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

$$F = ma = 6.3x10^{-7} x7 = 4.41x10^{-6}$$

$$\therefore; 4.41x10^{-6} = 9m; m = 4.9x10^{-7}$$

$$F == \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2} = 4.41x10^{-6} = 9x10^9 x \frac{q^2}{\left(3.2x10^{-3}\right)^2}$$

$$q^2 = 5.02x10^{-21}; q = 7.1x10^{-11} = 71x10^{-12} = 71pC$$

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

F F

+Q +Q

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

+Q +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.

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 problem

$$F = \frac{1}{4\pi\varepsilon_o}\frac{q^2}{r^2} = 9x10^9\,\frac{\left(1.6x10^{-19}\right)^2}{\left(2.6x10^{-15}\right)^2} = 34N$$

$$a = \frac{F}{m_p} = \frac{34}{1.67x10^{-27}} = 2.04x10^{-28}\,m/s^2$$

$$v = v_o + at; 3x10^8 = 0 + 2.04x10^{-28}\,t$$

$$\therefore t = 1.5x10^{-20}\,s$$

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 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 of **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

$$F = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2} = 9x10^9\,\frac{\left(1.6x10^{-19}\right)^2}{\left(5.1x10^{-11}\right)^2}$$

$$= 9x10^9\,\frac{2.56x10^{-38}}{2.6x10^{-21}} = 8.86x10^{-8}\,N$$

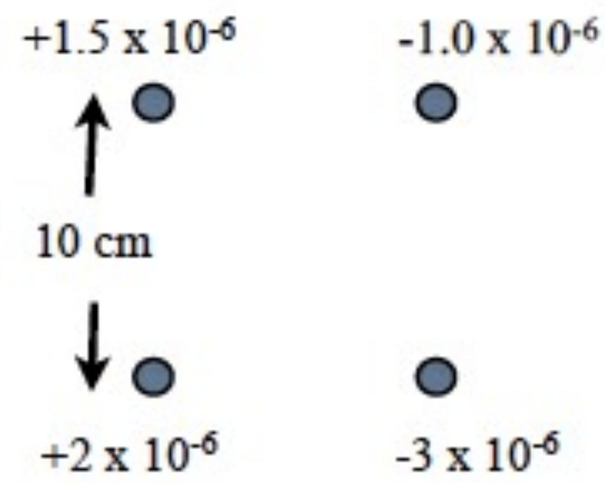
$$a = \frac{F}{m} = \frac{8.86x10^{-8}}{9.1x10^{-31}} = 9.7x10^{22}\,m/s^2$$

$$a = \frac{v^2}{r};v = \sqrt{ar} = \sqrt{9.7x10^{22}\,x5.1x10^{-11}} =$$

$$\sqrt{4.95x10^{12}} = 2.22x10^6\,s$$

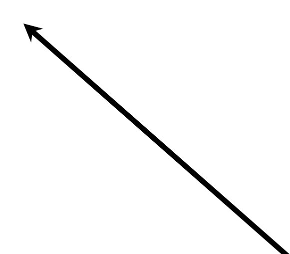
A hydrogen atom is composed of a nucleus containing a single proton, about which a single electron orbits. The electric force between the two particles is 2.3×10^{39} times greater than the gravitational force! If we can adjust the distance between the two particles, can we find a separation at which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

A. Yes, we must move the particles farther apart.
B. Yes, we must move the particles closer together.
C. No, at any distance



Four charges sit at the corners of a square which is 10 cm on a side. The charge at bottom left is +2 x 10^{-6} C, at the bottom right is -3 x 10^{-6} C, at the top left is 1.5 x 10^{-6} C and at the top right is -1 x 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 more difficult problem as it involves adding vectors. Let's start by calculating the force between the two right hand charges. Both are negative, so the force is repulsive, hence UP.

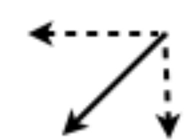
$$F = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2} = 9x10^9 \frac{3x10^{-6}x1x10^{-6}}{.1^2} = 2.7N$$ ↑

Now for the force between the two top charges. The force is attractive.

$$F = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2} = 9x10^9 \frac{1.5x10^{-6}x1x10^{-6}}{.1^2} = 1.35N$$ ←

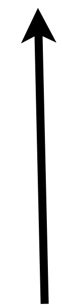
Finally, the diagonal force which is also attractive.

$$F = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2} = 9x10^9 \frac{2x10^{-6}x1x10^{-6}}{.14^2} = 0.9N$$



A more difficult problem as it involves adding vectors. Let's start by calculating the force between the two right hand charges. Both are negative so the force is repulsive, hence UP.

$$F = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2} = 9x10^9\,\frac{3x10^{-6}x1x10^{-6}}{.1^2} = 2.7N$$

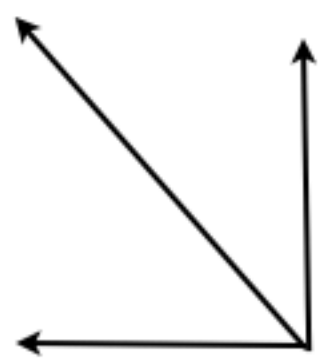


Now for the force between the two top charges. This force is attractive.

$$F = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2} = 9x10^9\,\frac{1.5x10^{-6}x1x10^{-6}}{.1^2} = 1.35N$$

Finally, the diagonal force, which is also attractive

This force has both a horizontal component in the same direction as the 1.35 N force and a vertical component in the opposite direction to the 2.7 N force. As the angle is 45 degrees, the two components will be equal they will each be 0.707 x 0.9N = 0.637. I keep several significant figures for intermediate calculations, and then concern myself with significant figures at the end.
The total forces are then 2.063 in the vertical direction (UP) and 1.987 in the horizontal direction.



