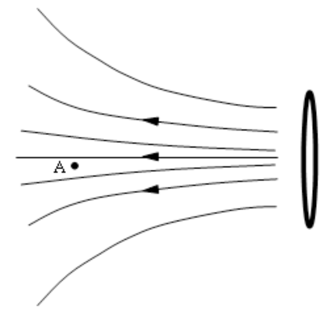
 Name ____________________________

Abstract concepts: Fields

I. Analogy to electric field: Wind

The point of this tutorial is to introduce *electric fields*. But instead of doing so immediately, we'll start with an analogy to wind.

A. An industrial-strength fan creates the wind pattern indicated in this diagram. Someone holds a small kite at point A. Then the person holds a larger kite at that same point. In both cases, the kite directly faces the fan and therefore catches the wind.



1. In what sense is the wind stronger on the large kite than it is on the small kite?

2. In what sense is the wind equally strong at both kites?

3. A student says,

   The wind *itself* is equally strong at point A no matter which kite you hold there—or even if you *don't* hold a kite there. The large kite feels more *force* than the small kite because it has more area and therefore catches more wind, not because the wind itself is stronger.

   Does this student agree with the answers you just gave? If not, do you think the student makes good points? In what ways do you disagree?

As a convenient catchphrase, let's define the *wind field* as the strength and direction of the wind itself at a given point (whether or not an object is held there). So, according to the student, the wind field at point A stays the same whichever kite you put there; but that same wind field produces a different wind *force* on kites of different sizes.

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B. Now you'll figure out a way to define the wind field more precisely.

1. The smaller kite has cross-sectional area 0.50 m^2. When held at point A, it feels a wind force of 3.0 N. The larger kite has exactly twice the cross-sectional area (1.0 m^2) of the smaller kite. What wind force would you expect the larger kite feel at point A? Explain.

2. Now a kite of cross-sectional area 2.0 m^2 is held at point A. What wind force do you expect it to feel? Why?

3. Here's the punch line. Each of the three kites from question (1) and (2) feels a different wind *force* at point A. But they should each feel the same wind *field* because the wind itself is the same at point A no matter which kite you hold there. Is there some number having to do with wind force and cross-sectional area that's the *same* for all three kites and could therefore work as a definition of wind field? This is hard; try it for a while, and if you get stuck, move on to the next question.

4. Here are two proposed definitions of wind field: (i) wind field = wind force × cross-sectional area, or (ii) wind field = wind force ÷ cross-sectional area. Which of those definitions, if either, better captures the intuitive sense of what wind field is supposed to mean (as discussed on page 1)?

5. Let's think more about the "better" definition of wind field from question (7). What are the units of that number?

6. Explain what that definition of wind field means in terms your roommate could understand (assuming your roommate isn't a physics person).

✯ *Consult an instructor before you proceed.*

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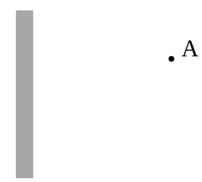
C. Does the wind force depend on the fan, the kite, or both? What about the wind field? Briefly explain.

II. Applying field ideas to electric stuff

We just saw that the wind field is the strength and direction of the wind, independent of whether the wind acts on anything. In general, a field is the strength and direction of *something*, independent of whether that something acts on an object. Let's apply these ideas to electric fields.

A glass rod is given a positive charge by rubbing it with silk.



A. You hold a bead with a small charge at point A. Then you pull it away and hold a bead with a larger charge at that same point.

1. Is there an intuitive sense in which the bead with more charge feels a *greater* "electric effect" from the rod at point A? Explain.

2. Does that sense correspond to a larger electric *force*, a larger electric *field*, or both?

3. Is there an intuitive sense in which both beads feel the *same* "electric effect" from the rod at point A? Explain. *Hint:* Think of wind.

4. Does that sense correspond to the same electric *force*, the same electric *field*, or both?

B. When using an analogy to learn, it's important to think about both the strengths and limitations of the analogy.

1. In what ways are wind fields and electric fields similar?

2. In what ways are wind fields and electric fields different?

C. As we saw with kites, the property of an object that determines how much it responds to a given wind field is its cross-sectional area.

1. What property of an object determines how much it responds (*i.e.,* how much force it feels) in a given electric field? Explain.

