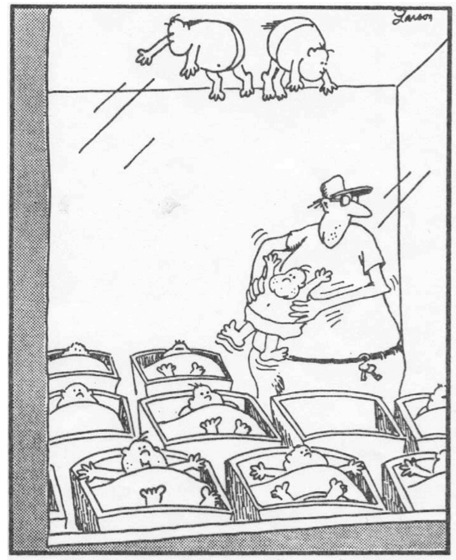
Physics 4L, Spring 2010 — Problem set 3
Due Tuesday 9 February in class, except the self-test problem,
which is due Thursday 11 February in class

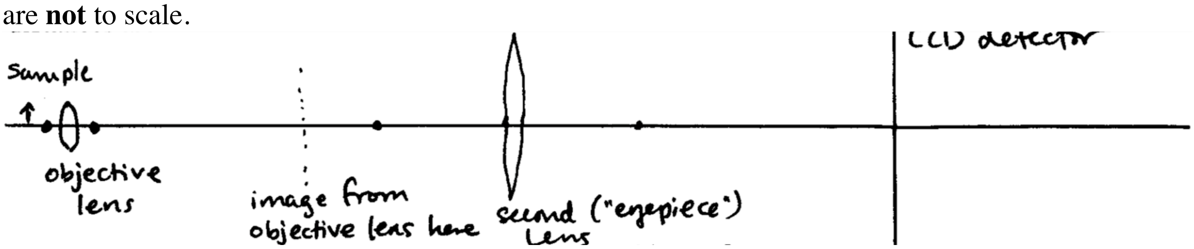


Late at night, and without permission, Reuben would often enter the nursery and conduct experiments in static electricity.

If you feel you need more practice with vectors: I recommend problems 21, 44, and 46 from Chapter 20. **These are not required and you should not hand them in,** but I will include them in the problem set solutions.

Wolfson problems:
Chapter 20, problems 43, 49, and 52

Additional problems:
1. You are using a microscope that produces an image on the light-sensitive detector of a CCD camera rather than an image viewed with your eye through an eyepiece. The microscope is equipped with a 40x objective lens (i.e. the objective produces an image that is magnified to 40 times the sample's size) and a second converging lens that produces an additional 2x linear magnification of the real image produced by the objective lens. The arrangement of the sample, the two lenses, and the CCD detector is shown in the figure below; the distances in the figure are **not** to scale.



(a) Compared to the image produced by the objective lens, is the image on the CCD camera upright or inverted? Compared to the original sample, is the image on the CCD camera upright or inverted?
(b) The focal length of the eyepiece lens is +10 cm. Find the distance from the eyepiece lens to the CCD detector and the distance from the eyepiece lens to the image formed by the objective lens.
(c) The sample is 2 mm from the objective. How far apart are the objective lens and the eyepiece lens?
Do **not** try to use the Wolfson formulas about compound microscopes for this problem; they do not apply (this microscope uses lenses differently)! Just consider image formation by the series of two lenses.

2. An electric field strength of 3×10^6 N/C is strong enough to ionize air molecules and create a spark. This phenomenon is referred to as "dielectric breakdown" and is the mechanism by which lightning occurs.
(a) How much excess charge can you put on a metal sphere of 10 cm radius in air without causing breakdown in the neighboring air?
(b) If enough charge was present to cause breakdown, where would breakdown be most likely to occur?
(c) Compared to a 10 cm sphere, can you put more or less charge on a metal sphere of 1 mm radius without causing breakdown?

