PHYS 1441 – Section 002
Lecture #5

Wednesday, Sept. 13, 2017

Dr. Jaehoon Yu

- Chapter 21
  - The Electric Field & Field Lines
  - Electric Fields and Conductors
  - Motion of a Charged Particle in an Electric Field
  - Electric Dipoles

Announcements

- 1^{st} Term exam
  - In class, Wednesday, Sept. 20: DO NOT MISS THE EXAM!
  - CH1.1 to what we learn on Monday, Sept. 18 + Appendices A1 – A8
  - You can bring your calculator but it must not have any relevant formula pre-input
    - No phone or computers can be used as a calculator!
  - BYOF: You may bring one 8.5x11.5 sheet (front and back) of handwritten formulae and values of constants for the exam
  - No derivations, word definitions, or solutions of ANY problems !
  - No additional formulae or values of constants will be provided!
- Colloquium today at 4pm in SH100
  - Dr. L. Matthews of Baylor Univ.

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Cosmic Dust Bunnies and Laboratory Dust Crystals: An introduction to complex plasma research

Lorin Swint Matthews
CASPER, Baylor University, Waco, TX

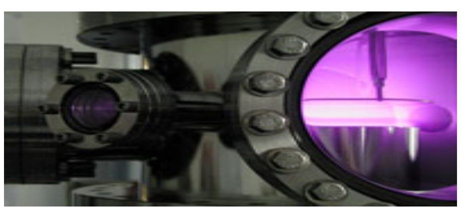
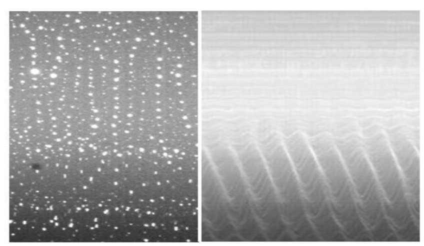
Wednesday September 13, 2017
4:00 Room 100 Science Hall

Abstract

Plasma, consisting of ions, electrons, and neutral particles, is a ubiquitous component of the universe. Dust is also a common component, and when it is immersed in a plasma, it is termed a dusty or complex plasma. The ions and electrons collide with the dust grains, charging them, and in turn the charged dust influences the motion of plasma particles.

Complex plasmas can be found naturally in the clouds surrounding developing protostars and protoplanets, the ephemeral rings around planets, in cometary tails, and even around earth. Dusty plasmas have been purposely created in the lab to study their basic characteristics to learn how to control and exploit them. In the last twenty years, experimental dusty plasmas have become an increasingly interesting research topic due to the dust's ability to self-organize.

This talk will give an overview of the basic physics of dusty plasmas and the current numerical and experimental research being conducted at CASPER, the Center for Astrophysics, Space Physics, and Engineering Research, at Baylor University.


Refreshments will be served at 1:30 p.m. in the Physics Library

Reminder: Special Project #2 – Angels & Demons

- Compute the total possible energy released from an annihilation of x-grams of anti-matter and the same quantity of matter, where x is the last two digits of your SS#. (20 points)
  - Use the famous Einstein's formula for mass-energy equivalence
- Compute the power output of this annihilation when the energy is released in x ns, where x is again the first two digits of your SS#. (10 points)
- Compute how many cups of gasoline (8MJ) this energy corresponds to. (5 points)
- Compute how many months of world electricity usage (3.6GJ/mo) this energy corresponds to. (5 points)
- Due by the beginning of the class Monday, Sept. 25

The Electric Field

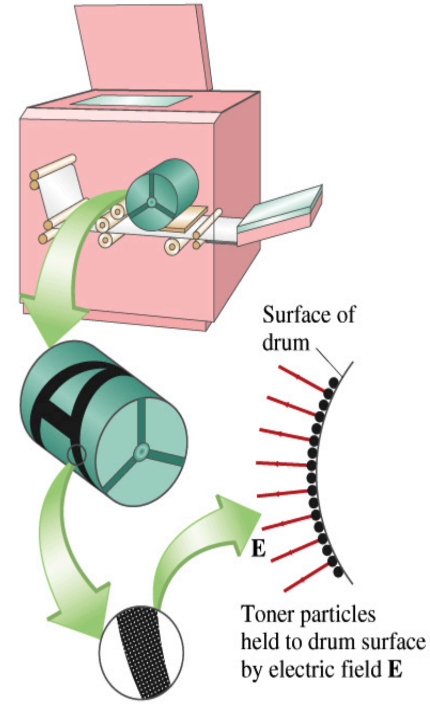
- The electric field at any point in space is defined as the force exerted on a tiny **positive** test charge divide by magnitude of the test charge
  - Electric force per unit charge

