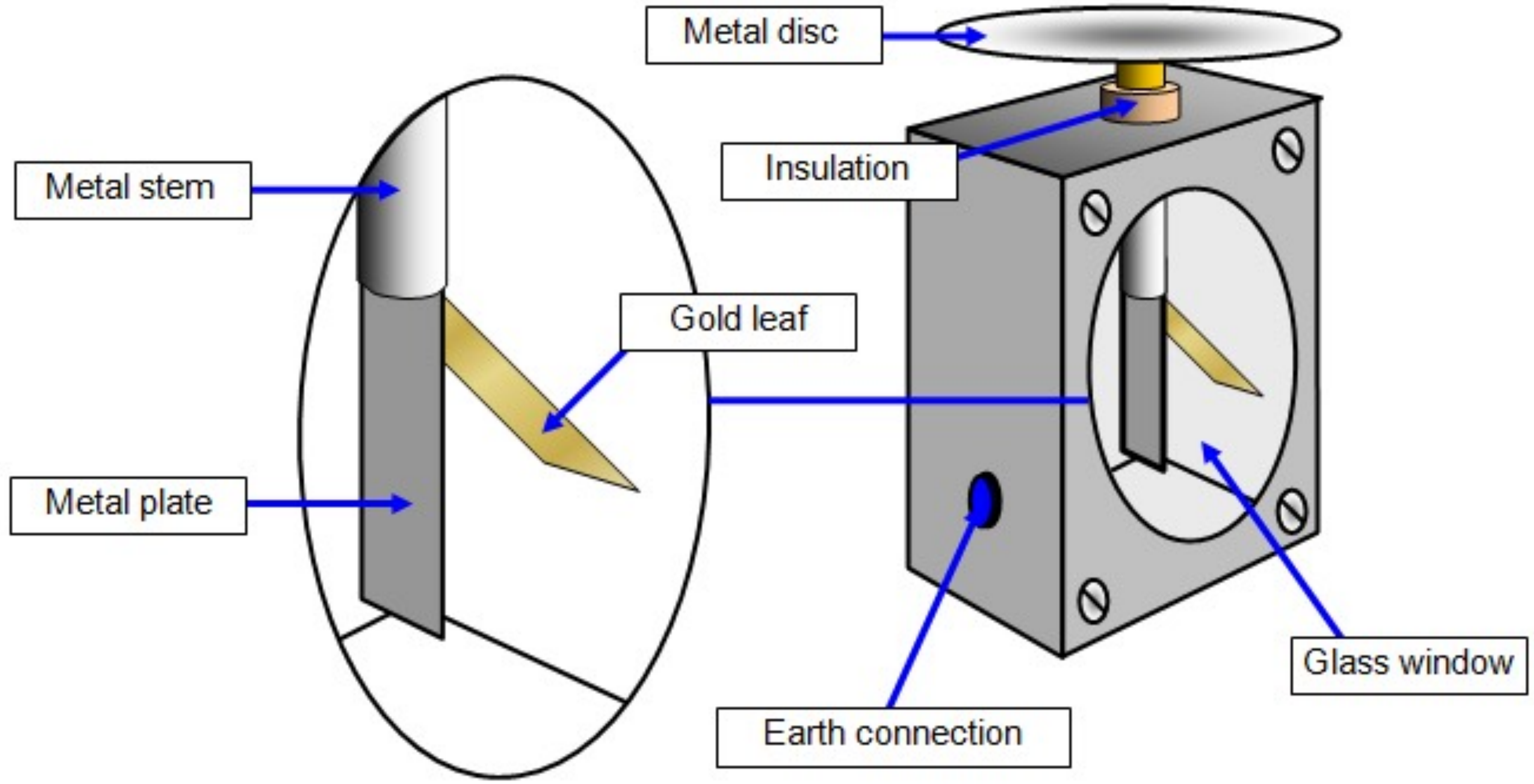
5. *Neutral* objects have an *equal mixture* of positive and negative charge.

6. The rubbing process charges the objects by *transferring* charge (usually negative) from one to the other. The objects acquire equal but opposite charges.

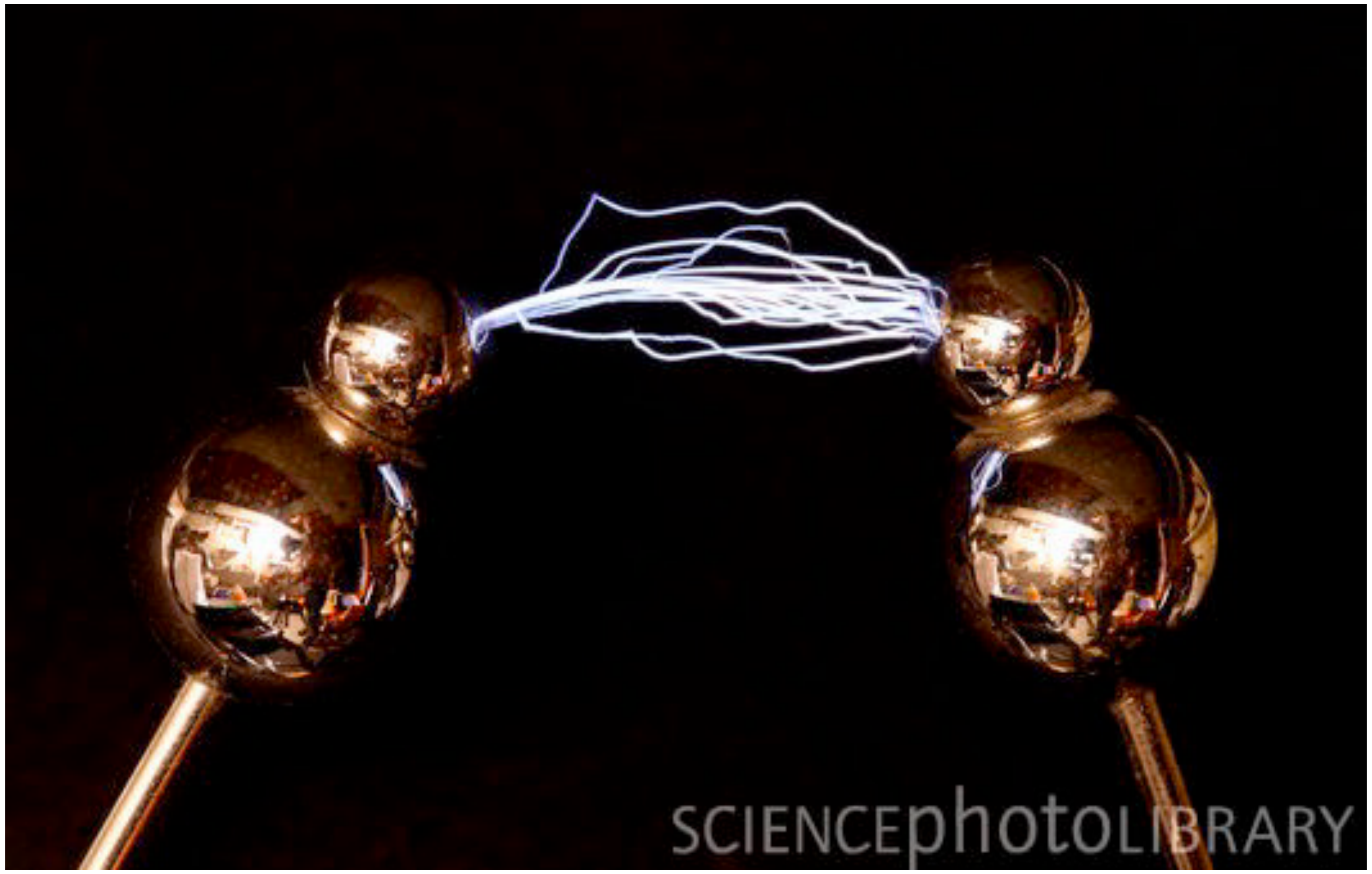
7. Charge is conserved: It cannot be created or destroyed.

Attractive electrical forces were discovered in ancient times. But repulsive electrical forces were not discovered until the 18th century, just some 300 years ago. So we know there are two different types of electrical charge.

Suppose there were a third type of charge. How would you test for it?


Metal disc
Insulation
Metal stem
Gold leaf
Metal plate
Glass window
Earth connection

Wimshurst Machine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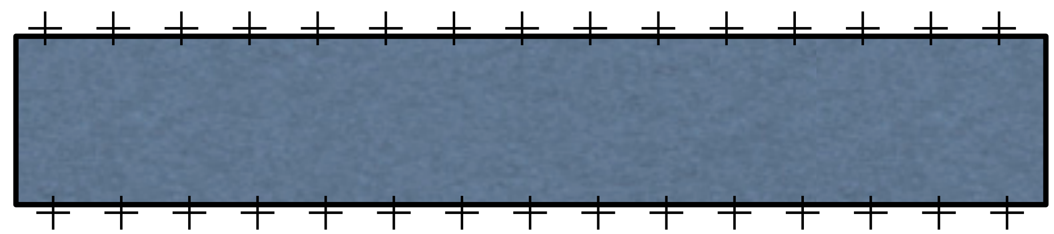
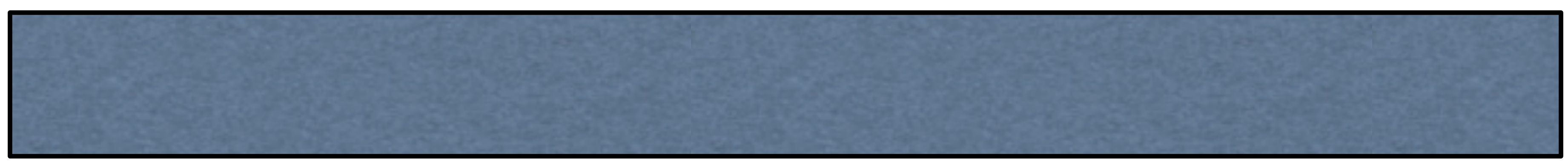
The definition of positive and negative for charges is a purely arbitrary one. The world would not be different if all electrons were positive and all protons negative.