The final vector is the square root of the sum of the squares of the two sides and is F = 2.86 N. The angle is 46 degrees with the horizontal.

Which of the following four statements is NOT true?

The Electric Force

A) decreases as the square of the distance between two charged particles.
B) between a proton and an electron is much straonger than the gravitational force between them.
C) between two protons separated by a distance ***d*** is larger than that between two electrons separated by the same distance ***d***.
D) may be either attractive or repulsive.

When the electric charge on each of two charged particles is doubled, the electric force between them is

A) multiplied by two.
B) multiplied by four.
C) the same.
D) none of the above

a) Two positive charges, each of 20 μC are a distance of 1.5 m apart.

Calculate the force on one of them.

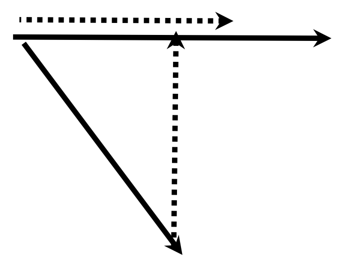
b) Now a third charge, of the same value is brought in and placed such that the three charges form an equilateral triangle. Calculate the force now.

Answers a) 1.6 N b) 2.77 N

a)

$$F = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2} = 9x10^9\,\frac{20x10^{-6}\,x20x10^{-6}}{1.5^2} = 1.6N$$

b)



$$1.6\cos 60 = 0.8; 1,6\sin 60 = 1.39$$

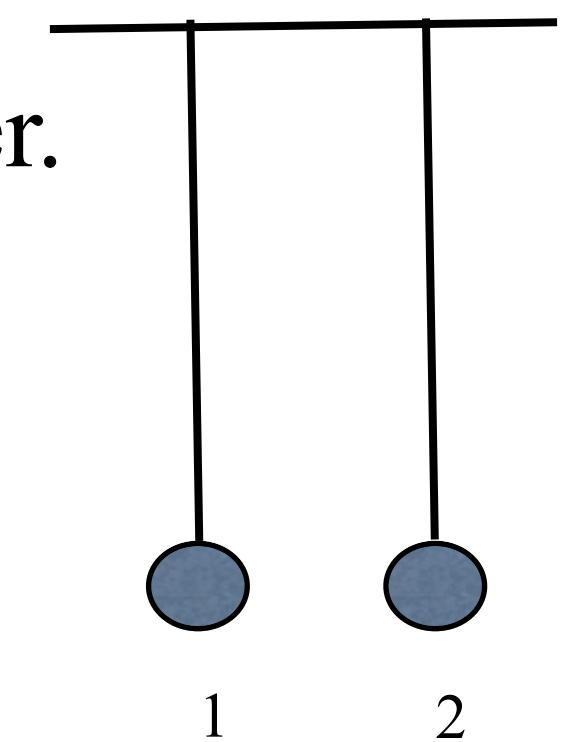
$$1.6 + 0.8 = 2.4$$

$$F = \sqrt{2.4^2 + 1.39^2} = \sqrt{7.69} = 2.77\,N$$

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.

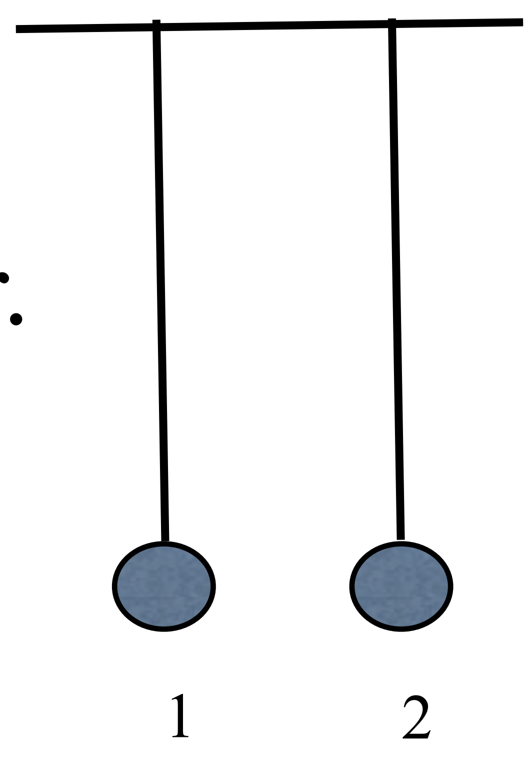
Both balls are touched by a negatively charged rod.

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.



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.

Ball 1 is touched by a negatively charged rod and ball 2 by a positively charged rod.

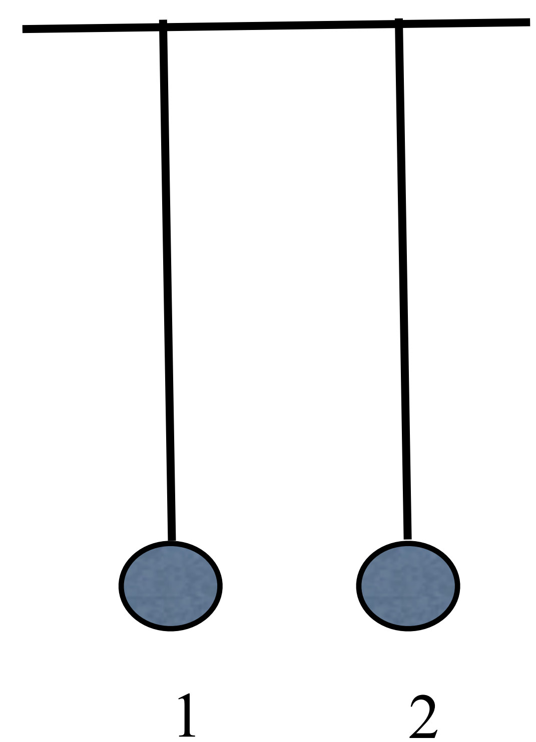


A) They do not attract or repel on another.
B) The repel by equal amounts.
C) They attract by equal amounts.
D) None of the above is true.