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

- What kind of quantity is the electric field?
  - Vector quantity. Why?
- What is the unit of the electric field?
  - N/C
- What is the magnitude of the electric field at a distance r from a single point charge Q?

$$E = \frac{F}{q} = \frac{kQq/r^2}{q} = \frac{kQ}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

Example 21 – 5



- **Electrostatic copier**. An electrostatic copier works by selectively arranging positive charges (in a pattern to be copied) on the surface of a nonconducting drum, then gently sprinkling negatively charged dry toner (ink) onto the drum. The toner particles temporarily stick to the pattern on the drum and are later transferred to paper and "melted" to produce the copy. Suppose each toner particle has a mass of 9.0×10^{-16}kg and carries the average of 20 extra electrons to provide an electric charge. Assuming that the electric force on a toner particle must exceed twice its weight in order to ensure sufficient attraction, compute the required electric field strength near the surface of the drum.

The electric force must be the same as twice the gravitational force on the toner particle.

So we can write $F_e = qE = 2F_g = 2mg$

Thus, the magnitude of the electric field is

$$E = \frac{2mg}{q} = \frac{2 \cdot \left(9.0 \times 10^{-16} kg\right) \cdot \left(9.8 m/s^2\right)}{20\left(1.6 \times 10^{-19} C\right)} = 5.5 \times 10^3 N/C.$$

Direction of the Electric Field

- If there are more than one charge present, the individual fields due to each charge are added vectorially to obtain the total field at any point. $$\vec{E}_{Tot} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \vec{E}_4 + \ldots.$$
- This superposition principle of electric field has been verified by experiments.
- For a given electric field **E** at a given point in space, we can calculate the force **F** on any charge q, **F**=q**E**.
  - What happens to the direction of the force and the field depending on the sign of the charge q?
  - The **F and E** are in the same directions if $q > 0$
  - The **F and E** are in the opposite directions if $q < 0$

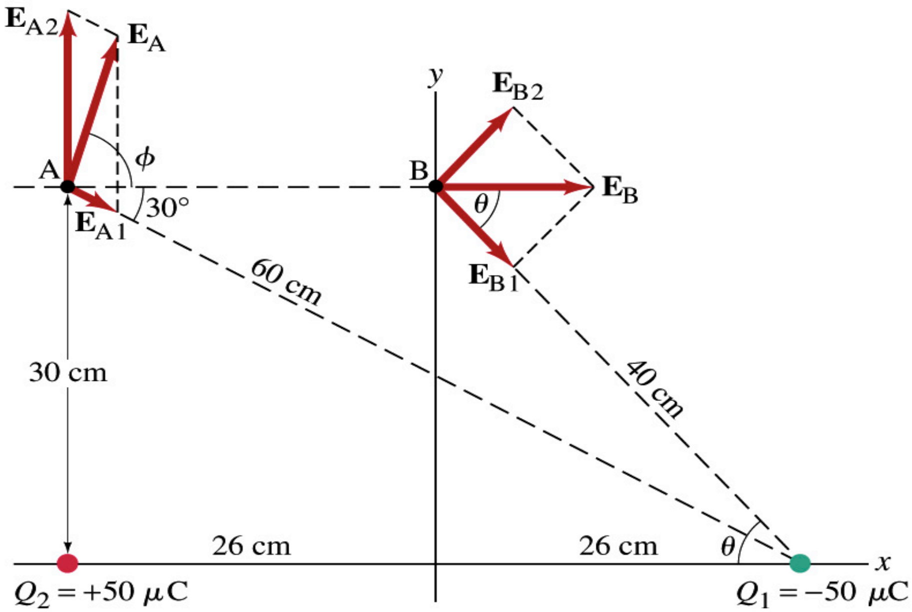
Example 21 – 8

- **E above two point charges**: Calculate the total electric field (a) at point A and (b) at point B in the figure on the right due to both the charges Q_1 and Q_2.