Only electrons, negative particles, can physically move from one object to another. If the are *added* to an object, that object becomes *negatively* charged. If they *leave* an object, that object becomes *positively* charged. Protons do not move from one object to another. Atoms which have an extra electron are called ***negative ions***. Atoms which have lost an electron are called ***positive ions***.

Positively Charged Insulating Rod



Uncharged Metal Rod



How many forces act on the uncharged metal rod?

A) None

B) An attractive force

C) A repulsive force

D) Both an attractive and a repulsive force.

We can charge insulator materials, plastics, amber, glass, wool, silk, etc by rubbing. But that does not work with conductors. Can we charge conductors and, if so, how?

And if we touch conductors, do they share charge?

Two lightweight electrically neutral conducting balls hang from threads and are close to one another (but not touching). Answer the following questions using the choices below the questions.

a) Both balls are touched by a negatively charged rod.
b) Ball 1 is touched by a negatively charged rod and ball 2 by a positively charged rod.
c) Both are touched by a negatively charged rod but ball 2 has more charge placed on it.
d) Only ball 1 is touched by a negatively charged rod.

A) They do not attract or repel on another.
B) The repel by equal amounts.
C) They attract by equal amounts.
D) None of the above is true.

Ions are atoms or molecules which have gained or lost electrons in some process. In liquids and gases, but not in solids, both positively and negatively charged ions may migrate from one liquid or gas to another.

The number of molecules of water is a glass of water is GREATER than the number of glasses of water in ALL OF THE OCEANS AND LAKES ON EARTH.

Answer each of the following questions with **A** for **True** and **B** for **False.**

a) Electrons are negative particles.

b) Areas which are positively charged are caused by the movement of protons.

c) Negatively charged areas occur because electrons are attracted to each other.

A hollow metal sphere is electrically neutral (no excess charge). A small amount of negative charge is suddenly placed at one point P on the surface of the metal sphere. If we check on this excess negative charge a few seconds later we will find one of the following possibilities:

A. All of the excess charge remains right around P.

B. The excess charge has distributed itself evenly over the outside surface of the sphere.

C. The excess charge is evenly distributed over the inside and outside surface.

D. Most of the charge is still at point P, but some will have spread over the sphere.

E. There will be no excess charge left.

A hollow sphere made out of electrically insulating material is electrically neutral (no excess charge). A small amount of negative charge is suddenly placed at one point P on the outside surface of this sphere. If we check on this excess negative charge a few seconds later we will find one of the following possibilities:

A. All of the excess charge remains right around P.

B. The excess charge has distributed itself evenly over the outside surface of the sphere.

C. The excess charge is evenly distributed over the inside and outside surface.

D. Most of the charge is still at point P, but some will have spread over the sphere.

E. There will be no excess charge left.

$$F = k\frac{q_1 q_2}{r^2}$$

Coulomb's Law

Coulomb's Law is true **ONLY** for point charges or charges so tiny they may be thought of as a point. NOT TRUE for objects with different shapes.

$$k = \frac{1}{4\pi\varepsilon_o}$$

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

Coulomb's Law

$$\frac{1}{4\pi\varepsilon_0} = 9x10^9$$

$$\varepsilon_0 = 8.85x10^{-12}$$

We use the symbol q (sometimes Q) for charge. It is measured in units called Coulombs in honour of M. Coulomb and the symbol for the charge unit is C. It has not occurred before the introduction of electricity. It is a fundamental unit and extends the list of fundamental units to Four. They are the metre, the second, the kilogram, and the coulomb. They measure distance, time, mass, and electrical charge. Every other unit in science, the Newton, the Joule, the Watt, etc are all names given to combinations of these four basic units.

So far as we know, distance, time, and mass are all continuous units, that is, we can have any size of these. But we already know that electrical charge is quantised, which means that there are “chunks” of charge and nothing smaller that that. The smallest unit of charge is that on the electron and on the proton, although with different signs of course. That value is 1.6×10^{-19} Coulombs. This is a very small number but ALL charge in the universe is an integer number of this value. In macroscopic cases, that integer is a very big number but on the atomic scale it is always, 1, 2, 3, 4, etc. For atoms we call this number the Atomic Number.

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Two tiny objects have equal charges, call them $q_1 = q_2$.
One of them has a mass of 6.3×10^{-7} kg but we do not know the mass of the other one.
They are separated by 3.2 mm and they move apart under the electric force, which is repulsive.
Their initial accelerations are measured and prove to be $7\ m/s^2$ for the known mass but $9\ m/s^2$ for the unknown mass.
Calculate the unknown mass and the value of the equal charges.

Answer: $m_2 = 4.9 \times 10^{-7}$ kg; q = 71pC

Two small objects each with a net charge of +Q exert a force of magnitude F on each other.

We replace one of the objects with another whose net charge is +4Q:

The original magnitude of the force on the +Q charge was F; what is the magnitude of the force on the +Q now?

A) 16F B) 4F C) F D) F/4 E) other

For the exact same arrangement, what is now the force on the +4Q charge?

A) 16 F

B) 4F

C) F

D) F/4

E) other

Now we move the two charges a distance 3 times farther apart.

+Q +4Q

Now what is the magnitude of the force on the +4Q charge?

A) F/9
B) F/3
C) 4F/9
D) 4F/3
E) other

Two protons are in a Helium nucleus. The charge on each is $q = 1.6 \times 10^{-19}$ C and the distance inside this nucleus is just 2.6×10^{-15} m. They are very close as the nucleus is very small. What is the force between them? Given their mass is $m = 1.67 \times 10^{-27}$ kg, what acceleration will they have as they are pushed apart? How long will it take for them to reach the speed of light which is 3×10^{8} m/s?

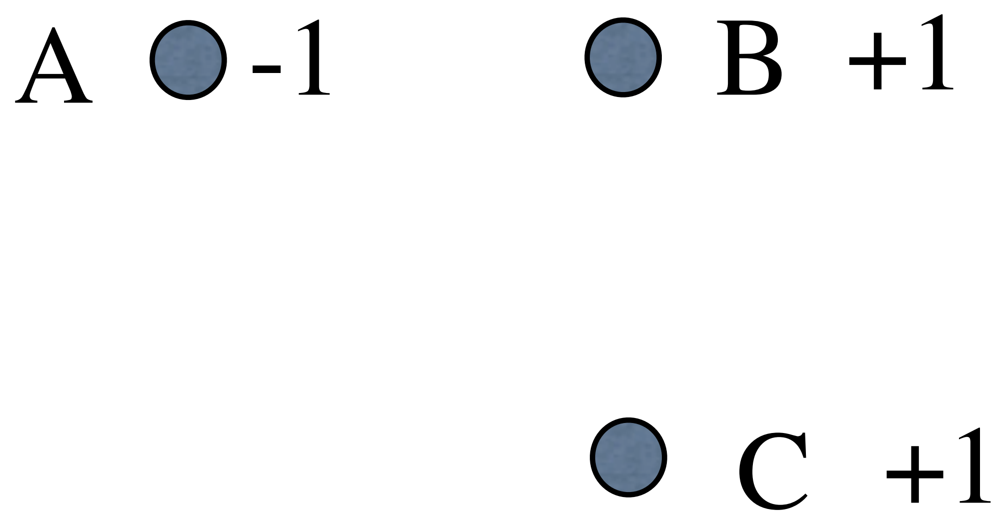
Answers: $F = 34.$ N ; $a = 2.04 \times 10^{28}$ m/s^2 ; $t = 1.5 \times 10^{-20}$ s

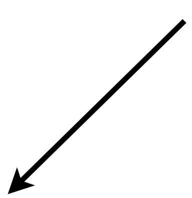
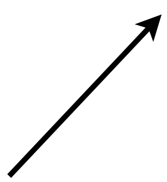
Ridiculous values for a and t as one needs Special Relativity for such a problems.

Ah, Vectors!

Forces exist in Nature and they have a magnitude (a size) but also a direction. Thus they are Vector quantities. Everything you learned about Newton's Laws and motion due to mechanical forces ALSO applies to motion under Electrical forces. A Force is a Force, no matter where it comes from, a mechanical push or pull, or an electrical or magnetic push or pull

Which of the arrows is in the direction of the net force on charge B?



A)  B)  C)  D)  E) none of these

Two identical insulated conductors are charged so that one has a charge of $-6\mu C$ and the other a charge of $12\mu C$. They experience a force of **F** N when placed a distance **d** m apart. They are now briefly brought into contact with each other and returned to their original positions. The force they experience now is:

A) 9**F**/8
B) **F**
C) **F**/4
D) **F**/8

In the model of the hydrogen atom created by Niels Bohr, we imagine the electron revolving in an orbit about the proton in the same way that the Earth rotates about the Sun. The charges on the proton and electron have the same magnitude (opposite signs of course), that is $e = 1.6 \times 10^{-19}$ C. The mass of the electron is $m = 9.11 \times 10^{-31}$kg. The electron is 5.1×10^{-11} m from the proton. Calculate the force on the electron, the acceleration, and the velocity of the electron in its orbit.