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.

Both are touched by a negatively charged rod but ball 2 has more charge placed on it.

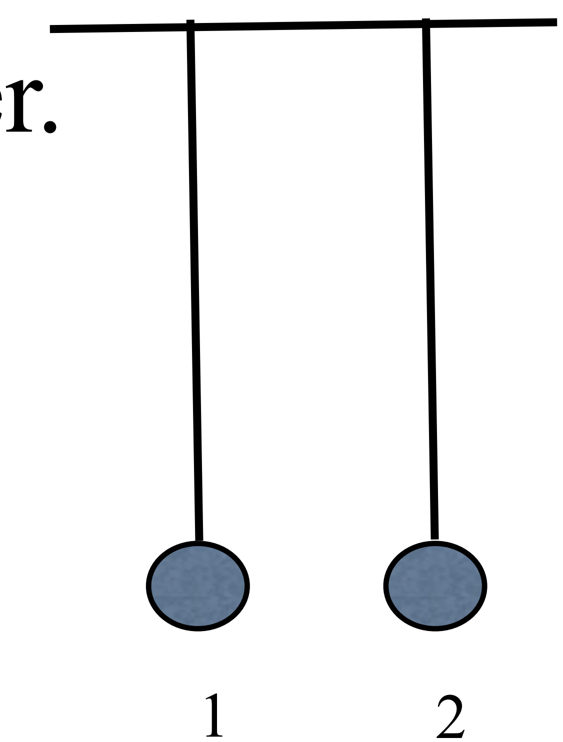
A) They do not attract or repel on another.
B) The repel by equal amounts.
C) They attract by equal amounts.
D) None of the above is true.

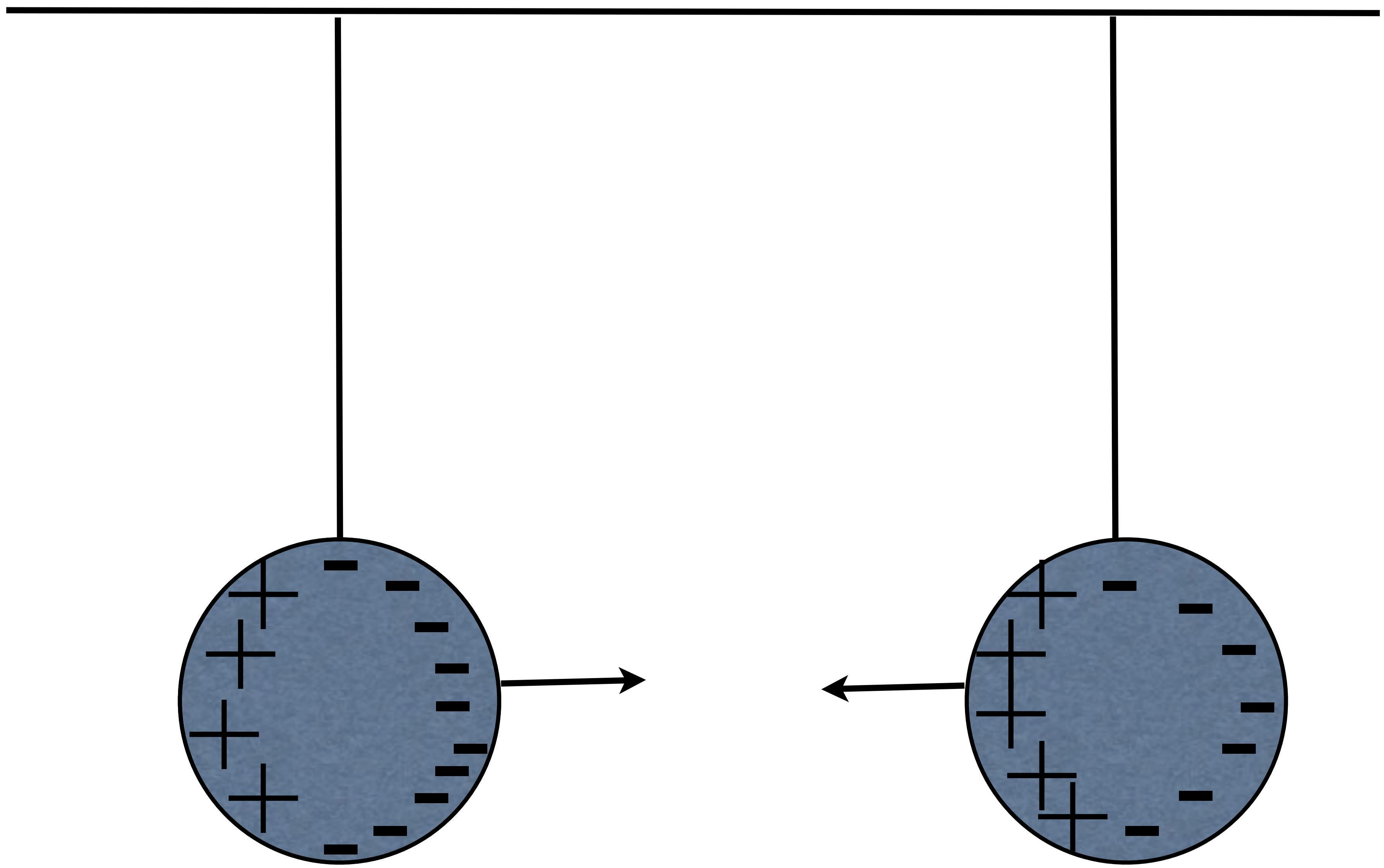


Two lightweight electrically neutral conducting balls hang from threads and are close to one another (but not touching). Answer the following questions using the choices below the questions.