How do we solve this problem?

First, compute the magnitude of fields at each point due to each of the two charges.

Then add them at each point vectorially!



First, the electric field at point A by Q_1 and then Q_2.

$$\left|E_{A1}\right| = k\frac{Q_1}{r_{A1}^2} = \frac{\left(9.0\times10^9\ N\cdot m^2/C^2\right)\cdot\left(50\times10^{-6}\,C\right)}{\left(0.60m\right)^2} = 1.25\times10^6\ N/C$$

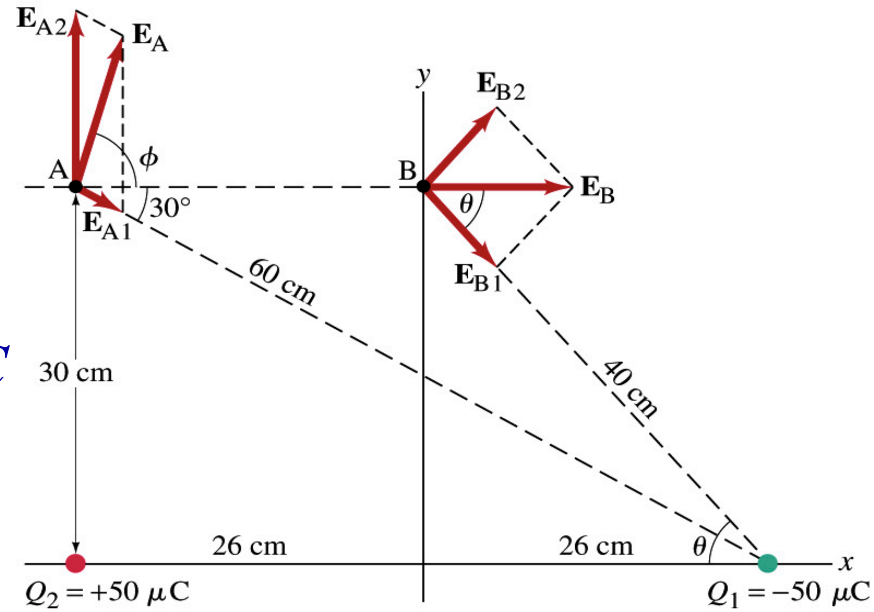
$$\left|E_{A2}\right| = k\frac{Q_2}{r_{A2}} = \frac{\left(9.0\times10^9\ N\cdot m^2/C^2\right)\cdot\left(50\times10^{-6}\,C\right)}{\left(0.30m\right)^2} = 5.0\times10^6\ N/C$$

Example 21 – 8, cnt'd

Now the components of the electric field vectors by the two charges at point A.

$$E_{Ax} = E_{A1}\cos 30 = 1.1\times 10^{6}\ N/C$$

$$E_{Ay} = E_{A2} - E_{A1}\sin 30 = 4.4\times 10^{6}\ N/C$$



So the electric field at point A is

$$\vec{E}_A = E_{Ax}\vec{i} + E_{Ay}\vec{j} = \left(1.1\vec{i} + 4.4\vec{j}\right)\times 10^{6}\ N/C$$

