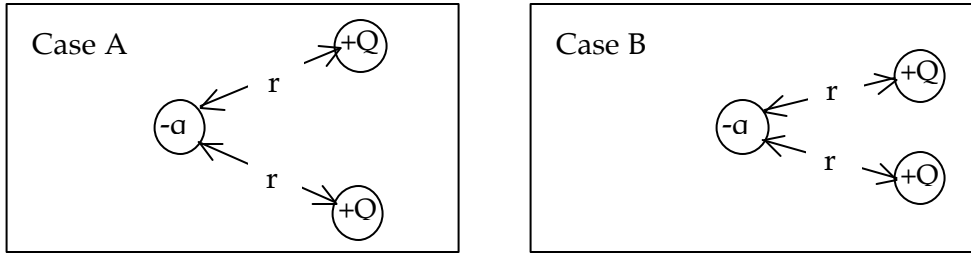


- 1) Suppose you have three charged particles arranged as shown in Case A or as shown in Case B. In which case, if either, is there a stronger force on the $-q$ charge?

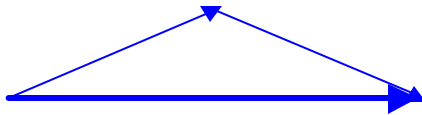


- a) First just use your intuition (Maybe think of people pulling with ropes?) to answer the question.

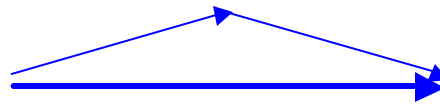
If I think of two people pulling with ropes, they're pulling more together in case B than in case A. (Imagine an even larger angle between the ropes, and the two people would be opposing each other.) So I'd expect that the force on $-q$ in case B would be stronger.

- b) Now consider what Coulomb's Law would say.

Coulomb's Law would say that the strength of each of the pulls is $F = \frac{kqQ}{r^2}$, and I'm not worried about the sign because I know the direction of the forces: The force by a $+Q$ charge on the $-q$ charge is toward $+Q$. Forces are vectors, so they add as vectors the way they always have. So Case A is this addition:



And Case B is this:



So Case B comes out just a little bit stronger.

- c) If your answers for a) and b) were contradictory, how can you reconcile them?

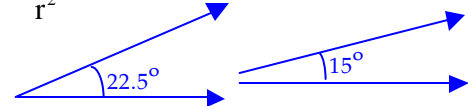
Many people forget to add the forces as vectors, and get $F_{\text{total}} = 2 \frac{kqQ}{r^2}$ for both cases.

Adding the forces as vectors gives an answer that fits more closely with common sense!

- 2) Let's try that question with some numbers. Suppose Q is $50 \mu\text{C}$ (that's $50 \times 10^{-6} \text{ C}$), $-q$ is $2 \mu\text{C}$, and r is 4 cm . And suppose in Case A the two lines are 45 degrees apart, and in Case B they are 30 degrees. Calculate the total force on $-q$ for each.

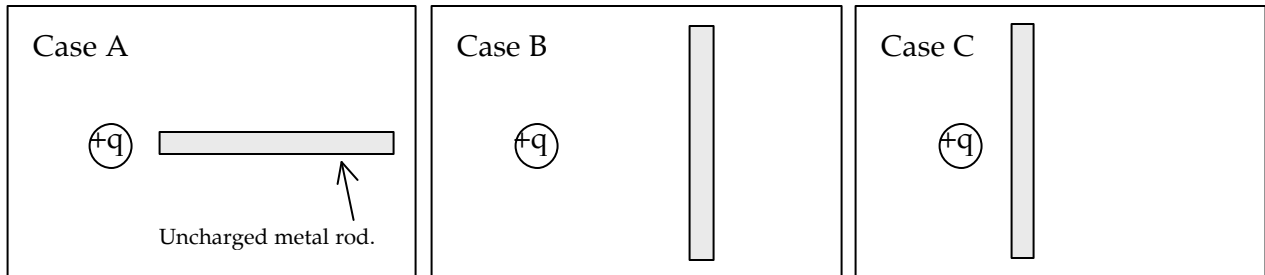
This is just review from adding vectors in 121. The y -components cancel; we need only add the x -components. The strength of each individual pull is $F = \frac{kqQ}{r^2} = 560 \text{ Newtons}$.

The x components of the two forces in case A are $F \cos 22.5^\circ$:
 $= 520 \text{ Newtons}$, so the total for case A is 1040 Newtons .



For Case B, the x -components are $F \cos 15^\circ = 540 \text{ N}$ so the total is 1080 , just a bit stronger.

3) Suppose you have an object with excess charge $+q$ placed near an uncharged metal rod as shown.



a) Consider Case A:

i) Sketch the charge distribution on the rod.



ii) Is there a net electric force on the rod? Explain.