Only ball 1 is touched by a negatively charged rod.

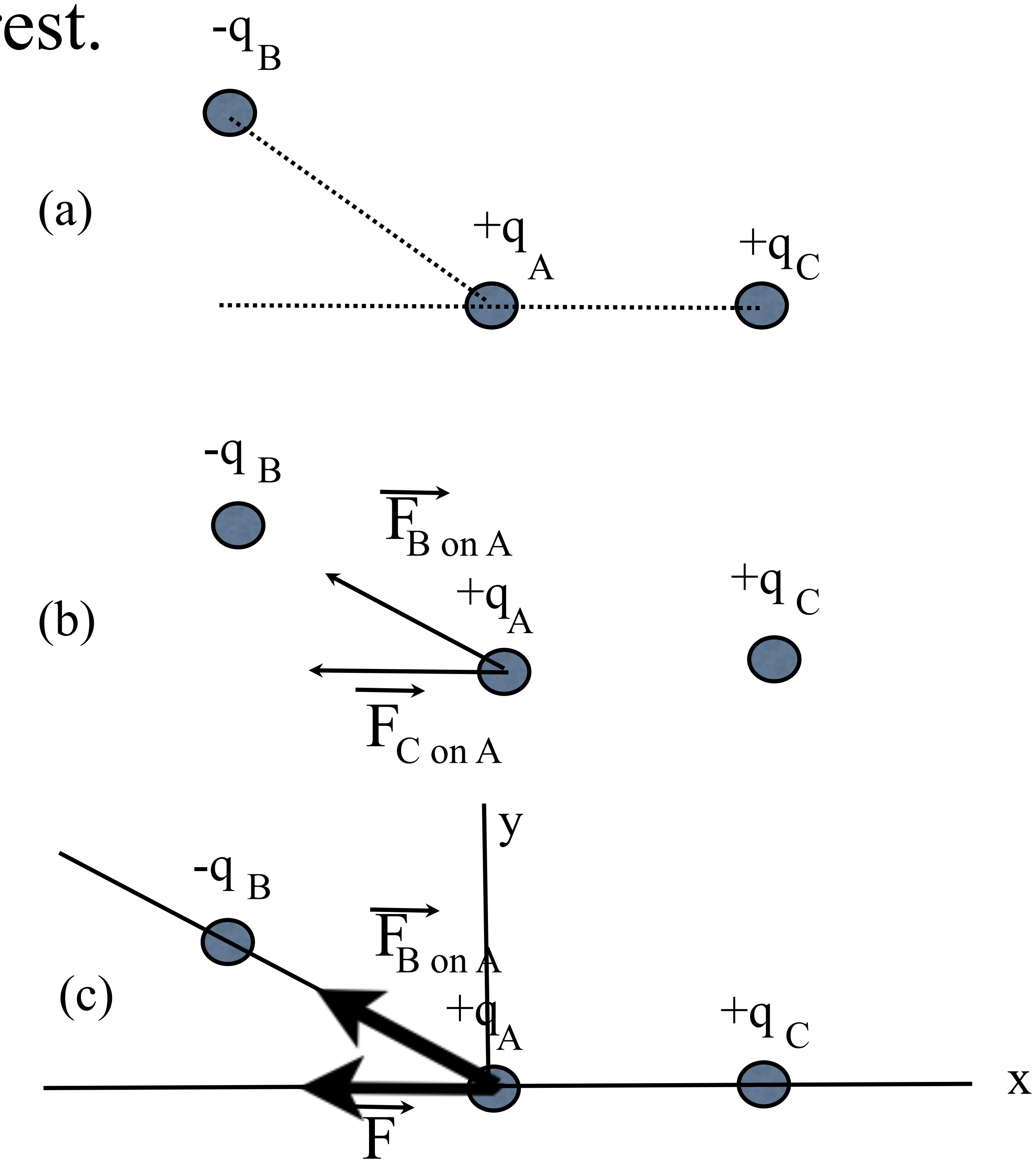
A) They do not attract or repel on another.
B) The repel by equal amounts.
C) They attract by equal amounts.
D) None of the above is true.





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 digram 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.