The magnitude of the electric field at point A is

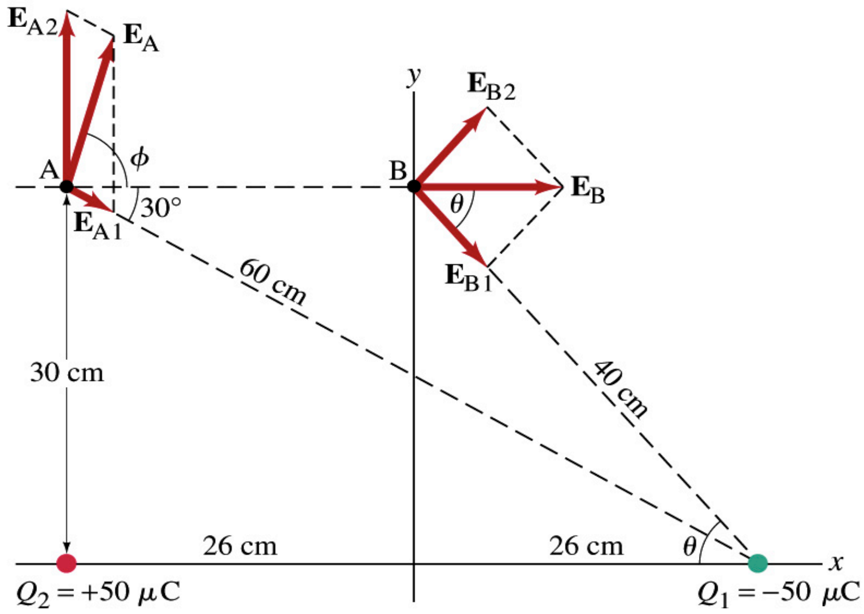
$$\left|E_A\right| = \sqrt{E_{Ax}^2 + E_{Ay}^2} = \sqrt{(1.1)^2 + (4.4)^2}\times 10^{6}\ N/C = 4.5\times 10^{6}\ N/C$$

Now onto the electric field at point B

Example 21 – 8, cnt'd

Electric field at point B is easier due to symmetry!

Since the magnitude of the charges are the same and the distance to point B from the two charges are the same, the magnitude of the electric field by the two charges at point B are the same!!



$$\left|E_{B1}\right| = k\frac{Q_1}{r_{B1}} = \left|E_{B2}\right| = k\frac{Q_2}{r_{B2}} =$$

$$= \frac{\left(9.0\times10^{9}\ N\cdot m^2/C^2\right)\cdot\left(50\times10^{-6}\,C\right)}{\left(0.40m\right)^2} = 2.8\times10^{6}\ N/C$$

Now the components! First, the y-component! $E_{By} = E_{B2}\sin\theta - E_{B1}\sin\theta = 0$

Now, the x-component! $\cos\theta = 0.26/0.40 = 0.65$

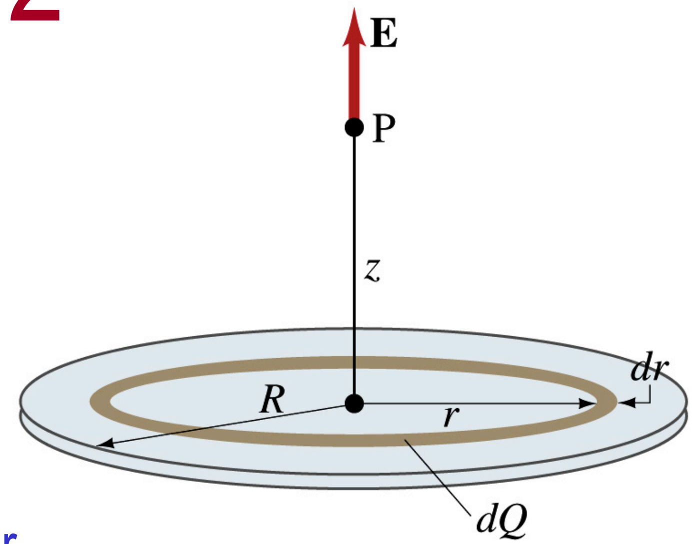
$$E_{Bx} = 2E_{B1}\cos\theta = 2\cdot2.8\times10^{6}\cdot0.65 = 3.6\times10^{6}\ N/C$$

So the electric field at point B is $\vec{E}_B = E_{Bx}\vec{i} + E_{By}\vec{j} = \left(3.6\vec{i} + 0\vec{j}\right)\times10^{6}\ N/C = 3.6\times10^{6}\vec{i}\ N/C$

The magnitude of the electric field at point B $\left|E_B\right| = E_{Bx} = 2E_{B1}\cos\theta = 2\cdot2.8\times10^{6}\cdot0.65 = 3.6\times10^{6}\ N/C$

Example 21 – 12

- **Uniformly charged disk**: Charge is distributed uniformly over a thin circular disk of radius R. The charge per unit area (C/m^2) is σ. Calculate he electric field at a point P on the axis of the disk, a distance z above its center.



