Waves and Fields (PHYS 195): Week 10

Spring 2021 v1.0

Intro:

Magnetic fields will be the topic this week. We'll carefully study the field of a coil of wire and the torque on a current loop in a magnetic field. This is critical for the design of motors. The problems are a problem mix on frequency or Doppler shift, charge, and electric fields.

Reading:

- HRW 26.1 - 2 (reading on current) and 29.1-3
- HRW 28
- HRW 28 and 33.

Our study of magnetic fields will encompass all of Chapter 28 and Sections 1 to 3 of Chapter 29. We started with the material from Chapter 29.

We save the delightful material on the dynamics of electric and magnetic fields in Chapters 30-32 for Phys 295.

Physics Topics:

- "$\vec{B}$ from moving charges" or the Biot-Savart Law
- Magnetic moment
- Lorentz force $q\mathbf{v} \times \mathbf{B}$ and $I\ell \times \mathbf{B}$

Math Topics:

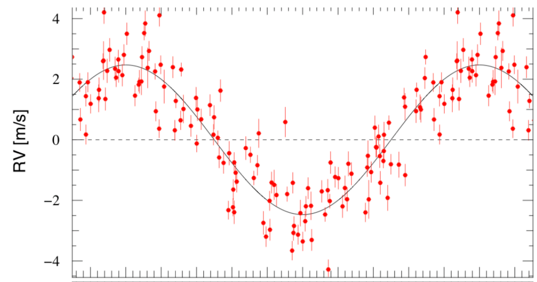
- Cross products
- Line integrals

Problem Set: Due Tuesday April 13 at 11:59 on gradescope code ZR34XK

(1) Alice taps a hammer to one end of a long, thin steel cylinder. This makes a sound in both air and steel. Bob listens with an ear close to the other end of the cylinder and hears the tap sound twice, separated by an interval of 0.12 s. If the speed of sound in air is 343 m/s then what is the length of the cylinder? Assume that the steel has a bulk modulus of 1.6×10^{11} N/m^2 and a density of 8000 kg/m^3.

(2) A truck with a nasty whine at 1610 Hz and a constant velocity overtakes and passes a cyclist moving at 2.44 m/s. After the truck passes by the cyclist hears a frequency of 1590 Hz. How fast is the truck moving?

(3) **Exoplanet Search** Hooray! Suppose that you discover a Doppler shift signal at the edge of your equipment's sensitivity. Using the relative velocity method find the planet's mass. Here's the data

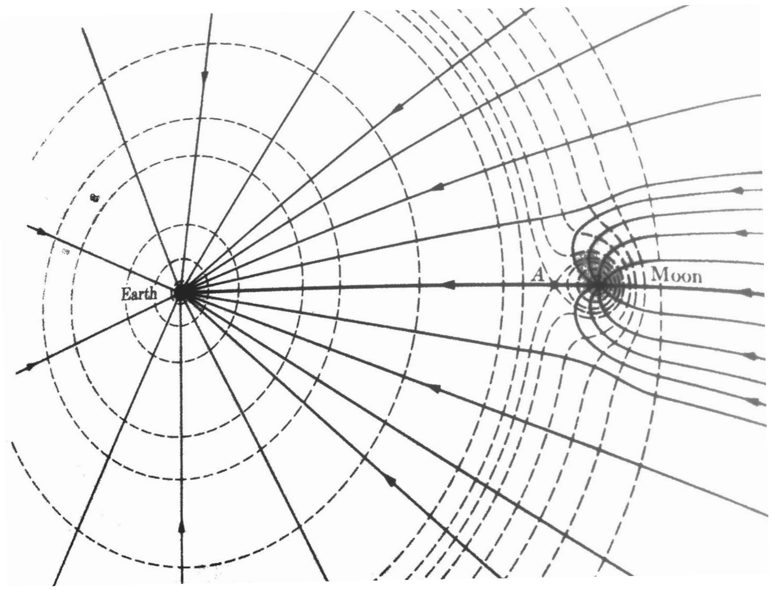


(from Mayor et. al. 2009)
The mass of the star is just under the mass of the sun, $M = 1.5 \times 10^{30}$ kg. The orbital period of the newly discovered planet is 9.62 days. Gleaning the needed data from the plot, what is the mass of this planet? How large is it compared to Earth's mass? $M_{Earth} = 5.98 \times 10^{24}$ kg

(4) **The Tape Experiments:** (You will need Scotch Tape. I have put a dispenser outside my office, G052. Feel fee to use this.)
  (a) Stick a roughly 10 cm strip of tape on a smooth, dry surface such as a desk. Fold over one end to make a handle. With a quick motion, pull up the tape from the surface. You now have a charged object!
  Fix the tape to the edge of the desk, back of a chair or other convenient surface. Try bringing other objects close to the tape. What happens? Make a table of your results. Include as one of your objects in your table another piece of tape prepared in the same way.
  (b) Stick two strips of tape sticky side down and label them "B" for bottom. (Be sure to make handles.) Press another strip on top along each of these strips. Label these "T" for top. Briskly pull the pairs off the surface. Then pull the strips apart (separating top and bottom). How do the B strips interact? The T strips? The B and T? Try out the different objects on your B and T strips. Record what happens in your table. As you do the experiments it is important to keep your hands and other objects away from your strips of tape. (Why?)
  (c) Overall in your results is there a difference between the occurrence of "attraction" and "repulsion"?
  (d) How can you characterize the strength of the interactions?
  (e) What is the minimum number of types of charge needed to account for your observations? Explain your result, referring to your table.
  (f) Can you determine which charge is which? Think carefully on this one. Although it is not immediately apparent, you have found a very deep aspect of the world called 'gauge symmetry'.

(5) **Play electric hockey!** How? Follow the hockey link on the course web site. For the purposes of this problem I'll define "elegant solutions" as those with the smallest number of charges.
  (a) Add the electric field. Click on the1st level of difficulty. Find an elegant solution. When you have one, make a pdf of a screen shot of the configuration. Describe your method of solution.
  (b) Move on to the second level of difficulty and find an elegant solution. Capture a screen shot of your solution.

(6) **Gravitational field** Here is the field diagram of the Earth-moon system:



(a) What do the dashed lines represent?
(b) What is the significance of point A?

(7) *Carlo's Configuration* You have two charges of $+4q$ each and one charge of -$1q$ and are free to place them where you choose.
  (a) Place the origin of a coordinate system at the $-1q$ charge. Where would you place the $+4q$ charges so that there is no net force on any of the charges?
  (b) Using a full page of paper carefully sketch the electric field of your configuration.
  (c) What is the nature of the equilibrium for the $-1q$ charge (stable, neutral, or unstable)? Assume that the two $+4q$ charges are fixed. Investigate this quantitatively. Hint: Try displacing the charge in different, orthogonal directions. Alternately, do a Taylor expansion around the equilibrium point. Expect some subtleties.

(8) **Kelvin Water Dropper**: The "mysterious" Kelvin Water Dropper which, as demonstrated in lecture Friday March 15, is capable of creating a large buildup of charge. When the electric field between the brass spheres is high enough, we observed an electrical breakdown - a spark - in the gap. This spark occurred at roughly 20 s intervals as the water flowed. Using text and field diagrams explain this phenomenon. *Hints: Assume an initial slight asymmetry of charge between the two buckets. Tap water is a good conductor. Follow the charge as the drop forms and falls. Carefully draw the electric field lines around the cylinder as a drop forms. Explain how the large electric fields are generated.*

Lab:

A look ahead. . .

Interference HRW Chapter 35