Setlist L4 (90 minutes)

Introduction to electrostatics.
Prep: Bring electroscope, balloons, bits of paper. Sweater and ballon PhET. Charges and Fields PhET. Electric field worksheet

1. The four forces, the standard model, and the reason we learn electromagnetism.
2. Clicker Question: Socks in the dryer - D
3. Properties of charge.
4. Sweater and Balloon PhET. Charging a ballon. Do it with charges off first. Why does the balloon stick to the sweater? Why does it stick to the wall?
5. Conductors and Insulators. Polarization. Rubbing insulators causes charge to move. Draw balloon picking up paper.
6. Electroscope demo - draw possible charge configurations
7. Clicker Question - charge left on an electroscope. - A
8. Coulomb's Law
9. Activity: Have them work out the force at a point. Unit vector review
10. Superposition of forces
11. Clicker Question: no net force - F
12. Clicker Question: equilateral triangle (superposition in 2D) - C

13. The electric field - the field is a physical thing that can appear independent of charge. It's not just a trick.
14. Definition of the electric field. Charges and Fields PhET.
15. Superposition of Electric Fields.
16. Worksheet

Electrostatics

Charge: 1) "2 types, positive and negative." Net charge is the difference in positive and negative charges. In day to day experience,

- protons: positively charged, immobile
- electrons: negatively charged, free to move

2) "Charge is quantized." It appears as integer multiples of $\pm e$. (except for quarks, which have fractional charge).

3) "Like charges repel, unlike attract."

4) "Like momentum and energy, charge is conserved." The symmetry associated with it is not obvious. It has to do with the phase of the electron wave-function.

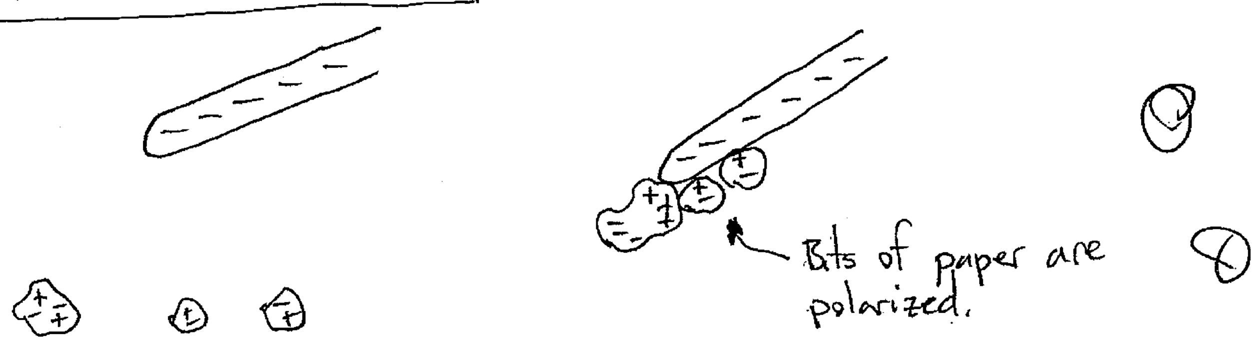
Clicker: Socks in the dryer

Demo: Charging spatula, lifting bits of papers.

How does an uncharged object get moved by a charged one?