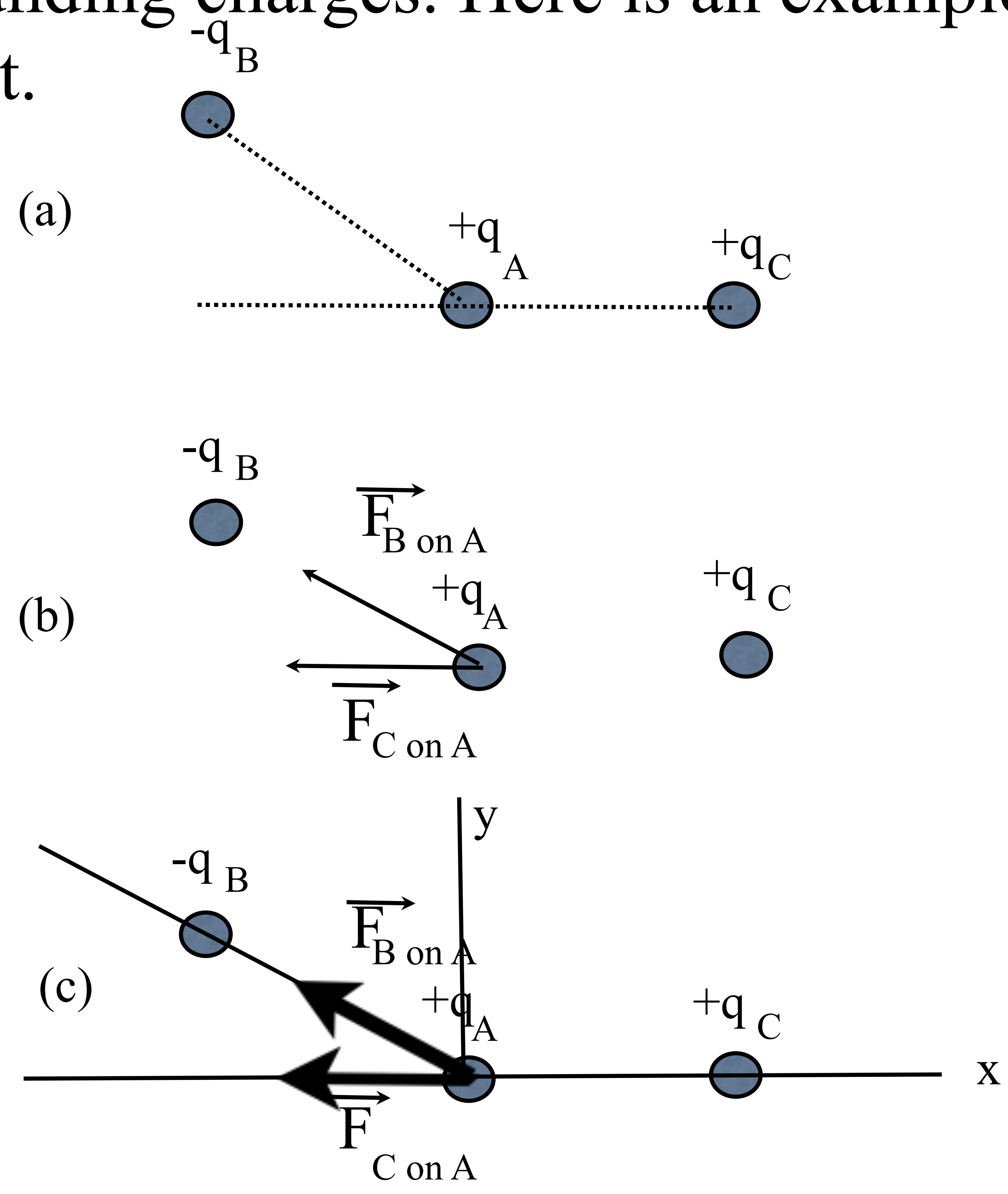
Answers: $F = 8.86 \times 10^{-8}$ N ; $a = 9.7 \times 10^{22}$ m/s^2 ; $v = 2.2 \times 10^6$ m/s

A hydrogen atom is composed of a nucleus containing a single proton, about which a single electron orbits. The electric force between the two particles is 2.3×10^{39} times greater than the gravitational force! If we can adjust the distance between the two particles, can we find a separation at which the electric and gravitational forces are equal?

1. Yes, we must move the particles farther apart.
2. Yes, we must move the particles closer together.
3. No, at any distance

Steps to Solving Problems using Coulomb's Law

1. Sketch the array of charged objects and draw arrows to represent the anticipated direction of forces on the charged object of interest due to the surrounding charges. Here is an example, where q_A is the charge of interest.



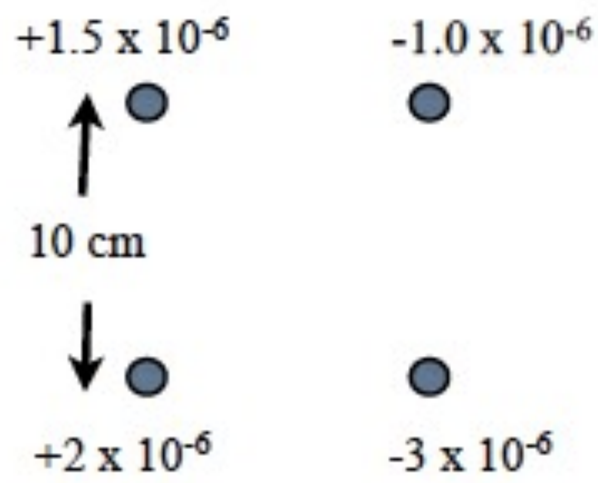
2. Use Coulomb's Law to calculate the *magnitudes* of the individual forces on the charged particle of interest.
3. Determine the directions of the forces and create a free-body diagram like that of part (b) in the slide above.
4. Choose a coordinate system and sketch it on your diagram as in part (c)
5. Calculate the perpendicular vector components of each force force along the coordinate directions using the expression $F_x = F \cos\theta$ and $F_y = F \sin\theta$ where F is the magnitude of the force on particle A.
6. Determine the signs (plus or minus) of these components based on their direction.
7. Combine all the force components that act along the same line. This is simple addition or subtraction.

8. Combine the resulting components to get the magnitude of the resultant force, using the expression

$$F_{net}^2 = F_x^2 + F_y^2$$

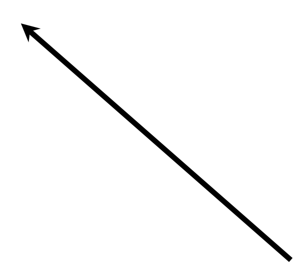
9. Determine the angle at which the force acts (relative to the positive x axis) using

$$\tan\theta = \frac{F_y}{F_x}$$



Four charges sit at the corners of a square which is 10 cm on a side. The charge at bottom left is $+2 \times 10^{-6}$ C, at the bottom right is -3×10^{-6} C, at the top left is 1.5×10^{-6} C and at the top right is -1×10^{-6} C. Calculate the force on the top right charge due to the other three.