(Problem set continues on the back)

3. (Clarification of Wolfson problem 62) Consider a pair of dipoles located as in Figure 20.29 (with Wolfson problem 62).

(a) Is the force attractive or repulsive? Answer with a brief qualitative argument.

(b) Find an *exact* expression for the net force (magnitude and direction) that the left dipole exerts on the right dipole, by summing the forces that the charges of the left dipole exert on the charges of the right dipole. (There are a lot of terms; feel free to use a calculator to simplify. Hint: the terms proportional to x^4 should all cancel.) Confirm that the direction is consistent with your answer to (a).

(c) Show that in the limit $x >> a$, the magnitude of the force is approximately $6kp^2/x^4$, where p is the dipole moment of either dipole.

4. You and a friend are blowing up balloons for your four-year-old nephew's birthday party, and idly decide to investigate some physics. You rub one balloon on your wool sweater until it acquires a charge of +3q, and rub another balloon on your fleece scarf until it acquires a charge of -2q. You hold these two balloons a distance d apart ($d >>$ diameter of the balloons). If your friend now charges up a third balloon, where can your friend hold that balloon so that there is no net electrostatic force on it, and does it matter how much charge is on the third balloon?

Hint: The three balloons must all be in a line, and you can choose that line to be the x-axis (or any other axis) to simplify the calculation.

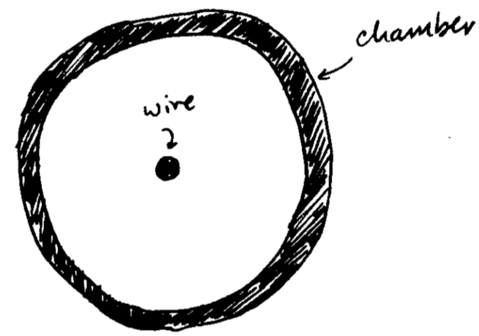
Also: The quadratic formula is useful for solving this problem. If you're rusty using it, take a look at the posted problem online "lens problem with quadratic equation."

For extra credit: Explain briefly why the third balloon must be placed on the line through the positions of the first two, in order for there to be no net electrostatic force on it.

Self-test problem, PS 3 Name ______________________________

You may spend up to 25 minutes on this problem. Do your work on this sheet and turn it in separately. Do not work with others or refer to the textbook, though you may consult the equation sheet posted online. Your score on this problem will not be included in your homework grade; it is solely for feedback to you. (However, you *will* receive credit for one homework problem for completing it.)

An electrostatic precipitator can remove up to 99% of the small particles from the smoke of coal-burning power plants and other sources of industrial pollution. In such a precipitator, a long straight metal wire of length L = 1.0 m and diameter 5.0 mm is charged uniformly with a total charge of 0.10 μC. The charged wire is surrounded by a cylindrical metal chamber of inner diameter 40 cm, so that the wire is on the axis of the chamber, and the smoke passes through the chamber. The figure to the right shows a cross-section through the precipitator cut perpendicular to the axis of the chamber and the wire.



(a) Sketch the electric field lines inside the chamber on the cross-sectional diagram provided above, and indicate the distribution of charge on the chamber with "+" and "-" signs.

(b) The electric field in the precipitator ionizes some of the gas molecules; the ions then stick to some of the small particles in the smoke. In which direction do the negatively charged particles move? In which direction do the positively charged particles move?

(c) The electric field of the wire also polarizes those particles that do not become charged. In which direction do the polarized particles move, and why?

(d) Inside the chamber, where will the electric field be the strongest, and what is its strength there?

Problem continues on the back

(e) Ignoring the effects of gravity, what is the acceleration of a speck of coal dust with mass 100.0 μg and charge 0.10 nC in the precipitator, when the speck is 1.5 cm away from the surface of the wire? Assume the speck is not near the ends of the precipitator. Is ignoring gravity a reasonable approximation?