→ polarization

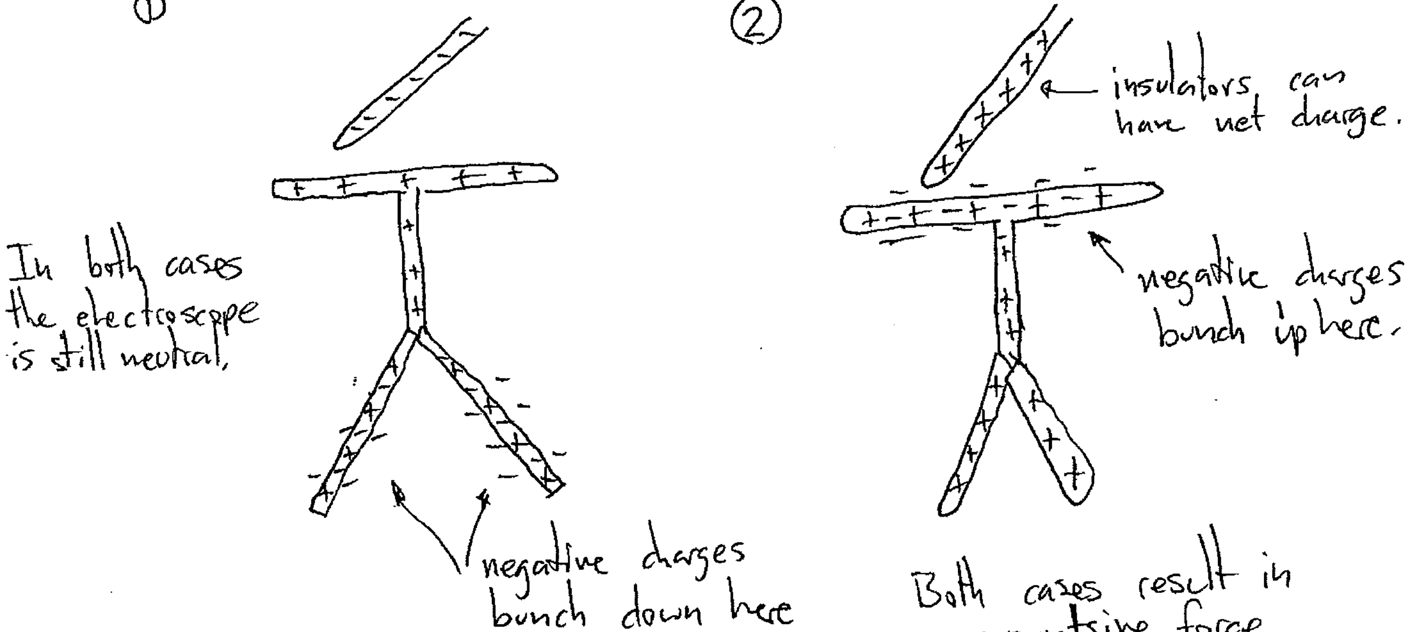
PhET: balloon and sweater



Electroscope

* Spatula is an insulator, charges don't move easily
* Wire is a conductor, charges move easily.

One of two things is happening.

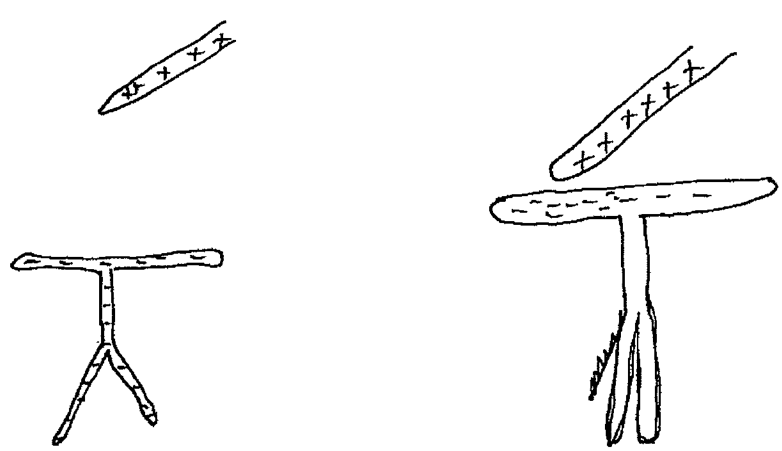


Both cases result in a repulsive force.

Charge by induction

Clicker question: What charge is left on the object?

We can demonstrate that the opposite charge must be left on the electroscope. by charging the spatula and bringing it close again. We see that the leaves fall back together.