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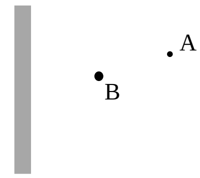
2. Does the electric field felt by a bead at point A depend on the charge of the rod, the charge of the bead or both? Explain.

3. Suppose point B is at the location shown at the right. Intuitively, is the electric field at point B greater than, less than, or equal to the field at A? Why?



4. Two different beads are held at points A and B. Could it be the case that the bead at B feels a weaker electric force than the bead at A? Explain.

✯ *Consult an instructor before you proceed.*

III. Clarifying the meaning of electric field

A. When held at point B, a bead of charge 2.0 nanocoulombs is repelled by the rod with a force of 10 N. The charge on that bead is now doubled, to 4.0 nanocoulombs, and the bead is again held at point B.

1. What force do you expect the bead now feels from the rod?

2. Now a bead of charge 5.0 nanocoulombs is held at B. What electric force do you expect it feels from the rod?

3. So, the 2.0, 4.0, and 5.0 nanocoulomb beads feel different electric *forces* at point B. But the electric *field* at B is the same no matter which bead you hold there, just as the wind field at a given point in front of the fan doesn't depend on which kite you hold there. Is there some number having to do with electric force and bead charge that's the same for all three beads at point B and could therefore formalize the concept of electric field?

B. Let's explore the meaning of the number and equation you just chose.

1. What are the units of that number?

2. Explain what that number means, and why it corresponds to the notion of electric field, in terms your roommate could understand.

C. You'll now "translate" these concepts into an equation. Let E denote the electric field created by a rod or other collection of charges; let q denote the charge of a bead or other particle placed in the field; and let F denote the electric force felt by that particle. Write an equation relating E, q, and F.

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IV. From concepts to problem solving

To correctly apply the formula you just figured out, you need to relate it to he underlying concepts when thinking through a problem. This problem gives you practice doing so when you have lots of information to deal with. If you find yourself getting confused, think back to the wind.

In this diagram, beads 1 and 2 carry charges 1.0 nC (nanocoulombs) and 2.0 nC, respectively. P is just a point in space, not a charge. The electric force exerted on bead 2 by bead 1 is 12 N. The overall electric force that would be felt by a 2.5 nC charge at point P is 20 N; but a 2.5 nC particle is not present for now.

A. First let's think about the effect of bead 2 on bead 1.

1. Find the electric force exerted by bead 2 on bead 1. Yes, you have enough information; use a basic law of physics from last semester.

2. Find the electric field due to bead 2 at the location occupied by bead 1.

3. Is your part A.2 answer greater than, less than, or equal to the electric field due to bead 1 at the location occupied by bead 2? Explain.

B. Given that beads 1 and 2 feel different fields, it's reasonable to expect that they also feel different forces. But they don't! To reconcile this apparent conflict, explain in intuitive terms how beads 1 and 2 can end up experiencing the same force even though they feel different fields. Hint: Think of a bigger and littler fan facing and blowing on each other.

C. The charge on bead 1 is now tripled. How does that affect

1. the electric field due to bead 2 at the location occupied by bead 1? Explain.

2. the electric field due to bead 1 at the location occupied by bead 2? Explain.

3. the force felt by bead 2? Explain.

4. the force felt by bead 1? Explain.

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D. Bead 1 is now returned to its initial, 1.0 nC charge. Find the overall electric field due to beads 1 and 2 combined at point P, when a 2.5 nC particle occupies point P. (Reread the paragraph before part A for relevant information.)

E. The 2.5 nC charge at P is replaced by a 5.0 nC charge. Find.

1. the overall electric field due to beads 1 and 2 at P when the 5.0 nC charge is present.

2. the electric force on that 5.0 nC charge.

V. Study strategies in first-semester vs. second-semester physics

You may have heard a former physics student give a piece of advice something like this:

> With forces and motion, you can use your everyday experiences and in many cases your common sense to help you learn. But in second-semester physics, with really abstract concepts, you can't rely on intuitive ideas at all; you have to use a less common-sense, more abstract style of learning.

You won't be surprised to hear that one of our goals in this tutorial was to "take on" this common piece of advice. But that doesn't mean we were convincing!

What's your current opinion (subject to change, of course) about the former student's advice? Specifically, what role, if any, do you see common sense playing in your learning of the abstract ideas in this course. Please say what *you* think, not what you think *we* think!

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