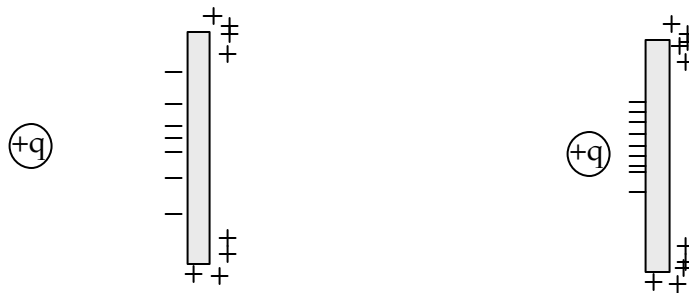
The $+q$ pulls electrons toward it, in the rod, leaving $+$ behind. That builds up negative charge on the side closer to $+q$, closer than the $+$ charge on the other side, so the attraction is stronger than the repulsion.

iii) Is there a net electric force on the charged object $+q$? Explain.

Same thing: The negative charge is closer than the positive, so the attraction is stronger. And, again, Newton's Third Law applies!

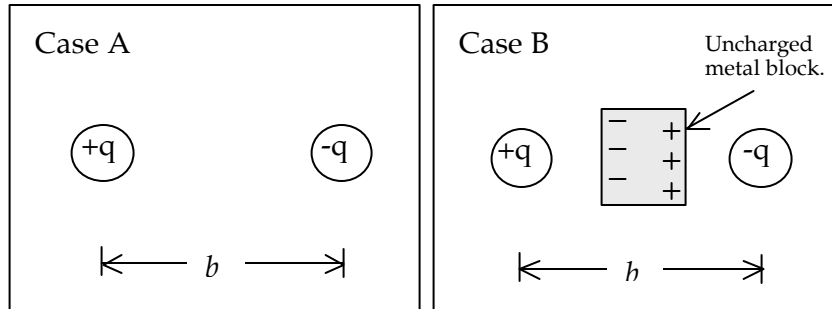
b) Now consider Cases B and C. Which configuration leads to the strongest force on the $+q$ charge: Case A, Case B, or Case C? (This one's hard! Feel free to give an uncertain answer, but try to explain just what it is that makes you uncertain.)

Well, it's a tough one! My answer is that A is the strongest, then C, then B, but I heard some awfully good reasons to think C is stronger than A. For all of them, electrons in the rod are going to be attracted toward the $+q$, leaving positive charge on the parts of the rod that are furthest. The closer $+q$ is, the stronger it attracts, so more negative charge will build up near it – it will take more negative charge building up to keep other electrons away. So A or C will be the strongest. Now... for C, maybe you can end up with more negative charge near the $+q$, since there's more surface of the rod? But then for A, the distance to the positive charge at the other end is the largest, so that would mean the weakest repulsion. In the end, I'm left uncertain whether A or C is strongest. For B, it's further away, and there's not as much difference in the distances between $+q$ and the negative and positive charges in the rod.



That would be a 5 point answer, what I just gave, even though I came up uncertain.

- 4) Suppose that you have two charged objects separated by a distance b . In Case A there is a force between these two objects. Case B shows the two objects, but now an uncharged block of metal has been placed between them.



- a) In Case B, after the block has been placed between the charged objects, is the force on the positively charged object (labeled $+q$) *greater than*, *less than*, or *equal to* the force on that object in Case A with no metal block?

Greater than! Even without that $-q$ on the other side, if you put a metal block there the $+q$ would induce a dipole and there'd be a net attraction. Put the $-q$ back in, and that only adds in the $\frac{kq_1q_2}{r^2}$ attraction between $+q$ and $-q$.

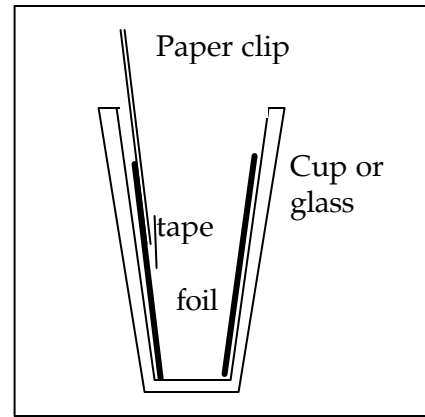
- b) A reasonable person could have the intuition that it "putting an object in the way shields the electric force." Compare that bit of common-sense thinking to the model, and explain in what way, if any, it would need to be refined to agree with our basic model of two charges and Coulomb's Law.