Answer: 2.87 N at an angle of 46^{o} with the vertical

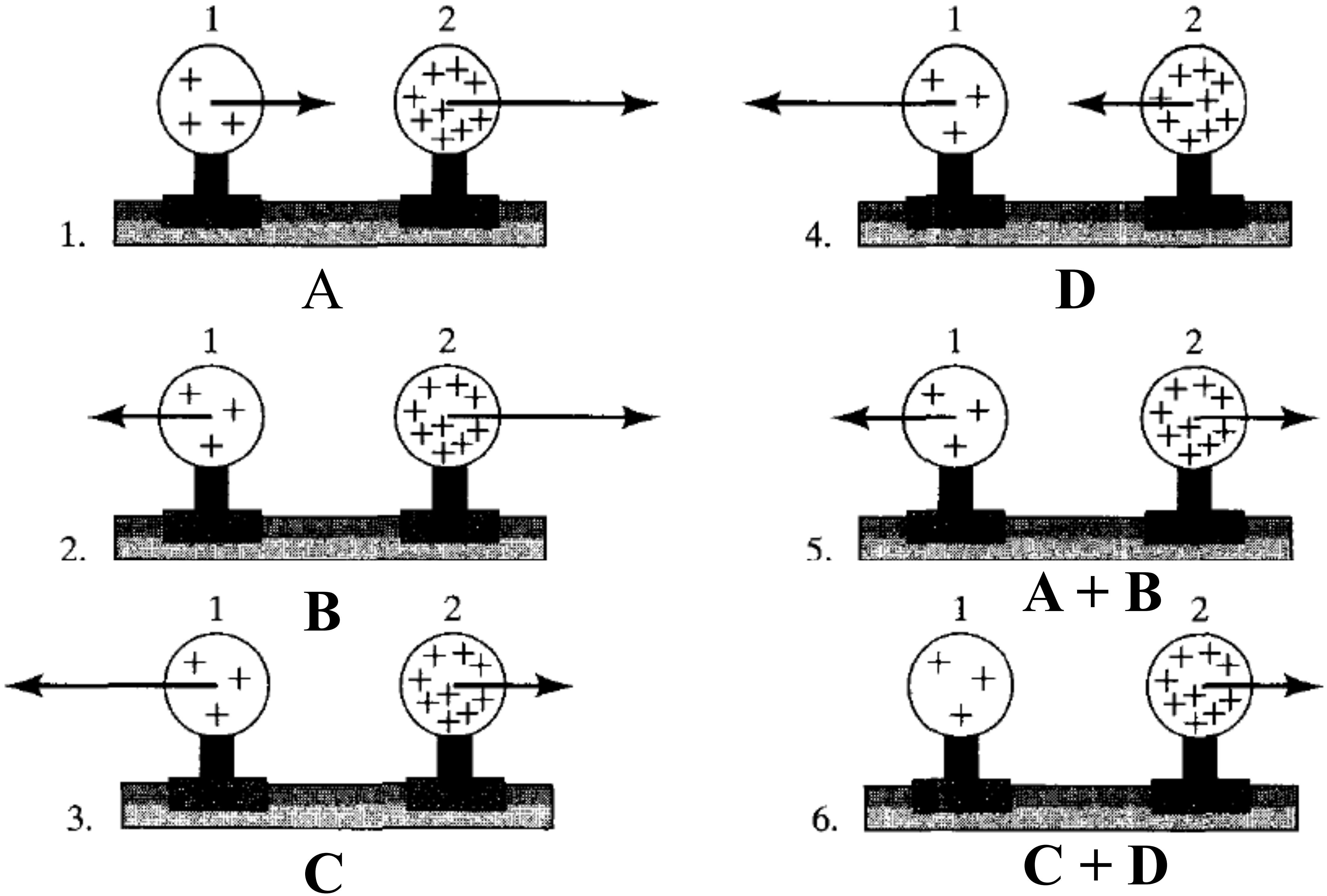


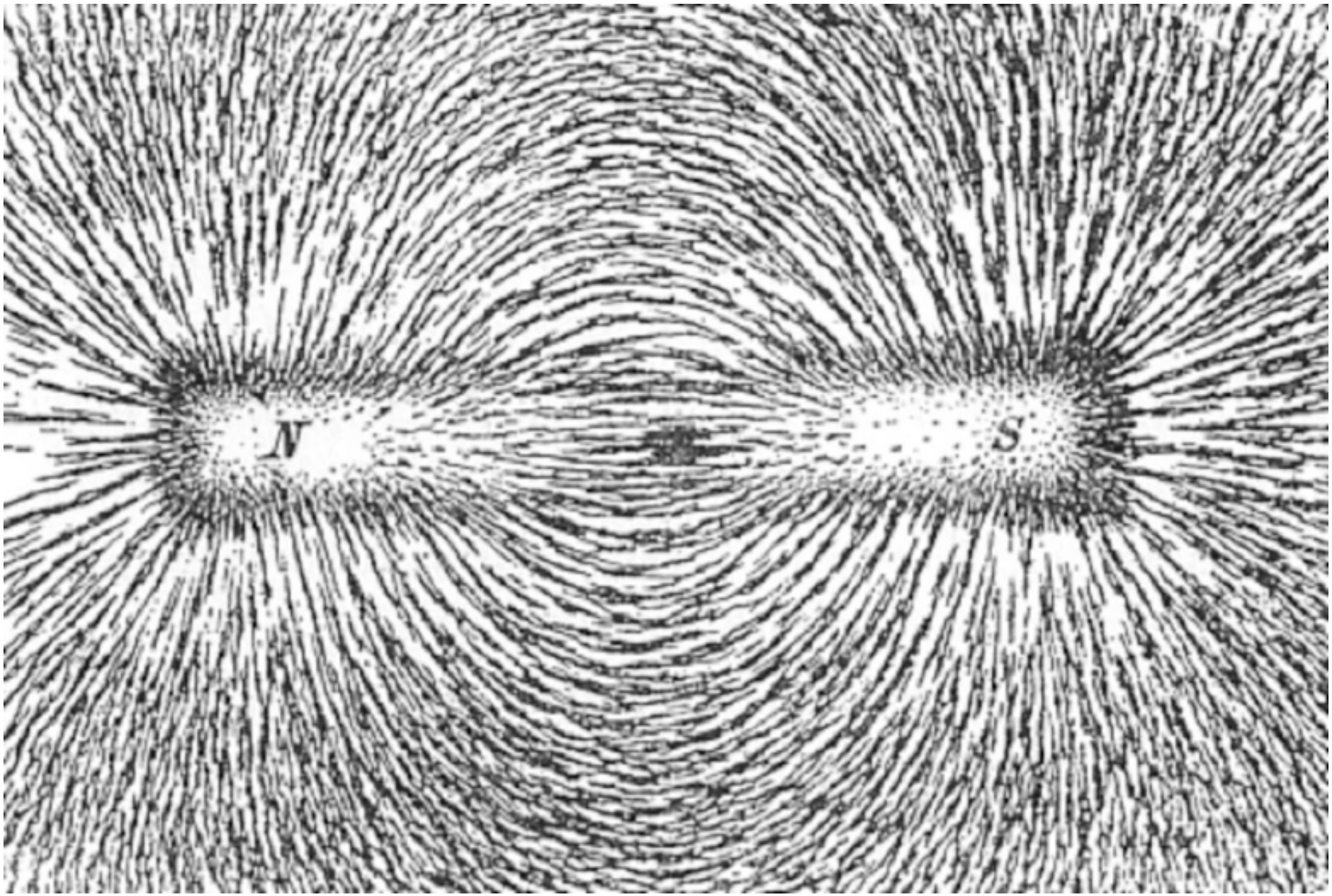
a) Two charges, each of 20 μC are a distance of 1.5 m apart. Calculate the force on one of them.

b) Now a third charge, of the same value is brought in and placed such that the three charges form an equilateral triangle. Calculate the force now.

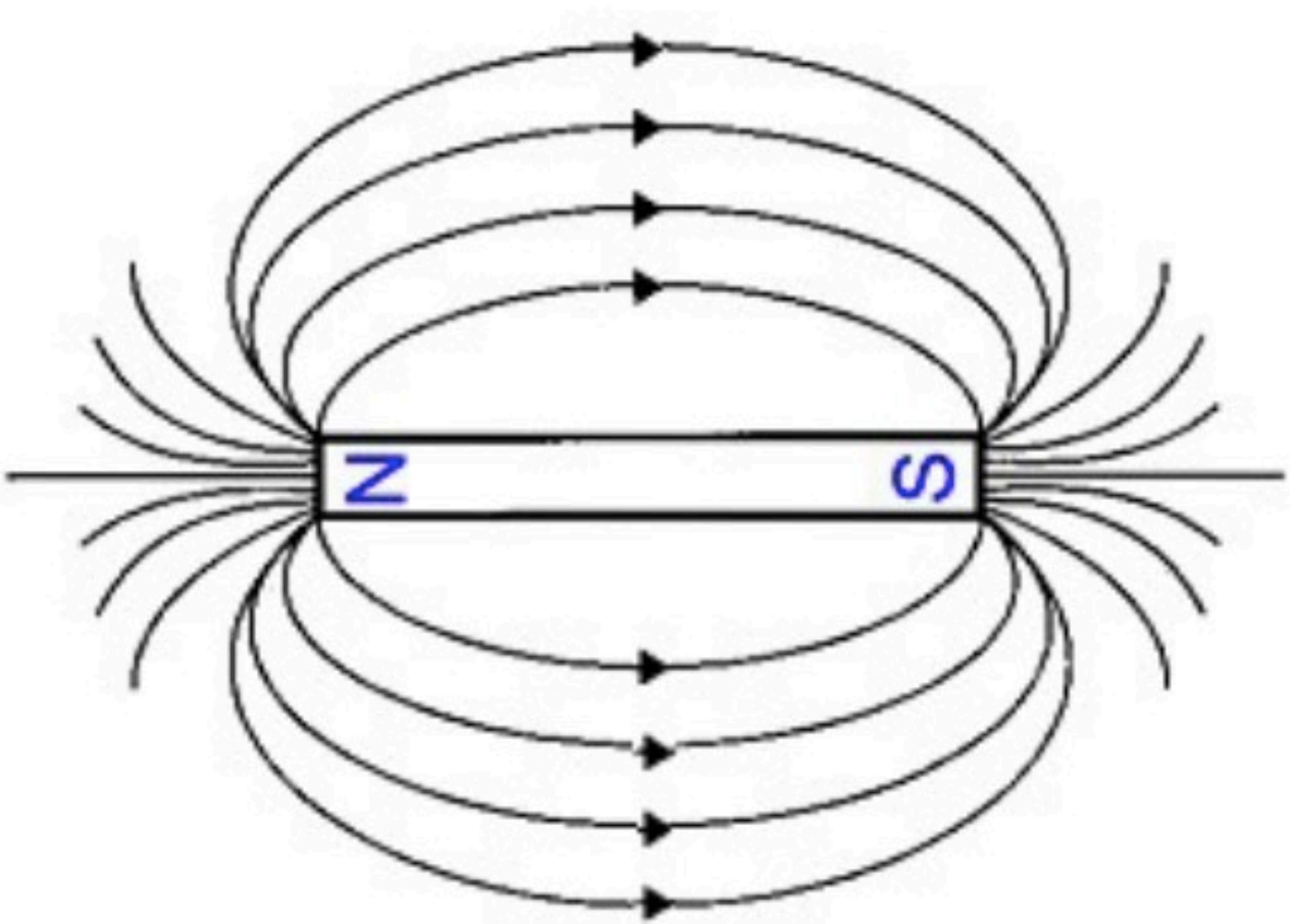
Answers a) 1.6 N b) 2.77 N

Two uniformly charged spheres are firmly fastened to and electrically insulated from frictionless pucks on an air table. The charge on sphere 2 is three times the charge on sphere 1. Which force diagram correctly shows the magnitude and direction of the electrostatic forces:

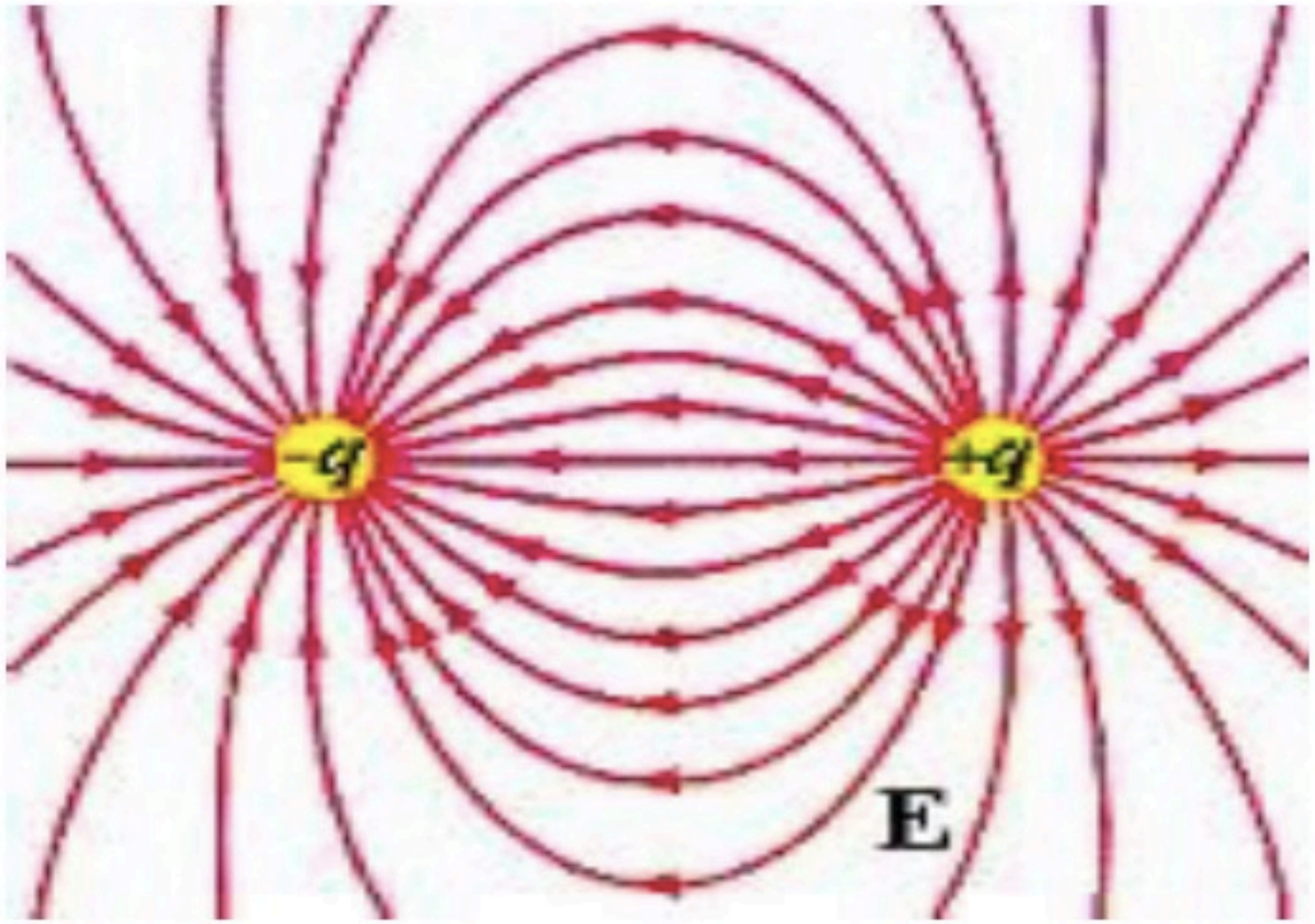




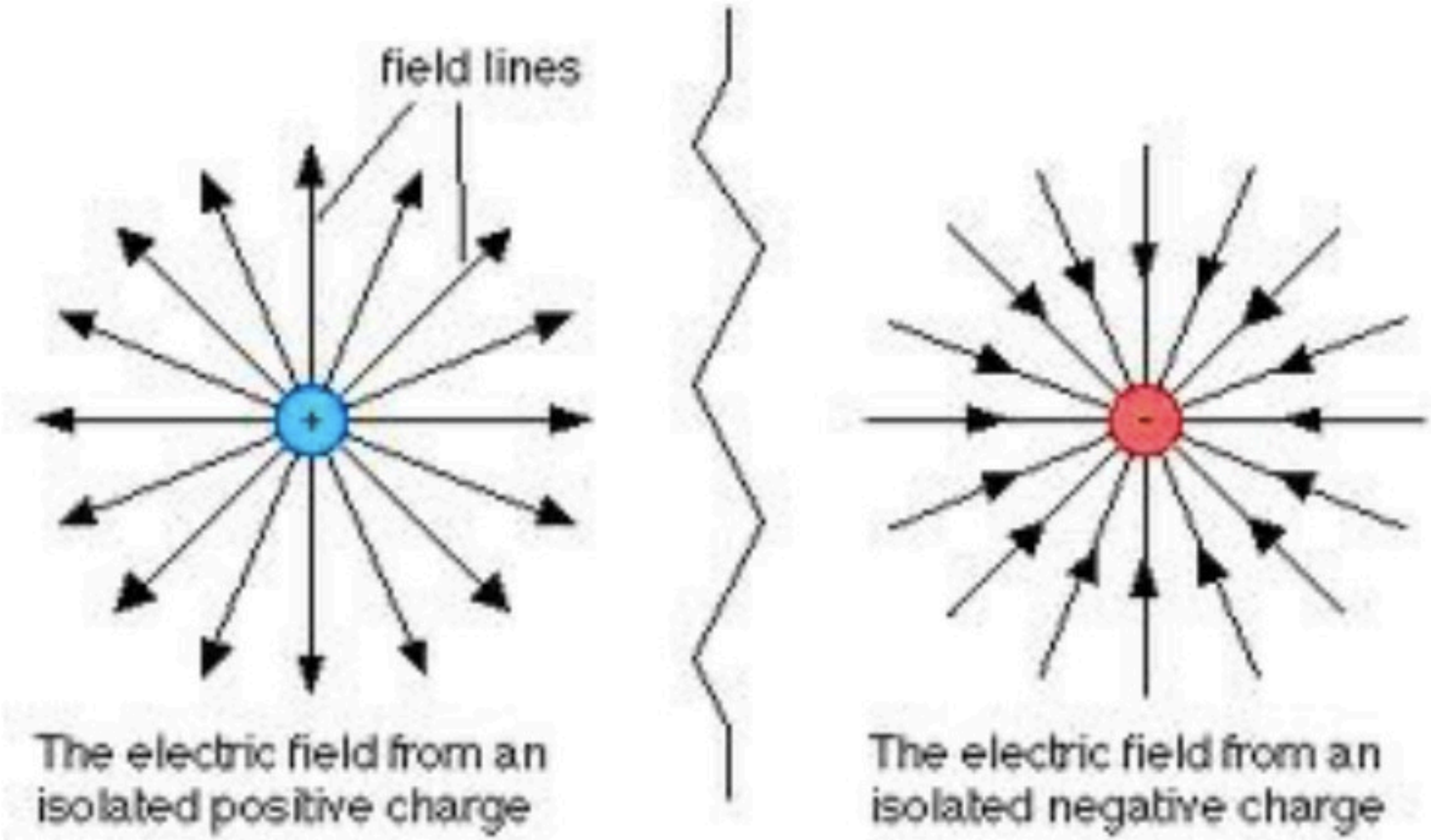
Bar magnet with iron filings



Bar magnet with schematic lines



Electric Charges analogous to the Bar Magnet


field lines
+
-
The electric field from an isolated positive charge
The electric field from an isolated negative charge

Question: How do we test for the presence or absence of an electric effect at some point in space?

Answer: We take a charged object, we could call it a probe, and see if there is a force on it at that point. If there is an electric effect, that is, if there are electric charges somewhere, then there will be a force on our charged object.

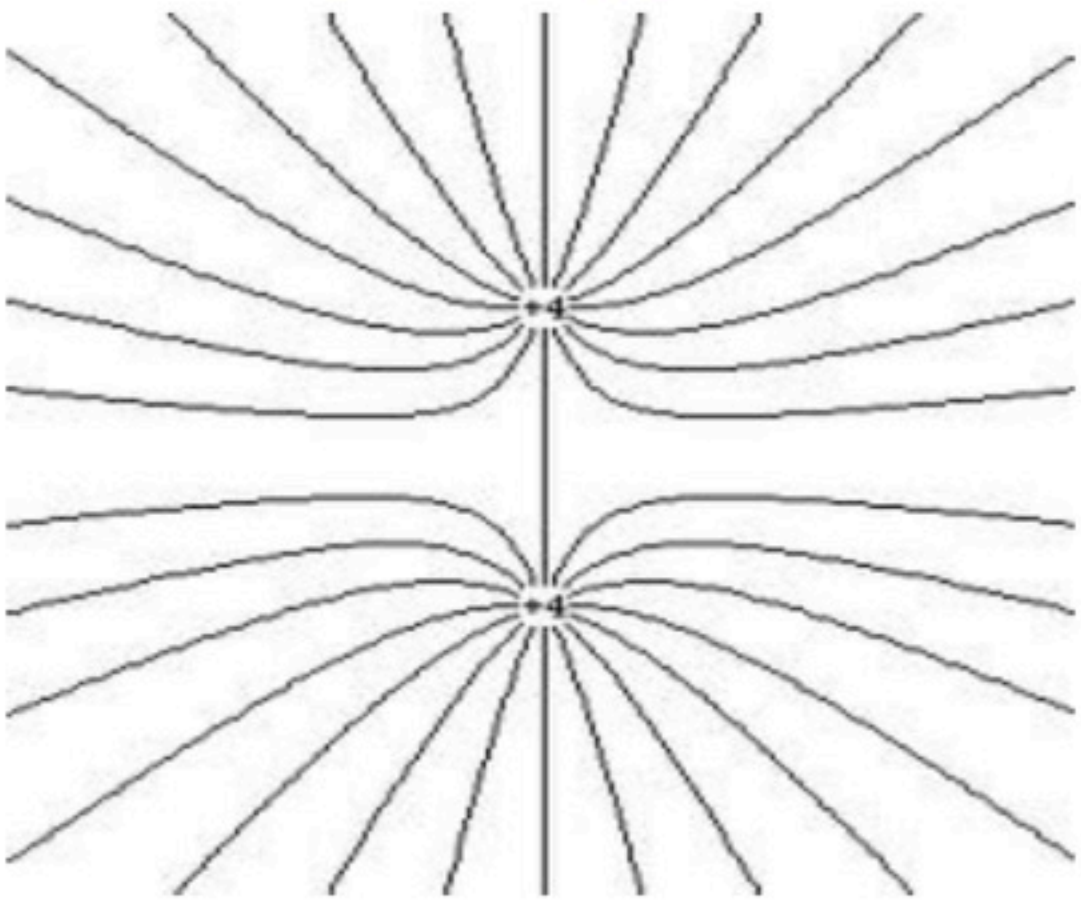
1. Use an object small enough that it does not affect the arrangement of whatever charges are creating the force.
2. As **Force** is a vector, there will both a magnitude and direction to the force on our charged probe.
3. The Force will depend on whatever charges exist in space AND the size of our probe.
4. Remove the involvement of the probe in the force by dividing the force by the charge on the probe.
5. Call the resultant vector the **Electric Field**!