How do we solve this problem?

First, compute the magnitude of the field (dE) at point P due to the charge (dQ) on the ring of infinitesimal width dr.

From the result of example 21 – 11 (please do this problem yourself)

$$dE = \frac{1}{4\pi\varepsilon_0}\frac{zdQ}{\left(z^2+r^2\right)^{3/2}}$$

Since the surface charge density is constant, σ, and the ring has an area of 2πrdr, the infinitesimal charge of dQ is

$$dQ = 2\pi\sigma r dr$$

So the infinitesimal field dE can be written

$$dE = \frac{1}{4\pi\varepsilon_0}\frac{zdQ}{\left(z^2+r^2\right)^{3/2}} = \frac{1}{4\pi\varepsilon_0}\frac{2\pi z\sigma}{\left(z^2+r^2\right)^{3/2}} rdr = \frac{\sigma z}{2\varepsilon_0}\frac{r}{\left(z^2+r^2\right)^{3/2}} dr$$

Example 21 – 12 cnt'd

Now integrating dE over 0 through R, we get

$$E=\int dE=\int_0^R \frac{1}{4\pi\varepsilon_0}\frac{2\pi z\sigma}{\left(z^2+r^2\right)^{3/2}}r\,dr=\frac{z\sigma}{2\varepsilon_0}\int_0^R \frac{r}{\left(z^2+r^2\right)^{3/2}}dr$$

$$=\frac{\sigma}{2\varepsilon_0}\left[-\frac{z}{\left(z^2+r^2\right)^{1/2}}\right]_0^R=\frac{\sigma}{2\varepsilon_0}\left[1-\frac{1}{\left(z^2+R^2\right)^{1/2}}\right]$$

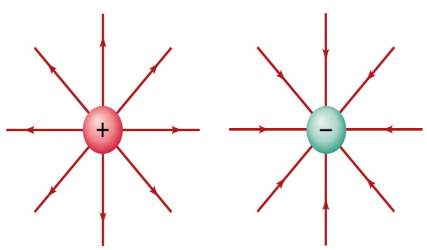
What happens if the disk has infinitely large area?

$$E=\frac{\sigma}{2\varepsilon_0}\left[1-\frac{1}{\left(z^2+R^2\right)^{1/2}}\right]\Rightarrow E=\frac{\sigma}{2\varepsilon_0}$$

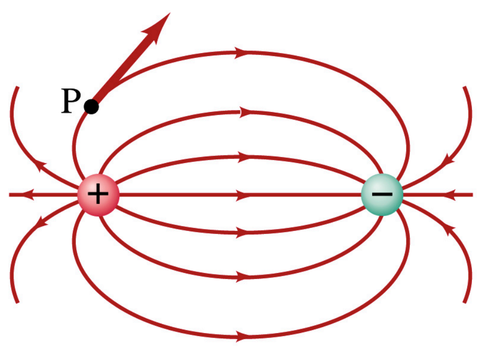
So the electric field due to an evenly distributed surface charge with density, σ, is $E=\frac{\sigma}{2\varepsilon_0}$

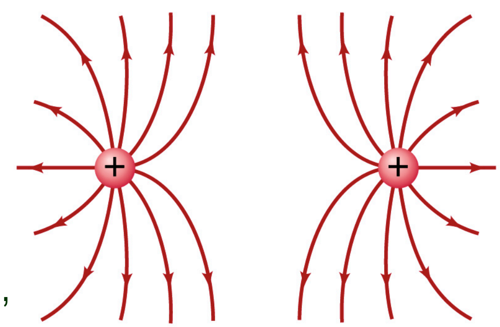
Field Lines

- The electric field is a vector quantity. Thus, its magnitude can be expressed by the length of the vector and the direction by the direction the arrowhead points.
- Since the field permeates through the entire space, drawing vector arrows is not a good way of expressing the field.
- Electric field lines are drawn to indicate the direction of the force due to the given field on a **positive test charge**.
  - Number of lines crossing unit area perpendicular to E is proportional to the magnitude of the electric field.
  - The closer the lines are together, the stronger the electric field in that region.
  - Start on positive charges and end on negative charges.