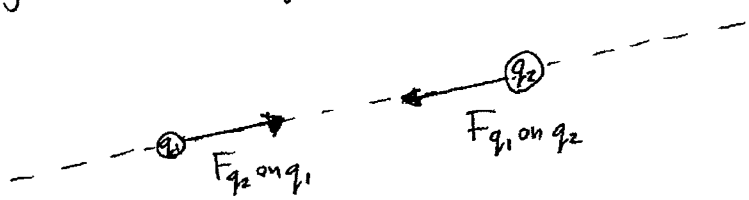
Quantifying the force between charges

Coulomb's Law: The magnitude of the force between two particles with charges q_1 and q_2 is

$$F_{1 on 2} = F_{2 on 1} = k \frac{q_1 q_2}{r^2}$$

where $k = 9 \times 10^9 \, Nm^2/C^2 = \frac{1}{4\pi\epsilon_0}$.

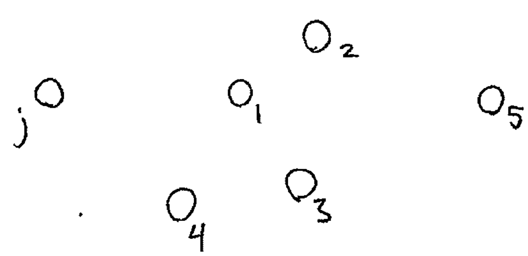
The direction of the force is given by the line joining the 2 charges.



Clicker question: two charges sheres touching

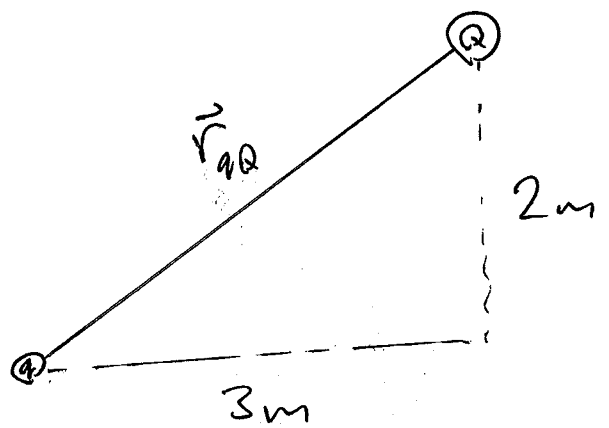
Superposition:

If there are many charges, the total force on one charge is the sum of the force from each charge.



$$\vec{F}_{net\,j} = \vec{F}_{1 on j} + \vec{F}_{2 on j} + \vec{F}_{3 on j} + \ldots = \sum_i \vec{F}_{i on j}$$

An example:



the force is

$$\vec{F} = F_{qQ}\,\hat{r}_{qQ}$$

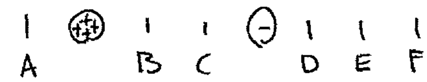
$$F_{qQ} = \frac{kqQ}{r^2} = \frac{9\times10^{-9}\,(2\times10^{-9}\,C)(1\times10^{-9}\,C)}{\left(\sqrt{3^2+2^2}\right)^2} = 1.38\times10^{-9}\,N$$

$$\hat{r}_{qQ} = \frac{\vec{r}_{qQ}}{|\vec{r}_{qQ}|} = \frac{3\hat{i}+2\hat{j}}{\sqrt{2^2+3^2}} = 0.83\,\hat{i} + 0.55\,\hat{j}$$

$$\vec{F} = (1.38\times10^{-9}\,N)(0.83\,\hat{i} + 0.55\,\hat{j})$$

$$= (1.15\,\hat{i} + 7.65\,\hat{j})\times10^{-9}\,N.$$

Clicker question: Charges in a line



We know to cancel it must be A, D, E, F. It can't be A because the particle with 4q is too close. We want the magnitudes to be equal,

$$\frac{4q}{r_1^2} = \frac{q}{r_2^2} \Rightarrow \left(\frac{r_1^2}{r_2^2}\right) = \frac{4q}{q} \Rightarrow \frac{r_1}{r_2} = 2.$$

The point that matches that condition is F.