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

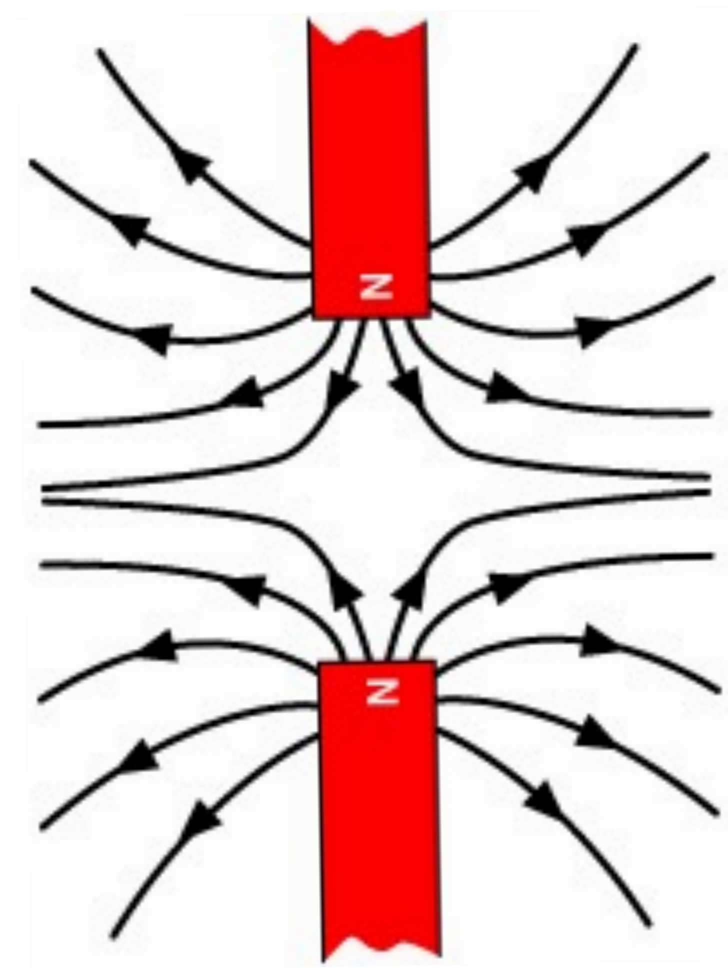
For a Point Charge creating the field, where we know the force from Coulomb's Law

$$E = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}$$

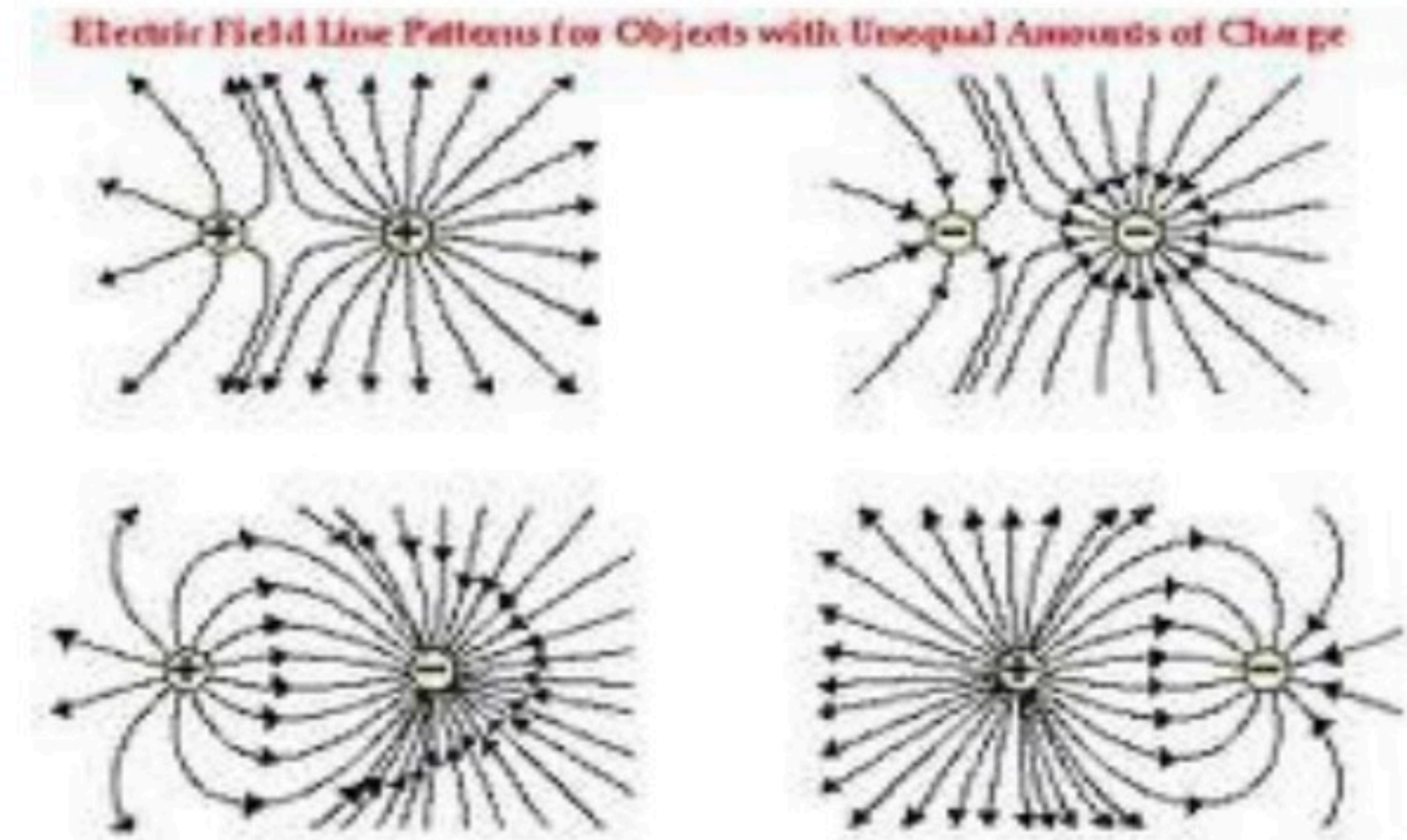
E fields point AWAY from positive charges and TOWARDS negative charges



Electric Field for Identical Like Charges



Magnetic field for like poles


Electric Field Line Patterns for Objects with Unequal Amounts of Charge
+
+
−
−
+
−
+
−

What is the magnitude of a point charge whose electric field 50 cm away has a magnitude of 2.0 N/C?

Answer: 56 pC or 56 x 10^{-12} C = 56 pC

A positive charge is placed at rest at the centre of a region of space in which there is a uniform, three-dimensional electric field. (A uniform field is one whose strength and direction are the same at all points within the region.)

When the positive charge is released from rest in the uniform electric field, what will its subsequent motion be?

A) It will move at a constant speed.

B) It will move at a constant velocity.

C) It will move at a constant acceleration.

D) It will move with a changing acceleration.

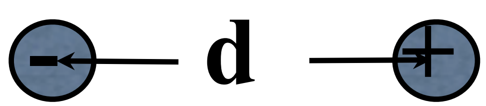
E) It will remain at rest in its initial position.

Two opposite charges of equal magnitude 2.0×10^{-7} C are held 15 cm apart. What are the magnitude and direction of the electric field E at the point midway between the charges?

Answer: 6.4×10^{5} N/C directed from + charge toward - charge.

What would the E field be if the two charges were of the same sign??

Many atoms are electrically symmetric, that is the electrons are arranged symmetrically about the nucleus at the centre of the atom. But some atoms and many molecules and ions are not so arranged. The electrons are not symmetric with respect to the nucleus. Instead of having a basic spherical shape, they are ellipsoidal or shapes even more complicated. The most common case is the dipole.



A dipole then is a neutral object with two equal and opposite charges, but separated by some distance ***d***. Such an object can experience forces in external electric fields. Such forces are often what holds molecules together. But they can also experience torques, the word we use for turning effects.

Torque equals force times distance x sine of the angle between them. In equation form then, using the Greek T (or tau) for Torque we have

$\tau = F\ r \sin \theta$

Force and distance are both vectors and we are multiplying two vector quantities. You learned to do this in mechanics to get the physical quantity called Work (W). Except that Work involved the COSINE of the angle rather than the SINE.

Therefore, multiplying vectors is not the same as multiplying numbers (called scalars in maths, not scalers as would be for something that counts or climbs mountains). We can have $A\ B \cos \theta$ or $A\ B \sin \theta$. To separate them we use two different symbols for multiplication as follows