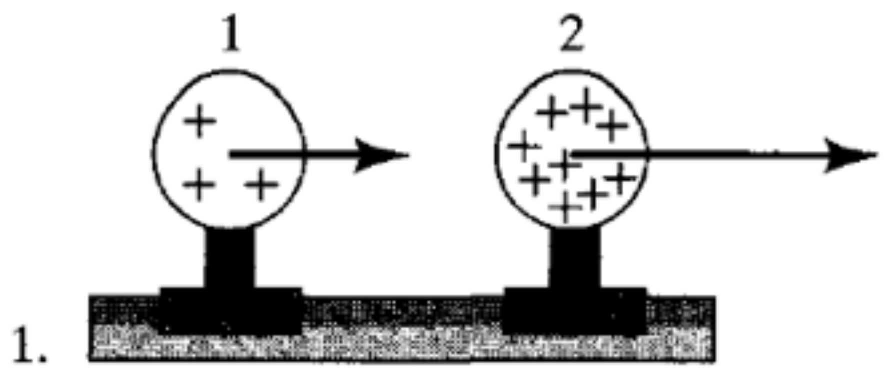
8. Combine the resulting components to get the magnitude of the resultant force, using the expression

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

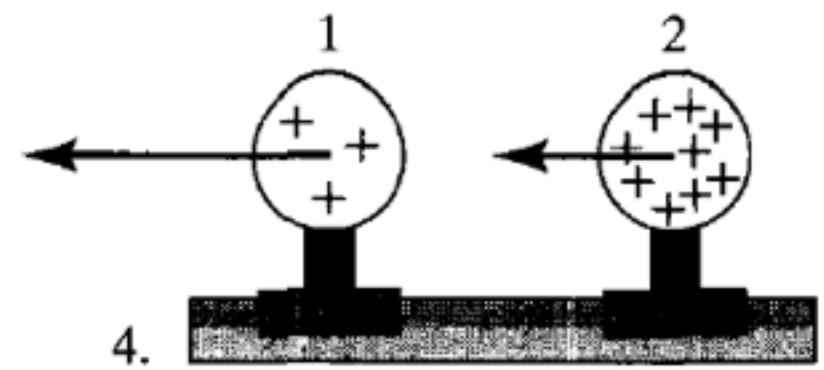
9. Determine the angle at which the force acts (relative to the positive x axis) using

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

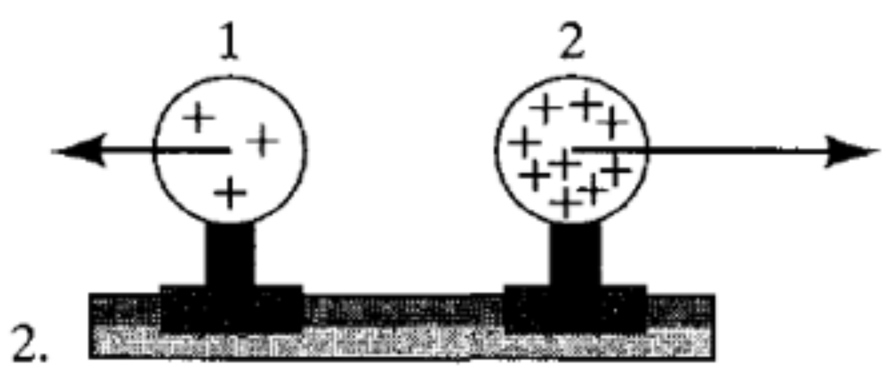
Two uniformly charged spheres are fastened to insulated stands. The charge on sphere 2 is three times the charge on sphere 1. Which force diagram correctly shows the magnitude and direction of the electrostatic forces:



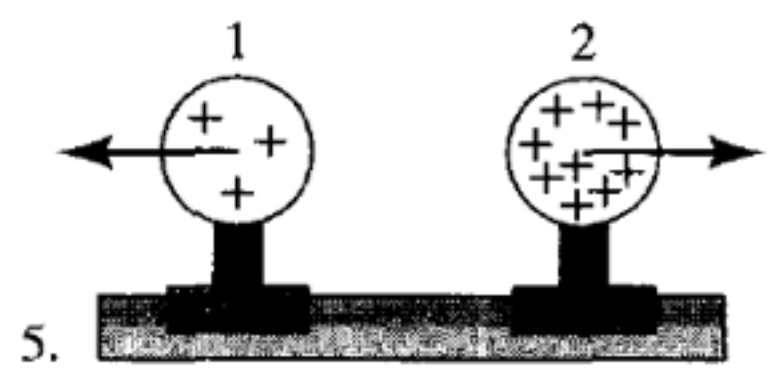
A



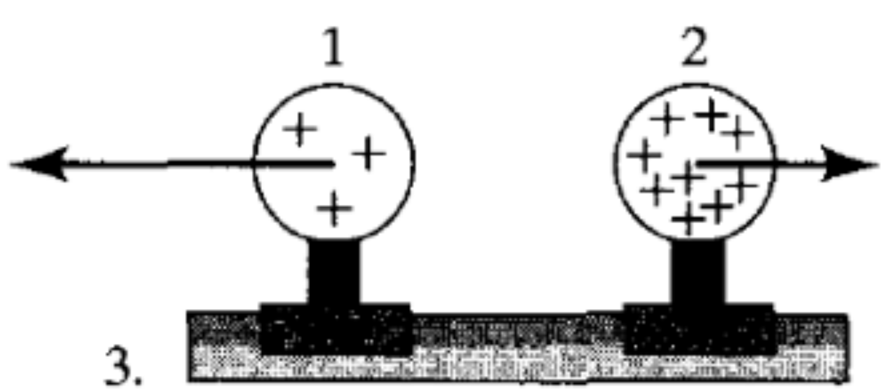
D



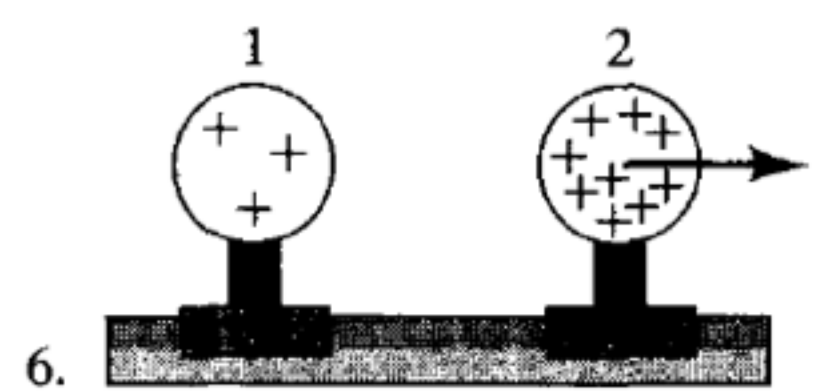
B



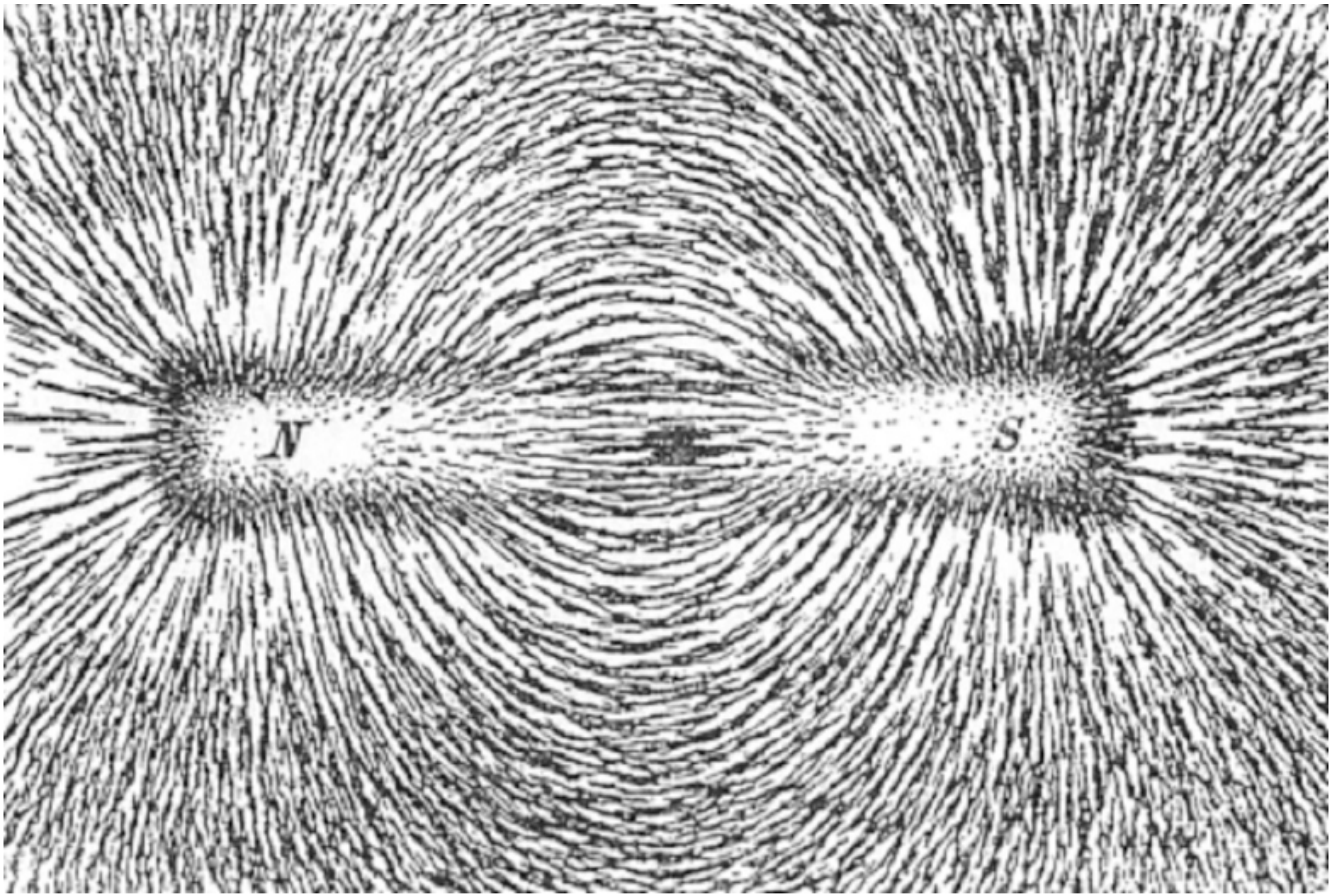
A + B



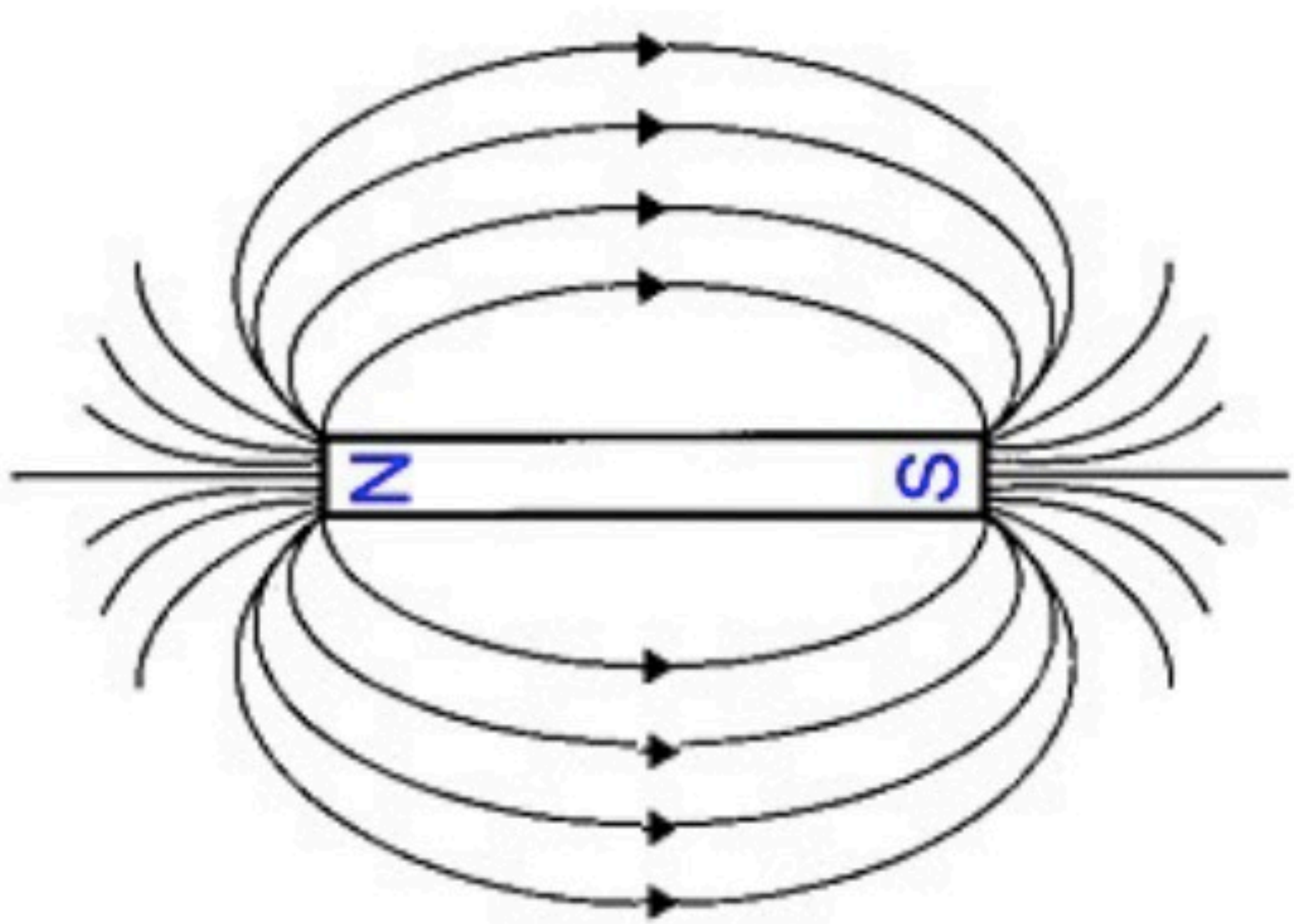
C



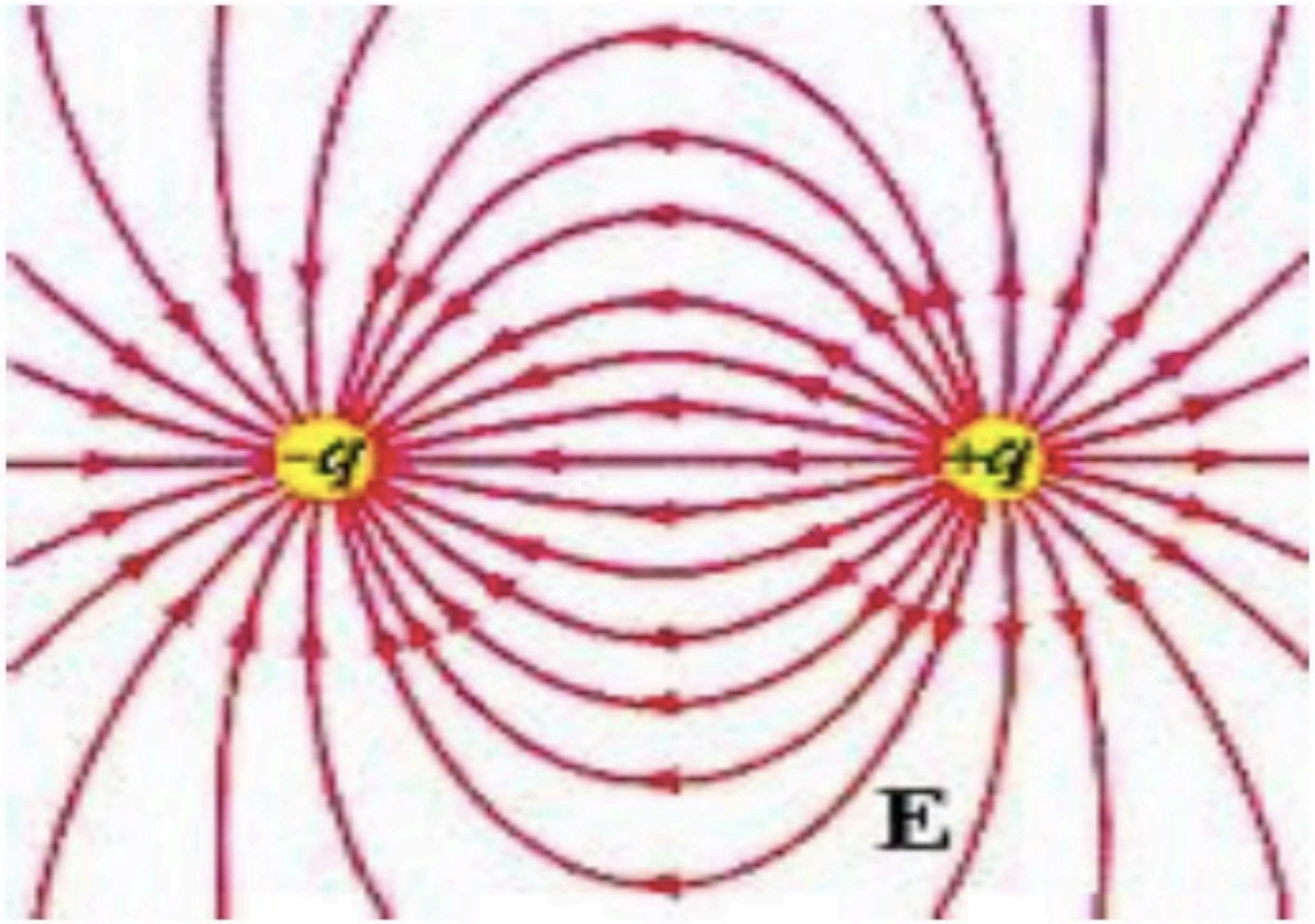