That intuition would work for all kinds of things. If $+q$ and $-q$ were interacting by sending things or signals back and forth between them, then putting something in the middle could "block" the signals. (So, a cell phone sends signals back and forth to an antenna somewhere, and if you're in a building the walls of the building can block that.) But like Newton's Law of Gravitation, Coulomb's Law is a direct interaction between q_1 and q_2 – there's nothing in that model about stuff or signals moving between the charges, so there's nothing to block. (That bothered Newton a lot, having that kind of direct "action at a distance" – but he decided to live with it. It also bothered physicists after Newton, and later models try to get rid of action at a distance. So the refining continued, of both common sense and of these models.)

Of course, another part of common sense agrees well with the answer in a: If you have one thing that's attracting $+q$ to the right, and you introduce another thing that attracts it to the right, then it's attracted more strongly!

- 5) This problem is about a device for storing charge. You could actually build one and try it—that would be great—or you could just think through what should happen according to the basic model. (Just don't make it too big: A device like this the size of a large bucket could kill you! And don't even make a little one if you wear a pace-maker.)

Get a plastic or Styrofoam cup or a glass cup or jar and line the inside with aluminum foil. Unfold a paper clip and tape one end to the aluminum foil inside so that the other end sticks out of the cup.



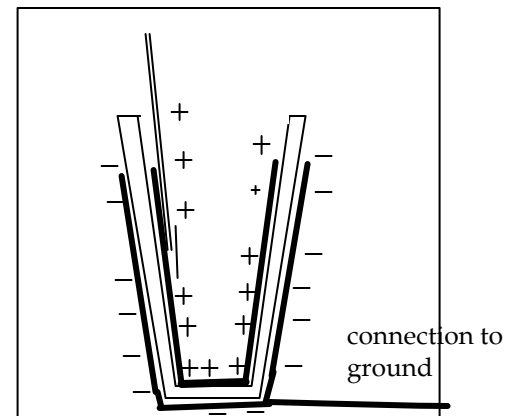
a) Now go build up a net charge on yourself by shuffling around in your socks, maybe, so that if you were to touch something you'd get a shock. Suppose you have a net negative charge on you and you touch the end of the paper clip. Does the inside of the cup (the foil) now have a charge?

Yes, the inside of the foil should have a small charge. If the shuffling around gave you a net + charge, then when you touch the foil you'd pull off some electrons, leaving with a small, net + charge too.

b) If you were now to go shuffle around some more, come back and touch the paper clip again, explain why you won't be able to put much more negative charge on the foil inside.

It wouldn't be so easy, because it already has a net + charge. So if you come along and touch it again, the net + on the foil will be attracting electrons, and you might be able to pull a few more away, but you'd be limited by the fact that every time you pull off some electrons the foil has that much more of an excess positive charge.

c) Here's a way to solve the problem: Add a wrapping of aluminum foil to the *outside* of the cup, without letting it touch the inside layer or the paper clip. And use another paper clip or other foil to connect the foil on the outside to some other large, conducting object—the best thing would be to a metal water pipe. If you put negative charge on the inside foil, what charge would you expect on the outside foil?



This is similar to the contentious problem we did in lecture! With the excess + charge on the inside foil, electrons will be attracted to the outside foil, and they can come to that foil through the metal in the pipe. So the outside foil will get a build-up of - charge. (The cross-sectional drawing in the assignment may have been misleading: The inside foil is all one piece, and the outside foil is all one piece. I've fixed it here.)

d) Explain why that outside foil will make it easier to add more negative charge to the inside foil.

Now there's all that negative charge there, on the outside foil, and they repel electrons! So when you come along with a net positive charge, and you touch the paper clip again, all that negative charge on the outside foil can help to counteract the positive charge on the inside foil, and the electrons have an easier time leaving.

e) If you do this for a while—shuffle, touch the clip, shuffle, touch the clip—you can end up with a lot of charge stored! When you get tired of it, disconnect the outside foil from that water pipe (or whatever you used). Now try touching the outside foil with one hand and the inside foil (or the paper clip) with the other. What should happen?

The positive charge and the negative charge on the inside and outside foils are attracting each other. If you provide a route for charge to flow, then they can get together! You'll get a nice spark out of it, as the excess negative charge on the outside, all those extra electrons, move through the conductor (you!) to get to the positive charge on the inside.

This device is called a "Leyden Jar," and it's how Ben Franklin stored charge from lightning. (Well, he used glass, not Styrofoam.) And a Leyden jar is a kind of *capacitor*, which is something we'll be talking more about as we go. Another kind of capacitor, more what people typically think of when they use the word, is the pair of plates in the next question.

- 6) Here's another device to think about. Two metal plates, held apart by some insulating material, start with opposite charges. And then someone runs a wire, as shown from one plate to the other. Draw two more sketches to show what happens, one to show how the charges end up, and another to show the intermediate state, after you connect the wire but before the charges have stopped moving.