$$\tau = Fr\sin\theta = qEd\sin\theta$$

$$qd = p$$

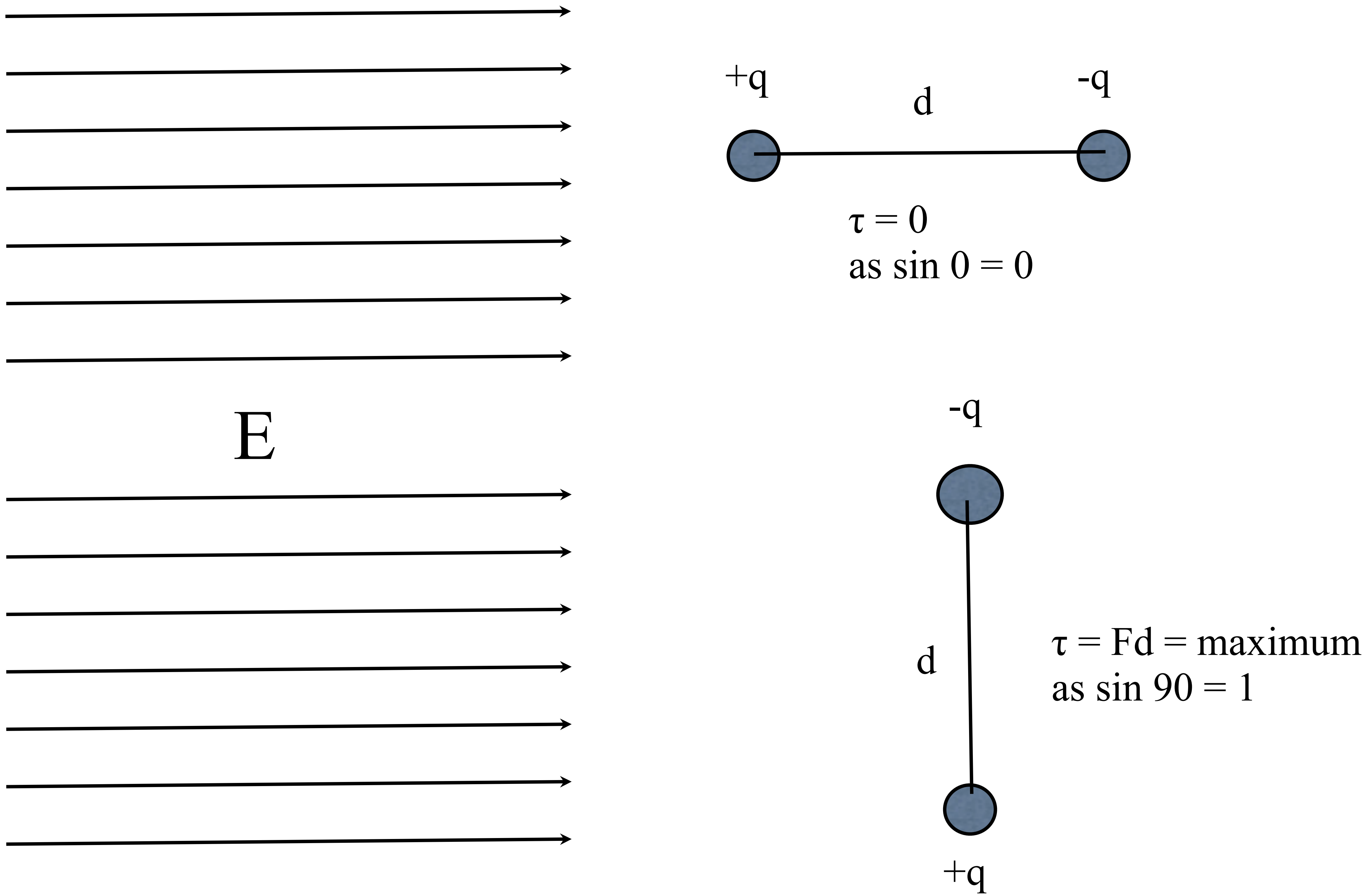
$$\therefore \tau = Ep\sin\theta$$

In this case, the variable d is the distance between the two charges. If I multiply this distance (metres) by the value of either charge (they are identical) I get a quantity called the **Dipole Moment** and the symbol is p. It is measured in Coulombs times Metres. In atomic systems, it is a very small number.

$$W = Fr\cos\theta = \vec{F} \bullet \vec{r}$$

$$W = Fr\sin\theta = \vec{F} \times \vec{r}$$

These are called
Dot Product and
Cross Product
respectively


+q
d
-q
τ = 0
as sin 0 = 0
E
-q
d
τ = Fd = maximum
as sin 90 = 1
+q

An electric dipole consists of charges of +2e and -2e where e = fundamental charge on an electron or proton and is equal to 1.6×10^{-19} Coulombs. The charges are separated by a distance of 0.78 nm. It is in an electric field of strength $E = 3.4 \times 10^{6}$ N/C. Calculate the magnitude of the torques when the dipole moment is a) parallel to the field, b) perpendicular to the field, and c) antiparallel to the field.

Answer: b) 8.5×10^{-22} N-m

An electric dipole has a dipole moment

$$\mathbf{p} = (3.00\mathbf{i} + 4.00\mathbf{j})(1.24 \times 10^{-30})\ \text{C-m}$$

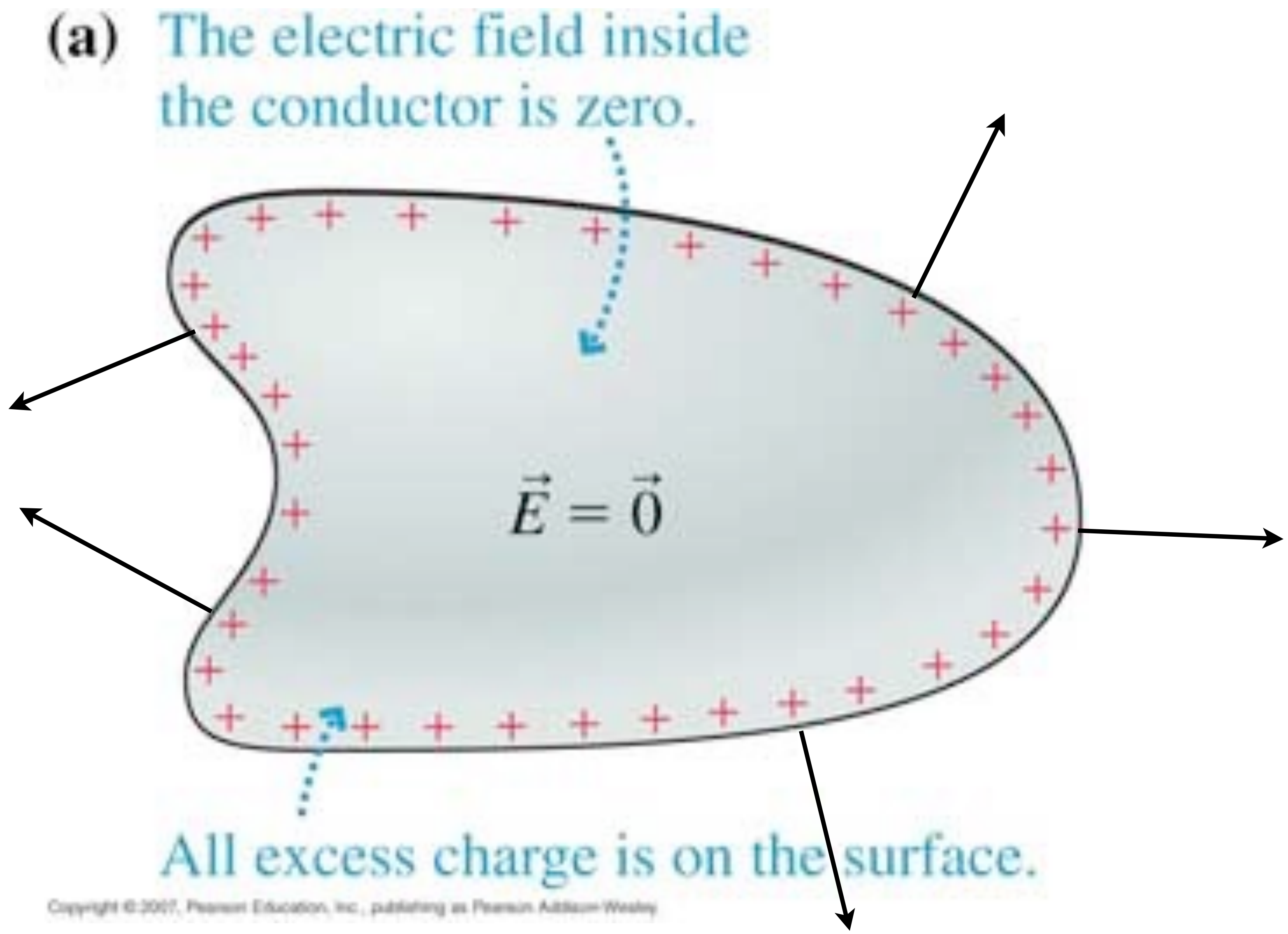
It sits in an electric field

$$\mathbf{E} = (4000\ \text{N/C})\ \mathbf{i}$$

What is the torque acting on it?

Answer: $-1.98 \times 10^{-26}\ \mathbf{k}$ N-m

Yet another, not so easy fact, is that *Torque* is also a vector. Its direction is always perpendicular to the plane formed by the Electric field and the separation distance. Thus, it is perpendicular to the plane of rotation.