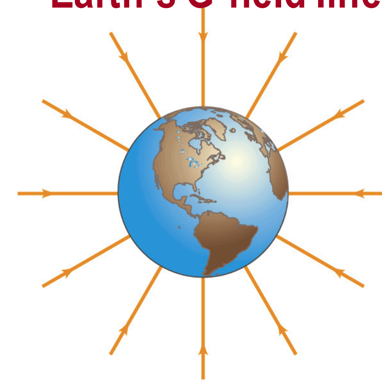


(a) (b)



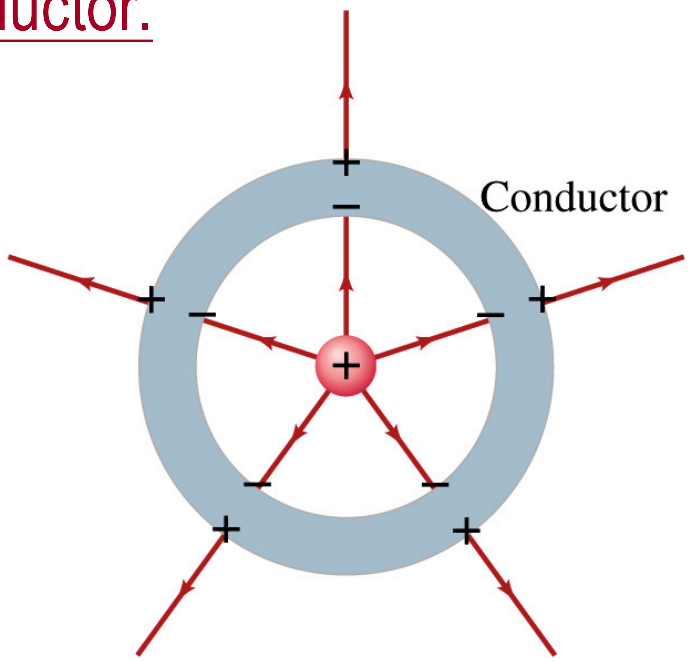


Earth’s G-field lines



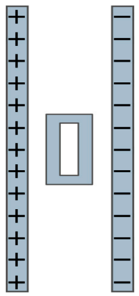
Electric Fields and Conductors

- The electric field inside a conductor is ZERO in static situation. (If the charge is at rest.) Why?
  - If there were an electric field within a conductor, there would be force on its free electrons.
  - The electrons will move until they reached the position where the electric field becomes zero.
  - Electric field can exist inside a non-conductor.
- Consequences of the above
  - Any net charge on a conductor distributes itself on the surface.
  - Although no field exists inside a conductor, the fields can exist outside the conductor due to induced charges on either surface
  - The electric field is always perpendicular to the surface outside of a conductor.

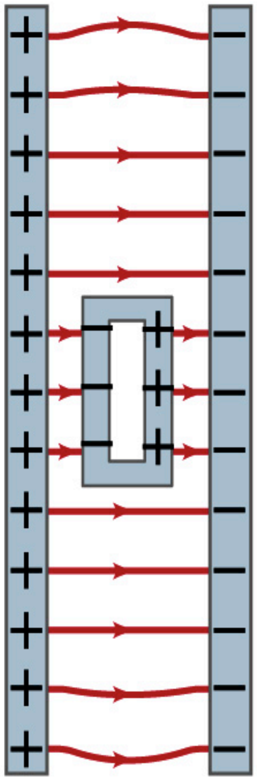


Example 21-13

- **Shielding, and safety in a storm.** A hollow metal box is placed between two parallel charged plates. What is the field like in the box?



- If the metal box were solid
  - The free electrons in the box would redistribute themselves along the surface so that the field lines would not penetrate into the metal.



- The free electrons do the same in hollow metal boxes just as well as it did in a solid metal box.
- Thus a conducting box is an effective device for shielding. ➔ Faraday cage
- So what do you think will happen if you were inside a car when the car was struck by a lightening?