C + D



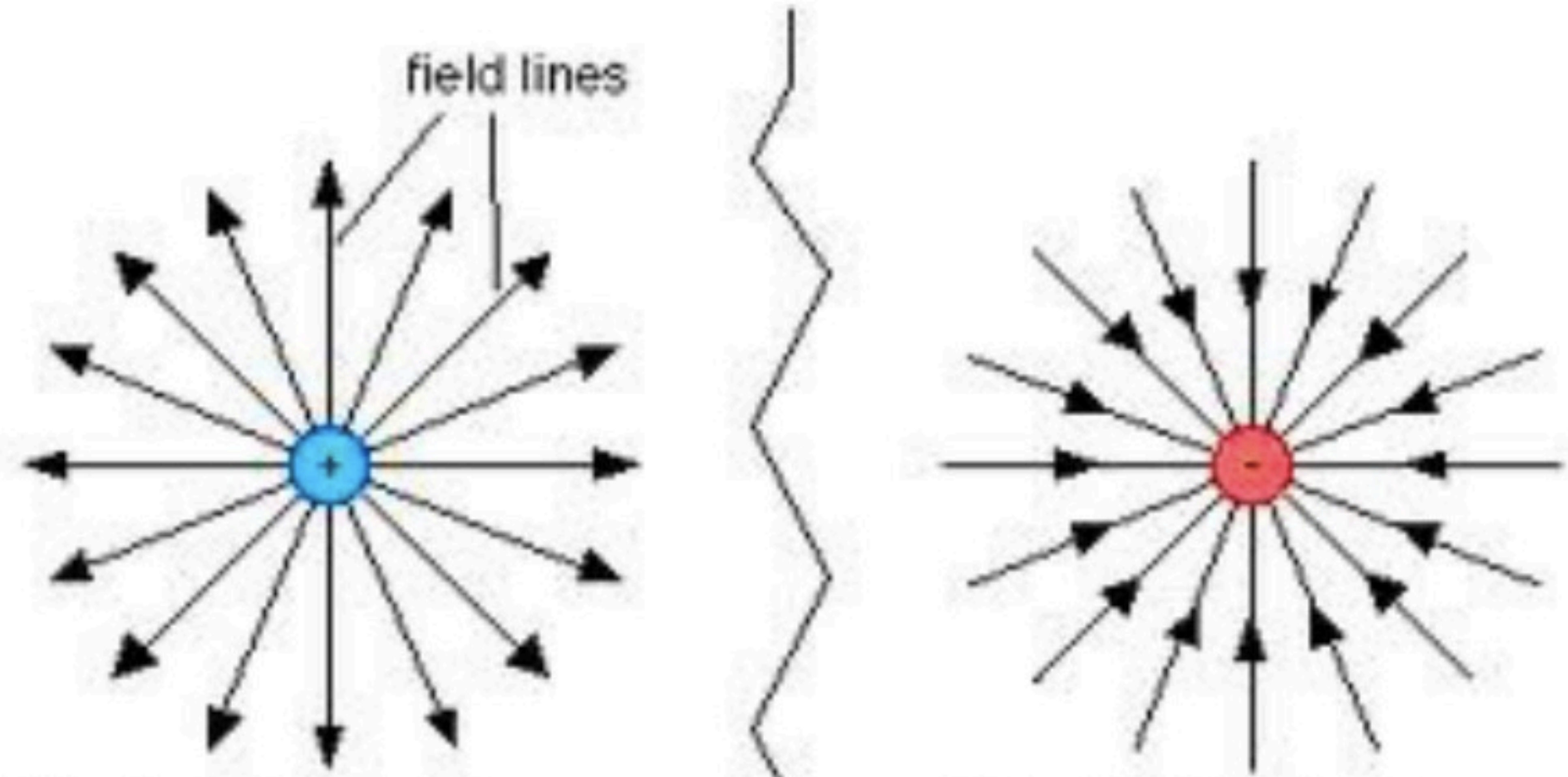
Bar magnet with iron filings



Bar magnet with schematic lines



Electric Charges analogous to the Bar Magnet



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

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 56×10^{-12} C = 56 pC

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

$$q = \frac{Er^2}{9x10^9} = \frac{2x(0.5)^2}{9x10^9} = 5.55x10^{-11} = 56x10^{-12}$$

$$= 56pC$$

10^{-3} = milli

10^{-6} = micro

10^{-9} = nano

10^{-12} = pico

10^{-15} = femto