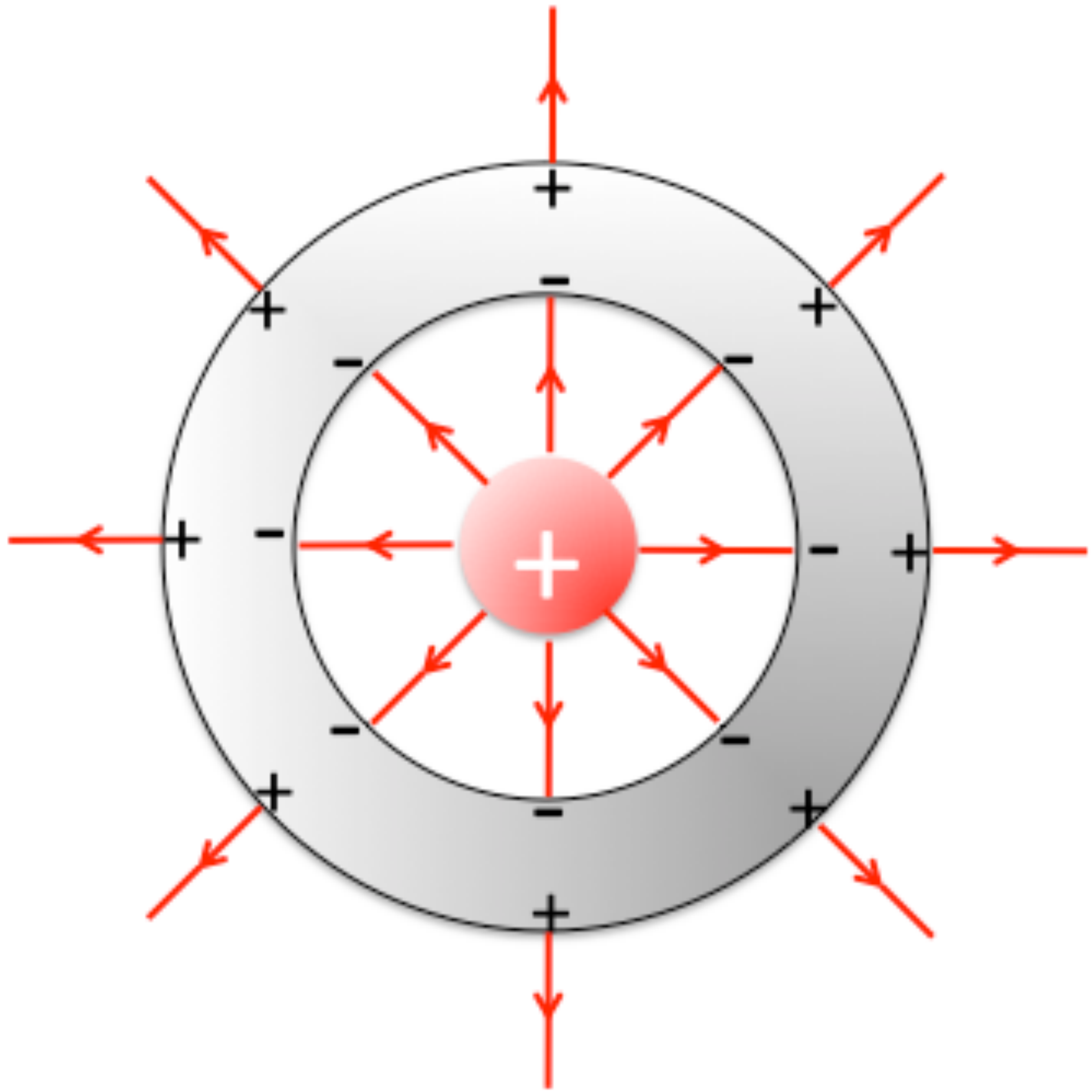


A Charged Conductor

The Electric Field due to this arrangement must be perpendicular to the surface

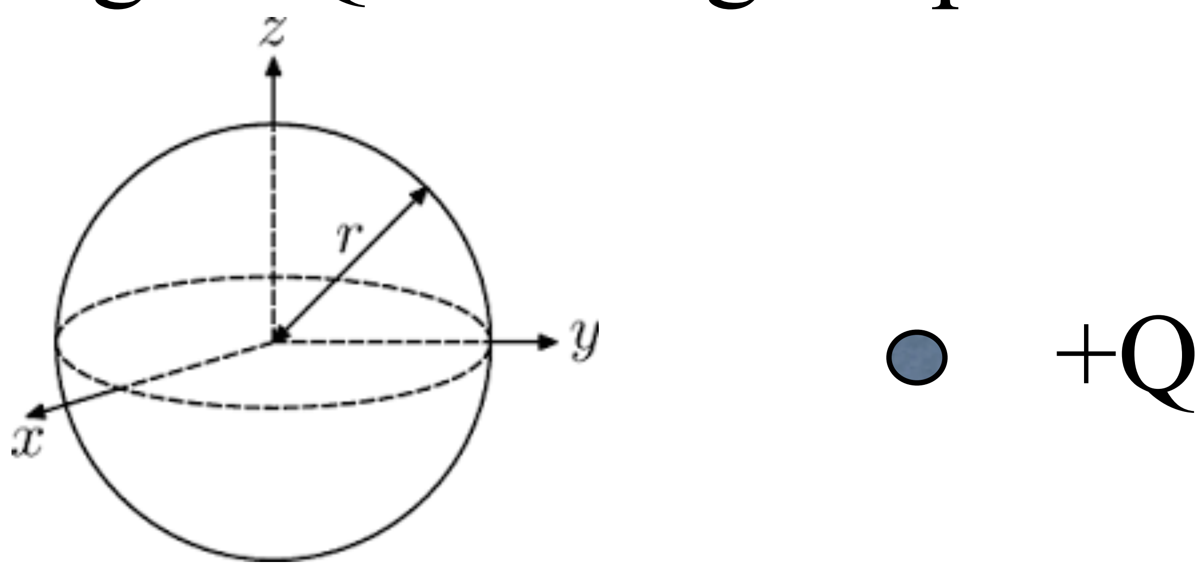
Electric fields exert forces on charged particles. In a conductor (a metal), there are charged particles which are free to move if a force exists. Therefore, an electric field inside a conductor would make charges move. They will move and rearrange themselves so that the field inside the conductor is zero. Then they can stop moving as there will no longer be a force.

Conclusion: Electrostatic Fields cannot exist inside a conducting material!



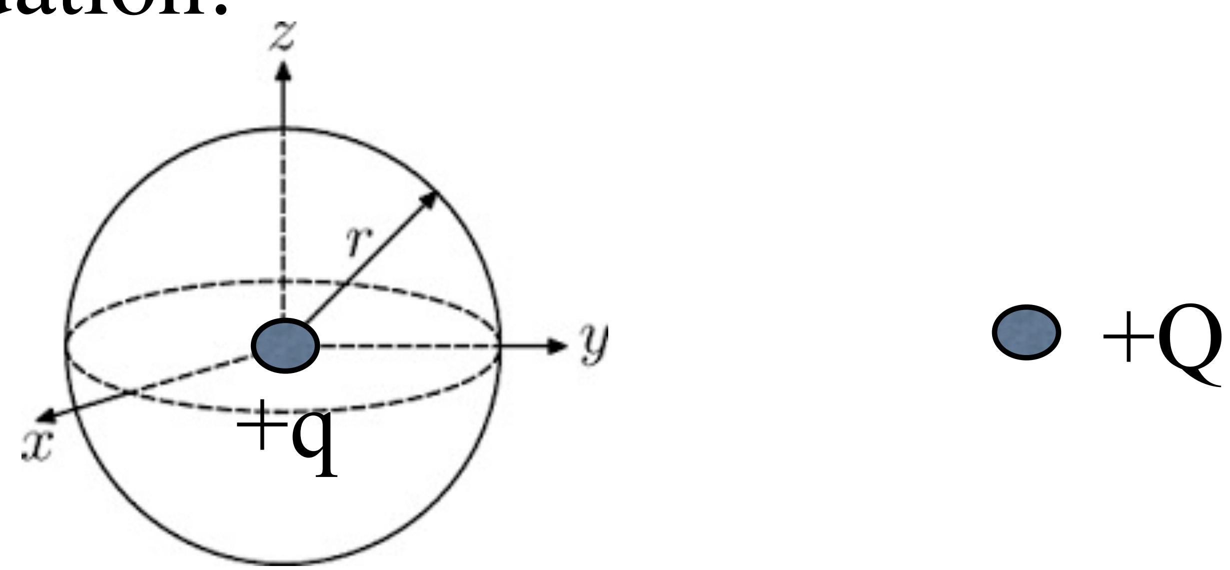
Positive charge inside a conducting cavity

The figure below shows a hollow conducting metal sphere which was given initially an evenly distributed positive (+) charge on its surface. Then a positive charge +Q was brought up near the sphere as shown. What is the direction of the electric field at the centre of the sphere after the positive charge +Q is brought up near the sphere?



A) Left
B) Right
C) Up
D) Down
E) Zero field

The figure below shows an electric charge q located at the centre of a hollow uncharged conducting metal sphere. Outside the sphere is a second charge Q. Both charges are positive. Choose the description below that describes the net electrical forces on each charge in this situation.



(a) Both charges experience the same net force directed away from each other.

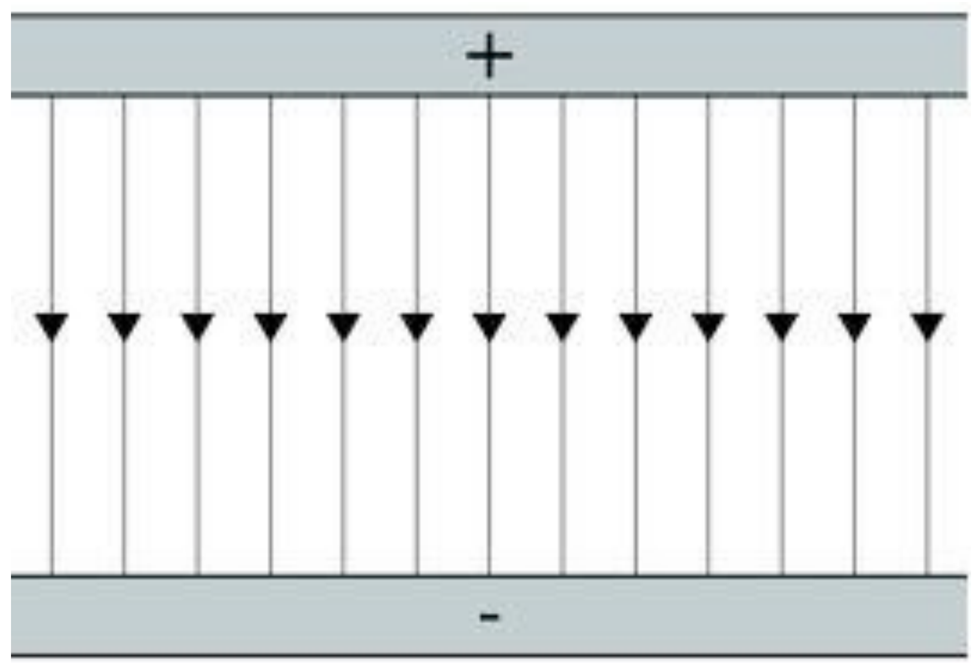
(b) No net force is experienced by either charge.

(c) There is no force on Q but a net force on q.

(d) There is no force on q but a net force on Q.

(e) Both charges experience a net force but they are different from each other.

A particularly important and useful case is that of two identical metal plates, one with a positive charge and the other with an equal amount of negative charge. The plates are parallel and close together. Since Electric field lines start on positive charges and end on negative ones, these field pictures are particularly simple.



The lines start on the positive plate, end on the negative, and are parallel (except just near the edges). Staying away from the edges gives us this picture of the field.

A calculation gives the electric field in the region between the plates as parallel, uniform and of a value

$$E = \frac{Q}{\varepsilon_o A} = \frac{\sigma}{\varepsilon_o}$$

$$\sigma = \frac{Q}{A}$$

$$\varepsilon_o = 8.85x10^{-12}$$

The quantity σ (sigma, the Greek letter *s*) is the ratio of the charge on each plate to the surface area of that plate. It is called the surface charge density and is measured in Coulombs/m^2.

Capacitors, with their simple electric fields, are of great use in electric circuits, as we shall see. They are devices for storing electric energy.

They are used, for example, as the means of storing considerable amounts of electric energy used in defibrillator units. These units are used by paramedics to shock the hearts of patients whose hearts have stopped (cardiac arrest) and restart the heartbeat.

Hearts

Electric fences